Bord Iascaigh Mhara
Irish Sea Fisheries Board

Seal depredation and bycatch in set net fisheries in Irish waters

Ronan Cosgrove, Michelle Cronin, David Reid, Martha Gosch, Michael Sheridan, Nicholas Chopin and Mark Jessopp

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Fisheries Resource Series

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Summary

Interactions between seals and fisheries are thought to be increasing in Irish waters. Following requests by the Irish fishing industry to address this issue, a pilot observer programme was carried out in set net fisheries to update information on the level of interactions and identify potential mitigation measures. A total of 91 days at sea corresponding to 358 hauls and 1071 km of gear were observed on three vessels operating off the west and south west coasts over a one year period. Fisheries observed were gill nets for hake and pollack, trammel nets for turbot and tangle nets for crawfish and other species. The study included an assessment of the economic impact of depredation, investigation of factors affecting depredation and bycatch, as well as discussion of potential measures for mitigating and managing interactions. Key points are summarised as followed:

Economic impact of depredation

- Averages of 18% of pollack, 10% of hake and 59% of monkfish landings were depredated by seals.
- Proportions of fish damaged and related economic impact of seal depredation in set net fisheries have substantially increased since the 1990's.
- Total loss of landings could rise to over 50% in both the pollack and hake fisheries when potential numbers of fish entirely removed from nets are taken into account.
- The upper limit of the total annual value of seal damaged fish in pollack and hake set net fisheries is €1.7m.

Factors affecting depredation

- The duration of gear deployment (Soak time) had a significant effect on the level of depredation in the pollack fishery but not in the more offshore hake fishery.
- Depredation was more likely to occur in more northerly and easterly/shallow locations in both the pollack and hake fisheries.
- Depredation increased as pollack and hake trips unfolded.
- Depredation was correlated with landings of the target species in the pollack fishery and with the amount of gear deployed in the hake fishery.
- No significant difference in the size of depredated and undamaged fish was observed in the pollack and hake fisheries.
- Monkfish depredation was more likely to occur in more northerly locations and where seal bycatch was more prevalent.

Decreasing depredation

- Operational mitigation measures carried out at the fisheries level offer the most potential as solutions in the short term.
- Smart fishing techniques such as deployment of gear for short periods and working gear in relation to changes in tidal currents are essential to reduce depredation in inshore waters.
- Faster hauling speeds could reduce depredation and a variety of operational practices can be examined in this regard.
- Systems which actively deter seals from the vicinity of vessels such as acoustic deterrents have strong potential to further mitigate seal depredation in deep set net fisheries.

Bycatch of cetaceans and other species

- In addition to seals, a range of cetacean, elasmobranch, seabird and fish species were observed as bycatch across set net fisheries.
- Cetacean bycatch mortalities consisted of two common dolphins, three harbour porpoises and one Northern Minke whale.
- All cetacean bycatch data are compiled annually and submitted to the EC and ICES to assess population impact.
- Conservation status for bycaught elasmobranch species ranged from least concern for the starry smooth hound to critically endangered for the common skate.
- A total of 34 common skate were observed as bycatch. Some 76% of these were reported as being alive when released but tagging studies are required to assess long term survivability.

- In relation to seabirds a total of five common guillemots were reported as bycatch.

Seal bycatch

- No seal bycatch was observed in gill net fisheries suggesting that risk of seal bycatch in the observed gill net fisheries is low.
- Seal bycatch in a trammel net fishery targeting turbot in deep water off the Clare coast was substantially lower compared to a tangle net fishery conducted off Mayo
- A total of 58 grey and 10 harbour seals were observed as bycatch primarily in a tangle net fishery conducted off Mayo.
- An estimated 88% of grey seals and 75% of harbour seals were juveniles while an estimated 56% of grey seals and 70% of harbour seals were male.
- Almost three times as many seals were caught in 320mm compared to 270mm mesh size in the tangle net fishery.

Factors affecting seal bycatch

- Analysis of factors affecting seal bycatch was restricted to the tangle net fishery off Mayo.
- Numbers of bycaught seals were significantly higher in larger meshed tangle nets deployed in deeper water.
- A clear link between presence of seal bycatch and landings of monkfish and crawfish was evident.
- No relationship between seal bycatch in tangle nets and landings of spider crab or skates and rays was observed.
- The absence of a significant effect of soak time on seal bycatch in the tangle net fishery raises questions about inclusion of this variable in effort metrics for the tangle net fishery.

Seal bycatch status and mitigation

- Risk of seal bycatch varies considerably in relation to the characteristics and location of large mesh set net fisheries.
- Increasing numbers of seals in Irish waters indicate that seal populations are currently maintaining themselves.
- In spite of high fisheries bycatch, an increasing population is used to classify the conservation status of grey seals as favourable in other EC member states such as Finland.
- The largest increases in localised grey seal populations in Ireland have occurred in areas with the highest set net fishing effort and where tangle netting for crawfish is most prevalent.
- Survival of grey seals in the first year of life is known to be low so it is likely that a component of bycaught juvenile seals would ultimately fail to survive due to other factors.
- Set net fisheries may be net contributors to the reproductive capacity of seals in Irish waters through provision of a steady food source.
- Seal bycatch in tangle nets does, however, pose a threat to seal conservation on the west and south west coasts of Ireland and development of bycatch mitigation measures should be encouraged.
- Reduced mesh size and improved net visibility have major potential to substantially reduce seal bycatch rates in the tangle net fishery for crawfish.
- A discussion between fishermen and net makers on optimal net design in terms of reducing seal bycatch should be facilitated.

Managing seal – fisheries interactions

- Whether their interests lie in maintaining a viable business or wildlife conservation, the absence of national policy in relation to the seal – fisheries issue, leads to polarisation of viewpoints and increasing conflict amongst stakeholders.
- Early and effective stakeholder participation is a key principle of the ecosystem approach and a legal requirement of the Marine Strategy Framework Directive (MSFD).
- The Irish seal focus group is the ideal forum to discuss and develop consensus amongst key stakeholders on the future direction of seal – fisheries management policy in Ireland.
- Research and development of highlighted mitigation measures should be prioritised as part of this process.
- A similar spatial management unit system to the UK would be appropriate for assessing the impact of seal bycatch in Ireland at population level.

1 Introduction

Increasing levels of interactions between pinnipeds (seals and sea lions) and fishing activities is a growing problem globally and a major threat to the livelihood of many small-scale coastal fishermen. Levels of pinniped damage to the catch (depredation) and gear damage have risen in recent decades due to increasing levels of protection and corresponding population growth particularly in areas such as the Baltic Sea (Fjalling, 2005; Gunner Lunneryd *et al*., 2003; Königson *et al*, 2009a; Westerberg *et al*., 2000, 2006).

The issue of bycatch where animals suffer injury or mortality due to entanglement in fishing gear is of major concern where species are rare or endangered e.g. the Mediterranean monk seal (Monachus monachus) (Tudela, 2004). Bycatch also needs to be considered in relation to more abundant pinniped populations. Under the habitats directive, member states of the European Community are legally obliged to monitor and maintain all pinniped species at favourable conservation status.

In the Baltic increases in seal bycatch are thought to be linked to increases in seal populations. Roughly 20% of the annual production of grey seal pups is thought to die in fishing gear in Finnish waters each year while the numbers of seals taken as bycatch in Swedish fisheries is increasing. Climate change and environmental contamination are thought to be the most serious threats to Finnish seal populations. Seal bycatch is also acknowledged as a threat and work to reduce incidental bycatch to a minimum level is on-going. Given that grey seal populations are increasing the conservation status of grey seals is, however, thought to be favourable as defined under the Habitats Directive. Indeed population control measures are currently permitted in EC member state Finland as a means of reducing the impact of grey seals on fishing and fish farming industries as well as facilitating their commercial exploitation (FMAF, 2007).

Seal populations in Irish waters are also increasing (Ó Cadhla *et al*., 2013; Duck and Morris, 2012) and interactions between seals and fisheries are a source of increasing conflict. Fishermen whose livelihoods are directly impacted have reported major increases in levels of depredation in recent years (Cronin *et al*., 2013). Numerous calls for the State to deal with this issue culminated in a major outcry regarding depredation levels at an Industry Science Partnership conference hosted by the Irish Marine Institute in June 2010.

Baseline data on the scale of interactions are, however, required before management actions can be properly considered. Although depredation rates of up to 30% occurring across a range of set net fisheries have recently been reported by Industry (Cronin *et al*., 2013), the most recent studies on this issue are over 10 years old and new data are required before this issue can be scientifically assessed.

This pilot study aimed to collect and analyse baseline information on seal – fisheries interactions in a range of Irish set net fisheries in different geographic locations. Factors affecting depredation and bycatch rates are modelled with a view to identifying measures which can significantly reduce seal – fisheries interactions. Results are discussed in relation to a range of potential measures for mitigating and managing interactions.

2 Background

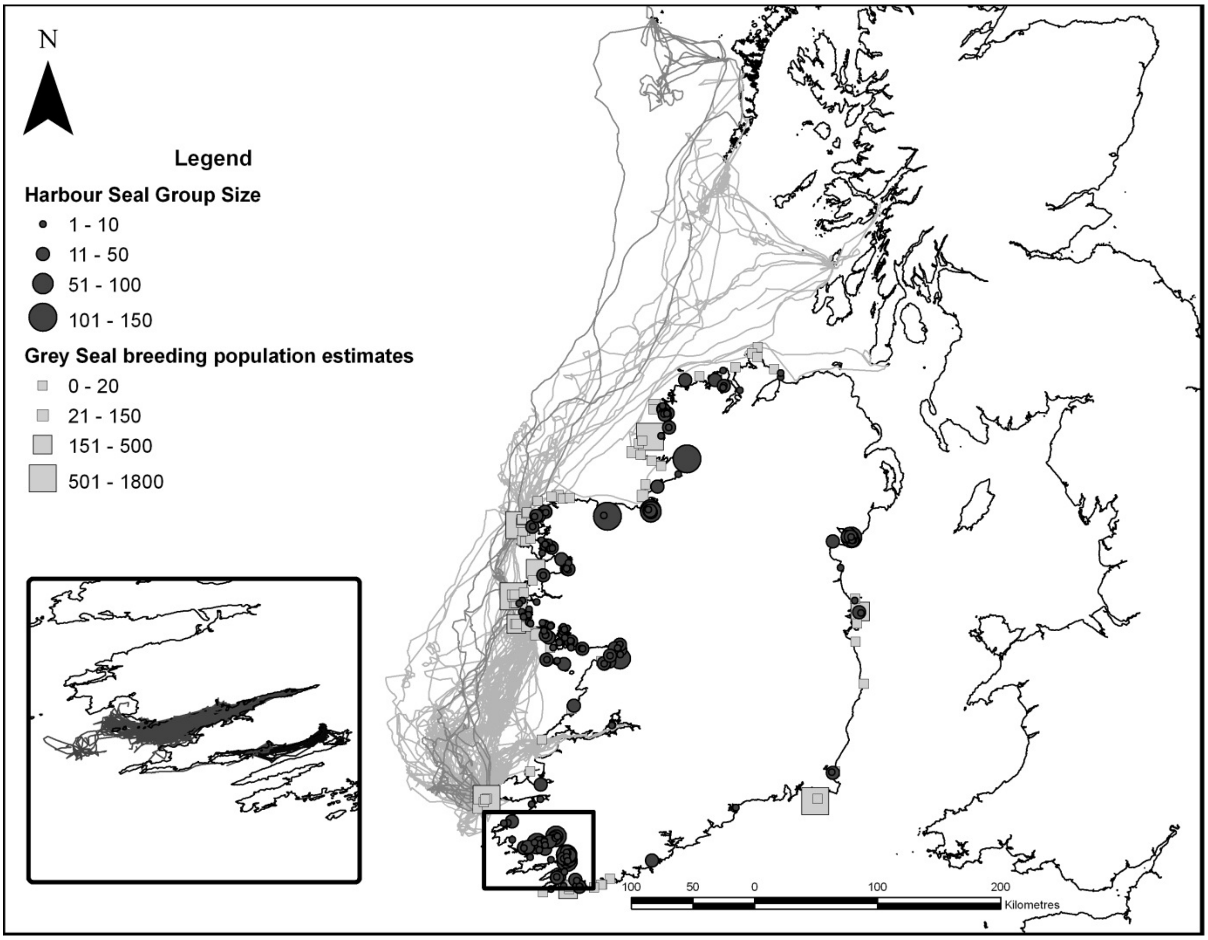

Figure 1. Map of best estimates of population size of harbour and grey seals in Ireland obtained in 2003 and 2005 respectively and at sea distribution of tagged animals (reprinted from Cronin *et al.* (2013) with permission from Elsevier).

2.1 Seals in Irish waters

Two species of seal are found in Irish waters, the harbour seal *(Phoca vitulina)* and the grey seal *(Halichoerus grypus)* (Figure 1). The population of grey seals using the Irish coastline is part of a larger western European stock centred in northern Britain and stretching to western France, the eastern North Sea, the Faroe Islands, Iceland, Norway and the northwest coast of Russia (Bonner 1972). There is currently no information on the genetic structure of grey seals using haul-out sites on the Irish coastline (Cronin *et al*., 2013). The harbour seal occurs in Europe from the Arctic Ocean at Svalbard, Norway, to the Barents Sea, the southern Baltic Sea and the eastern North Atlantic from the British Isles south to Portugal. Although yet to be proven, it is thought that harbour seals using terrestrial haul-out sites and the waters surrounding the island of Ireland are of the same genetic stock or population (Cronin *et al*., 2013).

Recent population surveys suggest that seal populations are increasing: Ireland's current grey seal population numbers approximately 7,824 – 9,365 animals of all ages compared to 5509 – 7083 in 2005. Growth in the grey seal breeding population appears to have continued since the mid 1990's and possibly dating to the early 1980's. Since 2005 this growth seems to be most pronounced around a number of key breeding areas of key importance in a national context. Increases in pup production in the top four breeding areas ranged from 89% at the Inishark and Inishgort groups of islands off North West Galway, 70% off the Blasket Islands in Kerry, 36% off the Inishkea Group of islands off Mayo to 6%

from Sturall to Maghera on the Donegal coast (Ó Cadhla *et al*., 2013). Aerial surveys conducted in 2011 and 2012 primarily to assess harbour seal populations also counted grey seals. A total of 2964 grey seals were counted in Ireland compared to 1309 in 2003, an overall increase of 126.4% (Duck and Morris, 2012).

Based on population surveys carried out in the Republic of Ireland in 2003 (Cronin *et al*., 2007) and Northern Ireland in 2002 (Duck, 2006) the population of harbour seals for the entire island was estimated at 6950 in 2003. Recent aerial surveys resulted in counts exceeding 2003 figures by 18.1%. Care should be taken in the interpretation of aerial count figures for both grey and harbour seals figures as they involve assumptions concerning seal haul-out behaviour and regional distribution between survey years (Duck and Morris, 2012). Both species are considered to be of Least Concern (low risk of extinction) according to the International Union for Conservation of Nature (IUCN).

2.2 Irish set net fisheries

A set net can be defined as a length of multi- or monofilament mesh suspended between a buoyant head rope and a weighted foot rope. Gill net selection is known to depend on a variety of factors besides mesh size: net construction, visibility and stretchability of the net, net material and the shape and behaviour of the fish. Entangling more than gilling is affected by net construction. The probability of a fish being entangled is thought to depend on the so-called "hanging ratio" or "hanging coefficient" which basically describes the length vs. height ratio of the meshes or the stretch capacity of the mesh. Hanging ratios are usually in the range of 0.2 to 0.7 and the smaller the hanging ratio the larger the probability of entangling (Sparre and Venema, 1992).

The principle bottom set net fishing gears deployed by Irish vessels are gill, tangle and trammel nets. Gill nets are constructed so that the meshes are virtually square in shape and large enough that the fish can get its head through, but not its body so that it becomes caught by the gills on attempting to back out (Sainsbury, 1996). Irish gill net fisheries principally target hake *(Merluccius merluccius)*, cod *(Gadus morhua)*, pollack (Pollachius pollachius) and saithe *(Pollachius virens)*. The head rope floats above the footrope that is set hard to the bottom and the meshes are spread relatively tautly between the two with a hanging ratio of approximately 0.5. Mesh size typically varies from 120 mm for hake and pollack up to 150 or 160 mm for cod in Irish fisheries (Cosgrove *et al*., 2005). Irish tangle net fisheries target crawfish *(Palinurus elephas)*, spider crab *(Maja brachydactyla)* monkfish *(Lophius sp.)* and a variety of species of ray. Tangle nets consist of loosely hung large meshes which operate by entangling or wrapping the catch in several meshes. Tangle nets are deployed with a weighted footrope to keep the net down but without floats on the head rope, generally relying on inherent buoyancy in the head rope and water current to provide some degree of spread. Mesh size varies from 150 – 330 mm depending on the species targeted with a hanging ratio of around 0.33.

Trammel nets are constructed by joining three parallel sheets of netting where the outer sheets are made of netting with very large meshes. The middle sheet is very loosely hung allowing bags of this netting to be drawn through the larger mesh sizes of the outer net sheets. This design results in fish being caught by gilling and entangling similar to conventional gill nets or tangle nets but also fish to be taken in the bags of inner netting (Hovgård and Lassen, 2000). In Ireland, trammel nets have traditionally been used in inshore areas to fish bait for crustacean pot fisheries. In addition they are used to fish for flat fish species such as turbot *(Scophthalmus maximus)* and plaice *(Pleuronectes platessa)* with a typical internal mesh size of 270 mm and hanging ratio of around 0.5 for larger species like turbot. A similar system to tangle nets is used to maintain some degree of vertical spread.

A total of 52 vessels over 10 m in length engaged in set net fisheries in 2011 (Source: log book data; Sea Fisheries Protection Authority (SFPA)). No logbook data are available for Irish vessels under 10 m although an estimated 112 part time and full time inshore (< 12 nautical miles from shore) vessels are thought to have participated in tangle net fishing for crawfish in 2011 (BIM, 2012).

2.3 Seal – fisheries interactions

Previous data gathered in Ireland suggest that the grey seal is the primary species involved in interactions with commercial fisheries in inshore set net fisheries (McCarthy, 1985; Collins *et al*., 1993; BIM, 1997; Kiely *et al*., 2000). Little is known about the level of interactions with the harbour seal as most studies have focused on grey seals. No recent estimates of losses due to seal depredation are available in Irish waters with the most recent studies conducted in the 1990's. Depredation rates of up to 30% were observed in an the inshore monkfish tangle net fishery on the south coast (Collins *et al*., 1993), 7.7% in the Dingle hake gill net fishery and 10% in the Mayo cod spring gill net fishery (BIM, 1997). A 2010 questionnaire in relation to seal depredation distributed to fishermen through the Federation of Irish Fishermen (FIF) provides a more recent qualitative assessment. Depredation rates of 20 – 30% were reported across gill net, tangle net and trammel net fisheries for pollack, monkfish, cod, hake and turbot in coastal and offshore locations along the west, south and east coasts. The spring fishing season was identified as having the greatest operational interactions across inshore fisheries although interactions were noted year-round depending on location (Cronin *et al*., 2013).

Again, no recent studies have been carried out on bycatch of seals in Irish set net fisheries and there are remarkably few onboard observations or quantitative estimates in available literature on this issue. A total of 51 grey seals were brought ashore by vessels participating in the Mayo cod fishery from 1994 – 1996. Almost all animals were juvenile with an even sex ratio and although onboard observations were carried out, no quantitative estimates of bycatch rates were provided (BIM, 1997). Some eighteen immature seals were landed by vessels as bycatch from a tangle net fishery targeting monkfish in the south east of the country in 1997 and 1998. However, no seals were observed as bycatch during twenty days of onboard observations despite relatively good temporal observer coverage across the months April to September during this period (Kiely *et al*., 2000).

2.4 Legal framework

Ireland is signatory to several international conventions that have relevance to seal conservation and protection. These include the CMS or Bonn Convention, Bern Convention and OSPAR (Oslo and Paris Conventions for the protection of the marine environment of the North-East Atlantic). In addition a range of National and European legislative provisions aimed at protecting and managing seals and their habitats as well as prevention of trade in seal products exist: Nationally, the Irish Wildlife Act (1976) and subsequent Wildlife Amendment Act (2000) make it an offence to hunt or injure seals up to 12 nautical miles offshore unless permission is granted from the relevant government minister. It is also an offence to wilfully interfere with or destroy their breeding or resting place. It is not an offence, however, to unintentionally injure or kill or destroy the breeding or resting place of a seal while engaged in fishing.

At EC level, trade in seal products is prohibited according to Commission Regulation (EU) No 737/2010. In terms of species and habitats protection, the Habitats Directive (92/43/EC) forms the cornerstone of Europe's nature conservation policy. Transposed into Irish national law under the European Communities (Birds and Natural Habitats) Regulations 2011 (SI 477/2011), the Directive is built around two pillars: the Natura 2000 network of protected sites and the strict system of species

Table 1. Designated SACs for seals in Irish waters

Grey seal	Harbour seal
Blasket Islands	Ballysadare Bay
Duvillaun Islands	Clew Bay Complex
Horn Head and Rinclevan	Cummeen Strand/Drumcliff Bay (Sligo Bay)
Inishbofin and Inishark	Donegal Bay (Murvagh)
Inishkea Islands	Galway Bay Complex
Lambay Island	Glengarriff Harbour and Woodland
Roaringwater Bay and Islands	Kenmare River
Saltee Islands	Kilkieran Bay and Islands
Slieve Tooey/Tormore Island/Loughros Beg Bay	Killala Bay/Moy Estuary
Slyne Head Islands	Lambay Island
	Rutland Island and Sound
	Slaney River Valley
	West of Ardara/Maas Road

protection. Both species of seals occurring in Irish waters are listed under Annexes II and V of the Directive.

In relation to the Natura 2000 network, Article 3 of the Directive requires Member States to set up special areas of conservation (SACs) for Annex II species. It is envisaged that this will enable the natural habitat types and the species' habitats concerned to be maintained or, where appropriate, restored at a favourable conservation status in their natural range. Under Article 6 Member States are required to establish the necessary conservation measures involving if need be, appropriate management plans specifically designed for the sites which correspond to the ecological requirements of Annex II species present on the sites. Furthermore, Member States are required to take appropriate steps to avoid, in SACs, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives in the Directive. Currently there are ten and thirteen SACs designated for grey and harbour seals respectively (Table 1.)

Under Article 11 Member States are required to undertake surveillance of the conservation status of the natural habitats and species with particular regard to priority natural habitat types and priority species. Although included under this provision, neither species of seal occurring in Irish waters is a priority species.

According to the European Commission[1] this provision is not restricted to Natura 2000 sites and data need to be collected both in and outside the Natura 2000 network to achieve a full appreciation of conservation status.

Neither species of seal occurring in Irish waters is listed under Annex IV as a species in need of strict protection. Under Article 14, however, if in the light of the surveillance provided for in Article 11, Member States deem it necessary, they shall take measures to ensure that the taking in the wild of specimens of species of wild fauna and flora listed in Annex V as well as their exploitation is compatible with their being maintained at a favourable conservation status.

Favourable conservation status of a species is defined as follows:

(a) population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats, and

(b) the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future, and

(c) there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

1 http://ec.europa.eu/environment/nature/knowledge/rep_habitats/index_en.htm

3 Methods

Table 2. Details of vessels participating in the study

Vessel code	Region	Length (m)	Engine power (bhp)	Spencer Carter Net hauler	Net flaking machine
1	Dingle	22	415	Nh10	Yes
2	North Kerry	12	122	Nh05	Yes
3	Mayo	16	114	Nh05	No

3.1 Fishing operations

A pilot observer programme in Irish set net fisheries was conducted over a period of approximately 1 year from June 2011 to July 2012. Three vessels participated in the study, one offshore vessel based in Dingle in the south west of Ireland, an inshore vessel based in North Kerry in the south west of Ireland and an inshore vessel based in Mayo in the mid-west of the country (Table 2). Although a number of vessels applied to participate in the study, these vessels were selected with a view to observing a range of set net fisheries in different geographic areas. Targets of two 6 day trips per season over a full year on the offshore boat and 3 days a month over 9 months on each of the inshore boats were set at the outset of the project in order to maximise temporal and spatial coverage. Onboard observers from the Irish Sea Fisheries board (BIM), Coastal Marine Research Centre (CMRC) and the Marine Institute (MI) accompanied the vessels during normal commercial fishing operations.

Standard green or blue monofilament gill nets with 120 mm mesh size, twine diameter of 0.58 mm, 60 meshes deep, hanging ratio of 0.5 and net floats on the head rope for buoyancy were used by all vessels. Tangle net gear consisted of green monofilament netting in two mesh sizes of 270 to 320 mm with 0.65 mm twine diameter, approximately 10 meshes deep, 0.33 hanging ratio and polypropylene head ropes to provide some degree of buoyancy. Other than large meshed outer panels and a hanging ratio of approximately 0.5, trammel gear characteristics were similar to the 270 mm tangle nets.

3.2 Data collection and analysis

A detailed data collection protocol outlined methods for recording data on depredated fish, bycatch and fishing operations. Pictures of damaged fish were collected, catalogued and shared amongst observers in order to develop a standardised approach to damage classification. Seal damage to fish was characterised by a large v-shaped bite and removal of all or part or the visceral cavity, all or part of the body or removal of the skin and all or part of the visceral cavity. Although it is possible that depredation by other species such as conger eels or elasmobranchs with similar shaped bites occurred, depredated fish frequently came aboard still moving when seals were observed in the vicinity of the vessel permitting observers to build up a good picture of damage attributable to seals. Also large elasmobranchs capable of large v-shaped bites were infrequently observed as bycatch suggesting minimal interactions. Smaller elasmobranchs and conger eels would be incapable of large v shaped bites and probably incapable of more meticulous removal of skin or visceral cavities.

Set net operations are typically mixed species fisheries targeting specific species but also retaining or discarding a range of other species which can also be subject to depredation. Gill net fisheries observed in this study were characterised by high catch compositions and depredation rates of the target species hake and pollack. Tangle and trammel net fisheries were characterised by an absence of depredation of target species but high depredation rates of non-targeted but valuable monkfish. Thus, this study focussed primarily on depredation of these three key species. Estimated numbers of damaged and undamaged fish were produced by sampling the catches. All seal damaged fish were generally counted and, where possible, measured, while large landings were generally subsampled.

Table 3. Explanatory variables considered in relation to standardised response variables

	Response variables			
	DPUE			SPUE
Independent variables	**Pollack**	**Hake**	**Monkfish**	**Seals**
Categorical:				
Vessel	✓	✓	✓	✓
Season	✓	✓		
Day or night time deployment (Day/night)	✓			
Mesh size			✓	✓
Depth (3 levels)		✓		
Landings per unit effort (LPUE) (3 levels)	✓	✓		
Gear deployed per day (Gear day^{-1}) (4 levels)		✓		
Continuous:				
Month			✓	✓
Haul sequence	✓	✓	✓	
Gear deployed per day (Gear day^{-1})	✓			
Soak time (hrs)	✓	✓	✓	✓
Depth (m)	✓		✓	✓
Latitude index	✓	✓	✓	✓
Longitude index	✓	✓	✓	✓
Seal bycatch (no. km^{-1})			✓	
Crawfish (no. km^{-1})			✓	✓
Total Monkfish (no. km^{-1})				✓
Whitefish (no. km^{-1})				✓
Depredated Monkfish (no. km^{-1})				✓
Depredated Whitefish (no. km^{-1})				✓
Flatfish (no. km^{-1})				✓
Spider crab (no. km^{-1})				✓

In terms of bycatch, incidences of bycaught seals, cetaceans, elasmobranchs and birds were recorded for each haul. Where possible animals were measured (length and girth in the case of seals), sexed, photographed and stomach and tissue samples were taken for follow up studies. Seal carcass widths were also estimated on the basis of diameter = girth/π to examine potential relationships between morphometrics and susceptibility to bycatch in different mesh sizes. Seal morphometric measurements were not normally distributed and potential differences in morphometrics of seals caught in different mesh sizes were thus examined using non parametric two sample Kolmogorov Smirnov (KS) tests.

Unless otherwise stated, standard deviation (SD) is used to describe the measure of sample variability throughout the study. Length frequency samples of damaged and undamaged fish were analysed for differences in size selection of depredated fish to assess whether fish size should be included in data models. Subsets of data by species and vessel were checked for normality and analysed using one way analyses of variance (Anova) with size (Fork Length (cm)) as the response variable and damaged (True or False) as the factor.

Although potentially a function of landings as well as depredation, proportions of potential landings which were depredated were estimated to provide an overview of the economic impact of depredation. This was carried out on a comparative basis to previous studies (BIM, 1997, Collins *et al*., 1993):

Potential landings damaged (%) = DF (%)

Total number of fish damaged = TL DF

Total number of fish landed = TL F

DF (%) = (TL DF/ (TL DF + TL F))*100

Modelling of potential explanatory factors (Table 3) was carried out to assess causes of seal depredation and bycatch. A standard unit of effort was derived by dividing the total length of gear in each haul into 1 km stations. The numbers of seal damaged fish and bycaught seals were divided by the total number of 1 km stations in a given haul to provide standardised response variables; depredation per unit effort (DPUE) and seal bycatch per unit effort (SPUE). Response variables were converted to integers where Poisson models were attempted. Frequency distributions and variance around the mean of response variables were examined to determine appropriate models. Explanatory variables were pair plotted to investigate and eliminate multi-colinearity between independent variables before models were applied.

Pollack and hake

Pollack and saithe were grouped together as "Pollack" to provide a more comprehensive data set for modelling factors affecting depredation. Standard gill nets with 120 mm mesh size and hanging ratio of 0.5 were used in these fisheries so gear characteristics other than net length were excluded from this analysis. Insufficient data were available across the gill net fisheries to include month as a factor in the models. Instead seasons defined as follows were included; summer: June – August, autumn: September – November, winter: December – February, spring: March – May. In addition to restricting deployments to short soak periods, one of the principle operational methods currently employed by some gill net vessels to reduce depredation involves deploying gear overnight. Evidence that seals use visual cues to detect fishing gear (Fjalling *et al*, 2007) supports this practice and so a day night factor was included.

A major component of depredation in gill net fisheries observed in this study consisted of seals actively depredating catches while nets were being hauled. Marine mammals are known to respond to potential acoustic cues like hydraulic winch tones, and propeller cavitation etc. (Thode *et al*, 2006). Attraction of seals to vessel noise could result in the numbers of animals in proximity to vessels and associated depredation increasing as trips unfold so sequential haul number within a trip was included. The amount of gear deployed (all gear types) was included as a potential index of the scale of activity on a given day which could also be linked with vessel noise. Available data on landings of the target species (no. km^{-1} of gear) (Landings per unit effort (LPUE)) were also included as the quantity of fish present in a net could be a factor in attracting seals. Soak time, defined as the amount of time a net is deployed in the water can be incorporated into an effort metric if multiplied by the length of gear (Murray, 2009). Utilisation of this metric in this manner, however, assumes a linear relationship between landings or in this case depredation and soak time, neither of which were apparent in this dataset. Instead soak time was included independently in the model to evaluate whether this factor made a significant contribution to depredation. The depth at which gear was deployed (Gear depth) was included while latitude and longitude indices were included as spatial factors: Haul end points ranged from 50.45 – 54.00 N and 8.67 – 11.83 W degrees respectively. Latitude (x – 50) and Longitude (x – 8) indices were derived to provide effective geo-indices of northern and western ranges of gear deployment. Vessel 1 operated over a wide geographic area and carried out the majority of fishing effort in the pollack fishery so a separate model restricted to this vessel was also carried out.

Monkfish

Monkfish were primarily taken as a bycatch in tangle net operations by Vessel 3 off Mayo and trammel net operations by Vessel 2 off North Kerry. Thus Vessel effectively acted as a proxy for gear type in subsequent analyses. Sufficient data were available in these fisheries to include month instead of season as a factor. Soak times in these fisheries were substantially higher than gill net operations and depredation was not observed to occur during the hauling process. Thus level of vessel activity around nets was not considered relevant in this fishery and Haul sequence number was excluded in order to restrict the analysis to meaningful covariates. Seal bycatch (no. km^{-1} of gear) was included as a factor given the occurrence of seal bycatch in both fisheries and high depredation rates of monkfish.

Seals

Bycatch of all relevant species were described but modelling of variables affecting bycatch was restricted to seals. Analyses of individual and grouped seal species were attempted. Landings (no. km^{-1} of gear) of individual commercial species were included to examine if the presence of specific species affected bycatch. The issue of one bycatch event affecting the probability of subsequent bycatch events has been raised in a number studies (King, 1989; Rossman, 2010; Zollett, 2011). This was dealt with in the current study by carrying out a simple binomial regression with logit link function to model the probability of factors affecting the presence or absence of seal bycatch. However, a wide range of bycatch studies have also been carried out which take account of all count data. In particular Negative binomial and Zero inflated negative binomial models have been used in bycatch and fisheries studies where the species of interest occurs in relatively low numbers and the data are over dispersed (Hilborn and Mangel, 1997; Minami *et al.*, 2007; Sullivan *et al.*, 2006; Teo and Block, 2010). These modelling approaches were also examined in the current study to make optimal use of the dataset.

Model validation

A stepwise selection process using Akaike information criterion (AIC) was used to select which variables to include in final depredation and bycatch models (Burnham and Anderson, 2002). Models were validated using goodness of fit tests, comparisons with other models and plots of model residuals. Model fitting and selection was performed using the R language (v 2.15.2), goodness of fit tests for logistic regressions were carried out using Minitab and Systat while maps of fishing effort and depredation were created using ArcGIS.

4 Results

4.1 Observer coverage and fishing operations

A total of 91 days at sea corresponding to 358 hauls and 1071 km of gear were observed over the course of the study. Over 96% of hauls were observed by a core of three observers, each of whom was primarily assigned to one specific vessel for the duration of the programme. Some 41 days at sea were observed on Vessel 1, 14 on Vessel 2 and 36 on Vessel 3. Poor weather in an exposed location resulted in the target for Vessel 2 not being met but it was possible to carry out more days on Vessel 3 to compensate for this. A range of gear types were observed during the study. Vessel 1 was restricted to gill netting operations for hake, pollack and saithe. Vessel 2 fished trammel nets for turbot and gill nets for pollack while Vessel 3 undertook tangle netting for crawfish, skates, rays and spider crabs and gill netting for pollack (Table 4).

Pollack fisheries occurred in inshore and offshore locations, hake fishing was predominantly carried out in offshore locations while trammel net and tangle net operations were carried out in inshore areas (Figure 2). Major differences in operational practices were observed across fisheries and vessels. The times when gear was deployed varied distinctly from 23:00 to 06:15 for Vessel 1 to 18:00 – 00:40 for Vessel 2 and 08:30 – 18:00 for Vessel 3. Mean soak times varied from 14.48 ± 9.91 hours for gill net hauls, to 167.29 ± 15.92 hours per trammel net haul to 244.44 ± 152.48 hours per tangle net haul. Mean depths at which gear was deployed were 38.82 ± 11.80 m in the tangle net fishery, 97.20 ± 3.30 m in the trammel net fishery, 77.97 ± 43.99 m in the pollack fishery and 152.04 ± 24.51 m in the hake fishery.

Table 4. Observed fisheries and fishing effort

Vessel	Gear Type	Target group	Mesh size (mm)	Days at sea	Hauls (No.)	Mean Gear length (km haul^{-1})	Stations (No.)	Mean Stations (No. day^{-1})
1	Gill net	Hake	120	26	88	6	493	18.96
		Pollack	120	15	47	6	263	17.53
2	Gill net	Pollack	120	8	23	3	74	9.25
	Trammel	Turbot	270	6	24	3	65	10.83
3	Gill net	Pollack	120	9	52	1	52	4.33
	Tangle net	Crawfish, Ray, Spider crab	270	12	35	1	35	3.18
			320	15	89	1	89	6.85
			Totals	**91**	**358**		**1071**	

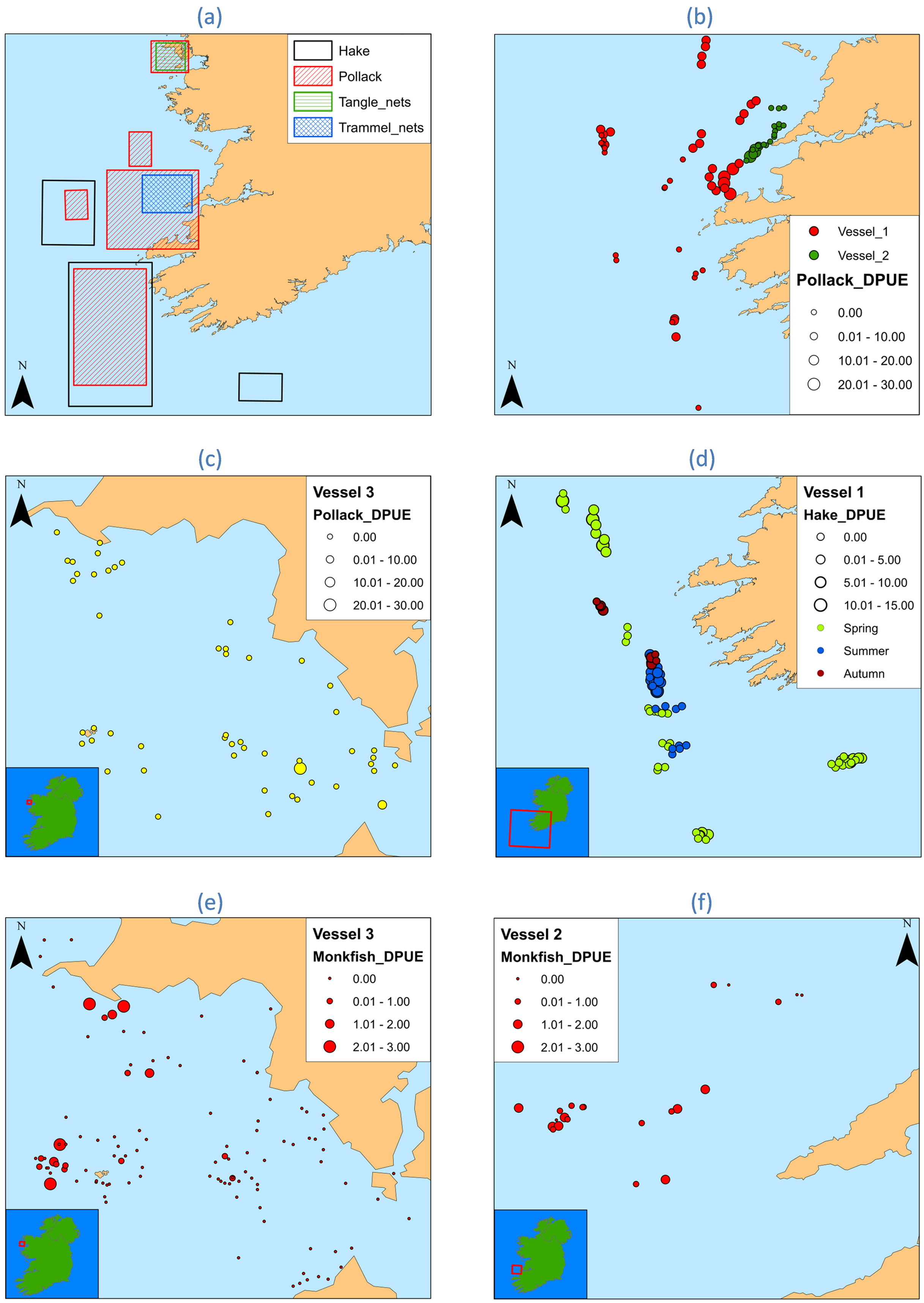

Figure 2. Maps of (a) fishing areas and damage per unit effort for (b) pollack in gill nets off the south west coast (c) pollack in gill nets off the Mayo coast (d) hake in gill nets (e) monkfish in tangle nets off the Mayo coast (f) monkfish in trammel nets off the Clare coast

4.2 Depredation

Figure 3. (a) to (f) examples of seal depredation and (g) to (i) examples of fish damaged by other means

Depredation classification

With the exception of very rare incidences, depredation by seals was restricted to pollack, hake, other gadoids and monkfish. Damage to gadoids was clearly characterised by v-shaped bites removing all or part of the body or the viscera, or removal of the skin. Monkfish depredation was principally characterised by a v-shaped bite removing all or most of the fish tail (Figure 3). No depredated monkfish were observed coming aboard in a live state whereas depredated gadoids taken in gill nets frequently came aboard still moving particularly when seals were observed in the vicinity of the vessel. This indicated that depredation was occurring while the nets were being hauled.

Observed depredation

Mean number of damaged fish (no. km^{-1} of gear) (DPUE) was highest on Vessel 1 in the pollack fishery. Mean DPUE was over 3 times higher on Vessels 1 and 2 compared to Vessel 3 in this fishery. The proportion of potential pollack landings depredated by seals was highest on Vessel 2, lowest on Vessel 1 with an average of ~18% across all three vessels. Mean DPUE and proportion of the catch damaged were lowest in the spring in the hake fishery observed on Vessel 1. Mean DPUE of monkfish was substantially higher in the trammel net fishery compared to the tangle net fishery due to higher catch rates for this species by Vessel 2. Proportions of monkfish damaged were similar across vessels however with an overall average of ~ 59% of monkfish damaged by seals (Table 5).

Table 5. Mean numbers of damaged fish per unit effort (DPUE) and total proportionate numbers of fish damaged

Species	Category	Gear Type	Mesh Size	Mean DPUE	SD	% Fish Damaged
Pollack	Vessel 1	Gill net	120	11.95	5.97	16.92
	Vessel 2	Gill net	120	9.62	7.88	22.12
	Vessel 3	Gill net	120	2.64	4.76	19.06
	Total	**Gill net**	**120**	**7.62**	**7.29**	**17.73**
Hake	Autumn	Gill net	120	5.70	2.03	13.99
	Spring	Gill net	120	4.61	3.19	9.56
	Summer	Gill net	120	5.84	3.05	10.38
	Total	**Gill net**	**120**	**5.16**	**3.08**	**10.22**
Monkfish	Vessel 2	Trammel net	270	0.60	0.54	62.30
	Vessel 3	Tangle net	270	0.14	0.43	55.56
	Vessel 3	Tangle net	320	0.26	0.72	54.76
	Total			**0.29**	**0.65**	**58.93**

Effect of fish size on depredation

Mean sizes of depredated and undamaged fish were relatively similar for all data subsets. No significant differences in sizes of damaged and undamaged fish were observed for hake, pollack or saithe on Vessel 1. No significant difference was observed between damaged and undamaged pollack on Vessel 3. Seal damaged pollack were significantly larger on Vessel 2 but a difference of just 1.19 cm was observed and no significant difference was observed when pollack data from the two inshore vessels were pooled (Table 6).

Table 6. Size comparison of undamaged and damaged fish

		Undamaged			Damaged			One way Anova	
Vessel	Species	No.	Mean (cm)	SD	No.	Mean (cm)	SD	P value	Adj. R^2 (%)
Vessel 1	Hake	418	77.51	9.82	405	78.92	7.63	0.230	0.51
Vessel 1	Pollack	181	78.48	11.75	266	78.73	9.26	0.800	<0.01
Vessel 1	Saithe	370	75.44	11.47	353	76.70	11.78	0.150	0.16
Vessel 2	Pollack	966	56.19	4.99	250	57.38	4.86	0.001	0.85
Vessel 3	Pollack	313	60.41	6.64	30	57.93	6.94	0.053	0.81
Vessels 2 & 3	Pollack	1279	57.22	5.73	280	57.44	5.11	0.561	<0.01

Modelled depredation

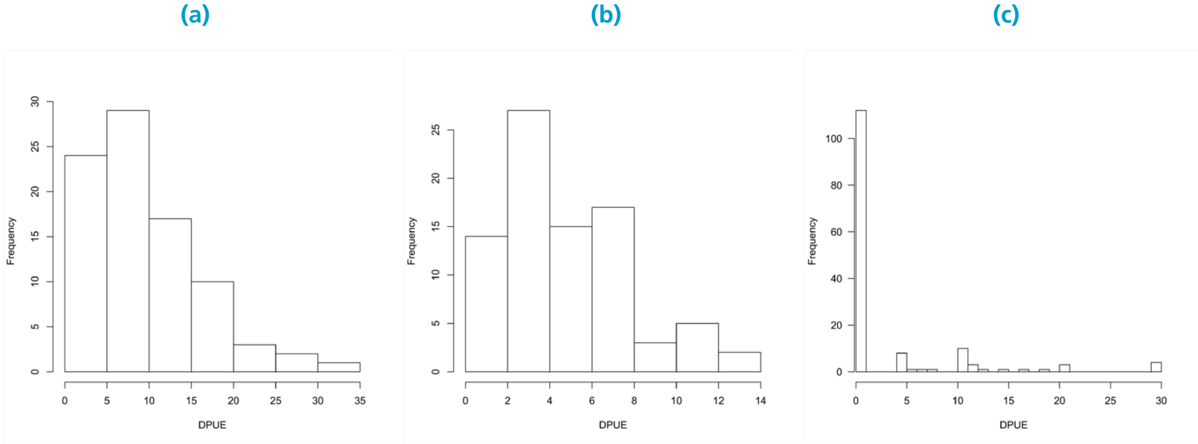

Figure 4. Frequency distributions of the response variable damage per unit effort for (a) pollack (b) hake and (c) monk fisheries

Pollack

Depredation was significantly higher on Vessels 1 and 2 compared to reference Vessel 3 and positively correlated with soak time. Vessel 2 was not significantly different to Vessel 1. Other factors individually modelled in place of Vessel were also significant but did not improve the model fit in terms of AIC: LPUE (533.72), Gear day^{-1} (531.62) and Season (535.60). Depredation was significantly worse during autumn and winter compared to summer and spring in the latter model run (Table 7).

For individual Vessel 1, depredation was more likely to occur in more northerly and easterly locations in nets with longer soak times and higher LPUE. Haul sequence was significantly and positively correlated with depredation indicating that depredation levels increased as trips unfolded (Table 8). Season was not significant in this model.

Landings of less than 10 fish (no. km^{-1} of gear) were excluded as ineffective fishing operations thereby reducing the number of zero DPUE values and the dataset from 112 to 86 records. A pair plot of explanatory variables in the data set for three vessels revealed correlations between the Vessel factor and Gear day^{-1}, LPUE, Season, Day/night, Depth and Geoindices factors. Season, Gear day^{-1} and to some extent LPUE were also correlated with geoindices and depth. Soak time and Haul sequence number were not correlated with other factors and separate model runs including these factors and each of the correlated variables in turn were attempted. The response variable DPUE was correlated with LPUE (Pearson correlation coefficient = 0.45 $P < 0.001$). In order to deal with this LPUE was grouped as follows: 10 – <50, 50 – < 100, >= 100 and included as a categorical variable in regression models. The frequency distribution of the response variable approached a Poisson distribution (Figure 4(a)) so a general linear model (GLM) with Poisson distribution was initially attempted.

A goodness of fit test consisting of a Chi-square test based on the residual deviance and degrees of freedom showed that the model did not fit the data (P=0, P>0.05 required). Furthermore a Quasi-poisson update applied to the model provided a dispersion parameter >1 indicating that the data were over dispersed. A Negative binomial model was therefore attempted. This type of model allows for the variance to differ from the mean and is often used to model count data when the data are found to be over dispersed (Hilbe, 2007). However a Chi-square test based on the residual deviance and degrees of freedom showed that, although an improvement over the Poisson model, the model did not fit the data (P=0.041, P>0.05 required).

Finally a Zero inflated negative binomial model was successfully attempted. This consisted of a Negative binomial regression with log link function to model count coefficients and a Binomial regression with logit link function to model excess zeros (Long, 1997; Minami *et al.*, 2007). The model was compared to a Null model without predictors using a Chi-squared test on the difference of log likelihoods yielding a significant p-value (<0.001) indicating the model was statistically significant. No covariates were significant in the Binomial model for excess zeros but the factors Vessel and Soak time were significant in the Negative binomial model of remaining positive count data.

For individual Vessel 1, a pair plot of explanatory variables revealed correlations between Season and Latitude index, and Depth and Geoindices so separate model runs were attempted using either Season or Geoindices and either Depth and Geoindices. The optimal model was a Poisson model containing the factors Latitude index, Longitude index, Soak time, Haul Sequence and LPUE. A Chi-squared test based on the residual deviance and degrees of freedom indicated that the Poisson model fitted the data (P=0.61 P>0.05 required). A Quasi-poisson update applied to the model provided a dispersion parameter of 0.94 indicating that the data were not over dispersed. A Negative binomial model applied to the dataset did not meet some default convergence limits and did not improve the model fit in terms of AIC (234.56). No clear patterns occurred in the plots of residual diagnostics further suggesting that this model was appropriate for this data set (Figure 5).

Hake

Depredation was more likely to occur in more northerly locations, in shallower water during autumn months. Haul sequence was significantly and positively correlated with depredation indicating that depredation levels increased as trips unfolded. Depredation was also likely to be worse when large amounts of gear were deployed (Table 9).

Landings of less than 10 fish (no. km^{-1} of gear) were excluded as ineffective fishing operations thereby reducing the number of zero DPUE values and the dataset from 88 to 83 records. A pair plot of explanatory variables in the hake data set revealed a strong correlation between the Longitude index and Depth variables and this was dealt with by substituting one variable for the other. A tri-modal distribution of depths was observed and depth was therefore converted to a categorical variable with three levels: 100 – 139, 140 – 179, 180 – 219 m. The amount of gear deployed in a day was also converted to a categorical variable given the occurrence of 4 distinct levels of gear deployed: 10 – 14.99, 15 – 19.99, 20 – 24.99 and 25 – 29.99 km day^{-1}. The response variable DPUE was correlated with LPUE (Pearson correlation coefficient = 0.30, $P < 0.001$). In order to deal with this LPUE was grouped, 10 – <50, 50 – < 100, >= 100 and included as a categorical variable in the model. The frequency distribution of the response variable approached a Poisson distribution (Figure 4(b)). The optimal model was a Poisson model containing the continuous factors; Haul Sequence, Latitude index and categorical variables Season, Gear day, and Depth. Neither Soak time nor LPUE were significant in this model.

A Chi-squared test based on the residual deviance and degrees of freedom indicated that the Poisson model fitted the data (P=0.75, P>0.05 required). A Quasi-poisson update applied to the model provided a dispersion parameter of 0.75 indicating that the data were not over dispersed and a negative binomial model applied to the dataset did not meet some default convergence limits and did not improve the model fit in terms of AIC (356.85). Zero values appeared as outliers in the residuals versus fitted values, QQ-plot of residuals and scale location diagram. However no clear patterns occurred in the plots of residuals against fitted residuals for independent variables (Figure 6). A Zero inflated poisson model was also attempted to try and improve the residual fits but failed due to lack of convergence and singularities so the standard Poisson model was retained.

Monkfish

Monkfish depredation was more likely to occur in more northerly locations where seal bycatch was more prevalent.

A pair plot of explanatory variables revealed significant correlations between the Vessel factor and Mesh size, Depth, Latitude and Longitude indices factors. A strong correlation was also observed between Geoindices and Depth. This was dealt with by carrying out separate model runs using either Vessel or correlated variables, and either Geoindices or Depth. The monkfish data set was characterised by a high proportion of zero values where no catch of monkfish occurred so a Zero-inflated logistic model (Long, 1997) was therefore considered appropriate for this dataset. Variance was generally substantially higher than the mean of the response variable (Table 10) so a Zero inflated negative binomial regression was therefore carried out. The response variable damaged monkfish (no. km^{-1} of gear (DPUE)) was multiplied by 10 as integers were required were for this analysis (Figure 4(c)). The optimal model as adjudged by AIC contained the factors SPUE and Latitude and Longitude Indices. Excess zeros in the model were positively correlated with latitude and negatively correlated with longitude indicating that zero values catches were more likely to occur to the north and the east of the study area. Latitude and Seal bycatch (no. km^{-1} of gear) were positively correlated with DPUE when the remaining count data were modelled (Model 3a). This model was also run using Vessel and Depth factors instead of latitude and longitude indices but this did not improve the model fit in terms of AIC. The model was compared to a Null model without predictors using a Chi-squared test on the difference of log likelihoods yielding a significant p-value (<0.001) indicating the model was statistically significant. A standard negative binomial model was also attempted but a Chi-square test based on the residual deviance and degrees of freedom of showed that the model did not fit the data (P=0, P>0.05 required).

Table 7. Zero inflated negative binomial model of depredated pollack from 3 vessels

Model type	Factors	Estimate	SE	z value	p-value
logit model for excess zeros	(Intercept)	0.719	0.927	0.775	0.438
	Vessel 1*	-20.478	4610.268	-0.004	0.996
	Vessel 2*	-20.344	6821.681	-0.003	0.998
	Soak time (hours)	-0.069	0.054	-1.269	0.204
Count model	(Intercept)	0.978	0.347	2.820	**0.005**
	Vessel 1*	0.977	0.218	4.472	**<0.001**
	Vessel 2*	0.778	0.230	3.381	**<0.001**
	Soak time (hours)	0.039	0.016	2.475	**0.013**
	Log(theta)	1.571	0.246	6.389	**<0.001**
Theta = 4.812, Log-likelihood: -246.5 on 9 Df, AIC: 511					
Reference variable: *Vessel 3					

Table 8. Poisson model of depredated pollack from Vessel 1

Model type	Factors	Estimate	SE	z value	p-value
Count model	(Intercept)	1.545	0.601	2.572	**0.010**
	Soak time (hours)	0.047	0.013	3.719	**<0.001**
	LPUE 10 <50*	-0.449	0.127	-3.529	**<0.001**
	LPUE 50 – <100*	-0.551	0.131	-4.211	**<0.001**
	Latitude index	0.469	0.127	3.702	**<0.001**
	Haul sequence	0.026	0.009	2.935	**0.003**
	Longitude index	-0.251	0.119	-2.111	**0.035**
Null deviance: 111.82 on 43 Df, Resid. deviance: 30.71 on 37 Df, AIC: 231.08					
Reference variable: *LPUE >=100					

Table 9. Poisson model of depredated hake from Vessel 1

Model type	Factors	Estimate	SE	z value	p-value
Count model	(Intercept)	0.572	0.385	1.486	0.137
	Haul Sequence	0.093	0.012	7.914	**<0.001**
	Latitude index	0.578	0.101	5.699	**<0.001**
	Spring	-0.738	0.243	-3.034	**0.002**
	Summer	-0.772	0.254	-3.043	**0.002**
	Gear day^{-1} 1 15-19.99**	0.188	0.244	0.772	0.440
	Gear day^{-1} 20-24.99**	0.278	0.228	1.221	0.222
	Gear day^{-1} 25-29.99**	1.238	0.302	4.103	**<0.001**
	Depth 140-179***	-0.234	0.172	-1.364	0.173
	Depth 180-219***	-0.765	0.363	-2.107	**0.035**
Null deviance: 161.32 on 82 Df, Residual deviance: 62.99 on 73 Df, AIC: 354.85					
Reference variables: *Autumn, **Gear day^{-1} 10–14.99**,***Depth 100-139					

Table 10. Zero inflated negative binomial model of depredated monkfish from 2 vessels

Model type	Factors	Estimate	SE	z value	p-value
logit model for excess zeros	Intercept	7.94	3.237	2.452	**0.014**
	SEALPUE	-0.02	0.223	-0.104	0.918
	Latitude index	2.47	0.575	4.292	**<0.001**
	Longitude index	-9.28	2.886	-3.215	**0.001**
Count model	Intercept	1.933	1.145	1.688	0.091
	SEALPUE	0.198	0.095	2.088	**0.037**
	Latitude index	0.463	0.143	3.243	**0.001**
	Longitude index	-0.145	0.917	-0.158	0.875
	Log(theta)	1.884	0.400	4.715	**<0.001**
Log-likelihood: -162.3 on 9 Df, AIC = 342.62					

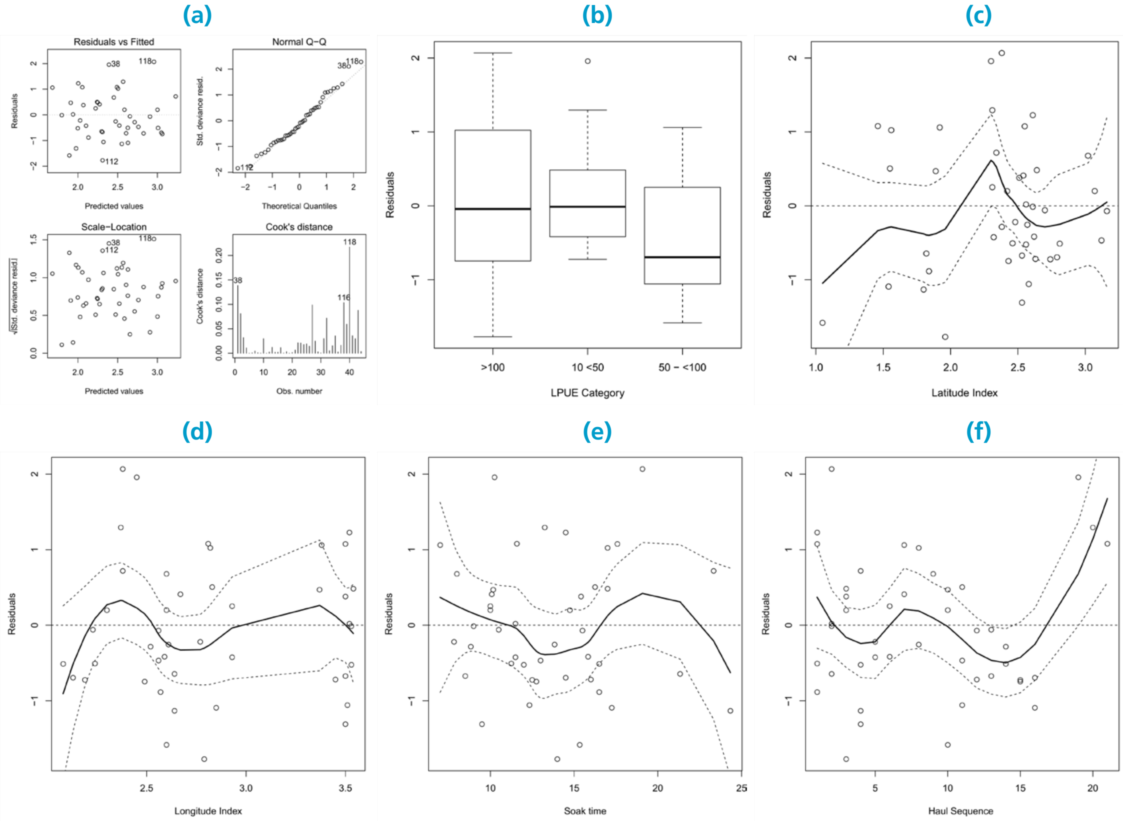

Figure 5. Model residuals for Vessel 1 in pollack fishery: (a) standard regression output: residuals versus fitted values, QQ-plot of residuals, a scale location diagram and Cook's distances and (b) to (f) residuals versus fitted values for LPUE, Latitude and Longitude Indices, Soak time and Haul Sequence respectively

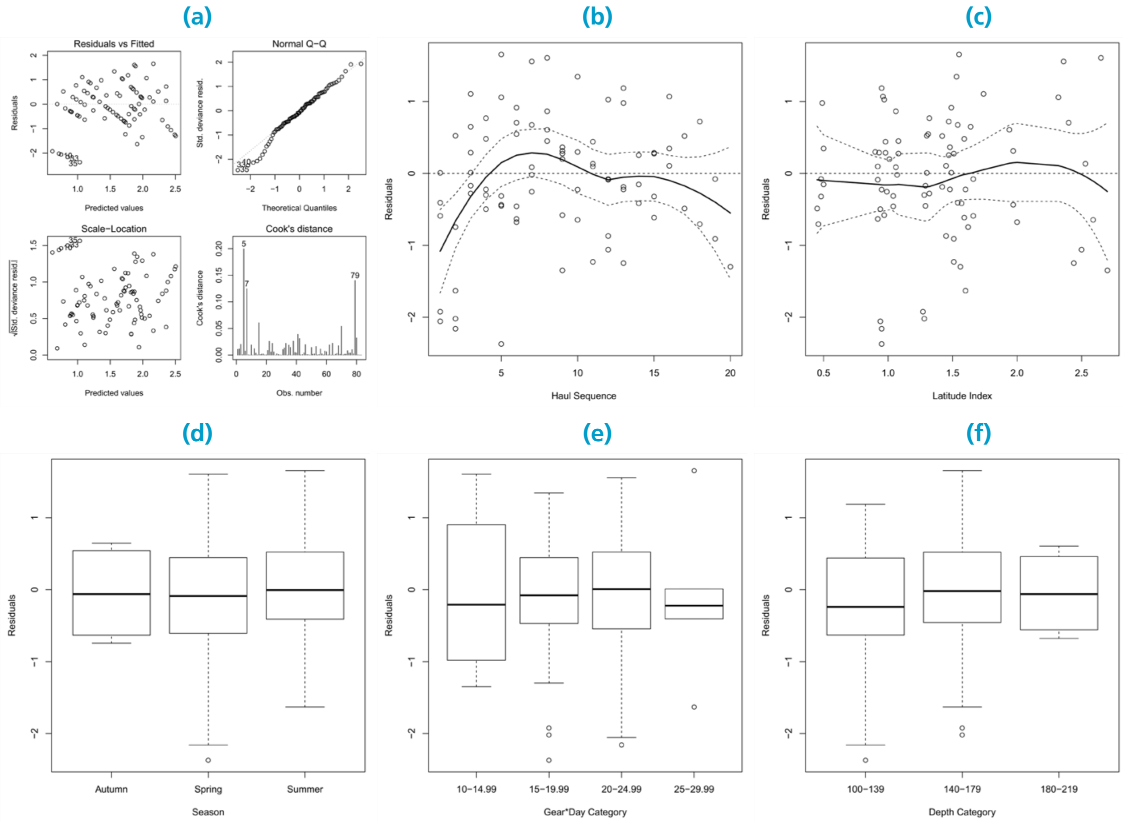

Figure 6. Model residuals for Hake: (a) standard regression output: residuals versus fitted values, QQ-plot of residuals, a scale location diagram and Cook's distances and (b) to (f) residuals versus fitted values for Haul Sequence, Latitude Index, Season, Gear deployed and Depth categories respectively.

4.3 Bycatch

Table 11. Observed bycatch by gear type

Nets	Gill	Tangle		Trammel	Totals
Mesh size (mm)	**120**	**270**	**320**	**270**	
Phocids					
Harbour seal *(Phoca vitulina)*			8	2	10
Grey seal *(Halichoerus grypus)*		8	47	3	58
Cetaceans					
Common dolphin *(Delphinus delphis)*				2	2
Harbour porpoise *(Phocoena phocoena)*	1		2		3
Northern minke whale *(Balaenoptera acutorostrata)*				1	1
Elasmobranchs					
Common skate *(Dipturus sp.)*	2	2	25	5	34
Porbeagle *(Lamna nasus)*	1				1
Six gill shark *(Hexanchus griseus)*				2	2
Spurdog *(Squalus acanthias)*	77				77
Tope/Smooth hound *(Galeorhinus galeus) / (Mustelus sp.)*	40			1	41
Sea birds					
Common guillemot *(Uria aalge)*	4		1		5
Other					
Sunfish *(Mola mola)*			1		1

A range of phocid, cetacean, elasmobranch, sea bird and other species were observed as bycatch across all fisheries. Cetacean bycatch consisted of two common dolphins, three harbour porpoises and one Northern minke whale all of which were reported as dead when released. Five species of elasmobranchs were observed as bycatch. Irish commercial fishing vessels are currently not permitted to land common skate, porbeagle or spurdog and none of the other reported elasmobranch species taken as bycatch are generally landed. The critically endangered common skate is the elasmobranch species of most concern in this data set with most specimens caught in tangle nets during spring and summer months. Some 76% of common skate were reported as being alive when released across all fisheries. A total of five common guillemots were observed as bycatch primarily in gill nets deployed by Vessel 2.

Grey and to a lesser extent harbour seals were the predominant protected species observed as bycatch. A total of 58 grey and 10 harbour seal bycatch mortalities occurred primarily in tangle nets but also in trammel nets during the study (Table 11). Grouping seal species together, mean seal bycatch (no. km^{-1} of gear) (SPUE) was 2.7 times higher in 320 mm compared to 270 mm mesh size in the tangle net fishery off Mayo. Mean SPUE in the 270 mm tangle net gear employed off Mayo was 2.9 times higher than trammel net gear with the same mesh size employed off the Clare coast (Table 12). An estimated 88% of grey seals and 75% of harbour seals were juveniles while an estimated 56% of grey seals and 70% of harbour seals were male.

A comprehensive sample of measurements taken from 30 grey seals was available from the tangle net fishery off Mayo. (Table 13). It is interesting to note that estimated diameters of seal mid-lines were similar in size to the smaller 270 mm mesh. No significant differences were observed in any of the measured morphometrics across different mesh sizes however (KS test, $P > 0.2$ in all cases). This suggests that factors other than the size of seals in relation to mesh size are responsible for substantial differences in bycatch rates across different mesh sizes.

Table 12. Mean number of seals taken as bycatch per unit effort (SPUE)

				Grey seal		Harbour seal		Grouped seal	
Vessel	Gear type	Mesh	Stations	SPUE	SD	SPUE	SD	SPUE	SD
Vessel 2	Trammel net	270	65	0.05	0.12	0.03	0.11	0.08	0.15
Vessel 3	Tangle net	270	35	0.23	0.55	0.00	0.00	0.23	0.55
	Tangle net	320	89	0.53	1.12	0.09	0.32	0.62	1.19
			Totals	**0.38**	**0.93**	**0.07**	**0.26**	**0.44**	**0.99**

Table 13. Grey seal morphometrics, d = estimated mean diameter

Mesh Size	Number animals	Length (mm)		Neck Girth (mm)			Behind flipper girth (mm)			Mid-line girth (mm)		
		Mean	SD	Mean	SD	d	Mean	SD	d	Mean	SD	d
270	6	1493	162	507	34	161	835	68	266	857	80	273
320	24	1441	169	480	36	153	823	92	262	874	88	278

Modelled seal bycatch

In terms of presence or absence, seal bycatch was more likely to occur as the numbers of monkfish and crawfish landed increased (Table 14).

In terms of count data, seal bycatch was more likely to occur as months progressed, in larger mesh size and at greater depths (Table 15).

A pair plot of explanatory variables which revealed a strong correlation between geo-indices and depth was dealt with by carrying out separate model runs using either geo-indices or depth. Attempted model runs including Vessel 2, separate seal species and geo-indices instead of depth were unsuccessful due to singularities and insufficient data. Thus, modelling focussed on grouped seal species in a relatively restricted geographic area off Mayo which accounted for 92% of bycaught animals, thereby providing a more concise and potentially more robust data set.

Results of a binomial regression for presence of seal bycatch showed that seal bycatch was significantly positively correlated with crawfish and monkfish landings (Table 14). In terms of diagnostics, an AIC of 140.21 for the binomial model was a substantial improvement over the Null model (AIC 151.41). A Chi-squared test on the difference of log-likelihoods between these models produced a p-value of <0.001 so the model was statistically significant. Model slopes were also significantly different from zero (G = 19.53, p < 0.001). The results of goodness of fit tests (Pearson, Deviance and Homer-Lemeshow: p > 0.05) showed insufficient evidence that the model did not fit the dataset adequately. The concordant percentage was high (71.1%) indicating that the model was likely to be reliable for prediction purposes.

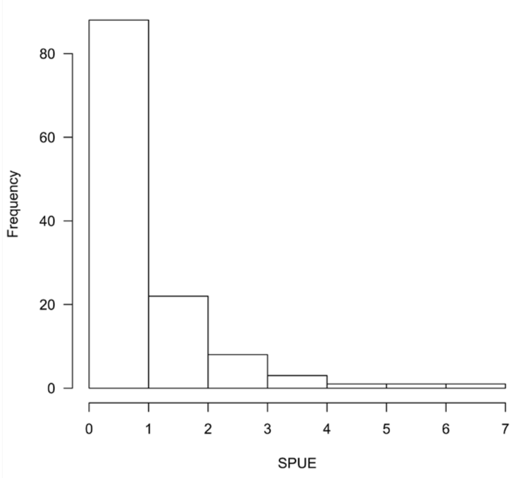

Figure 7. Frequency distribution of the response variable seal bycatch per unit effort (SPUE)

The seal count data set was characterised by a high proportion of zero values where no bycatch occurred (Figures 7, 8). The optimal model for count data was a zero inflated negative binomial model (Table 15). Excess zeros in the binomial model were explained by Month, Mesh size, Depth and Crawfish factors. Zero bycatch events were more likely to occur as months progressed in larger 320 mm mesh size nets, deeper water and where less crawfish were present in the gear.

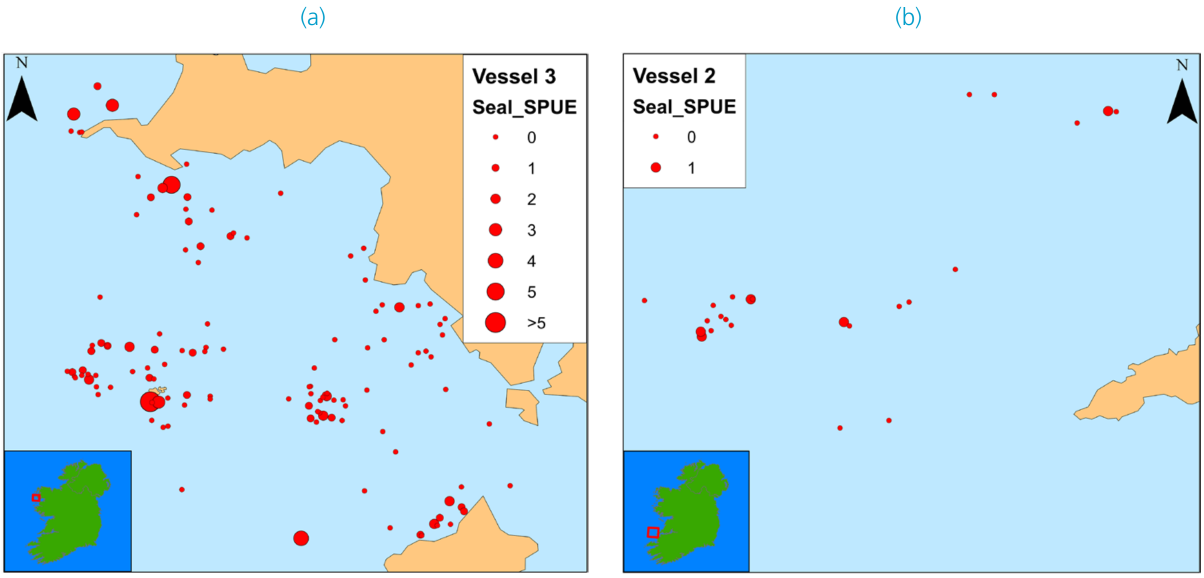

Figure 8. Seal bycatch per unit effort off (a) Mayo (b) Loop head (Co. Clare)

Results of the negative binomial model of remaining count data showed that bycatch was significantly correlated with month, mesh size and depth. Seal bycatch was predicted to be 7.65 times higher in 320 mm versus 270 mm mesh size. The Zero Inflated Model (Table 15) was an improvement over the Null model (AIC 24.89) and a Chi-squared test on the difference of log-likelihoods between these models produced a p-value of >0.001 so the model was statistically significant. A Poisson model run was attempted but a Chi-square test based on the residual deviance and degrees of freedom of showed that the model did not fit the data (P=0.004, P>0.05 required). Using the same test, a standard negative binomial model was found to fit the data (P=0.99). However a Vuong's non-nested hypothesis test (Vuong, 1989) produced a p-value of <0.001 suggesting that the Zero inflated model produced a superior fit.

Table 14. Binomial model with logit link function for presence of seal bycatch, Vessel 3

Model type	Factors	Estimate	SE	z value	p-value
logit model	Intercept	-0.470	0.743	-0.633	0.527
	Depth	-0.029	0.020	-1.438	0.151
	Total monkfish	0.923	0.438	2.105	**0.035**
	Crawfish	0.232	0.079	2.957	**0.003**
Residual deviance: 132.84 on 120 Df, AIC: 140.84					

Table 15. Zero inflated negative binomial model of seal bycatch, Vessel 3

Model type	Factors	Estimate	SE	z value	p-value
logit model for excess zeros	Intercept	-15.686	6.434	-2.438	**0.015**
	Month	0.979	0.432	2.265	**0.024**
	Mesh 320*	5.103	2.091	2.440	**0.015**
	Depth	0.125	0.053	2.356	**0.019**
	Crawfish	-0.493	0.217	-2.272	**0.023**
	Total Monkfish	-0.808	0.460	-1.758	0.079
Count model	Intercept	-5.228	1.043	-5.013	**<0.001**
	Month	0.302	0.091	3.332	**<0.001**
	Mesh 320*	2.035	0.534	3.814	**<0.001**
	Depth	0.043	0.014	3.164	**0.002**
	Crawfish	-0.099	0.051	-1.947	0.052
	Total Monkfish	-0.017	0.146	-0.114	0.909
	Log(theta)	1.395	1.128	1.237	0.216
Theta = 4.035, Log-likelihood: -102.3 on 13 Df, AIC: 230.68					

*Reference categorical variable: Mesh 270

5 Discussion

5.1 Economic impact of depredation

This study primarily focussed on the direct effects of seal depredation on catches in Irish set net fisheries. In terms of indirect effects, the potential economic impact of increasing seal populations on the same resources targeted by fishermen (O'Boyle and Sinclair, 2012; Rindorf *et al*., 2013) falls outside the scope of the current study. Another indirect effect which is known to have a major impact in other gill net fisheries is the cost associated with 'hidden losses'. Referring to the entire removal of fish from nets without leaving any visible trace, hidden losses attributable to grey seals corresponded to between 15 and 36% of the total potential landings in the Baltic Sea cod gill net fishery over two years in the mid 2000's. For every damaged fish observed, approximately four fish were lost to seals (Königson *et al*., 2009b). Although dedicated studies on hidden losses in Irish gill net fisheries are required to provide more accurate figures, similarities in gear types and the nature of interactions with seals suggest that comparable levels of hidden losses could apply.

No previous studies on depredation of pollack in Irish waters are available for direct comparison. Information is available, however, from a previous study conducted on cod, a member of the same gadoid family as pollack, in an inshore gill net fishery conducted off Mayo in the early 1990's (BIM, 1997). The overall proportion of visually observable seal depredated pollack in the current study (18%) was considerably higher than the proportion of cod (10%) observed in the 1990's study suggesting that the economic impact of seal depredation on inshore gill netting may have increased substantially.

The three study vessels carried out a total of 32 days at sea in ICES areas VIIj and VIIb over a one year period targeting pollack and saithe with gill nets. Detailed landings figures for pollack are incomplete for the study period (MI, 2012). Given the range of vessel types and areas sampled under the current study, however, sampling is thought to be relatively representative of the pollack gill net fishery off the west and south west coasts. Uptake of the Irish pollack quota which was 1030t in 2012 has been high in recent years. Pollack has a preference for wrecks and rocky bottom habitat, making it difficult to catch with trawls (MI, 2012) and gill netting is the principal method used to target this species in Irish waters. Assuming roughly 80% of the Irish quota is taken by gill nets and a price of €2.18 per kg (MI, 2009) the Irish pollack gill net fishery was worth approximately €1.8m at first point of sale in 2012. Based on an overall depredation rate of 18%, the total value of pollack depredated by seals is thought to be in the region of €0.4m in 2012. Taking into account potential hidden losses the value of depredated fish could range from €0.72 to €1.18m.

The overall proportion of visually observable depredation of 10% of potential hake landings in the current study represents a substantial increase over the 7% rate observed in the same fishery in the mid 1990's. Fishing for hake typically occurs in offshore locations and is almost exclusively targeted by vessels over 15m in size. A total of 7 Irish vessels over 15m engaged in hake set net fisheries in 2012. Vessel 1 is a key player in the hake set net fishery and sampling conducted onboard this vessel as part of this study is thought to be relatively representative of the entire hake gill net fleet. The Irish quota for hake was 1704 tonnes in 2012 (MI, 2012). The metier share of the gill net fishery is around 24% with the rest of the quota taken predominantly by demersal trawls (MI and BIM, 2011a). Based on a price of €2.52 per kg (MI, 2009) the Irish hake set net fishery was worth approximately €1.03m in 2012. Based on an overall depredation rate of 10%, the total value of pollack depredated by seals is estimated at €114,000 in 2012. Taking into account potential hidden losses the total value of seal depredated fish could range from €286,000 up to €526,000. The total loss of fish taken by seals from nets rises to over 50% of the catch in both the pollack and hake fisheries when potential hidden losses are taken into account.

The observed depredation rate of 59% of monkfish in the current study is approximately twice as high as depredation rates observed in similar fisheries off the south coast in the early 1990's (Collins *et al*., 1993) and also much higher than the qualitative estimates of 20 – 30% provided by fishermen in recent questionnaires (Cronin *et al*., 2013). Insufficient data are available to permit extrapolations regarding the total value of seal depredated fish in tangle or trammel net fisheries but estimations of the daily loss experienced by the study vessels are possible. Although catch rates in the current study were low, monkfish is a high value species and the economic impact of seal depredation was high in the case of the Clare trammel net fishery. An average of 6.33 depredated monkfish per day was landed in this fishery. Based on an average sample weight of 3.5 kg per fish and a market price of €4.25 per kg (MI, 2009), the estimated value of visually observable seal damaged monkfish was €94 per day at sea. This typically represents 15 – 25% of the daily gross value of fish landed and a substantial economic loss to this fishery. An average of one seal damaged monkfish per day at sea was observed in the Mayo tangle net fishery resulting in negligible economic losses in this fishery. Monkfish were primarily taken as commercial bycatch in the observed fisheries. It is thought that directed set net fisheries for monkfish are no longer commercially feasible off the south west coast of Ireland due to seal depredation so this effective closure of a fishery due to seal depredation also undoubtedly has a major economic impact. The impact of seal depredation on the important spring gill net fishery for cod in the south east has yet to be studied. Additional impacts of depredation which are difficult to quantify but have substantial economic implications for fishermen include damage to fishing gear and increased fuel consumption by vessels seeking to avoid seals.

5.2 Factors affecting depredation

The usefulness of modelling the effects of depredation on the full pollack dataset including all three vessels was limited with the Vessel factor effectively acting as a proxy for other correlated variables. Thus significantly lower seal depredation of pollack on Vessel 3 in Mayo could be related to differences in landings (LPUE), quantities of gear deployed (Gear day^{-1}) season or location of fishing operations. Lower depredation could also be related to intrinsic characteristics of individual vessels such as noise levels associated with fishing operations or proximity to seal colonies or haul-out sites. Seal depredation was affected by soak time and estimated to increase by 4% for each increase of one hour in gear deployment.

Modelling of factors affecting pollack depredation on individual Vessel 1 provided a more useful analysis due to the absence of major correlations. Seal depredation was again affected by soak time and predicted to increase by approximately 5% for each increase of one hour in gear deployment. Soak time did not affect seal depredation in the hake fishery. Differences in the effect of soak times between the hake and pollack fisheries could be related to depth. While well within the range of grey seal benthic dive depths, the mean depth of nets observed in the hake fishery of 152.04m (± 24.51), exceeds the average depth of benthic dives conducted by grey seals in the area (Jessopp *et al*., 2013) and was almost twice as high as the mean depth of nets observed in the pollack fishery (78m ± 44). Seals were visually observed on a number of occasions in the vicinity of surface marker buoys before hauling commenced and fish were actively depredated during hauling. This suggests that seals were waiting near the surface to commence depredation. This type of approach would be typical of a learned behaviour which greatly assists in reducing energetic demands of diving on nets to take the catch. It is reasonable to assume that the deeper nets are deployed, the more likely seals are to engage in this type of behaviour thereby effectively reducing or in the case of the current study, negating the effect of soak time. This has major implications for the development of mitigation measures and warrants further investigation as discussed below.

In contrast to the pollack fishery, landings per unit effort (LPUE) was not significant in the hake fishery and this may be related to the more offshore location of the hake fishery where seal activity may be less prevalent. This could also be related to differences in the nature of fishing operations for each species. Pollack tend be captured in relatively large groups or aggregations related to underwater rocky peaks or wrecks resulting in slower hauling speeds and increased opportunity for depredation while gear is being hauled. In contrast hake are caught on more even ground and tend to be more evenly dispersed in fishing gear so higher landings may have less of an impact on hauling speeds and, by extension, depredation.

Higher depredation rates observed in autumn in the hake fishery could be related to seals increasing foraging effort pre-breeding (peak seal breeding period in southwest Ireland is October). Grey seals generally spend more time at sea during the summer months and more time ashore during the breeding and moulting periods between September and April (Cronin *et al*., 2013). However they still forage during these periods. The foraging range of grey seals tracked in southwest Ireland was highest in spring, lowest in summer, and increased again in the autumn to an average of 50 km from Dingle (Cronin *et al*., 2013), which is within the range of the hake fishery in the southwest. Variable levels of depredation across seasons could also be related to seasonal availability of free swimming prey.

The effect of spatial factors on seal depredation was consistent between the pollack and hake fisheries. Higher levels of depredation experienced by Vessel 1 to the north and east of pollack fishing operations and in more northerly and shallower areas in the hake fishery could be associated with more densely populated grey seal areas (Cronin *et al*., 2013) and higher levels of seal activity in more inshore waters.

Higher depredation rates in relation to Haul sequence within a trip experienced by Vessel 1 in pollack and hake fisheries indicates that depredation rates increased as trips unfolded. This could be associated with increased levels of vessel activity and noise which could attract seals to the area of operation. Similar to haul sequence, increased seal depredation in relation to relatively large amounts of gear deployed in a day in the hake fishery could also be related to increased levels of activity and noise associated with fishing operations.

Insignificant differences in the size of depredated and undamaged fish in the present study are consistent with previous findings (BIM, 1997). Other factors such as access to prey, degree to which fish are enmeshed, position in the net or freshness are therefore more likely to influence selection of fish by seals.

5.3 Bycatch

In spite of relatively high levels of depredation, no seal bycatch was observed in gill net fisheries suggesting that the risk of seal bycatch in observed gill net fisheries is low. Some 51 seals were landed by vessels fishing cod using gill nets off the Inishkea Islands off the Mayo coast in the 1990's (BIM, 1997). The latter fishery differed from the pollack fishery observed in the current study in that relatively large meshed nets of up to 178 mm were employed. The cod fishery was also located directly adjacent to the Inishkea Islands which is home to a major grey seal breeding colony whereas observed pollack fishing effort in the current study was located further south in areas less densely populated by grey seals.

Seal bycatch in the current study occurred in larger meshed tangle and trammel net fisheries and was particularly prevalent in the former. Larger mesh sizes in bottom set nets are in general known to be problematic with respect to seal bycatch (Bonner *et al*., 1989; Sjare *et al*., 2005). Depredation of monkfish in the trammel net fishery conducted of the Clare coast was high which suggests a reasonable amount of interaction with seals in this fishery. Substantially lower seal bycatch rates observed in the trammel net fishery off Clare compared to the tangle net fishery off Mayo (Table 12) could be related to the more offshore location or substantially deeper gear deployment depth (See section 4.1) of trammel nets. Juvenile seals, which formed the main component of seal bycatch in this study, may have a lower propensity to move to more offshore locations or greater depths associated with the observed trammel net fishery.

Seal bycatch was substantially and significantly higher in larger meshed tangle nets with model results predicting the numbers of seals caught in the 320 mm mesh to be 7.65 times higher than the 270 mm mesh size tangle nets. The reasons underlying differences in bycatch rates in different mesh sizes are unclear, however, due to the absence of significant differences in bycaught seal morphometrics across mesh sizes. Other gear characteristics such as twine thickness and hanging ratio were thought to be partially responsible for relatively high seal bycatch rates in Scottish tangle net fisheries for crawfish (Northridge, 1988). Other than mesh size, gear metrics of tangle nets observed in the current study were the same across mesh sizes, however, suggesting that differences in bycatch rates were due to differences in mesh size or some other unquantified gear characteristic(s). Significant correlations between seal bycatch and monkfish in the tangle net fishery can be explained by a strong motivation to target monkfish in nets given the high proportions of depredated monkfish observed. The significant relationship between seal bycatch and crawfish is more difficult to explain due to the absence of depredated crawfish in the fishery. Bycaught seals were frequently observed next to crawfish in nets suggesting that seals were indeed attracted towards the fishing gear by crawfish. Curiosity is a common trait of pinniped species (Allen *et al*., 2012) and the absence of any remnants of depredated crawfish in observed hauls suggests that curiosity rather than predation may have been the basis of this attraction. These results demonstrate a link between seal depredation or attraction to fishing gear and bycatch in set net fisheries. This has potential implications in terms of managing seal interactions in this specific fishery in that measures which effectively mitigate depredation also have potential to mitigate bycatch and vice versa. The absence of a significant effect of soak time on seal bycatch in the tangle net fishery suggests that this variable should be excluded from effort metrics derived for this fishery.

The prevalence of juveniles and minor differences in the sex ratio of seals taken as bycatch is consistent with previous studies (BIM, 1997; Kiely *et al*., 2000). Older seals may be more adept at avoiding bycatch or may, in some cases, be capable of breaking free from set nets if they become entangled. The positive correlation between seal bycatch number and month is partially explained by the absence of observed seal bycatch in January and February of the study period in spite of a moderate level of observed gear deployment at that time. This could

Table 16. Increases in pup production in key grey seal breeding areas between surveys conducted in 2005 and 2009-2012 (compiled from: Ó Cadhla *et al.*, 2013) and mean fishing effort for set net vessels over 10m in length operating in adjacent areas from 2010 to 2012 (Source: SFPA).

Counties	Breeding areas	Increase in pup production (%)	ICES Area	Mean fishing effort (Days at sea ± SD)
Kerry	Blasket Islands	70	VIIj	760 ± 95
Mayo and Galway	Inishkea Group, Slyne Head Islands, Inishark, Inishgort, etc.	55	VIIb	473 ± 91
Wexford and Dublin	Saltee Island, Lambay Island and Ireland's Eye	3	VIIa	248 ± 157
Donegal	Sturall to Maghera	6	VIa	13 ± 13

be related to lower levels of juvenile seal activity at this time and/or the moulting season which occurs around the same time. Significantly higher seal bycatch in tangle nets deployed at greater depths could be related to lower visibility of nets as light levels decrease in relation to depth. Neither monkfish nor crawfish catches were significantly correlated with seal bycatch in the count model of factors affecting seal bycatch. This further supports the suggestion that a mixture of poor visibility associated with greater depths and characteristics of the 320 mm mesh size gear, as opposed to attraction to prey, were primarily responsible for larger bycatch events. Similar conclusions were obtained from the Scottish study on seal bycatch in tangle net fisheries where both the dark background of the sea bed and poor head rope buoyancy and visibility were attributed to low net visibility and high bycatch (Northridge, 1988).

A total of 36 days at sea were observed on Vessel 3 while engaged in set net operations over a 12 month period for a total bycatch of 55 grey and 8 harbour seals. Mean total set net fishing effort for this vessel was 122 ± 10 days at sea from 2010 to 2012 (source Sea Fisheries Protection Authority). Assuming similar bycatch rates between years, a simple extrapolation of observed bycatch rates of 1.53 grey and 0.22 harbour seals per day at sea provides annual bycatch estimates of 187 grey and 27 harbour seals. Observations of tangle netting were restricted to one vessel operating in a relatively densely populated area for grey seals and insufficient data are currently available to derive total bycatch estimates on a larger scale. Knowledge of interactions from the present study, proximity of grey seal colonies (Cronin *et al.*, 2013) to crawfish fisheries (MI, 2007) as well as similar preferences for rocky habitats (MI and BIM, 2011b: Jessopp *et al.*, 2013) suggest that the general risk of seal bycatch in tangle net fisheries for crawfish on the west and south west coasts may be high. However, observed seal bycatch risk in a tangle net fishery for crawfish and turbot conducted in Roaringwater Bay off the south coast was low (MI, 2011). This geographic variability in bycatch rates highlights the need to carry out observer work in a variety of locations to properly assess bycatch risk.

Fisheries bycatch may pose a threat to seal conservation in some areas and mitigation measures should be encouraged to reduce this threat and improve the sustainability of the fisheries in question. Increasing numbers of seals in Irish waters indicates, however, that seal populations are currently maintaining themselves. The reasons that relatively high seal bycatch is not causing declines at population level could be related to high natural mortality of juvenile seals and benefits accrued from depredation: Survival of grey seals in the first year of life is low (Hall *et al.*, 2001) so it is likely that a component of bycaught juvenile seals would ultimately fail to survive due to other factors. Average survival of grey seal pups is known to vary from year to year depending on the average condition of breeding females. Female condition is likely to be, in part, a consequence of per capita food availability during pregnancy (Hall *et al.*, 2001). Levels of seal depredation observed in the current study suggest that set nets provide a steady source of readily accessible food to seals along the west and south west coasts thereby contributing to reproductive capacity and growing seal populations. A variety of seabird species are known to benefit at population level from preying on fish discards (Bearhop *et al.*, 2001; Votier *et al.*, 2013) so the concept of scavengers flourishing from fisheries output is not new.

Indeed the largest increases in localised grey seal populations have occurred in areas with the highest set net fishing effort (Table 16). It is not possible to reliably discern different gear types in official set net fishing effort data. It is interesting to note, however, that Kerry, with the highest increase in pup production (70%) is considered the "stronghold" for the crawfish tangle net fishery. Mayo and Galway which has the second highest compiled increase in pup production (55%) is the second most important area for the crawfish tangle net fishery (MI, 2007; MI and BIM, 2011b). The areas with the lowest increases in pup production have very little tangle net fishing effort; Tangle netting for crawfish is almost non-existent in area VIIa off Wexford and Dublin (MI, 2007) (3% increase in pup production) with most effort days thought to be attributed to the spring gill net fishery for cod. Almost no set net fishing effort of any gear type occurred in area VIa off Donegal (6% increase in pup production) in the last three years due to the introduction of closed areas to protect white fish species in the area.

The conservation status of all cetacean species taken as bycatch in this study is considered to be of least concern according to the International Union for Conservation of Nature (IUCN). All of these species are listed under Annexe IV of the habitats directive, however, and are subject to monitoring to ensure that incidental bycatch does not have a significant negative impact on the species concerned. Assessment of bycatch at population level is carried out through ICES working groups on bycatch of protected species (WGBYC) and marine mammal ecology (WGMME). Bycatch data from this study will be compiled with bycatch data from other sources and made available to ICES through an annual report to the European Commission (EC) carried out in respect of requirements under EC regulation 812/2004. It should be noted that effective, commercially available acoustic deterrent devices are available in the case of harbour porpoises where bycatch levels are deemed to be unacceptable.

Conservation status for bycaught elasmobranch species ranged from least concern for the starry smooth hound *(Mustelus asterias)* to critically endangered for the Common skate. Some 76% of common skate were reported as being alive when returned to sea but the longer term survivability of these fish is unknown. Tagging studies carried out in the UK have demonstrated relatively high survivability of skate species released from gill nets, long lines and trawls (Ellis *et al*., 2008). Mortality rates for fish released from tangle nets are unknown however and conventional tagging studies should be considered in Ireland to develop knowledge of this issue. The common guillemot is a species of least concern according to IUCN and is not listed under the Birds Directive (2009/147/EC).

5.4 Mitigation Measures

Operational and fishing gear modifications are thought to offer the most potential as short term solutions to increasing interactions between seals and set net fisheries. Soak time, a significant factor in the inshore pollack gill net fishery, can be controlled by fishermen. Vessel 3 was frequently observed deploying gill nets for short periods during the day, working the gear in relation to changes in tidal current and fish behaviour. Smart fishing techniques such as this are essential to minimise depredation in more inshore locations. Soak time was insignificant in the deeper hake gill net fishery. Our combined knowledge of seal behaviour during benthic dives and around fishing gear when depredation occurs suggests that depredation in deep set net fisheries primarily occurs during hauling when fish are close to the surface. Hence development of systems which minimise opportunities and/or deter seals from depredation during hauling should be encouraged.

Faster hauling speed has major potential to mitigate seal depredation. Modern gill net fisheries are generally highly mechanised with efficient net hauling and automated net flaking/storage systems which minimise manpower and maximise quantities of gear deployed. Removing fish from nets continues to be carried out manually, however, and large catches are likely to reduce hauling speeds and increase depredation as observed in the significant correlation between seal damage and commercial landings on Vessel 1 in the pollack fishery. A variety of operational practices could be explored to deal with this issue. Extra manpower could be employed to assist in clearing fish prior to stowing nets particularly during periods of heavy depredation. Systems whereby clearing fish from nets is postponed until after nets are hauled aboard, particularly when landings are large could also be examined. Shorter fleets of nets may be required to free up deck space to facilitate the latter approach.

Depredation is still likely to occur to some extent regardless of hauling speeds as observed in the hake fishery. Systems which actively deter seals from the vicinity of the boat during hauling have potential to further reduce depredation. Acoustic deterrent or harassment systems (AHDs) have successfully reduced depredation in aquaculture operations (Gotz, 2008; Harvey and Mate, 1987; Vilata *et al*., 2010), at the mouth of enclosed bays or rivers (Westerberg, 2010; Yurk and Trites, 2000), in gill net (Barlow and Cameron, 2003) and trap (Fjalling *et al*., 2006) fisheries. However, habituation, and difficulties in powering devices and effects of signals on other species such as cetaceans have been identified as limitations to long term success in these studies.

Restriction of signal deployment to hauling operations has a number of advantages in this regard. Set net fishing vessels tend to be highly mobile and the amount of time spent hauling gear and opportunities to habituate are considerably less than aquaculture operations where signals may be deployed on an almost continuous basis. In addition, although food motivation or reinforcement has an accelerating effect on habituation to aversive stimuli (Gotz and Janik, 2011) observations from the current study suggest that levels of motivation to depredate vary considerably. As well as complete removal of the fish body behind the head, seal depredation in the current study was also frequently characterised by removal of the skin or viscera leaving the majority of the fish body behind. This suggests that once sated, seals continue to engage in depredation which is driven by factors other than hunger and this may greatly reduce motivation to depredate if aversive stimuli are deployed. Acoustic devices deployed in the vicinity of vessels during hauling can be powered directly from the vessel so power limitations are not an issue. While signals of around 15 kHz and a relatively high source level of 179 dB re 1μPa rms at 1 m are known to reduce seal depredation (Fjalling *et al*., 2006), alternative signals which are likely to have substantially less impact on cetacean species are in a late stage of development for aquaculture operations (pers. comm. Thomas Gotz). Their potential use in set-net fisheries should be explored further.

A number of factors identified in the current study as having a significant effect on seal bycatch can be manipulated and have major potential to reduce the numbers of animals caught in tangle net fisheries. Dedicated experimental studies on the effect of different tangle net mesh sizes on seal bycatch including detailed examination of gear characteristics and the manner in which seals are entangled would greatly assist in confirming if smaller mesh sizes effectively reduce seal bycatch. Modifications to nets to improve their visibility to seals without negatively impacting crawfish landings could also be investigated. Indeed a discussion between net makers and fishermen on modification of nets specifically used to target crawfish would be very useful. Tangle nets used in the current study have been designed to catch a range of crustacean and fish species. Relatively low catch rates of fish species such as monkfish which are subject to high levels of depredation and deterioration due to long soak times suggest that fish landings are no longer an important component of tangle net fisheries for crawfish. Gear modifications which specifically focus on maintaining crawfish landings while reducing seal bycatch may therefore be feasible. Such modifications could include reductions in mesh size, twine thickness, higher hanging ratios and increased net visibility.

The results of this study suggest that a variety of factors other than gear type such as target species, areas and depths fished are also likely to have a major effect on seal bycatch rates. No significant correlations were observed between seal bycatch and landings of species such as skates and spider crabs in the tangle net fishery and these results are supported by diet studies which show no evidence of seals targeting these species (Cronin *et al*., 2013). Thus the risk of seal bycatch in fisheries specifically targeting these species is likely to be lower than fisheries targeting crawfish or monkfish. Substantially lower bycatch rates observed in the trammel net fishery compared to the tangle net fishery may be related to differences in depth of deployment of these large meshed gears. This suggests that bycatch risk may also decline in relation to large scale differences in gear deployment depths. Of course the impact of different levels of seal bycatch needs to be discussed but this study demonstrates that the effect of large meshed nets on bycatch varies considerably in relation to different characteristics of different fisheries. Continued effort to monitor bycatch in a variety of set net fisheries operating in different geographic areas is the optimal way to determine bycatch risk levels associated with specific fisheries.

In terms of other potential operational mitigation measures, fish traps have shown some potential as an alternative gear to gill nets in a cod fishery in the Baltic Sea (Königson *et al*., 2009a). The effectiveness of fish traps for species such as pollack or hake is unknown however and a major financial investment in diversification from gill nets would be required. Fish such as pollack can also be caught by jigging hooks. More mobile than set net fishing operations, this method may have some potential in certain areas but reports from industry suggest that line caught fish are also prone to seal depredation. Prior to the 1970s crawfish were effectively targeted with pots/traps in Ireland. The introduction of tangle nets in the 1970's is associated with a major decline in landings and catch rates so that pots are currently not thought to be a commercially viable fishing method for crawfish (MI and BIM, 2011b). Over the long term however, reintroduction of pots for crawfish has major potential as an alternative gear to tangle nets where required.

5.5 Management

Mitigation measures identified in this study have significant potential to reduce seal fisheries interactions, thereby improving the viability of businesses affected by depredation and reducing threats to seal conservation. Further research and development of these measures should be prioritised in any management process to deal with this issue. Further onboard observer work also needs to be carried out to assess the scale of interactions in fisheries not covered under the current pilot study.

A key issue in relation to assessing the impact of bycatch at localised population level for species such as grey seals is that they are widely distributed and migrate extensively (MI, 2011). Careful consideration therefore needs to be given to the definition of appropriate spatial units for management purposes. Recommended by ICES, regionalised seal management units (MUs) are proposed in the UK for grey and harbour seals (the same for both species) based on the locations of breeding colonies, haul-out sites, and on administrative boundaries (ICES, 2013). A similar MU system should be applied in Ireland given that seal populations are shared between the two countries and that this type of approach is recommended at EC level.

A comprehensive management plan which deals with the broad range of issues contributing to a growing seal – fisheries conflict in Ireland is urgently required. Recognising the need to strategically address such issues, EC member states such as Finland have already been down this road. The Finnish management plan for seal populations is based on extensive consultation with a wide range of interest groups and in the context of maintaining favourable conservation status, provides explicit management objectives for seal populations. (FMAF, 2007). Other than meeting basic requirements of the habitats directive, no management objectives for seal populations have been agreed and no seal management plan to deal with seal – fisheries issues is currently proposed in Ireland. Furthermore no consensus exists as to what optimal population growth or abundance should be In Irish waters. Recent seal population studies in Ireland have suggested that although seal populations are growing, the overall numbers of seals remain low compared with the UK especially considering the extent and availability of apparently suitable coastal habitat (Duck and Morris, 2012; Ó Cadhla *et al*., 2013). The current population of grey seals is estimated to be between 90,100 and 137,700 animals in the UK (SCOS, 2011) which is approximately 12 to 15 times higher than the current Irish grey seal population estimate. Commercial fishermen, fish farmers, recreational angling businesses and others whose livelihoods are directly impacted by growing seal populations are likely to have more conservative viewpoints regarding optimal seal population levels. Whether their interests lie in maintaining a viable business or conserving seals, the absence of clear policy in this regard creates confusion, uncertainty and further polarises viewpoints amongst key stakeholders. This is likely to result in further intensification of the seal fisheries conflict as seal populations continue to increase.

Early and effective stakeholder participation is a key principle of the ecosystem approach and a legal requirement of the Marine Strategy Framework Directive (MSFD). In line with this requirement, a focus group was recently set up in Ireland to promote discussion of issues surrounding the seal – fisheries conflict amongst a broad range of stakeholders. These include fisheries and environmental government agencies, fishermen’s representative organisations and NGOs. Now that updated information on seal populations and fisheries interactions is available, this focus group is the ideal forum to discuss and develop consensus amongst key stakeholders on the future direction of seal – fisheries management policy. The magnitude of the conflict in Ireland suggests that this process should commence as soon as possible.

6 References

Allen, R., Jarvis, D. and Mills, C. 2012. Entanglement of grey seals *Halichoerus gryptus* at a haul-out site in Cornwall, UK. MAR POLLUT BULL: 2815-2819.

BIM. 1997. The Physical Interaction between grey seals and fishing gear. An Bord Iascaigh Mhara Report to the European Commission, DG XIV. Ref PEM/93/06.

BIM. 2012. Review of Crawfish Technical Conservation Measures. Final Report. 14pp.

Barlow, J. and Cameron, G.A. 2003. Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. Marine Mammal Science, 19(2): 265-283.

Bearhop, S. Thompson, D.R., Phillips, R.A., Waldron, S., Hamer, K.C. *et al*. 2001. Annual variation in Great Skua diets: The importance of commercial fisheries and predation on seabirds revealed by combining dietary analyses. Condor 103:802-809.

Bonner, W.N. 1972. The grey and common seal in European waters. Oceanogr. and Mar. Biol. Ann. Rev. 10: 461-507.

Bonner, W.N. 1989. The natural history of seals. Christopher Helm, London. 196pp.

Burnham, K.P. and Anderson, D.R. 2002. Model Selection and Multimodel Inference. New York: Springer. 496pp.

Collins, M., Crummey, C., Neal, D. and Fitzgerald, R. 1993. Predator damage to net caught angler fish *(Lophius piscatorius and L. budegassa)* off the south coast of Ireland. ICES, N:17.

Cosgrove R., Browne D. and Robson S. 2006. Assessment of acoustic deterrent devices in Irish gill net and tangle net fisheries. Marine Technical Report, BIM.

Cronin, M., Jessopp, M. and Reid, D. 2013. Fishery-Seal interactions in Irish Waters: Current perspectives and future research priorities. Marine Policy. In press.

Duck, C.D. 2006. Results of the thermal image survey of seals around the coast of Northern Ireland. Environment and Heritage Service Research and Development Series. No 06/09, 1-7.

Duck, C. and Morris, C. 2012. An aerial survey of harbour seals in Ireland: Part 2: Galway Bay to Carlingford Lough. A Report for the National Parks & Wildlife Service of the Department of Arts, Heritage & the Gaeltacht (DAHG).

Ellis, J.R., Burt, G. and Cox, L. 2008. Thames ray tagging and survival. Fisheries science partnership, CEFAS Final report.

Fjälling, A. 2005. The estimation of hidden seal-inflicted losses in the Baltic Sea set-trap salmon fisheries. ICES Journal of Marine Science 62:1630-1635

Fjälling, A., Wahlberg, M., and Westerberg, H. 2006. Acoustic harassment devices reduce seal interaction in the Baltic salmon-trap, net fishery. ICES Journal of Marine Science, 63: 1751-1758.

Fjälling, A. 2007. The estimation of hidden seal-inflicted losses in the Baltic Sea set-trap salmon fishery. ICES Journal of Marine Science 62, 1630-1635.

FMAF. 2007. Management Plan for the Finnish Seal Populations in the Baltic Sea. Ministry of Agriculture and Forestry 4b. 96pp.

Gotz, T. 2008. Aversiveness of sound in marine mammals: psycho-physiological basis behavioural correlates and potential applications. PhD Thesis.

Gotz, T. and Janik, V. 2011. Repeated elicitation of the acoustic startle reflex leads to sensitisation in subsequent avoidance behaviour and induces fear conditioning. BioMed Central Neuroscience, Vol 12, 30pp.

Gunnar Lunneryd, S., Fjalling, A. and Westerberg, H. 2003. A large-mesh salmon trap: a way of mitigating seal impact on a coastal fishery. Journal of Marine Science 60, 1194–1199.

Hall, A.J., McConnell, B.J. and Barker, R.J. 2001. Factors affecting first-year survival in grey seals and their implications for life history strategy. J. Anim. Ecol. 70 (1): 138-149.

Harvey, B. R. and Mate, B. 1987. The feasibility of an acoustic harassment method to restrict movements of seals into Netart Bay, Oregon. In: Acoustical Deterrents in Marine Mammal Conflicts with Fisheries (Ed. by Mate, B. & Harvey, B. R.): Oregon Sea Grant ORESU-W-86-001.

Hilbe, J.M. 2007. Negative Binomial Regression. New York: Cambridge University Press. 251 pp.

Hilborn, R. and Mangel, M. 1997. The ecological detective. Princeton University Press, New Jersey, USA. 315pp.

Hovgård, H. and Lassen, H., 2000. Manual on estimation of selectivity for gill net and longline gears in abundance surveys. FAO Fisheries Technical Paper. No. 397. Rome.

ICES. 2013. Report of the Working Group on Marine Mammal Ecology (WGMME), 4–7 February 2013, Paris, France. ICES CM 2013/ACOM:26. 117 pp.

Jessopp, M., Cronin, M. and Hart, T. 2013. Habitat-Mediated Dive Behavior in Free-Ranging Grey Seals. PLoS ONE 8(5): e63720. doi:10.1371/journal.pone.0063720.

Kiely, O., Lidgard, D., McKibben, M., Connolly, N. and Baines, M. 2000. Grey seals: status and monitoring in the Irish and Celtic Seas. Maritime Ireland/Wales INTERREG Report No. 3. 76pp.

King, G. 1989. Variance specification in event count models: from restrictive assumptions to a generalized estimator. Am. J. Polit. Sci., 33: 762–784. doi:10.2307/2111071.

Königson, S., Lunneryd, S.G. and Ovegard, M. 2009a. The Norwegian two-chamber trap used in commercial fisheries in the Baltic. ICES SGPOT Report 2009.

Königson, S., Lunneryd, S.G., Stridh, H. and Sundqvist, F. 2009b. Grey seal predation in cod gill net fisheries in the central Baltic Sea. J. Northw. Atl. Fish. Sci., 42: 41–47. doi:10.2960/J.v42.m654.

Long, J. S. 1997. Regression Models for Categorical and Limited Dependent Variables. Thousand Oaks, CA: Sage Publications.

McCarthy, D. T. 1985. Interaction between seals and salmon drift net fisheries in the west of Ireland, Fishery Leaflet 126, Department of Fisheries and Forestry.

MI. 2007. The Stock Book, Annual Review of Fish Stocks in 2007 with Management Advice for 2008, Marine Institute, November 2007. 424 pp.

MI. 2009. Atlas of the Commercial Fisheries around Ireland, Marine Institute, December 2009. ISBN 978 1 902895 46 8. 58 pp.

MI. 2011. Appropriate Assessment of Fisheries and Aquaculture in Roaringwater Bay 2012 – 2016. The Marine Institute. 122pp.

MI. 2012. The Stock Book, Annual Review of Fish Stocks in 2012 with Management Advice for 2013, Marine Institute, November 2012. 600 pp.

MI and BIM. 2011a. Atlas of Demersal Discarding, Scientific Observations and Potential Solutions, Marine Institute, Bord Iascaigh Mhara, September 2011. ISBN 978-1-902895-50-5. 82 pp.

MI and BIM. 2011b. Shellfish Stocks and Fisheries Review. An assessment of selected stocks. The Marine Institute and Bord Iascaigh Mhara. 64pp.

Minami, M., Lennert-Cody, C.E. Gao, W. and Román-Verdesoto, M. 2007. Modelling shark bycatch: The zero-inflated negative binomial regression model with smoothing. Fisheries Research, 84: 210-221.

Murray, KT. 2009. Characteristics and magnitude of sea turtle by-catch in U.S. Mid-Atlantic sink gill net gear. Endang. Sp. Res. 8:211-224.

Northridge, S. 1988. Marine mammals and fisheries: a study of conflicts with fishing gear in British waters. Report to Wildlife Link.

O'Boyle, R. and Sinclair, M. 2012. Seal–cod interactions on the Eastern Scotian Shelf: Reconsideration of modelling assumptions. Fisheries Research doi:10.1016.

Ó Cadhla, O., Keena, T., Strong, D., Duck, C. and Hiby, L. 2013. Monitoring of the breeding population of grey seals in Ireland, 2009 – 2012. Irish Wildlife Manuals, No. 74. National Parks and Wildlife Service, Department of the Arts, Heritage and the Gaeltacht, Dublin, Ireland.

Rindorf, A., Schmidt, J. Bogstad, B., Reeves, S. and Walther, Y. 2013. A Framework for Multispecies Assessment and Management. An ICES/NCM Background Document, TemaNord 2013:550.

Rossman, M. C. 2010. Estimated bycatch of small cetaceans in northeast US bottom trawl fishing gear during 2000–2005. J. Northw. Atl. Fish. Sci., 42: 77–101.

Sainsbury, J.C. 1996. Commercial fishing methods : an introduction to vessels and gears. Fishing News Books, 359pp.

SCOS. 2011. Scientific advice on matters relating to the management of seal populations: 2011. NERC Special Committee on Seals. UK. 133pp.

Sjare, B., Walsh, D., Benjamins, S. and Stenson, G. B. 2005. An Update on Harp Seal Bycatch Estimates in the Newfoundland Lumpfish Fishery: 1999-2003. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/049.

Sparre P. and Venema S. C. 1992. Introduction to tropical fish stock assessment, Part 1. Manual. FAO. Fish. Tech. Pap. 306 /1 Rev. 1 FAO, Rome. 376 pp.

Sullivan, B. J., Brickle P., Reid, T. A., Bone D. G. and Middleton, D. A. J. 2006. Mitigation of seabird mortality on factory trawlers: trials of three devices to reduce warp cable strikes. Polar Biology 29: 745-753.

Teo, S., and Block, B.A. 2010. Comparative influence of ocean conditions on yellowfin and Atlantic bluefin tuna catch from longlines in the Gulf of Mexico. PlosOne 5:1-11.

Thode, A. M., Gerstoft, P., Burgess, W. C., Sabra, K. Guerra, M., Stokes, M. D., Noad, M. and Cato, D.C. 2006. A portable matched-field processing system using passive acoustic time synchronization. J. Ocean. Eng. 31(3):696–710.

Tudela, S. 2004. Ecosystem effects of fishing in the Mediterranean: an analysis of the major threats of fishing gear and practices in biodiversity and marine habitats. Studies and Reviews. General Fisheries Commission for the Mediterranean. No. 74. Rome, FAO. 44pp.

Vilata, J., Oliva, D. and Sepu´lveda, M. 2010. The predation of farmed salmon by South American sea lions *(Otaria flavescens)* in southern Chile. ICES Journal of Marine Science, 67: 475–482.

Votier, S.C., Bicknell, A., Cox, S.L., Scales, K.L. and Patrick, S.C. 2013. A Bird's Eye View of Discard Reforms: Bird-Borne Cameras Reveal Seabird/Fishery Interactions. PLoS ONE 8(3): e57376.

Vuong, H.Q. 1989. Likelihood Ratio Tests for Model Selection and non-nested Hypotheses. Econometrica, 57 (2): 307–333.

Westerberg, H., Fjälling, A., and Martinsson, A. 2000. Sälskador i det svenska fisket. (Seal damage in the Swedish fishery). Fiskeriverket Rapport 3:4-38.

Westerberg, H., Lunneryd, S-G., Fjälling, A., and Wahlberg, M. 2006. Reconciling Fisheries Activities with the Conservation of Seals throughout the Development of New Fishing Gear: A Case Study from the Baltic Fishery–Grey Seal Conflict. American Fisheries Society Symposium 587-598.

Westerberg, 2010. Potential solutions to seal – fisheries conflicts. Study note to the Directorate General for Internal Policies, Policy Department B: Structural and Cohesion Policies, Fisheries, European Parliament.

Yurk, H., and Trites, A.W. 2000. Experimental attempts to reduce predation by harbor seals on out-migrating juvenile salmonids. Transactions of the American Fisheries Society, 129:1360–1366.

Zollett, E. A. 2011. Conserving dolphins and fishermen: Combining science and local knowledge to reduce cetacean bycatch. ProQuest, UMI Dissertation Publishing, 160 pp.

Appendix I. Table of Acronyms

AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
BIM	An Bord Iascaigh Mhara (Irish Sea Fisheries Board)
CMRC	Coastal and Marine Research Centre
CMS	Convention on Migratory Species
DF	Degrees of Freedom
DPUE	Damage per unit effort
EC	European Community
FIF	Federation of Irish Fishermen
FMAF	Finnish Ministry of Agriculture and Fisheries
ICES	International Council for the Exploration of the Sea
IUCN	International Union for Conservation of Nature
LPUE	Landings per unit effort
KS	Kolmogorov Smirnov Test
MI	Marine Institute (Ireland)
MSFD	Marine Strategy Framework Directive
MU	Management Units
NGO	Non-governmental Organisation
OSPAR	Oslo and Paris Conventions for the Protection of the Marine Environment of the North East Atlantic)
P	Probability
QQ	Quantile – Quantile
SAC	Special Area of Conservation
SCOS	Special Committee on Seals
SD	Standard Deviation
SE	Standard Error
SFPA	Sea Fisheries Protection Authority
SPUE	Seals per unit effort
WGBYC	Working Group on Bycatch of Protected Species
WGMME	Working Group on Marine Mammal Ecology

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