Assessing Non-Lethal Seal Deterrent Options: Literature and Data Review (MMO1131)

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MMO1131: Assessing Non-Lethal Seal Deterrent Options: Literature and Data Review

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1 Project Background

Interactions between seals and fishing gear include depredation (taking catch) of fish catches by seals and bycatch of seals in fishing gear. Throughout England, particularly in the south-west, north-east and east, depredation is an issue for static net fisheries in particular, that leads to significant economic costs from loss of commercial catch, increased gear handling or gear damage. Seal-gear interactions can also lead to seal mortality through either legal shooting ('Netsmen's Defence') or as a result of accidental bycatch.

The Marine Management Organisation (MMO) Marine Conservation Team has to provide advice on interactions between seals and fishing gears. Defra policy is that prior to shooting, non-lethal methods should be tried and shown to be ineffective, but effective non-lethal seal deterrent alternatives to shooting are limited for application from fishing vessels in open water. In order to improve the specificity of advice, MMO would like to understand the interactions between seals and fishing gear and non-lethal deterrent options better to be able to offer advice that can reduce the need for shooting. This may also have positive side effects on fishing by reducing seal by-catch and net-based feeding.

The project therefore aims to explore the following seven objectives:

1. Understand how seals take fish from nets and what factors assist them (for example location, visual cues etc.);
2. Identify what factors influence depredation behaviour (for example opportunistic, or specialist individuals);
3. Identify the breeding populations of individuals undertaking depredation;
4. Review non-lethal deterrent measures currently available that may be appropriate for reducing the seal–gear interactions at sea;
5. Review what modifications to fishing gear or fishing tactics may mitigate seal depredation and bycatch;
6. Clarify potential impacts and benefits and risks to the fishing industry, managers and seals by implementing non-lethal measures, gear modifications or tactics identified through 5) and 6) and prioritise a sub-set of mitigation measures for testing;
7. Design and undertake testing in collaboration with the fishing industry of the most promising depredation deterrent measures.

This report presents a review of literature and data in order to assess:

- the distribution of seal colonies and of at-sea usage[1] around England (objective 3);
- the distribution of inshore fisheries and of static net fisheries around England, and in particular in the vicinity of the main areas of at-sea usage (objectives 3 and 7);
- the nature of seal-fishery interactions and the factors that influence them (objectives 1 and 2);

[1] The use of the marine environment (in contrast to terrestrial usage at haul-out sites), encompassing foraging and travelling behaviour

- current literature on available deterrent options and their effectiveness (objectives 4, 5 and 7);
- pros and cons of implementing non-lethal measures, gear modification and tactics to minimise depredation (objective 6).

2 Literature Review

2.1 Interaction between seals and fisheries

In England and Wales, the 'Netsmen's Defence' clause (section 9c) in the Conservation of Seals Act 1970 allows fishers to protect their catch and fishing gear from predatory seals by shooting (MMO, 2015). There is no requirement for fishers to report the number of seals removed, and as such the number of seals being shot is unknown. In Scotland, the Conservation of Seals Act 1970 has been repealed and replaced with the Marine (Scotland) Act 2010 (Part 6). This requires a licence to remove seals and numbers removed must be reported quarterly. Licences are only issued for the prevention of serious damage to river and estate fisheries and protection of health and welfare of farmed salmon (Marine Scotland, *pers.comm.*).

Lethal removal of seals is problematic both in terms of risks to seal conservation and ethical controversy (Nunny *et al.,* In Press), and its effectiveness is questionable as newly-arriving individuals can replace those removed (Anderson and Hawkins, 1978; Ross, 1988; Pemberton and Shaughnessy, 1993; Götz and Janik, 2013). Removal of individuals by capture and/or shooting is only effective in some fisheries (for example pontoon salmon traps (Königson *et al*., 2013), salmon farms (Morris,1996)) and depredation mainly occurs out of sight of the fisherman (Cronin *et al*., 2016). Furthermore, there is evidence to suggest that culling of higher-order predators can affect predation rates by other species; pinnipeds (seals, walruses and sea lions) forage on predatory fish which may feed on potential target species (Fraker and Mate, 1999; Götz and Janik, 2013). As such, non-lethal seal control methods may provide a more favourable solution. Therefore, any means to minimise the need for shooting is likely to be of benefit to the fishing industry, marine conservation and marine management.

The fishing industry and seals share fish resources, resulting in the potential for interaction and conflict. Seals around the UK, and indeed in other regions of the world, are known to feed on fish catches from fishing gear. This is known as depredation and is defined as the removal of, or damage to, captured fish or bait by marine predators. Passive gear fisheries (such as static nets, lines) suffer more from seal depredation compared with active gear fisheries (trawls) (NESFC[2], 2008; Cronin *et al.*, 2016). This is probably due to seal preference for areas of high relief (Anderwald *et al*., 2012) which are unsuitable for trawling. It is also easier for seals to feed at static gear, compared with mobile gear. However, seals are known to interact with trawlers, often being caught as by-catch (Morizur *et al.,* 1999). Depredation results in a lost or damaged catch which cannot be sold, and thus a reduction in landings. Seals may also compete for fish at a biological level (removal of prey from the open sea), though

[2] The North Eastern Inshore Fisheries and Conservation Authority (NEIFCA) replaced the North Eastern Sea Fisheries Committee (NESFC) in 2011, following the adoption of the Marine and Coastal Access Act 2010.

this is thought to be less important than operational-level interactions at nets (Cronin *et al*., 2016; Houle *et al*., 2016). Furthermore, seal damage to nets and pots has been reported as well as biting of nets during hauling of gear which may cause fish to be lost (NESFC, 2008). Interactions between seals and fishermen has been ongoing for a substantial amount of time (Rae, 1960; Rae and Shearer, 1965), and may be increasing due to increasing levels of protection and population growth of seals.

There are a substantial number of reports of seal depredation from fish farms around the UK, northern Europe, and America and Canada. Reports of seal depredation from wild sea fisheries are less numerous, but it is still a well-known problem around the UK. Impacts from depredation are reported on the northeast coast of England (NESFC, 2008), with up to 20% of individual catches in one month in 2006 estimated to be lost to seal depredation. This is in the form of damaged catch; loss of fish that are wholly removed from nets is difficult to quantify. Butler (2004) reported similar findings with 25% of catch taken by seals in the salmon fishery in the Moray Firth. In pollack and hake set net fisheries in Irish waters, 18% and 10% respectively were estimated to be lost to seal depredation (Cosgrove *et al*., 2013). Heap *et al*. (1986) found only 5% of catch to be depredated by seals in inshore set net fisheries. It seems mature seals are more efficient at extracting whole fish from nets, whereas juveniles tend to bite and rip parts of the fish (NESFC, 2008).

Cosgrove *et al.* (2013) note that previous data in Ireland suggests grey seals are the primary species involved in interactions with fisheries (evidenced further by lower harbour seal by-catch). This is likely the case in the rest of the UK, given the lower population numbers of harbour seals compared with grey seals (see Section 2.2). Therefore, most studies tend to focus on grey seal interactions and relatively little is known on the level of fishery interactions with harbour seals (Cosgrove *et al.,* 2013).

Given that most depredation occurs out of sight of fishermen, there may be an argument to suggest depredation is also attributable to other species such as scavengers (CSGRT, n.d.; BIM, 1997). For example, damage characterised by epidermal and subcutaneous erosive damage may be caused by the isopod *Natatolana borealis* and the amphipod *Orchomene nana* (skinners), and point damage may be caused by crustaceans such as the common crab *Cancer pagurus* (Kiely *et al.,* 2000). Internal damage may also be caused by hagfish *Myxine glutinosa* (Southern Fried Science, 2011), particularly in the north-east of England and Yorkshire (Christopher Sweeting, *pers. comm.*). In a gillnet fishery in Massachusetts, USA, spurdog *Squalus acanthias* accounted for nearly 2% of depredation whereas harbour seal only accounted for 0.4% of depredation (Rafferty *et al.,* 2012). Artisanal fisheries in the Mediterreanean also incur depredation from bottlenose dolphin *Tursiops truncates* (Brotons *et al.,* 2007). However, in many cases there is strong evidence that depredation of fish in North East Atlantic and UK fisheries is due to seals. Fish damage in Irish set net fisheries was generally characterised by large v-shaped bites or removal of all or part of the visceral cavity and skin (Cosgrove *et al*., 2013). Although other species may be capable of similar shaped bites (for example conger eel, elasmobranchs) they may not be capable of meticulous removal of skin, and seals have been observed in the vicinity of nets when damaged fish were hauled aboard alive (Cosgrove *et al*., 2013). Similar observations occur from Scottish fish farms, with evidence of damage to fish likely attributed to seals, such as lacerations possibly caused by flippers (Rae, 1960; Northridge *et al*., 2013). Furthermore, bycatch of other species such as elasmobranchs were rarely observed in depredated Irish fisheries (Cosgrove *et al.,* 2013). In other countries, there is video evidence of seals raiding fixed gear fisheries (Lehtonen and Suuronen, 2004; Königson *et al.,* 2013; Fujimori *et al.,* 2018).

Depredation by seals causes significant economic costs to the fishing industry in terms of lost or damaged catch. There are also additional impacts on fishermen due to costs of new materials to repair damaged gear, presence of seals dispersing fish from nets, and fuel consumption costs to relocate fishing activities away from seals (NESFC, 2008). The Cornish fishing industry estimated that seal depredation costs £100,000 annually (Bosetti and Pearce, 2003). In Irish waters, the upper limit of the total annual value of seal damaged fish in pollack and hake set net fisheries was estimated to be €1.7 million (Cosgrave *et al*., 2013). Westerberg *et al*. (2006) estimated the total loss of value due to direct and indirect costs of seal depredation to be between 15% and 20% of total catch value.

By-catch of seals in fishing gear can result in injury to or death of seals; an issue that may have consequences for seal conservation. By-catch from entanglement in nets is most often reported and seals seem to be less vulnerable to by-catch in mobile trawled gear (Hammond *et al*., 2008). However, demersal and pelagic fisheries using towed gear can result in seal by-catch, often resulting in fatalities (Moore, 2003; Sewell and Hiscock, 2005; Luque *et al.,* 2006). In Ireland, by-catch was mainly observed in tangle net fisheries with a larger mesh size (320 millimetres (mm)) compared to gillnet and trammel net fisheries (270mm mesh size) (Cosgrave *et al*., 2016). A total of 47 grey and 8 harbour seals were recorded as by-catch in 320mm mesh tangle nets between June 2011 and July 2012 from one 16 metre vessel, predominantly in inshore locations off the Mayo coast on the west of Ireland. The UK Cetacean[3] Strandings Investigation Programme reported 533 dead stranded seals in the UK during 2015, consisting of 376 grey seals, 50 common seals and 107 seals of indeterminate identity (CSIP, 2015). The majority were reported in Scotland (314), with smaller numbers in England (171) and Wales (48). No data is available for Northern Ireland. There is a good reporting network in Scotland, Wales and Cornwall, but coverage in the rest of England appears patchy. Twenty post-mortems were conducted in England but no data is given on the outcome.

2.2 Seal ecology, population and distribution

There are two species of seal that occur in UK waters: grey seal *Halichoerus grypus* and harbour seals (also known as common seal) *Phoca vitulina.* Other, Arctic, species occasionally occur in the UK, such as ringed seals *Phoca hispida*, harp seals *Phoca groenlandica,* bearded seals *Erignathus barbatus,* and hooded seals *Cystophora crystata* (SCOS, 2017).

Seals in the UK are generally considered to be common, and grey seals and harbour seals are recorded as 'Least Concern' under the ICUN Red List (though populations of harbour seal have declined in Scotland; see Section 2.2.2). However, both UK species are listed under Annex II and V of the Habitats Directive (92/43/EEC) and therefore Member States are legally obliged to monitor and maintain their populations

[3] The collective name for all whales, dolphins and porpoises

at a favourable conservation status (Cosgrove *et al*., 2013; Cosgrove *et al*., 2016). Furthermore, the UK has special responsibility in the EU for seals as a large proportion of European seal populations occur in UK waters. However, they are not listed under Annex IV, which means that killing and capture is allowed under strict conditions (Westerberg, 2010).

The ecology, population and distribution of the two native seal species occurring in the UK (grey and harbour seals) is reviewed in Section 2.2.1 and Section 2.2.2 respectively. Within each section, information at a UK level is initially reviewed. Given the high level of reports of incidences of seal-fishery interactions from the south-west region, additional detail on this region is also presented.

2.2.1 Grey seals

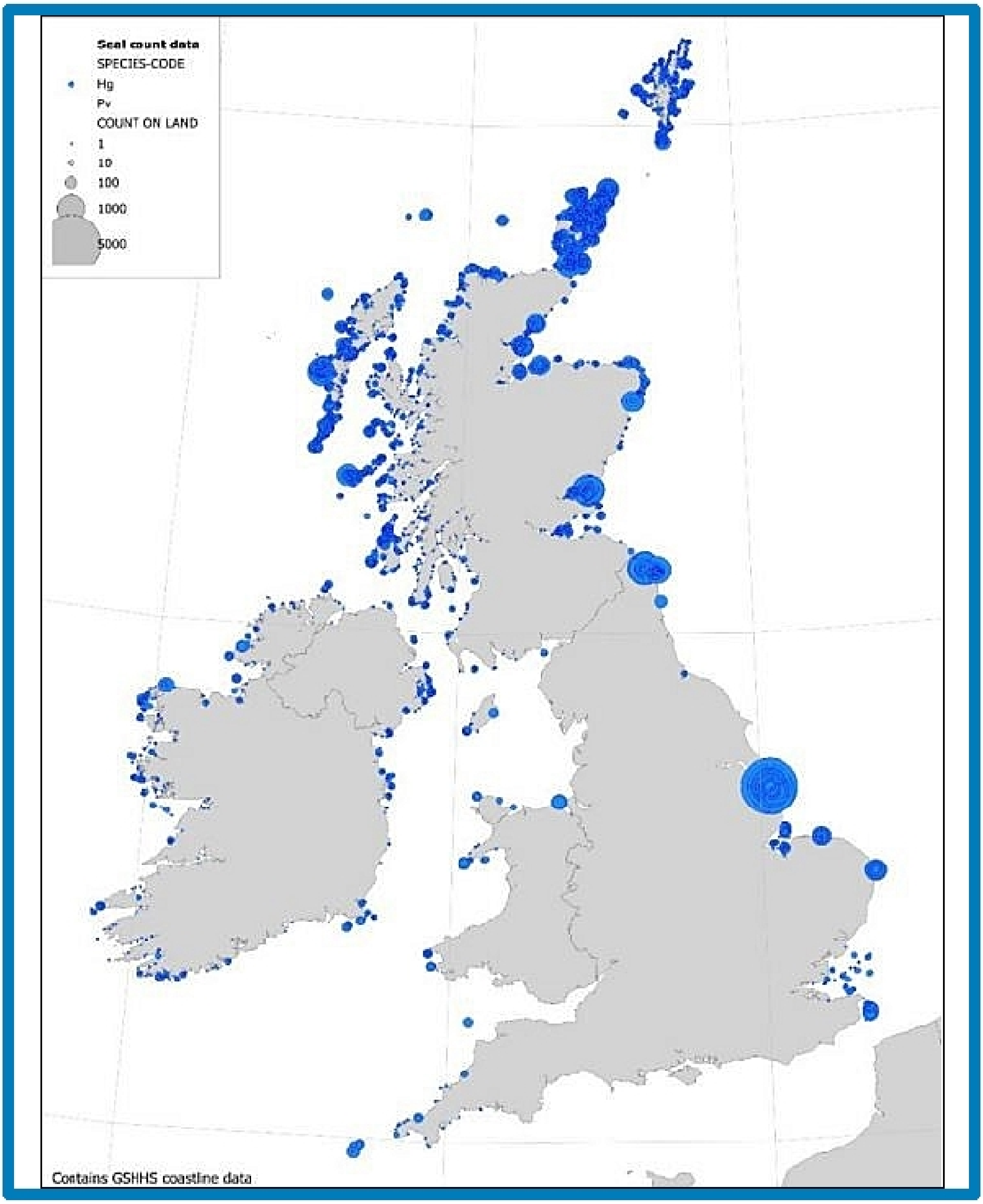
About 38% of the world's population of grey seals is found in Britain with over 88% of the British grey seals breeding in Scotland. There are also breeding colonies on the north and east coasts of mainland Britain, particularly around the Farne Islands, the Humber Estuary (Donna Nook), and around Great Yarmouth/Lowestoft and Southwold, and in south-west England and Wales (SCOS, 2017). The location of major grey seal colonies can be seen in Figure 2.1.

Grey seal numbers have generally increased in the UK since 1984 and are still increasing in the North Sea (Thomas, 2013), despite numbers being stable in the Northern and Western Isles (Jones *et al*., 2015). A survey carried out at the beginning of the 2010 breeding season estimated the total UK population to have been 111,300 (SCOS, 2011). During the same breeding season, UK grey seal production (number of new pups born each breeding season) was estimated at 50,174 (SCOS, 2011). The most recent best estimate for the UK grey seal population is 139,800 in 2015 (approximate 95% CI 116,500-167,100), with an estimated 60,500 grey seal production (SCOS, 2017) an increase of 25%.

The grey seal is the larger of the two seal species found in British waters and has a weight of over 300kg for males, and 150kg to 200kg for females (SCOS, 2015). Grey seals predominantly inhabit remote islands and coastlines, breeding on undisturbed beaches of cobble and boulders or within sea-caves along the coast. Pupping time occurs primarily from August through to December with September generally being the busiest month.

The diet of grey seals consists of a wide variety of prey including benthic and demersal fish (for example sandeels, cod, whiting, ling, haddock, plaice, sole flounder, dab), and may include squid or crustaceans (Emu, 2012; Gosch et al., 2014; Hammond and Wilson, 2016; SCOS, 2017). They mainly forage on the sea bed at depths of up to 100 metres (m) although they are capable of feeding at all depths on the UK continental shelf (Thomson *et al.,* 1991; Barker *et al.,* 2014; SCOS, 2017).

Figure 2.1 Haul-out count data for grey seals between 1996 and 2015. Source: Russell *et al*. (2017).



Grey seals can undertake wide ranging seasonal movements over several thousand kilometres (McConnell *et al*. 1999; Jones *et al*., 2015; Russel *et al*., 2017). However, while grey seals may range widely between haul out sites, tracking has shown that most foraging probably occurs within 100 km of a haul-out site (SCOS, 2017). For example, Cronin *et al*. (2013) found that the mean distance travelled by tagged seals during foraging trips was 50 km from haul out sites in south west Ireland. McConnell *et al*. (1999) found that most tagged grey seals stayed relatively close to haul out sites in the North Sea (mean distance of 39.8 km travelled on a foraging trip) with an average of 43% of the grey seals' time spent within 10 km of a haul out site. This is reflected in seal usage maps which shows the highest densities of seal movements to occur around the seal colonies with the largest populations (such as Orkney, North Rona, the Monach Isles, the Farne Islands, and Donna Nook) (Figure 2.2).

Grey seals in south-west England

In the south-west of England there is an estimated population of approximately 500 to 600 seals (Leeney *et al*., 2010; SCOS, 2017). This represents approximately 0.4% of the UK population.

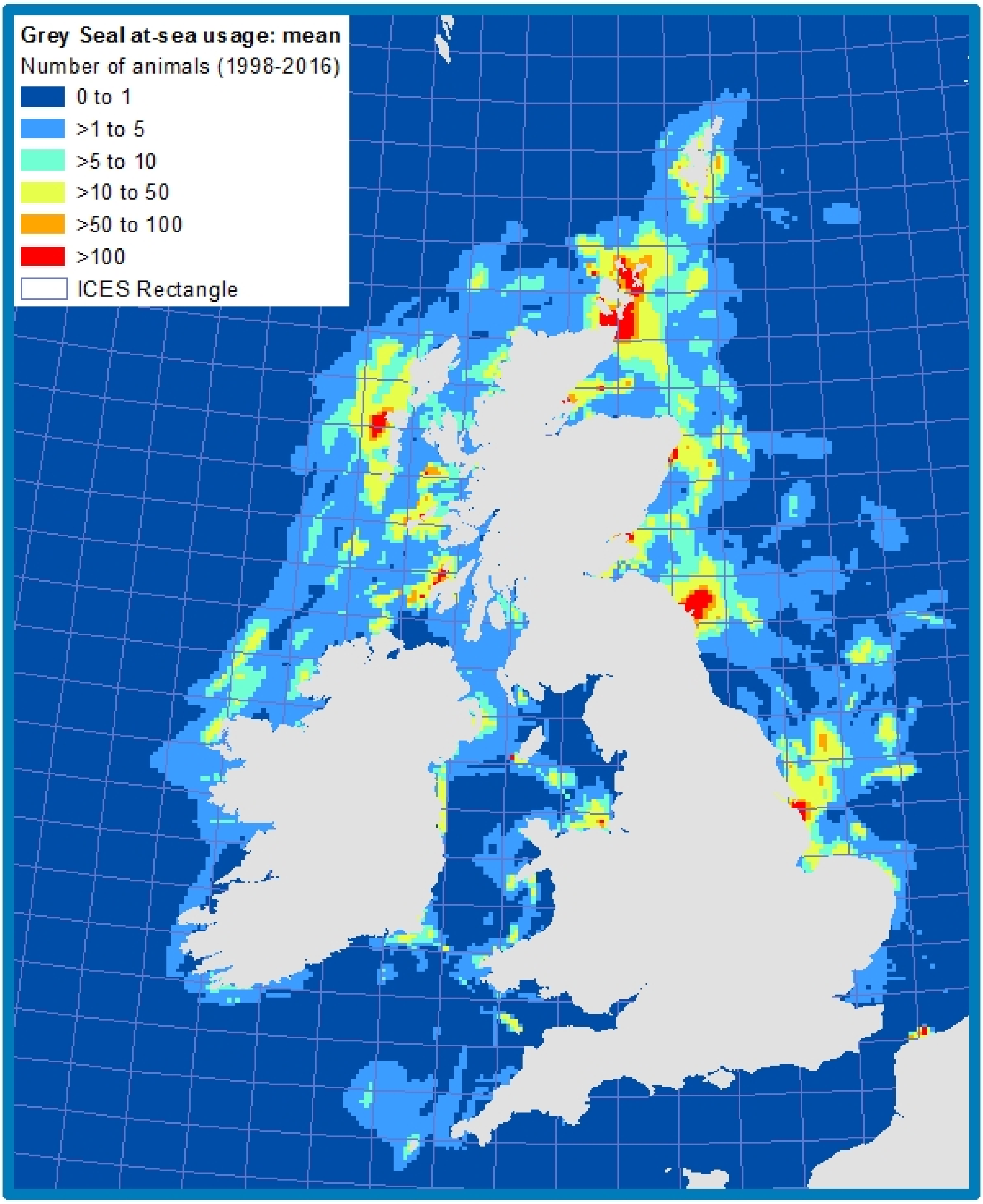
The largest grey seal populations in the region are recorded around the Isles of Scilly and Lundy Island. Leeney *et al.* (2010) found the largest grey seal colonies in the Isles of Scilly to occur around the Eastern Isles, Western Isles, and Norrard Rocks with 93, 165, and 25 hauled out grey seals recorded respectively. Westcott (2010) estimated that typically 125 grey seals were present at Lundy Island with little variation in numbers throughout the year. Annual pup production appeared to be 40 to 45 (26% to 32% of the population), probably varying from year to year according to sea conditions (Westcott, 2010).

Small colonies of seals also occur along the mainland coast of the South West (and associated small islets). Leeney *et al*. (2010) found the largest known haul-out sites along the north Cornish coast to be at Longships Island (near Land's End), Godrevy Island (St Ives Bay) and Boscastle, with 21, 27, and 23 seals hauled out, respectively. Between these sites smaller haul-out sites were also recorded including along the Land's End peninsula, near Newquay and the Trevose Head/Padstow area. There are no substantial aggregations of seals on the south Cornish coast from Land's End although Leeney *et al.*, (2010) recorded small colonies (<20 individuals) around Lizard Point and Mevagissey Bay. Small colonies have also been recorded around Looe Island (Cornwall Seal Group, 2009). In Devon, small colonies are present around Morte Point (North Devon), the Mew Stone (River Dart) and Start Point[4] (Curtin, 2009).

Grey seals in the South West have been recorded ranging widely between haul-out sites within the region and also travelling to more distant colonies. For example, research using photo-identification methods and tagging identified interchange between seals at haul-out sites in Pembrokeshire such as Skomer Island and Ramsey Island and sites in west Cornwall; a distance of over 170 km (Boyle *et al*., 2012; Jones *et al*., 2015; Russel *et al*., 2017). Grey seals have also been recorded travelling freely across the Irish Sea between sites along the coasts of Ireland and Cornwall/Isles of Scilly (Kiely *et al*. 2000; Jones *et al*., 2015; Vincent *et al*., 2017). Grey seals have also been tracked crossing the English Channel from Brittany to haul-out sites in south-west England (Härkönen *et al*., 2007; Vincent *et al*., 2005; Vincent *et al*., 2017).

[4] http://www.bbc.co.uk/devon/content/articles/2008/01/14/seal_man_feature.shtml

Figure 2.2 Mean grey seal at-sea usage.
Source: Russell *et al*. (2017).



Despite these large movements between colonies, most grey seal movements occur in relatively close proximity to haul-out sites (as stated in Section 2.2.1) with at-sea usage mapping showing the highest densities in the vicinity of the main colonies of the region (see Figure 2.1 and Figure 2.2; Russel *et al*., 2017).

2.2.2 Harbour (common) seals

Approximately 30% of European harbour seals are found in the UK; this proportion has declined from approximately 40% in 2002 due to the more rapid recovery and higher sustained rates of increase in the Wadden Sea population (SCOS, 2017). Harbour seals are widespread around the west coast of Scotland and throughout the Hebrides and Northern Isles. On the east coast, their distribution is more restricted with concentrations in the major estuaries of the Thames, The Wash and the Moray Firth. England holds approximately 16% of the UK harbour seal population, with 79% in Scotland and 5% in Northern Ireland (SCOS, 2017). The location of major harbour seal colonies can be seen in Figure 2.3.

In Scotland, there have been general declines in harbour seal abundance in several regions, such as Orkney, Shetland, and the east coast, but this is not universal with some regions having increasing or stable harbour seal populations such as the Western Isles (Lonergan *et al*., 2007; Duck *et al*., 2013; Jones *et al*., 2015). Jones *et al*. (2015) summarise possible causes of declines in harbour seal numbers including vessel interactions (Bexton *et al*., 2012), diseases (Hall *et al*., 2006; Harris *et al*., 2008), biotoxin exposure (Hall and Fame, 2010), and inter-specific competition with grey seals (Bowen *et al*., 2003; Svensson, 2012). Estimated UK populations of harbour seals, based on counts on land and scaling by estimated proportion hauled out, totalled 43,500 in 2016 (approximate 95% CI: 35,600-58,000) (SCOS, 2017).

Harbour seals are found in a wide variety of coastal habitats and come ashore in sheltered waters, including on sandbanks, in estuaries and along rocky areas. Harbour seals normally feed within 40 to 50 km of their haul-out sites (SCOS, 2016). Harbour seals are generalist predators with varied prey, including sandeel, cod, herring, sprat, flatfish, octopus and squid (Tollit *et al.,* 1998; Kavanagh *et al.,* 2010; Wilson and Hammond, 2016).

Harbour seals are not believed to travel as far as grey seals, usually staying closer to haul out sites, typically within 40-60 km (Thompson *et al*., 1996; Cunningham *et al*., 2009; Tollit *et al*., 1998; SCOS, 2011). This is reflected in at-sea usage maps which show the highest densities of seal movements in close proximity to haul-out sites (Figure 2.4). However, seals tagged in The Wash have been observed making longer trips of between 75 and 120 km offshore during foraging trips averaging ten days in duration (SCOS, 2004). All seals tagged in The Wash were highly consistent in their individual foraging habits, repeatedly travelling to the same areas. No seasonality in behaviour was apparent, though diet varies seasonally based on the availability of prey (Hall *et al.,* 1998). All but one of the seals tagged remained faithful to the haul-out site at which they were recorded (SCOS, 2004).

Figure 2.3 Haul-out count data for harbour seals between 1996 and 2015. Source: Russell *et al*. (2017).

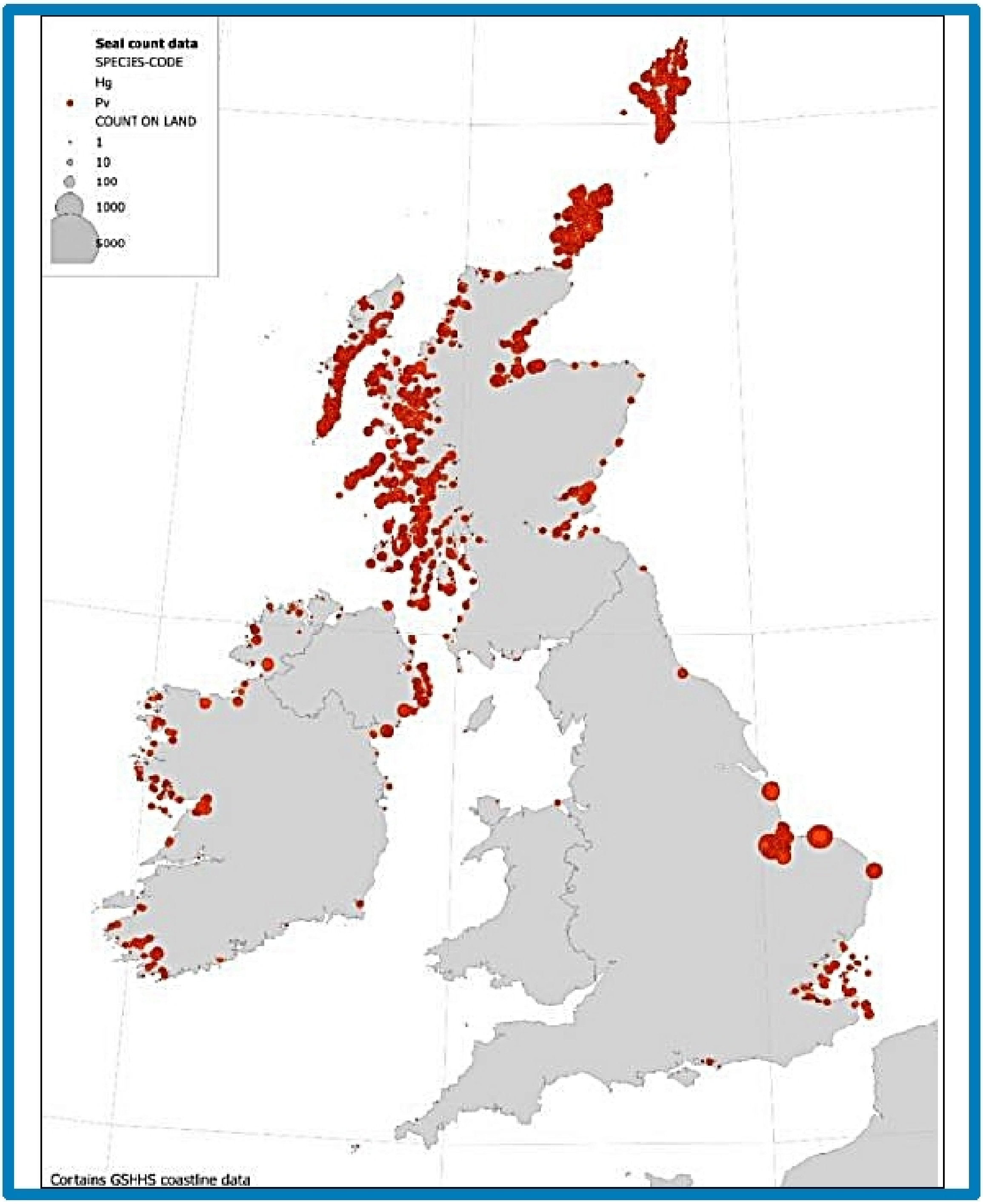
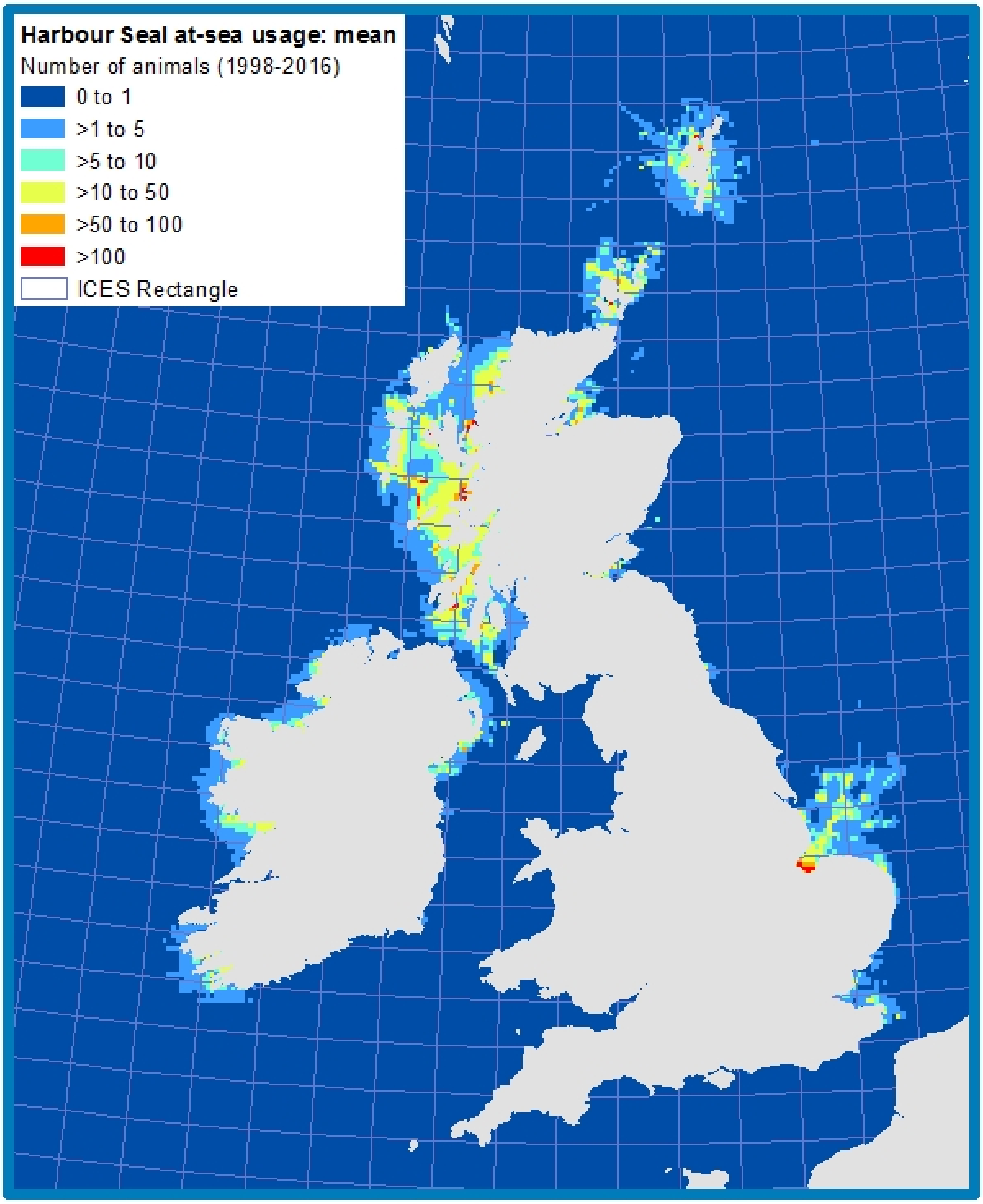


**Figure 2.4 Mean harbour seal at-sea usage.
Data source: Russell *et al*. (2017).**



Harbour seals in south-west England

Only very small numbers of harbour seals are present in the south-west of England, but are increasingly reported anecdotally (SCOS, 2017).

2.3 Fishing activities in regions with major seal colonies

As described above, within England, the main breeding colonies of grey seals are on the north and east coasts (around the Farne Islands, Donna Nook and on the Norfolk coast including the Wash) and the south west (primarily around the Isles of Scilly and Lundy), whilst harbour seal populations in England are concentrated around the Wash and the Thames. The main types of fisheries around these areas, in relation to the gears used and species targeted, are very briefly summarised below.

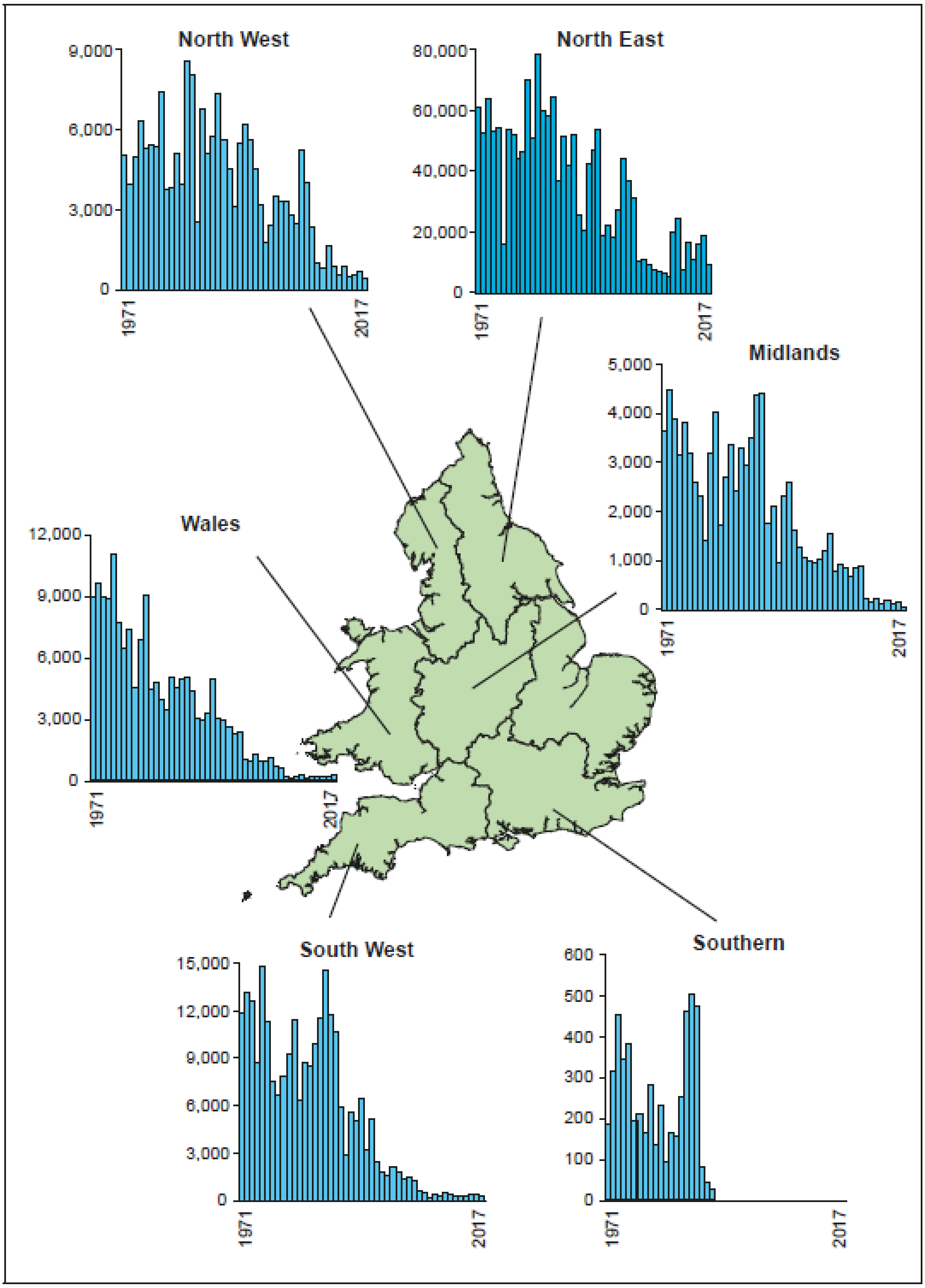
North-east England

In 2015, the majority of landings in the north-east of England (by volume) from over-15m vessels were caught using mobile gears, mainly dredges, demersal trawls and demersal seines, whilst only 2% were caught using passive gear such as gillnets, traps, pots, creels and longlines (MMO, 2017a). The most commonly-used gears by under-15m vessels in the north east are demersal trawls (for *Nephrops* and whitefish) followed by pots (targeting lobster, brown crab and whelk). There are relatively few vessels using nets, lines and dredges. This does not include data on salmon netters, which are licensed by the Environment Agency rather than the MMO. Figure 2.5 shows that the north-east of England lands the highest numbers of salmon (Cefas *et al.,* 2017). Fewer salmon are caught by rods, but the north east region still lands higher numbers compared with other regions.

The Farne Islands lie within the Northumberland Inshore Fisheries and Conservation Authority (IFCA) district, where the main species targeted are lobster and brown crab via pots and *Nephrops* via pots and trawls. Other gears are used to target other species, including gill nets for salmon and set nets for various finfish (Acoura, 2015).

Donna Nook is located on the Lincolnshire coast, just south of the Humber estuary close to the border between the North Eastern IFCA District and the Eastern IFCA. To the north and offshore the fisheries are dominated by vessels potting for brown crab and lobster, including beach-launched vessels along the East Yorkshire coast and larger vessels operating from Bridlington (East Yorkshire Coast, 2016). As summarised by NEIFCA (n.d.), to the south along the Lincolnshire coast, effort is mainly from small beach-launched boats. Effort is mainly directed using long-lines, gill and trammel nets at demersal species such as cod and rays. Some potting for crabs and lobsters takes place in the summer months.

Figure 2.5 Declared number of salmon caught by nets and fixed engines, 1971-2017.
Note: y-axes not to same scale. Source: Cefas *et al.,* 2017.



East England

In the Anglian region (off the Norfolk and Suffolk coasts), the most common fishing gears used include trawling, netting, rodding, long-lining and potting (Emu, 2012, cited in ABPmer 2013). Species targeted using nets include cod, sole, flounder, seabass (using gill and trammel nets), sharks and rays (using tangle and trammel nets) and herring (using drift nets) (Limpenny *et al*, 2011 cited in ABPmer, 2013). Vessel Monitoring System (VMS) and surveillance data from 2007-2009 indicated that netting activity was predominately concentrated around Lowestoft (ABPmer, 2013). Long-line vessels fish up to 60 miles offshore targeting cod, ray and sole from Lowestoft to Felixstowe Ferry.

Around the Norfolk coast specifically, vessels target mainly crab and lobster (using pots), whilst fishing activity in the Wash is mainly using mobile gears including shrimp beam trawls and dredges (HM Government, 2014; ABPmer & Ichthys Marine, 2015). Based on landings data from ICES rectangles adjacent to the Wash, a relatively small proportion of landings between 2009 and 2013 were caught using drift and fixed nets, compared to landings caught using beam trawls, dredges, other mobile gears and pots/traps (ABPmer & Ichthys Marine, 2015).

South-east England

In south-east England, the most commonly used gears by under-15m vessels are demersal trawls, followed by nets and lines. Fishing effort using nets and lines is highest adjacent to the Essex coast. There are relatively few vessels using pots and no vessels using mobile pelagic gear or dredges. The main demersal fish species landed are sole, bass, cod and plaice (MMO, 2016).

South-west England – Devon and Cornwall

The most commonly-used gears by under-15m vessels are pots, nets and lines. Potting effort (targeting lobster, brown crab and spider crab) is highest along the south Devon coastline. Vessels using nets and lines are also concentrated along the south Devon coast, with fewer vessels operating off the north coast. Demersal trawling is the most widespread activity by under-15m vessels, albeit by fewer vessels compared to those using pots, nets and lines. There are relatively few under-15m vessels using mobile pelagic gears and dredges. Cuttlefish are also an increasingly important fishery off the south Devon coast (Fishing News, 2017).

Within the Cornwall IFCA district, pots and nets are used within the 6 nautical mile (nm) limit. There is extensive netting along both coasts, but predominantly the southern coast, for a range of species including turbot, sole, plaice, haddock, cod and monkfish. Some vessels are involved in a seasonal net fishery for pilchards; there are 14 ring netters targeting sardines on the south coast, between Mounts Bay and Plymouth (an emerging fishery). A hake fishery, certified by the Marine Stewardship Council, has developed recently targeted with bottom-set nets outside 12nm (MMO, 2017b).

2.4 Distribution of net fisheries in England

More specific information regarding the distribution of net fisheries around England are provided in Figure 2.6 to Figure 2.8.

Figure 2.6 shows the value of landings from vessels (15m and over) using nets in 2016. The figure shows that there are important areas off the north and south coasts of Cornwall which are valuable areas for net fisheries. It should be noted that as this figure is based on VMS data, it only represents the fishing location and value of landings from vessels 15m and over[5].

Figure 2.7 shows the value of landings from drift and net fisheries, by ICES rectangle, around England. This data represents the value of landings by both over-15m vessels and under-15m vessels, although it may underestimate the value of catches landed by under-10m vessels which declare landings through the buyers and sellers register rather than through landings declarations. In addition to highlighting the high value of net fisheries off the north and south of Cornwall, the figure also highlights the importance of net fisheries (with respect to landings value) along the south coast of Devon, the west and east Sussex coastline and the Greater Thames Estuary and Suffolk coastlines.

To further capture areas that may be utilised by smaller inshore vessels, Figure 2.8 shows the number of inshore netting vessels sighted (standardised for IFCA patrol vessel effort) between 2007 and 2009, from the National Inshore Fisheries Data Layer. The figure indicates that the areas where under-15m netting activity is highest in England include:

- north-east England, particularly between Alnmouth and Tynemouth off the Northumberland coast
- the Greater Thames Estuary (with higher intensity areas around Margate, Mersea Island and Southwold)
- south-east England, particularly between Brighton and Hastings
- south-west England, particularly Lyme Bay, the south and north coasts of Devon and Cornwall and the Scilly Isles; and
- two areas in the north-west of England: off the Lancashire coast (adjacent to Blackpool) and off the Cumbrian coast (around St Bees Head).

Comparison of the figures showing the distribution of grey and harbour seals (haul outs and at-sea usage) and of areas of netting activity, indicate that there are potentially significant overlaps between seals and netting activity in the following areas in England:

- for grey seals:
    - the north east – specifically around Alnmouth;
    - the east coast – around Great Yarmouth/Lowestoft and Southwold;
    - the south west – particularly the Isles of Scilly, Land’s End and north Cornwall coast.

- for harbour seals:
    - the north-east – specifically off Tynemouth;
    - the east coast – around Great Yarmouth/Lowestoft;
    - the south-east – around Felixstowe and Sheerness, the Greater Thames Estuary, to Dover.

[5] Although vessels 12m and over have required VMS since 2013, the publically available VMS data still only represents vessels 15m and over.

Figure 2.6 Value of landings from over-15m vessels using nets, 2016.

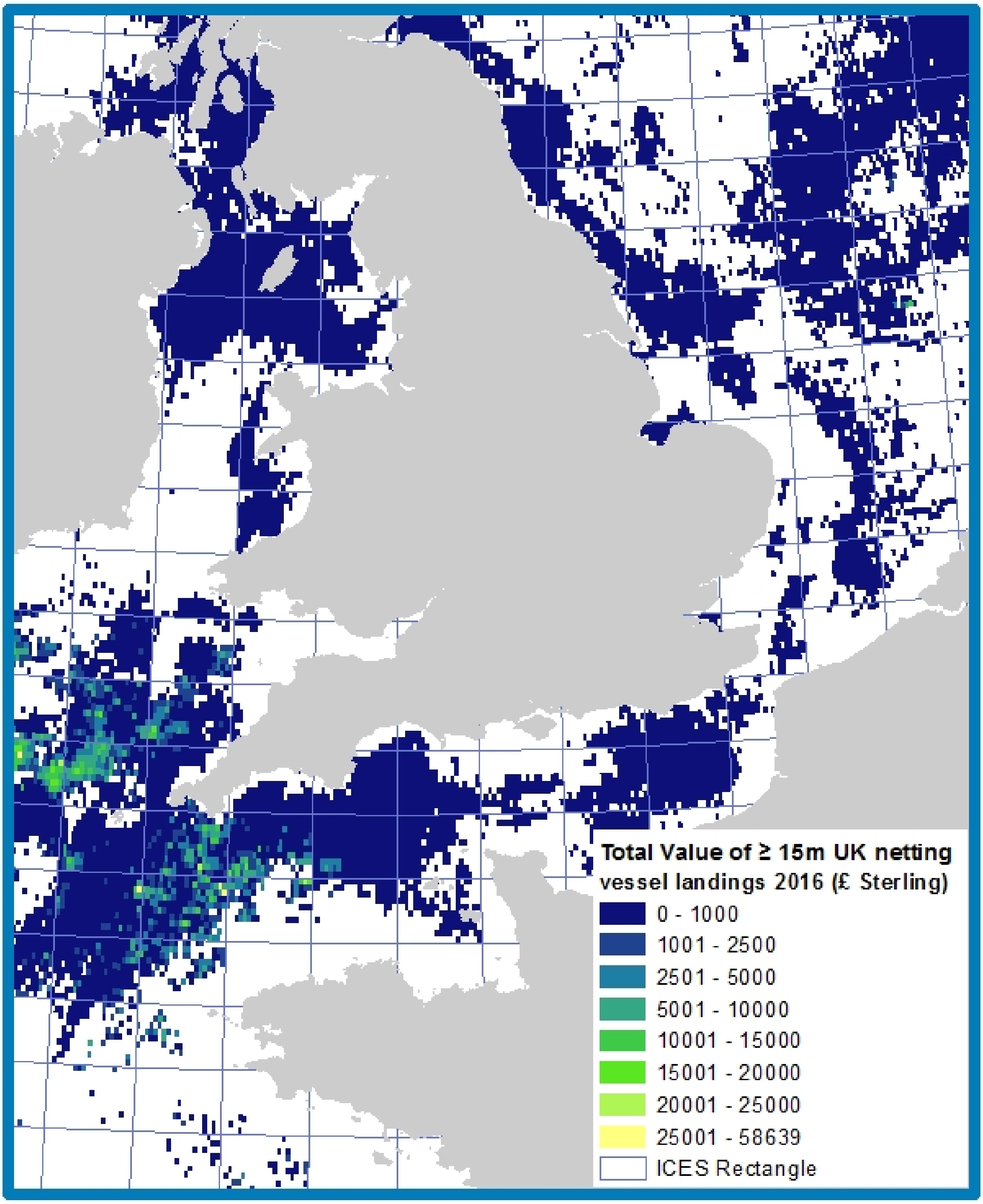


Figure 2.7 Value of landings by UK netting vessels (over-15m and under-15m), 2016.

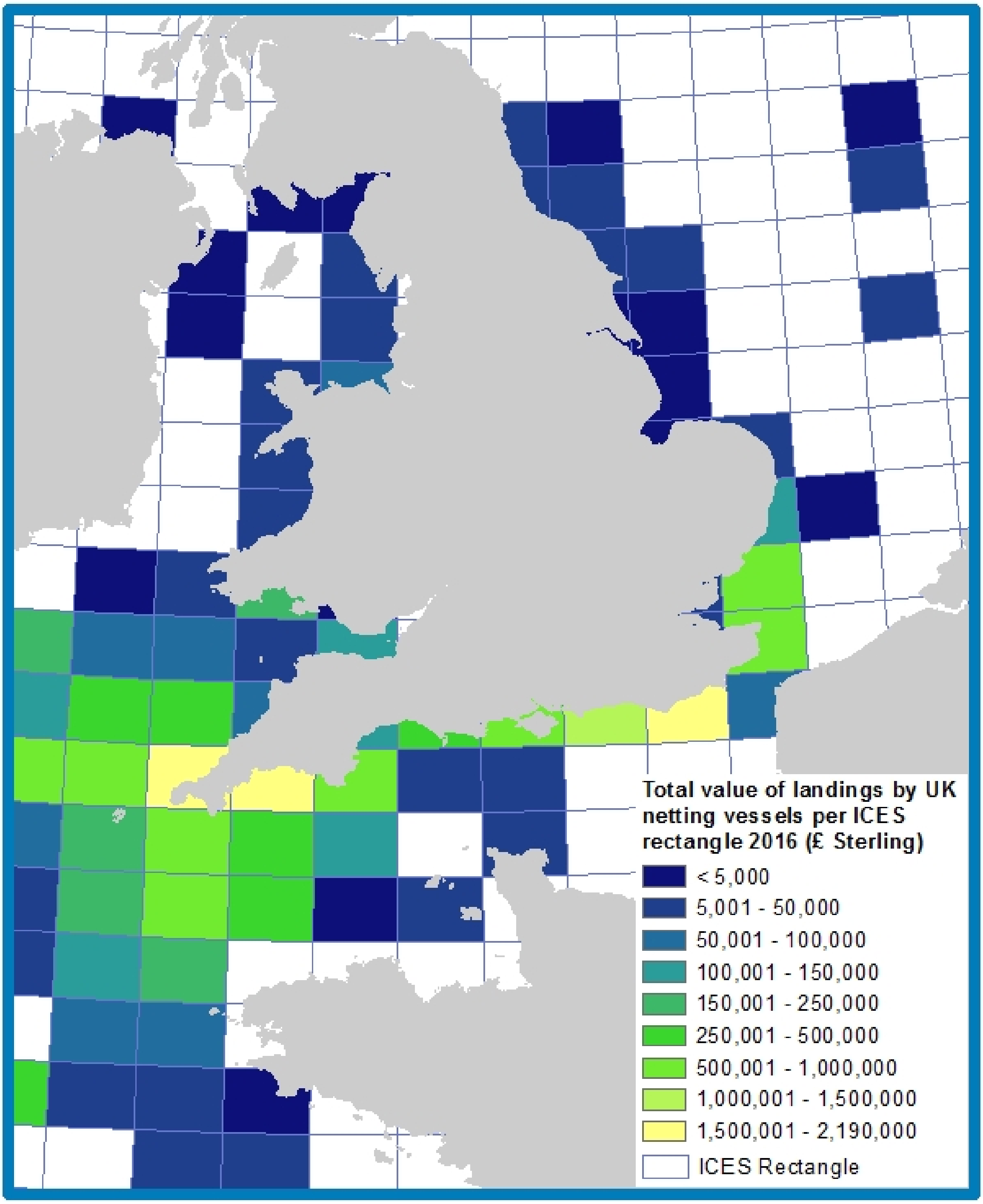
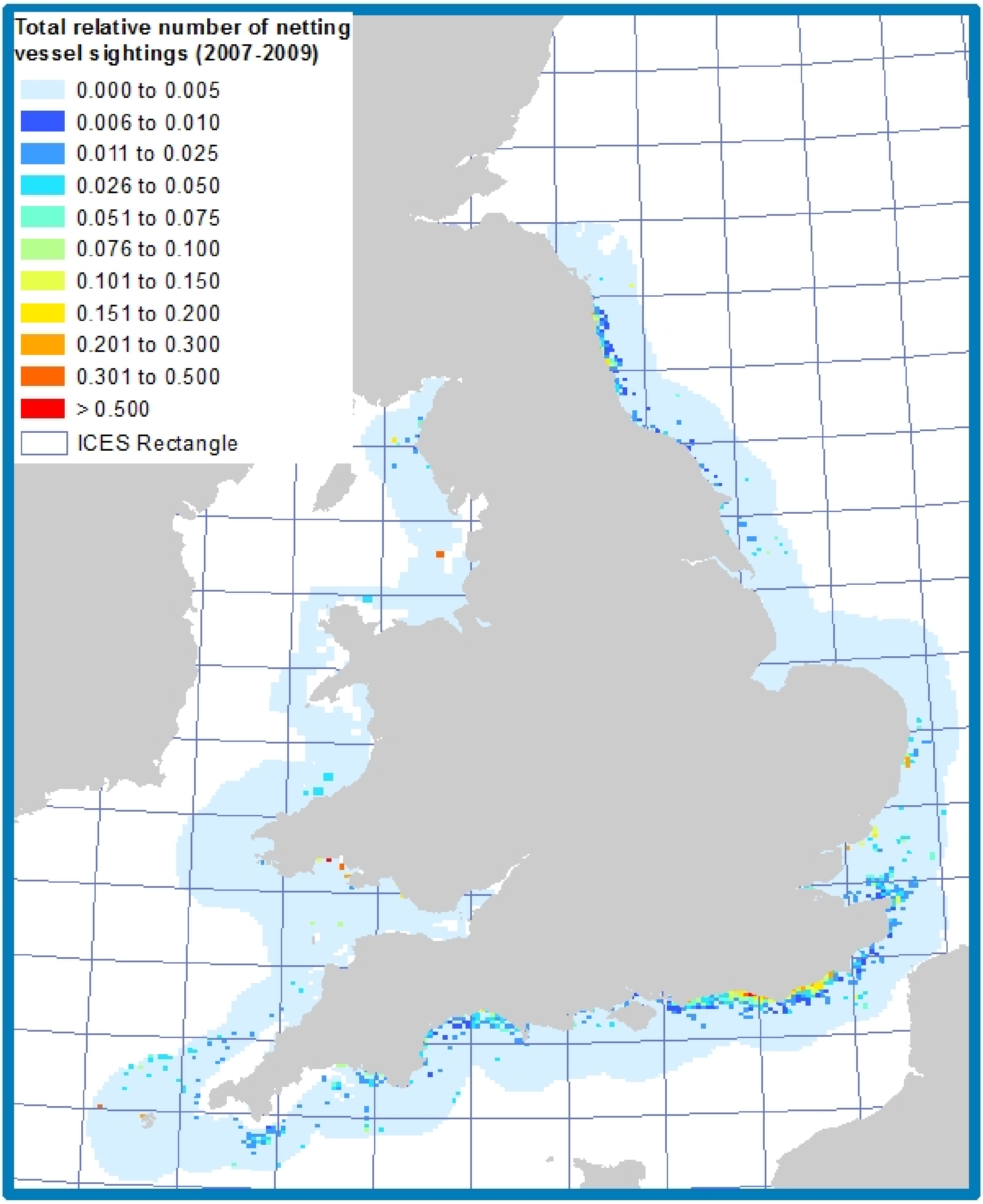


Figure 2.8 Relative number of netting vessel sightings from National Inshore Fisheries Data Layer (2007-2009).



2.5 Feeding behaviour in seals

Seals use a variety of mechanisms to detect and hunt for prey. Unlike dolphins and porpoises, seals do not detect prey using sophisticated active biosonar systems (echolocation) (Schusterman *et al.*, 2000). Pinnipeds must return to shore where airborne vocal communication is important for social interactions, and so airborne hearing has shaped the pinniped auditory system. However, seals use underwater passive acoustics to hunt, listening for prey species that may be swimming, struggling or foraging (Myrberg, 1981). Visual cues are also used by seals to detect prey (Schusterman *et al*., 2000; Fjälling, 2007). This is evidenced by seals having eyes primarily suited to vision in water rather than air, with large lenses and pupils, and densely packed rod-dominated retinas, allowing vision in less intense light (Landau and Dawson, 1970; Schusterman *et al*., 2000). Seals also use their vibrissae (whiskers) to detect food and movement (Schusterman *et al*., 2000; Dehnhardt *et al.,* 2001). They do this by detecting and following vibrations from hydrodynamic trails/wakes generated when objects move through the water (for example, fish) (Murphy *et al.,* 2017). Seals can locate and determine the direction of movements several minutes after the disturbance has been generated (Schulte-Pelkum *et al.,* 2007; Wieskotten *et al.,* 2010). The use of smell to detect prey is less documented, and Lavigne (2009) suggest seals keep their nostrils closed in water. However, harbour seals have been shown to detect, and be attracted to, ambient concentrations of dimethyl sulphide in the air (generated by some plankton types, the scent can be associated with high marine primary productivity) (Kowalewsky *et al.,* 2006).

2.5.1 Factors influencing depredation behaviour

Cosgrove *et al*. (2013) considered the influence operational fishing methods have on seal depredation in Irish waters. They conducted a study on three fishing vessels within pollack and hake set-net fisheries between June 2011 and July 2012. Depredation in the pollack fishery was more prevalent than in the hake fishery, with 18% and 10% of landings affected, respectively. The following factors were investigated by Cosgrove *et al*. (2013) and are reviewed in this section, based on Cosgrove *et al.* (2013) and supplemented with information from other studies where relevant:

- soak time
- depth
- hauling and haul speeds
- fishing activity (haul sequence and amount of gear deployed) and noise
- location
- season
- day/night deployment
- net type.

It is important to note that it is intrinsically difficult to separate these co-existing factors, and to identify which factors were acting as a proxy for other correlated variables. However, where there was an absence of major correlations between these factors, modelled information yielded useful analysis.

Soak time

Soak time of nets affected seal depredation, and was predicted to increase depredation by approximately 5% per hour of gear deployment. This was only applicable to the pollack fishery; the hake fishery did not seem to be affected by soak time. This effect of soak time on depredation was also found in Cape Cod’s fixed gear sector in Massachusetts, USA (Rafferty, 2008). The reasons for this may be associated with the increased noise or vibrations that caught fish release which may attract seals to the nets, with this effect increasing as more fish are caught over the soak time (Gosch *et al*., 2017). Otherwise, seals encountering nets by chance would also increase with time. The differences between the species and the effects of soak time may be attributed to depth (see below).

Depth

The variation in the effect of soak time on seal depredation may be related to depth. The mean depth of nets in the pollack fishery (78 ± 44 m) was less than mean depth in the hake fishery (152.04 ± 24.51 m). Although net depth in the hake fishery did not exceed the range of grey seal dive depths, it exceeded the average dive depth in the area (Jessop *et al*., 2013). Therefore, it may be the case that seals preferentially depredated on the shallower pollack nets due to easier accessibility. Seal depredation also generally occurred between 25 and 57m depth in Cape Cod, Massachusetts (Rafferty, 2008). It is also noteworthy that harbour seals (which were not considered the primary depredating species in the Cosgrove *et al.,* (2013) study) are shallower divers than grey seals, with most dives up to around 40-60m depth (Tollitt *et al.,* 1998; Gjertz *et al.*, 2001), and therefore may be limited in depredating deeper set nets.

Hauling and haul speeds

Cosgrove *et al*. (2013) suggested that seals tended to depredate fish during hauling for deeper nets, evidenced by seals on the surface near net marker buoys before hauling commenced. This reflects a learned behaviour which may reduce energetic demands of diving on deeper-set nets. Therefore, for deeper nets, it may be the case that soak time was less influential on seal depredation because seals were not depredating fish whilst nets were set. However, for shallower nets, depredation increased with soak time as seals did not need to wait for hauling to commence before feeding.

Slower hauling speeds may also allow seals to depredate more readily during hauling. The pollack fishery in Ireland is also associated with underwater rocky peaks or wreck habitat where pollack tend to be caught in large aggregations. The relief of these areas requires slower hauling speeds, which increases the vulnerability to depredation by seals (Cosgrove *et al*., 2013). In contrast, the offshore location of the hake fishery, as well as more even ground tends to disperse catches evenly in the nets. This means that greater catches (which are removed from nets during hauling) have less of an impact on hauling speeds, and therefore may be a cause of the lower levels of depredation by seals compared to pollack (Cosgrove *et al*., 2013).

Fishing activity and noise

In relation to the hake fishery, the amount of gear deployed in one day had a positive relationship with seal depredation, and seal depredation increased with sequential hauls (Cosgrove *et al*., 2013). This is thought to be related to the fact that seals may be gradually attracted to areas of fishing operation by the noise of a vessel, or fishing activity in general, resulting in a ‘dinner bell’ effect (Stansbury *et al*., 2016). In addition, sounds introduced to the marine environment with the intention of deterring predators may actually attract them (see Section 2.6.1).

Location

A relationship between the location of nets, and areas of usage by seals was observed by Cosgrove *et al*. (2013), with higher depredation in high-usage areas. This may also be the case with aquaculture installations; seals may not necessarily focus foraging activities close to farms, but may take advantage if farms are located in close proximity to their haul-out site (Nelson *et al*., 2006; Northridge *et al*., 2013; ICES, 2014). Fishermen and seals share fish resources so it is likely they target the same areas, and thus seals are more likely to encounter nets and depredate fish close to seal colonies or foraging areas (Gosch *et al*., 2017).

Seasonality

Seasonality may also influence depredation. In the hake fishery, higher depredation rates were observed in autumn, which may be explained by increased foraging effort prior to the breeding season (Cosgrove *et al*., 2013). Grey seals tend to spend most time at sea during summer, and ashore during breeding and moulting periods (between September and April) (Cronin *et al*., 2014; Vincent *et al*., 2017). Variations in depredation across seasons may also be related to availability of free swimming prey (Cosgrove *et al*., 2013). For example, winter decreases in zooplankton abundance may consequently affect both prey and predator abundance seasonally (Rafferty *et al.,* 2012).

Day/night deployment of gear/visual cues

Some gill net vessels currently deploy gear overnight in attempts to reduce depredation (Cosgrove *et al*., 2013). Evidence that seals use visual cues to depredate on nets supports this practice (Fjalling *et al*., 2007). Thompson (1991) also found that harbour seals in the Moray Firth fed more often during the day when feeding on winter clupeids. This may be because clupeids[6] formed dense schools in deep holes on the sea bed during the day, and migrated to the surface and dispersed at night. Thus, preferences for daytime feeding may be related to diel migrations of these species and success with capture. However, others suggest seals spend more time at sea at night, probably due to nocturnal changes in prey movements (Bjørge *et al*., 1995; Lesage *et al*., 1999). Predation of salmon in Scotland has also been recorded at night, though this may be aided by artificial illuminations (Carter *et al*., 2001). In Japan, Kuril harbour seals *Phoca vitulina stejnegeri* predating on a chum salmon setnet fishery became more active from sunset to night time (Fujimori *et al.,* 2018).

Net type

No evidence of the type of netting (for example gill net, trammel net, tangle net) or mesh size affecting depredation rates was found, although it was found to affect by-catch (see Section 2.1).

[6] Marine forage fish – from the family Clupeidae, typically having oily flesh, includes herrings and sardines

2.5.2 Individuals undertaking depredation

Net-foraging behaviour is a learnt behaviour and ‘specialised’ seals repeatedly return to depredate (known by identification of seals, usually photographic/video evidence), which suggests predator control could be specifically targeted at problem individuals (Scottish Salmon Growers Association, 1990; Morris *et al*., 1996; Graham *et al*., 2011; Cronin *et al*., 2016).

In the Moray Firth in Scotland, less than 1% of the local grey seal population were found to specialise in foraging for salmonids in rivers and were thereby regarded as ‘problem individuals’ due to increased interaction with fishing and angling interests (Graham *et al*., 2011). Furthermore, harbour seals raiding fyke nets in Sweden were the same individuals returning to the nets (Königson, 2011). Königson *et al*. (2013) filmed grey seals raiding a salmon trap fishery in Sweden and identified 11 individual problem seals, which were mainly adult males; 426 out 600 seal visits to the traps were made by these individuals over two seasons. These 11 individuals constituted approximately 1% of the local population, with the nearest haul out site being 45 miles south of the study area.

The Moray Firth Seal Management Plan only targets problem seals in rivers for shooting (Butler *et al*., 2008), despite Scottish fishermen believing all seals are responsible for depredation in salmon fisheries (Butler *et al*., 2011). It is likely that the number of individual seals undertaking depredation is site specific. However, most scientific studies suggest it is small percentages of seals from local populations that are responsible for depredation. Nevertheless, this highlights the need for management decisions to be based on a good understanding of seal-fishery interactions.

2.6 Non-lethal deterrent and avoidance measures to reduce seal-gear interactions

Broadly, deterrents are management techniques that use aversive stimuli to prevent animals using human resources (Ramp *et al*., 2011). Stimuli are required to be aversive, harmful, fearful, or noxious, eliciting a defensive response (Götz and Janik, 2010). A deterrent must cause enough real or perceived risk so that the costs of using a resource (i.e. caught fish in static nets) are greater than the foraging benefits of depredation (Schakner and Blumstein, 2013).

Available deterrent measures largely consist of acoustic deterrent devices (ADDs). This study also includes avoidance measures which include gear modifications, and/or consideration of fishing tactics where the intent is to reduce seal interactions as opposed to making those interactions aversive. They are reviewed below.

2.6.1 Acoustic deterrent devices

ADDs are the most documented method of deterring seals from fisheries to prevent depredation, particularly around fish farms (Quick *et al*., 2002; ICES, 2014). They work by emitting a noise from an underwater speaker that either causes pain or is distracting enough to create an aversion and causes the animal to flee an area (Jefferson and Curry, 1996). They operate at various duty cycles (amount of time a device is active during an on-off-cycle), pulse durations, and frequencies. However, there can be differences in the measured acoustic characteristics for ADDs across studies and manufacturer specifications as they can be affected by environmental conditions and power supplies. Most require a car battery (approximately 12 V), a transducer, amplifier and a speaker. Table 2.1 lists details of commonly used ADDs to prevent pinniped depredation. All ADDs discussed in the proceeding sections are marketed as pinniped deterrents.

Table 2.1 Acoustic characteristics of acoustic deterrent devices to prevent pinniped depredation.
Source: Adapted from Götz and Janik, 2013, 2015, 2016; Coram *et al*., 2014; Sparling *et al*., 2015 (and references cited therein).

Manufacturer	Model	Source Level (decibel (dB) re 1 micropascal (μPa) m)	Frequency (kilohertz (kHz))	Pulse durations (millisecond (ms))	Duty cycle
Airmar	dB Plus II	192 (root mean square) at 10.3kHz	10 (tonal - with harmonics)	1.4ms at 40ms intervals	50% to almost continuous during typical operation with >1 transducer
Lofitech	Universal Scarer	182 (root mean square) at 14.9kHz	14 (tonal - with harmonics)	~500ms over variable length blocks	10 to 25%
Ace Aquatec	Universal Scrammer 3	193 (root mean square) at 10kHz	10 - 65 (broadband)	3.3 to 14ms with 33.2 to 48.5ms intervals	50%
Terecos Ltd	DSMS-4	178 (root mean square) at 4.9kHz	2 - 70 (broadband)	Variable (~8ms in 8 or 16ms sequences)	Variable
Ferranti-Thomson	4X	200 (unspecified) at 25kHz	7 - 95 (broadband)	20ms repeated every 40ms	3% max.
Genuswave	SalmonSafe ™	180 (root mean square) at 1kHz	1 (central band)	200ms	0.8 to 1%

Range of deterrent effect

Predicting the aversiveness of an ADD relies on many contextual and species-specific factors such as ambient noise, bathymetry, geology, and hearing thresholds of seals (Coram *et al*., 2014). Therefore, it is difficult to determine the range of effectiveness for ADDs, compared to the theoretical range of audible detection. The range of effectiveness is likely to differ depending on the specific situation. Furthermore, behavioural responses are likely to be context specific (Ellison *et al.,* 2012). In other words, high-level sounds may trigger behavioural responses that are independent of species-specific hearing capabilities (Hawkins *et al.,* 2015). Behaviour may be more strongly related to the particular circumstances of the animal, the activities in which it is engaged, and the context in which it is exposed to sounds (Ellison et al., 2012).

A number of studies document the effective use of ADDs. Graham *et al*. (2009) tested a Lofitech Seal Scarer device in the River Conon and River North Esk, Scotland. Seal movements upstream, past the device, were reduced by approximately 50% when the device was switched on (periods of several days, up to one month continuously). However, the ADD did not significantly affect seal abundance in the study area. This could be due to a limited effective range of the ADD due to the shallow depths and constrained nature of a river environment.

A similar attempt to deter seal movement in Puntledge River, British Columbia, was undertaken by Olesiuk *et al*. (1996). This found that seals travelled upstream, past an ADD, in order to reach a well-known seal foraging site at a bridge. This may indicate that seals are prepared to tolerate ADDs where a motivation exists to do so (for example to reach a foraging or haul-out site) (Graham *et al*., 2009). However, another study in the same river placed an Airmar dB plus II ADD at the bridge foraging site. This prevented seals feeding within a 50m radius of the ADD (compared to a mean of eight individuals feeding in the absence of the ADD), and displaced seals to an alternative (though poor) feeding site downstream on subsequent nights (Yurk and Trites, 2000). Furthermore, Fjälling *et al*. (2006) found ADDs (Lofitech AS) in a salmon trap net fishery in the Baltic Sea reduced damage to both catch and gear and increased the amount of intact landed catch over three years.

An effective range of 60 to 250m has been reported for Genuswave Ltd ADD following field trails with harbour and grey seals (Götz and Janik, 2011; 2015). This is likely due to the use of fast rise times and startle responses in the noise profile of the device, which is reviewed further below (sub-section 'Frequency of ADDs and startle responses').

It may be the case that ADDs are effective in protecting relatively small areas such as narrow rivers (Harris *et al*., 2014), as acoustic signals vary depending on topography and are more constrained in a river environment (Gordon and Northridge, 2002; Northridge *et al*., 2010). Therefore, ADDs deployed in open sea locations may be less effective compared with semi-enclosed locations.

Habituation

Despite reports of the successful use of ADDs, it is evident there are still many uncertainties surrounding their effectiveness. Ineffectiveness has sometimes been attributed to habituation. Jacobs and Terhune (2002) showed that harbour seals familiar with the AirMar dB Plus II ADD signal showed no behavioural response when switched on; one individual approached within 45m of the device and seals passed close by to reach a haul-out site. The authors also measured sound pressure levels from ADDs around aquaculture sites in the Bay of Fundy, Canada, which averaged ~160 dB. Although seals would easily be able to hear this, they suggested this was unlikely to reach the pain threshold of seals, and so would offer poor protection from seal depredation, and may result in habituation. Mate and Harvey (1987) showed that while ADDs at salmon hatcheries reduced depredation for three years and reduced recruitment of new individuals, depredation returned to the original level after four years. Additionally, some studies revealed depredation to increase when ADDs were switched on, which may indicate an originally aversive sound had become a conditioned reinforcer (Geiger and Jefferies, 1987; Jefferson and Curry, 1996; Götz and Janik, 2013). Seals may also swim with their head above the surface to avoid the effects of ADDs, or may not be effected by ADDs due to deafness (Götz and Janik, 2013; Harris *et al.,* 2014; Gosch *et al*., 2017).

Hearing damage to seals and non-target species and habitat exclusion

The sound from an ADD is often designed to exceed a discomfort threshold or inflict pain in order to be efficient as a deterrent (Kastelein *et al*., 2006; Götz and Janik, 2013). Both risk hearing loss, and is of concern regarding the use of ADDs. Manufacturers of ADDs generally claim their products will not cause hearing damage (Ace-Hopkins, 2002). However, research suggests this still may be a contentious issue, and there is relatively little data to be able to rule out hearing loss. Users may also actively override in-built safety features. Given marine mammals have sensitive hearing, they may be particularly vulnerable to temporary threshold shifts[7] or permanent hearing damage if animals are exposed for long enough or habitually within areas close to transducers (Gordon and Northridge, 2002; Schakner and Blumstein, 2013; ICES, 2014). The marine environment is becoming increasingly noisy, and it would be preferable to avoid extra noise introductions which may be affecting aquatic life.

Estimates predict that a sound exposure level of 203dB re 1µPa^2 s (duration of exposure of 45 seconds to 48 minutes depending on ADD model, corresponding source levels and duty cycles) would cause a temporary threshold shift when harbour seals are less than 10m away from the sound source (Götz and Janik, 2013). The same sound exposure level would cause a temporary threshold shift when delphinids[8] are up to 3m away (Southall *et al*., 2007), and when porpoises are up to 89m away (Lucke *et al*., 2009). More conservative estimates by Götz and Janik (2013) suggest larger impact zones of 175m for bottlenose dolphins and 748m for killer whales. Permanent threshold shifts for the same sound exposure level are predicted to occur within 7m for seals, 2m for delphinids (Southall *et al*., 2007), and 9m for porpoise (Lucke *et al*., 2009). Götz and Janik (2013) suggest larger impact zones for permanent effects of 18m for bottlenose dolphins, and 35m for harbour porpoise. Permanent hearing damage over months or years may be expected within a zone of about 60m for pinnipeds, whilst odontocetes[9] may be affected up to 1 km (Götz and Janik, 2013). Nevertheless, as pinnipeds use passive acoustics for prey detection (Schusterman *et al*., 2000) and mating (van Parijs *et al*., 2000), even a weak hearing loss could impact individuals and lead to possible effects at population level (Götz and Janik, 2013). This could also render ADDs less effective and make animals more dependent on predictable food sources such as fishing nets (Götz and Janik, 2013). Impact zones for fish and other marine wildlife are much smaller or non-existent (Götz and Janik, 2013).

[7] A temporary threshold shift is hearing damage as a temporary but fully recoverable shift of hearing threshold. This may become permanent following exposure to sound pressure levels above the temporary threshold shift level, or prolonged exposure, known as a permanent threshold shift.
[8] Oceanic dolphins – dolphins in the sea including several big species whose common names contain "whale" rather than "dolphin", such as the killer whale and the pilot whales.
[9] Toothed whales – dolphins, porpoises and other whales with teeth such as beaked whales and sperm whale.

Other ecological issues with ADDs include the creation of habitat exclusion zones, masking of communication sounds, and inducing physiological changes such as stress (Götz and Janik, 2013). ADDs may cause displacement of non-target species from areas that may be important to their life history (Harris *et al*., 2014).

Northridge *et al*. (2010) reported that measurements at approximately 200m from an Airmar ADD (centre frequency of 10kHz) were 137dB re 1µPa. This resulted in reduced detections of harbour porpoise (measured by click detections) within this area, although complete exclusion did not occur possibly due to motivations to remain (for example feeding habitat) or habituation. This suggests the exclusion effect was voluntary rather than mandatory; harbour porpoise click detections recovered almost immediately when the ADD was switched off.

Johnston (2002) carried out experiments in the Bay of Fundy, Canada, and found porpoise density to be less during active ADD periods, with mean distances of 991±302m from the ADD, compared to mean distances of 364±261m during inactive periods. Morton and Symonds (2002) also found killer whales to be displaced by the introduction of ADDs on salmon farms in Canada from 1993 to 1999.

These studies all used Airmar devices, and there is evidence to suggest other devices, such as Terecos, cause weaker responses in harbour porpoise (Northridge *et al*., 2013; ICES, 2014). It has also been demonstrated that exposures to source levels of 165 dB re 1µPa at 12 kHz (similar to that of Lofitech devices), resulted in avoidance reactions up to 525m for porpoise, but seal observations increased within 100m of the device (Mikkelsen *et al*., 2017). This demonstrates that consideration needs to be given to the application of ADDs in multi-species habitats, and less sensitive species (seals) respond very differently to more sensitive species.

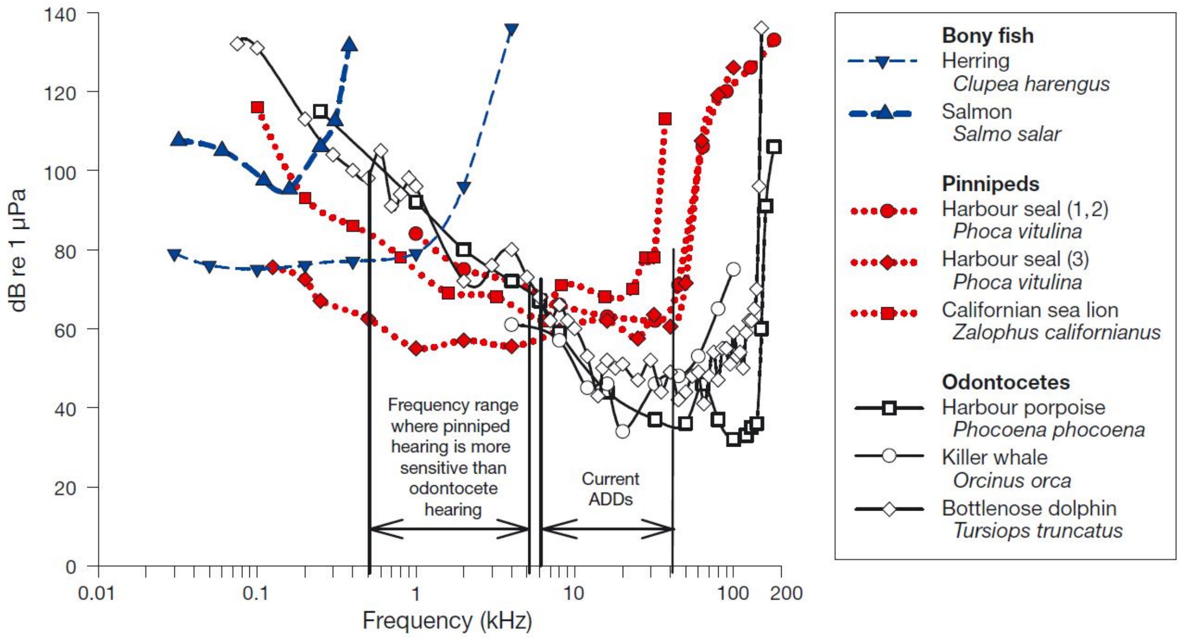
Frequency of ADDs and startle responses

As summarised by Götz and Janik (2013), the use of current ADDs have associated ecological effects like habitat exclusion zones for non-target species such as odontocetes. The relative high frequency of current ADDs may be attributable to this issue. Götz and Janik (2013) suggest ways to remedy effects on non-target species by exploiting lower frequency sounds (less than 5 kHz as opposed to ~10 to 40 kHz that most ADDs operate at) at which pinniped hearing is more sensitive compared to odontocetes (Figure 2.9). Although this may come in to the sensitive range of specialist hearing fish (fish with swim bladders/air cavities that aid hearing, such as herring) and baleen whales, evidence suggests most fish species (non-hearing specialists) show a rapid decline in sensitivity above frequencies of 500 to 1000 Hz, and as such are unlikely to be affected by frequencies discussed here (Kastelein *et al.,* 2007; Götz and Janik, 2013). In addition, hearing specialists such as clupeids are not more sensitive than odontocetes between 1 and 2 kHz (see Figure 2.9). However, potential effects on baleen whales, such as masking communicative signals and reducing communication space, needs further research (Götz and Janik, 2013).

Götz and Janik (2013) also suggest careful consideration of loudness and the effects on hearing; most ADDs operate close to the upper end of the dynamic range of pinnipeds and close to the pain threshold where there is some risk of permanent hearing damage (either immediately or over long exposures). Reducing duty cycles and signal durations would reduce the risk of hearing damage, and maximum sound pressure levels should be based on temporary threshold shifts for realistic exposure scenarios. Both exposure time and sound pressure level combinations are imperative considerations.

Most studies which test the use of current ADDs on depredation report some degree of ineffectiveness at deterring seals. This is primarily due to habituation particularly where there is motivation for pinnipeds to remain in an area (such as a food source). Methods to prevent habituation include classical conditioning paradigms, such as a fish treated with an emetic substance that causes sickness (unconditioned stimulus) associated with an artificial acoustic signal (conditioned stimulus). However, this does not seem to be very effective; an alternative may be to exploit startle responses of pinnipeds (Götz and Janik, 2013). Essentially this involves isolated sound pulses that have rise times[10] shorter than 15 to 20 ms and minimum amplitudes of at least 80 dB above auditory thresholds (Koch and Schnitzler, 1997). Grey seals have been shown to exhibit flight responses and signs of fear conditioning in response to startling stimuli (Götz and Janik, 2011). Seals also avoided a known food dispenser when also subjected to startling stimuli suggesting habituation did not occur, contrary to where animals are exposed to longer rise times.

Figure 2.9 Hearing thresholds for selected fish, pinnipeds and cetacean species.
Lower line indicates higher sensitivity. Note that most current ADDs (besides GenusWave Ltd) operate in a frequency range where cetacean hearing is more sensitive than pinniped hearing. Source: Götz and Janik (2013).



More recent studies by Götz and Janik (2015, 2016) further explored the use of startle responses to prevent depredation on salmon farms on the west coast of Scotland. Both used similar ADDs that emitted 2-3 octave-band noise pulses (200 ms duration)

[10] The time required for a pulse to rise from 10% to 90% of its steady value.

at a peak frequency of 1 kHz and sharp rise time less than 5 ms. Source levels were approximately 180 dB re 1µPa (Götz and Janik, 2015). An overall duty cycle of 0.8-1% was exhibited (Götz and Janik, 2016). This research has led to the development of a commercially available device, SalmonSafe™, which is available for lease from GenusWave Ltd[11].

Götz and Janik (2015) reported that seal tracks within 250m of the device were reduced by ~91%. No evidence of habituation was observed throughout the two-month study. Furthermore, the number of porpoises and common minke whales within 250m of the device was unaffected. Götz and Janik (2016) carried out a 12.5-month study and found sound exposure caused a 91% reduction in lost fish compared to pre-exposure levels, and a 97% reduction compared to control sites. Furthermore, a 93% reduction in the fish lost due to seal damage at a short-term test site was found. The sensitisation process to the startling stimuli may also have decreased dive times. Harbour porpoise and otter were also not affected by sound exposure; the central band at 1 kHz exceeded the auditory threshold of a seal by 98 dB at a 20m distance, whereas none of the 1/3 octave band exceeded the hearing threshold of a porpoise by more than 72dB (typically insufficient to trigger a startle response in mammals).

Despite reduced depredation, seal sightings at the surface increased within proximity to the devices (Götz and Janik, 2016). This is suggested to be because startling stimuli would drop below the startle threshold when the head is out of the water. Nevertheless, Götz and Janik (2015, 2016) report the use of a very effective ADD that did not show evidence of habituation, or effects on non-target mammal species due to the use of lower frequency sounds. Furthermore, supporting information submitted with Götz and Janik (2015) showed the signals used in these studies are unlikely to cause adverse effects on mammals, fish and invertebrates. The SalmonSafe™ ADD utilises these sound profiles investigated by Götz and Janik (2015, 2016).

Use of ADDs in static net fisheries

Much of the literature on ADDs and their use to prevent seal depredation is focussed on fish farms. Deployment of ADDs on fish farms is aided by a fixed structure that remains underwater (cages, pontoons), and associated platforms above the water, which aids installation of equipment, batteries etc. In contrast, static net features are not permanent, and the method of fixing a device to netting, the practical retrieval of the device, as well as power supply may not be feasible (Westerberg, 2010).

Large car batteries that are most often used to power commercially available ADDs will likely limit their applicability to deployment with static gear. As such, ADDs may only be employed in static net fisheries from vessels, and powering of devices from vessels would not be an issue (Hastie and Priede, 2011; Cosgrove *et al.*, 2013).

The North Eastern IFCA purchased Lofitech ADDs for use in net fisheries. These anecdotally worked well, but were vulnerable to malfunctioning following exposure to the environment, and maintenance costs were high, preventing ongoing use.

Commercially available ADDs are currently not designed to be submersed (surface control and power unit) and modification/developments may be required if they are to

[11] http://www.genuswave.com/

be used on static nets (Gosch *et al*., 2017). However, recent advances in small lithium-ion battery technology may make the deployment of ADDs on nets possible. Genuswave Ltd are currently in the process of producing a fully submergible pod for independent at sea deployment (Gosch *et al*., 2018; Figure 2.10).

Figure 2.10 Example of the fully submergible prototype ADD pod currently being developed by Genuswave Ltd.
Source: Thomas Götz and Gosch *et al*. (2018).

In fish farm operations ADDs are largely permanent additions to the marine environment. However, the use of ADDs in capture fisheries may only be introduced to the marine environment for as long as gear is deployed and/or hauled. Therefore, issues surrounding hearing loss, cetacean exclusion, and stress induction may be less pertinent (Cosgrove *et al*., 2013). Additionally, habituation may not be realised given nets are likely to be deployed in different locations and at different times, which may prevent seals from tolerating ADDs close to sporadic feeding opportunities at nets.

Initial studies using startle-eliciting ADDs (as specified by Götz and Janik, 2015, 2016) in static net fisheries were conducted in Irish waters by Gosch *et al*. (2017, 2018).

They showed preliminary evidence that these devices are effective at reducing depredation in set-net and jigging fisheries, whilst not affecting other marine mammals or seabirds. However, sample sizes were small and depredation with and without the device was generally low so these results have uncertainties. Gosch *et al*. (2017) also noted that the effective range of ADDs may limit the protection of long nets (circa. 4 km long), and found damaged fish to be hauled aboard dead, suggesting depredation was occurring away from the ADD before hauling. The study also found adult male seals (possibly the same individual) approached within 50m of the ADD, possibly due to deafness associated with old age, or too low a duty cycle/technical difficulties allowing approach.

2.6.2 Electrified netting

Electric currents can be used to prevent seals from feeding from passive gear and static net fisheries. This was tested on a gill-net fishery in the Fraser River, Canada (Forrest *et al*., 2009). A pulsed, low voltage DC electric gradient was transmitted through a gill net using two copper wire electrodes, one at the headline and one at 2m depth along the net. Salmon catch per unit effort was significantly greater for the treated (electric) section of the net compared to the non-treated section. There were no apparent injuries to animals during the study. However, this was tested in freshwater, and power to generate a sufficient voltage gradient in saltwater is more difficult (Westerberg, 2010). Nevertheless, preliminary trials of applying electrical currents in seawater have shown grey and harbour seals in captivity are responsive to low voltage pulses (Milne *et al*., 2012). Ace-Aquatech have recently developed an electric net to be deployed with their acoustic deterrent[12]. Empirical evidence of its effectiveness has not yet been gathered.

2.6.3 Gear modifications and alternative gear types

Anti-predator, or barrier nets have been used to block seals from reaching fish farms. Sepúlveda and Olivia (2005) carried out surveys of various methods of preventing sea lion *Otaria flavescens* depredation in salmon fish farms in Chile. Anti-predator nets were a commonly used protective device and were deployed in four arrangements. These either completely enclose the pen, or hung down to the substrate. Farmers reported nets to be either moderately or very effective. Coastal trapnet fisheries for salmon and whitefish in the Baltic used a wire grid to prevent seals entering nets, increasing undamaged catch by up to 70% (Lehtonen and Suuronen, 2004). However, means of deploying barrier nets around static fishing gear are likely to be impractical. Seals could be likely to find a way through the barrier to feed at static gear (Northridge *et al*., 2013), or the area to be enclosed would be too large. Barrier nets may also prevent or deter fish from reaching the static gear. Furthermore, they may increase the risk of bycatch unnecessarily (Northridge *et al*., 2013; ICES, 2014).

Pot, or fish trap fisheries are considered an alternative to gill-net fisheries in the Baltic using pots of a design developed in Norway (Bjordal and Furevik, 1988; Furevik and Løkkeborg, 1994; Westerberg, 2010). Pots are floated a distance above the seabed. This not only orientates the entrance to the pot downstream increasing catch efficiency, but the pot also moves away from seals when they attempt to push against

[12] http://www.aceaquatec.com/us3-overview

the side or top of the pot (Westerberg, 2010). Conversely, a pot laid on the seabed allows seals to gain purchase and fish can be chewed from the outside. Damage of this kind has been observed after depredation by harbour seals (Königson *et al*., 2007). Furthermore, anecdotal evidence exists for seals raiding cod and lobster pots in Scotland; a seal caught in a cod trap suggests seals may find a way into this type of gear (it may the case that the cod trap was pushed against the seafloor by currents etc., evidenced by benthic species capture, facilitating access).

Results from testing of a cod pot fishery show pots are a viable alternative to gill-net fisheries with similar catches in the Baltic Sea (Königson *et al*., 2010). It has also been suggested that the reintroduction of pots over the long term has potential as an alternative gear to tangle nets in Irish crawfish fisheries (Cosgrove *et al*., 2013). However, the effectiveness of potting for species such as pollack and hake is unknown, and major investment would be required for diversification of gear, and testing of its effectiveness for each target species (Cosgrove *et al*., 2013). Further gear modifications are also required to ensure gear is entirely protected from depredation. Indeed, more recent evidence provided by fishermen suggest seals may be able to adapt to take bait from pots in Irish fisheries (Cronin *et al*., 2014).

2.6.4 Visual and olfactory deterrents

Killer whale *Orca orca* is the major predator of seals and other pinnipeds in all global regions. Sepúlveda and Olivia (2005) analysed the effects of deploying fibreglass models of killer whales to reduce depredation by sea lion *Otaria flavescens* at a salmon farms in Chile. The authors interviewed salmon farmers and found models to be ineffective at reducing depredation, particularly after two months when sea lions appeared to get accustomed to the device.

‘Scarecrows’ have also been historically used in the Baltic fishery with fixed salmon traps (Westerberg, 2010). Small boats with man-like dolls were anchored beside traps. Anecdotal evidence from old fishermen suggests this may have been effective for one or several weeks, after which the boat was moved to a new place. After the cessation of seal hunting in Sweden in 1975, this method became obsolete as seals were less threatened by human presence.

Westerberg (2010) comments on the fact pinnipeds have a well-developed sense of smell in the air, and mothers recognise pups by smell at haul-out sites and will react over large distances to the smell of humans (see Section 2.5). Therefore, olfactory deterrent methods theoretically have potential to reduce depredation. Anecdotal information exists that bags of human faeces were hung on the leader nets of fish traps to deter seals. However, no modern studies have been conducted.

2.6.5 Fishing tactics

An understanding of the factors at an operational fishing level that affect seal depredation in static-net fisheries could theoretically be exploited to reduce seal depredation. Following the review in Section 2.5.1, the following methods may show potential to reduce seal depredation:

- set nets away from known locations of seals;

- increase net depth;
- increase haul speeds;
- reduce soak times;
- reduce amount of gear deployed/reduce haul sequences where possible;
- set nets overnight;
- target less active foraging periods in the season.

Of course, these modifications to fishing operations need to be balanced with the implications they may have on overall landings. It is likely that reductions in gear deployment and hauls would limit the potential for landings (depredated or not) and are therefore perhaps not suitable mitigation measure for set net fisheries. This may also be the case regarding the location (both area and depth) of net setting, soak times, as well as the timing (seasonally and day/night) of gear deployment. These measures would need to be at the discretion of fishermen, using their local knowledge, to determine if potentially reduced depredation is increasing marketable catch via these methods.

Faster hauling speed has potential to reduce depredation as well as increase fishing efficiency, as reported by Cosgrove *et al*. (2013). Modern net fisheries are highly mechanised to allow automated net hauling and flaking/storage (although this may not be the case on smaller vessels). This minimises personnel required and increases the amount of gear that can be deployed. However, manual removal of fish during hauling is still required, which slows hauling speeds for large catches, and could increase seal depredation during hauling. To remedy this issue, extra personnel could be used to remove fish from nets, particularly during periods of heavy depredation. But this increases fishing costs and may not be feasible for small vessels. Alternatively, methods of hauling nets completely and removing fish afterwards could be explored. To facilitate this option, shorter nets may be required to allow enough deck space to haul nets quickly. If mechanisms can be implemented that would increase haul speeds, it could form a promising mitigation measure in the short term (Cosgrove *et al*., 2013).

It is important to realise that definite evidence of how seals depredate fish in static net fisheries is limited, especially in the UK. To provide this evidence Gosch *et al*. (2018) planned to capture seal depredation at nets with underwater cameras (GoPro) but were unsuccessful.

3 Conclusions

There is evidence that certain aspects of operational fishing controlled by fishermen, can affect the level of depredation. Therefore, as a first means to reduce depredation, these options should be explored. This could be complemented with the use of ADDs on vessels during hauling, which may be beneficial since seal depredation in some fisheries may occur primarily during hauling and surrounding fishing vessel activity. Otherwise, deploying ADDs on nets may increase the effective range of deterring seals. ADDs that elicit startle responses, with low frequencies, low duty cycles and sharp rise times seem to be a promising type of ADD. They also limit noise impacts to seals and non-target species and the surrounding marine environment..

In conclusion, based on the literature review, the following options should be explored further for trial in English static net fisheries:

- ADDs deployed from vessels during hauling;
- ADDs deployed from nets (multiple units probably required), if appropriate battery technology is available;
- faster haul times (subject to feasibility of implementation);
- shorter soak times in shallow net fisheries;
- night setting.

Table 3.1 summarises the pros and cons of these options. These will be investigated further following the trial of these options in a further project phase.

Table 3.1 Pros and cons of seal deterrent options to trial in net fisheries.

Deterrent or fishing tactic	Pros	Cons
Vessel deployed startle-eliciting ADD (low frequency, sharp rise times, low duty cycles)	Practical implementation in terms of power supply	May only be effective at reducing seal depredation during hauling – will not be effective if seal depredation is taking place whilst nets are set
	Limited impacts to harmful effects to seals and non-target species	Relatively high initial costs compared to fishing tactics
	Early evidence suggests good effectiveness	
Multiple net-deployed startle-eliciting ADDs (low frequency, sharp rise times, low duty cycles)	May increase effective range of ADDs along entirety of net	Expensive
	May reduce the effect of soak time and depth on seal depredation	Difficulties in fixing multiple devices to net
	Early evidence suggests good effectiveness	Modification/development of ADDs required to be submersible and have reliable, small power sources
	Limited impacts to harmful effects to seals and non-target species	
Faster haul speeds	Evidence suggests may be effective for deeper-set nets that are beyond the diving range of seals whilst set	May be difficult to implement on small vessels
	Inexpensive	
Shorter soak times	Ease of implementation	May limit catch potential
	Inexpensive	
Night setting	Ease of implementation	Little evidence of reduced depredation – likely to be site specific
	Inexpensive	May be impractical for fishermen or have safety issues to consider

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