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A Pilot Study of Seal Predation on Salmon Stocks in Selected Irish Rivers and Estuaries

Iascach Intíre Éireann
Inland Fisheries Ireland

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Photo credit: Pedro Garcia-Izquierdo

Coastal & Marine Research Centre
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BEES
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Executive Summary

Inland Fisheries Ireland (IFI) funded the Coastal and Marine Research Centre (CMRC), University College Cork (UCC), in conjunction with partners in the School of Biology, Ecology and Environmental Science (BEES, UCC) and the Marine Institute (MI) to undertake a 2 year pilot study (2011-2013) to investigate seal predation on salmon stocks in the Moy and Slaney estuaries. The study began in August 2011 and continued to August 2013.

Salmonids were found in the diet of both grey and harbour seals using identification of salmonid bones recovered from the scat (faeces) of seals collected at seal haulout sites in the Moy and Slaney. Salmonids were recovered in relatively low numbers, representing only 1.6% of the total prey numbers in the Slaney and less than 5% in the Moy. However, due to the large size of individual salmonids, they comprised approximately 15% of the total prey biomass consumed. The presence of salmonids in the diet of seals is likely to represent consumption of both salmon (*Salmo salar)* and sea trout (*Salmo trutta*), with contribution to the diet related to seasonal abundance. Genetic techniques were employed to confirm salmonid species identification based on hard structures, with both salmon and sea trout DNA being detected in scats. The removal of salmonids by seals (or other predators) must be placed into context of the amount removed by fisheries; In the Moy 6,564 salmon were caught (non-release) by rod fisheries (5 year average, P Gargan IFI *pers comm*) which is likely to be far higher than that removed by seals in the area. However, smaller salmon population units are most vulnerable to predation, and even low levels of predation by "specialist" seals (or other predators) could have disproportionately large effects on small salmon population units such as in the Slaney.

Background:

Interactions between seals and the fishing industry are an on-going issue in Ireland and indeed globally across the range of most seal species. These interactions occur at both the operational (seal damage to catches and fishing gear, and bycatch of seals in fishing nets) and biological (competition for shared resources) level. Salmonid species such as the Atlantic salmon (*Salmo salar)* is a protected species (in freshwater habitats) under Annex II of the EU Habitats Directive. Atlantic salmon stocks in Ireland have declined by 75% in recent years (Anon 2008), and although conservation measures have been put in place, salmon stocks in many Irish rivers are below their conservation limits (Anon 2008). Numbers of migrating smolts of sea trout (*Salmo trutta*) have also decreased significantly since the 1970s (Byrne et al. 2004). With declines in fish stocks there has been increased interest in the extent of competition for resources between commercial fisheries and seals. Atlantic salmon is a commercially important fish species in Ireland. With the closure of the salmon drift net fishery in Irish waters (2006), depredation damage to net caught salmon is no longer a widespread issue. However, draft and snap net fisheries are still operational in some estuaries considered to have sufficient stock for harvesting. Salmon are also taken on rod and line as the fish moves into, and up the natal river to spawn. Quantitative information on impacts of seals on this fishery in Ireland is not currently available however feedback from Inland Fisheries Ireland (IFI) suggests that seal damage to line and snap-net caught salmon varies geographically from less than 1% in the Shannon estuary to 40% in the Moy estuary (Cronin et al. 2010).

Seal interactions with salmon can include predation and interference at aquaculture sites, predation on salmon stocks entering rivers, on adult salmon in the open sea and predation on outward migrating salmon smolts. There may also be indirect impacts of seals on salmon stocks and fisheries; the presence of seals in rivers and estuaries may alter fish behaviour, reducing rod catches and therefore the economic viability of these fisheries (Butler et al. 2006). Inland Fisheries Ireland (IFI) funded the Coastal and Marine Research Centre (CMRC), University College Cork (UCC), in conjunction with partners in the School of Biology, Ecology and Environmental Science (BEES, UCC) and the Marine Institute (MI) to undertake a 2 year pilot study (2011-2013) to investigate seal predation on salmon stocks in selected Irish rivers and estuaries. The study began in August 2011 and continued to August 2013.

Two rivers in which seal predation of adult salmon stocks has been problematic were selected for the study, namely the river Moy Co. Mayo and the river Slaney Co. Wexford. The Slaney has a peak Multi-Sea Winter (MSW) run of salmon from March to May, and a run of grilse (1 sea winter) in the summer months, peaking July/August. The Slaney river is below conservation limits (CL) for salmon, with no commercial fishery operating in the area. Local populations of seals consist mainly of grey seals, and large breeding and moulting grey seal colonies are located on the nearby Saltee Islands. A smaller number of harbour seals also inhabit the harbour. The Moy has a later salmon run than the Slaney, with a run of sprinf salmon April-May and a peak grilse run occurring over the July-August period. The Moy is presently above CL for salmon, and supports a fishery. Although seal haul-outs within the estuary comprise mostly of harbour seals, conservation officers report grey seals entering the estuary from locations outside, possibly from the large breeding and moult colonies on the Inishkea Islands.

The study aimed to:

1. Determine the seasonal abundance of local seal species in the river mouth and estuaries of the river Moy and river Slaney
2. Explore seasonal (and inter-annual where possible) levels of predation, diet and interaction between seals and fish stocks, particularly Atlantic salmon, in the two study rivers
3. Determine population-level rates of predation on salmon and other fish species using seal abundance estimates and telemetry data*
4. Explore the use of photographic identification to determine the number of individual seals involved in fish interactions
5. Assess changes in seal predation on salmon following the closure of the off-shore drift net fishery
6. Review seal management options in river/estuary situations

**The telemetry element of the project will be conducted in March/April 2014 and reported on separately late 2014, due to malfunction of tags deployed on seals in March 2013*

Methods

Study sites

The two study sites used in this study are shown in Figure 1.

Figure 1: Location of sampling sites in the Moy estuary and Wexford Harbour (Fishpal 2013).

The river Moy, Co Mayo

The river Moy flows approximately 110km from the Ox Mountains to Kilala Bay, where it then joins the Atlantic Ocean. The Moy is one of Ireland's most important and productive rivers for salmon angling, supporting a large rod fishery. In 2011, over 20% of all salmon caught in Ireland were caught in the river Moy (IFI 2011). The salmon season runs from the beginning of February to the end of September. Commercial fishing for salmon in the river ceased in 1999, and drift netting for salmon in Killala Bay (and all of Ireland) was banned in 2007. The estuary is home to large numbers of sea trout (*Salmo trutta*), and large stocks of sandeels (*Ammodytes* spp.), sprat (*Sprattus sprattus*), and shrimp species (P. Armstrong, IFI pers comm). The Moy estuary (54°11'N, 09°08W) is a designated Special Area of Conservation (SAC) with harbour seal as a feature of interest, and Special Protected Area under the EU Habitats Directive for waterbirds. The estuary runs approximately 10km from Ballina town to the Atlantic Ocean. It contains mostly muddy and sandy substrates and a large number of sandbars and mudflats that become exposed at low tide. The topography of these sandbars regularly shifts.

The river Slaney, Co Wexford

The Slaney flows approximately 117km from Lugnaquilla Mountain to Wexford Harbour, where it enters the Irish Sea. The estuary is part of the Slaney River Valley SAC and is protected under the Annex I of the EU Habitats Directive. Annex II protected species in the Slaney include salmon, lamprey (*Petromyzon marinus*), freshwater pearl mussels (*Margaritifera margaritifera*), twaithe shad

(*Alosa fallax*), and otters (*Lutra lutra*) (NPWS 2006). The lower Slaney estuary waterbody covers an area of 18.32km^2. The lower estuary, which includes Wexford harbour is home to a range of fish species, of which sand gobies (*Pomatoschistus minutus*), flounder (*Platichthys flesus*), three-spined stickleback (*Gasterosteus aculeatus*), and thick-lipped mullet (*Chelon labrosus*) are the most common (Central and Regional Fisheries Board 2009). The Slaney is currently below conservation limits for salmon, with no commercial fishery operating in the area. A rod fishery exists on the Slaney on a catch and release basis only. The MSW salmon run in the river Slaney occurs from January to May, with a run of grilse in the summer. Sea-trout run through June to August (Slaney River Trust 2013).

Estimating seal abundance in the river mouth and estuaries of the river Moy and river Slaney.

To determine the seasonal abundance of either species of seal at terrestrial sites, year-round surveys are essential. Estimates of abundance of both species of seal in the river mouth and estuaries of the rivers Moy and Slaney were undertaken over a 12 month period and seasonal change in abundance examined. As variables such as weather, time of day, state of tide, time of year and human disturbance affect the haul-out behaviour and therefore occurrence of seals at haul-out sites (Cronin 2007) repeat surveys at each site throughout the year were conducted to minimise variability in counts. Counts were conducted during a period 2 hours either side of low tide as the haul-out sites in the study areas are mostly inter-tidal.

Having considered the terrestrial distribution of seals in the two study areas and local knowledge of NPWS rangers and IFI staff, a combination of boat based and aerial surveys were conducted to achieve this objective in the Slaney estuary while a land based approach was deemed sufficient in the Moy. The frequency of counts and sampling methods for each of the two sites are detailed below.

Moy

Surveys of seals hauled-out in the Moy estuary were conducted from nearby vantage points, monthly from August 2011 to July 2012. Bi-monthly survey effort continued between July 2012 and Dec 2012. Each survey consisted of two days of land-based counts and one day of scat (faecal) collection. Land-based counts were achieved from a vantage point (N 54˚19.29, W 9˚12.48) located on the Feeny Farm that overlooked the entire mouth of the estuary. Counts were conducted using an Opticron GS 655 GA fieldscope mounted on a Manfrotto tripod with a Wimberley Head (WH-200). Counts were carried out hourly over the four hour tidal window (i.e. 2 hours either side of low water). Variables such as weather, wind direction, wind force, and disturbances were also noted.

Slaney

Boat surveys

Surveys of seals hauled-out in the mouth of the River Slaney were conducted bi-monthly, from September 2011 to September 2012 and monthly surveys from September 2012-August 2013. Between September 2011- 2012 surveys consisted of two days of boat-based counts and one day of scat collection; between September 2012 and August 2013 one day boat based count and scat collection. Due to the shifting sand-bars navigation within Wexford harbour is extremely difficult at low tide and local knowledge was sought from NPWS rangers and local seafarers. As a result of initial enquiries, surveys were subsequently conducted on a chartered RIB with an experienced local skipper to provide access to the seal haul-out sites. Rough seal abundance estimates were initially obtained from a distance of approximately 200m from the haul-out site to prevent disturbance to the seals, and more accurate counts conducted at progressively closer ranges until the seals deserted the haulout site. Surveys were scheduled to occur within two hours either side of low tide and during daylight hours.

Aerial surveys

Accurate counts of seals on sand-bars can prove difficult to obtain from sea level by boat, especially when seals are tightly aggregated in a haul-out group. As haul-out groups at the Slaney site at Raven point were large and tightly aggregated, seasonal aerial counts were conducted to augment (and validate) the boat-based counts.

Aerial surveys were conducted from a high-winged single-engine Cessna 172 aircraft. Oblique photographs were taken out of an opened window of the aircraft using a Canon EOS 1DS digital camera with a Sigma 70–210mm lens. Efforts were made to obtain near-vertical images by tightly circling the breeding colonies at an altitude of approximately 300m. This technique proved successful in surveying grey seals in Ireland previously by the CMRC (Cronin et al. 2007)

Aerial surveys of Wexford harbour were carried out on three occasions; February and October 2012 and February 2013. Similar to the Moy, each count was conducted over the four hour tidal window.

Assessing diet of grey seals and harbour seals at the two study sites

Scat collection

Scats were collected from haulout sites within the Moy estuary (see Figure 2a) every month from August 2011 to July 2012 and in September November and December 2012. These sandbars were exposed for about 3.5 hours between tides, and fully submerged at high tide. Scats were collected shortly after low tide, so as to maximise the time seals are allowed to haul-out undisturbed, and consequently increase the chance of scats being left behind. The sandbar was accessed by boat or by foot when possible. Not all sampling efforts were successful. As the numbers of scat samples from the Moy estuary were relatively low (compared to the Slaney) due to lower numbers of seals and intertidal sites (where scat is washed away), effort was continued until December 2012 at the Moy site. Seal haul-out sites adjacent to the Moy estuary were also examined for potential ancillary data.

Scats were collected from haul-out sites within Wexford harbour on a bimonthly basis from September 2011 to September 2012. Usually, the seals were hauled out at Raven Point,, but sometimes hauled out on a second sandbar (see Figure 2b). These sand bars were accessed by boat. Some of these sandbars were more exposed than those in the Moy, and not all were fully submerged at high tide. Scats were collected in separate polythene bags, labelled, and frozen at -20°C until processing.

Figure 2a: **The Moy estuary** and the location of haul-out site 1 (54°11'40.73"N, 9°7'59.51"W) and haul-out site 2 (54°10'59.18"N, 9°8'28.81"W) from which harbour seal scats were collected.

Figure 2b: **Wexford harbour** and the location of two seal haul-outs, haul-out site 1/Raven Point (52°20'20.28"N, 6°21'26.10"W) and haul-out site 2 (52°19'42.71"N, 6°22'38.29"W) from which grey seal scats were collected. Images sourced from Google Earth (2010).

Prey identification

Scat preparation

A total of 67 scats from the Moy and 80 from the Slaney were collected and processed. Scats were washed with water, through a series of nested sieves with a maximum mesh size of 5mm and a minimum mesh size of 0.25mm. Prey remains recovered from scats were stored in 70% alcohol for 24 hours, then air dried for a further 24 hours and stored for subsequent identification. Cephalopod beaks were stored indefinitely in 70% alcohol. Of the 67 scats from the Moy, only 48 contained identifiable prey remains. All 80 scats sampled from the Slaney contained identifiable prey remains.

For the purpose of analysis, months were allocated to season as follows: Spring (February to April), Summer (May to July), Autumn (September to October), and Winter (November to January). No samples were recovered in August.

Identification of prey

Otoliths

A binocular microscope fitted with an ocular micrometer was used to examine recovered otoliths. Published otolith guides (e.g. Härkönen 1986, Tuset et al. 2008) were used to identify otoliths to the lowest possible taxonomic level. Effort was made to identify each otolith to species level, or as close to species level as was possible. Often, species with similar otoliths could not be distinguished from one another due to erosion. These otoliths were usually grouped together, e.g. *Trisopterus* spp., Ammodytidae spp., *Merlangius merlangus*/*Micromesistius poutassou*. Many otoliths were too severely eroded to identify further than to family level, and these were labelled as such, e.g. unidentified Gadidae. In the case of some flatfish otoliths, which once eroded became difficult to identify, even to family level, these were identified as unidentified flatfish.

With the use of a graticule, otolith length and width was measured under the microscope to the nearest 0.01mm. Where possible, otoliths were identified as left or right. Published back-calculation regressions were used to calculate fish lengths and weights from otoliths. For the otoliths of some prey species, no reliable regressions were available. Most of these otoliths were found in relatively few numbers. In these cases, approximate estimates of prey length were calculated based on the proportions of otoliths and corresponding fish lengths published in identification guides (Härkönen 1986, Tuset et al. 2008). Fish weights were then calculated from fish length/weight relationships as found on fishbase.org.

Bones and other diagnostic features

In addition to otoliths, a range of other diagnostic bones were used to identify fish species. This allowed for species with easily digested otoliths to be more accurately represented in the diet. These bones included premaxillae, preoperculae, vertebrae, and dentaries. Bones were identified using guides (e.g. Watt et al. 1997) and reference collections. Bones were measured in the same way as otoliths. Any bones that were too large to be accurately measured by the graticule were measured instead with digital calipers. Various measurements were taken of the premaxillae and vertebrae including length, height, and width. Regressions (Watt et al. 1997) were used to calculate fish lengths from bony structures. Associated fish weights were calculated from length-weight relationships from fishbase.org and letsflyfish.com (in the case of salmonids). Note that reliable regressions were not available for all species. Consequently, calculated weights were not available for some individuals identified by vertebrae alone. Premaxillae, preoperculae, and dentaries could all be easily grouped into left and right. Cephalopods were identified by the lower beaks and eye lenses. Crustaceans were identified by chelae. Rajidae spp. (skates and rays) were identified by denticles. Note that cephalopod weights could only be calculated when the lower beaks were recovered. No weights could be calculated for crustaceans or skates and rays.

Prey quantification

The objective was to determine a minimum number of prey individuals from each scat. Left and right otoliths of the same species were paired together, unless they were clearly from a different fish based on size, degree of erosion, or colour. If each pair of otoliths represented one individual, this allowed for a more accurate minimum prey number to be determined. The same pairing method was applied to premaxillae, preoperculae, dentaries, crustacean chelae, and upper/lower cephalopod beaks. This reduced the possibility of artificially inflating the data, and counting the same individual prey item multiple times.

Indices of prey importance

A number of indices were used to calculate the relative importance of each prey species. These indices included the frequency of occurrence (%O), the percentage by number (%N), and the percentage by biomass (%W). Each of these indices have inherent bias so it is important to consider all three. The frequency of occurrence can overestimate the importance of species which might occur in a large number of scats, but in very low numbers. Conversely, the percentage by number can overestimate the importance of species which might occur in few scats but in very high numbers. The percentage by biomass is obviously biased towards heavy species, regardless of the numbers in which they occur.

Correction factors

Digestion coefficients (DCs) were applied to all otoliths to account for partial erosion. Correction factors were generally not available for structures other than otoliths, with the exception of salmonid bone, for which a correction factor was applied (Tollit et al. 2007b) to get a corrected weight of each salmonid. Species specific correction factors were applied in accordance with Grellier & Hammond (2006). When no species specific correction factors were available, a general correction factor (1.25*OL, 1.24*OW; (Tollit et al. 1997)) was applied. Prey species weights were compared with and without correction factors in order to examine the influences of correction factors on the results and the corrected weights used for prey biomass estimates.

Length-frequency distributions of the major prey groups were compiled. This allowed for a visual exploration of the size classes of prey targeted by the seals at each site. These distributions included both corrected and uncorrected lengths, when available. This allowed for further examination of the effect of correction factors.

Comparative analysis

The statistical software package PRIMER 6 (version 6.1.12) with a PERMANOVA+ add-on (version 1.0.2) was used to compare prey composition across species/sites and seasons. Two-way permutational multivariate analysis of variance (PERMANOVA) were run on both numerical abundance and biomass of prey species, and then again on relative biomasses of prey species. Note that a number of prey species included in the PERMANOVA on numerical abundance were excluded from the PERMANOVA on biomass, as no reliable means of estimating weights of certain prey species were available.

A large number of prey items were identified to a wide range of taxonomic levels. This led to a number of prey categories with a degree of overlap, e.g. plaice, flounder, plaice/flounder, and Pleuronectidae. For this reason, and to avoid artificially inflating the data with overlapping categories, prey species were grouped in such a way as to minimise such overlap while still maintaining reliable species abundances. For example, the categories, *Trisopterus* spp., *T. esmarki*, *T. luscus*, *T. minutus*, *T.luscus/minutus*, were combined into *Trisopterus* species. Pleuronectidae species were combined into the categories plaice/flounder and Pleuronectidae spp., as plaice and flounder otoliths were relatively easy to distinguish from all other Pleuronectidae otoliths. Furthermore, plaice appeared to be of some importance, so it was important not to lose this in the groupings if possible. To gain some insight into where the seals were feeding within the water column, prey species were also grouped into pelagic, demersal, and benthic species.

Abundance and biomass data were square root transformed to reduce any exaggerated influence that extremely numerous but small prey items or conversely, rare but extremely large prey species may have had. A Bray Curtis similarity matrix was then applied to the transformed data. The Bray Curtis similarity index is a measure of how similar each sample is to every other sample in the analysis, based on Bray Curtis distance. From this, multi-dimensional scaling (MDS) plots were produced to visualise and explore the data. This allowed for potential outliers to be identified and provided an initial visual insight into any grouping by season or site of the data.

As the two sites had either harbour seals or grey seals as the predominant species present, site was treated as a proxy for species in the analysis. However, as there was a minimal possibility that some grey seal scats were recovered among the harbour seal scats from the Moy, and *vice versa* in the Slaney, there was no certainty that scats from the Moy and the Slaney belonged exclusively to harbour seals and grey seals respectively. Therefore, for the purpose of analysis the site was treated as a factor in place of species.

Genetic analyses of seal scat for evidence of salmonids

A total of 76 scat samples were subsampled for DNA extraction (n= 304 samples; Moy 26 scats with 4 subsamples per scat, Slaney 50 scats and 4 subsamples per scat). Each subsample was stored in 90% ethanol for subsequent DNA extraction at Marine Scotland Science, Marine Laboratory, Aberdeen Scotland, by a team experienced in the technique (Matejusová et al. 2008). Approximately 200 mg material from each subsample collected at both study sites was washed in distilled water prior to DNA extraction. Three subsamples of scat were transferred to a 2ml microfuge and homogenized using a TissueLyser (Qiagen) at 20 Hz for 2 min in the presence of ASL buffer (QIAamp DNA Stool mini kit, Qiagen). Genomic DNA was extracted suing a QIAamp DNA Stool mini kit following manufacture's recommendations, eluted in 50µl of Elution buffer (QIAamp DNA Stool mini kit, Qiagen) and stored at -20^{o}C prior to further analyses.

Three different custom Taqman qPCR assays (Matejusová et al. 2008) were applied to determine the presence of seal (as positive control), salmon and trout DNA respectively, in scat material. The seal qPCR assay was multiplexed with the preoptimized internal postitive control (IPC) assay (Taqman Exogenous Internal Positive Control Reagents, Applied Biosystems, Life Technologies) to identify a presence of PCR inhibitors. Each qPCR reaction contained 2µl of genomic DNA (approximately 10 ng), 900nM each primer, 250nM probe, 1× ToughMix with ROX (Quanta Biosciences) and distilled water (Sigma) in a final volume of 20microl. The LightCycler 480 Real-time PCR System (Roche) was used to performed qPCR analyses following standard manufacturer's recommendations.

The results of the DNA testing for salmonids were compared to the results from the conventional prey identification using hard part remains to assess if samples that tested positive for either trout or salmon DNA had identifiable salmonid remains (and vice versa). Bones taken from seal scat identified as salmonid premaxillae were also sent to the laboratory for confirmation on positive identification as salmonids.

Consumption Estimates of prey species by seals in study areas

Fish consumption estimates by seals in the study areas were derived using a method similar to that of Hammond & Grellier (2006b). In each site the average daily fish consumption per seal was calculated. Species-specific energy values obtained from the literature (e.g. Spitz et al. 2010) together with the estimated value of average grey seal daily energy requirement of 5,497 Kcals (Sparling & Smout 2003) and harbour seal daily energy requirement of 4680Kcals (Härkönen & Heide-Jørgensen 1991) and the proportion of biomass that the main prey represented in the diet (based on scat samples from each site) were used to estimate the average daily prey consumption per seal. This was multiplied by seal counts (average per season) at each site to give seasonal estimates of each prey species/group consumed by seals. Biomass estimates assume that salmonid consumption is solely of salmon, not sea trout. Genetic analyses (see results section on genetic analysis) showed that 50% of scat samples that tested positive for salmonid DNA were sea trout, so estimates of salmonid consumption are therefore a 'worse-case scenario', and the contribution of salmon to this is likely to be 50% of the values reported.

Photographic identification of individual seals

Photo identification of individuals based on pelage markings can be used to examine fidelity of individuals to a particular location or to determine the number of seals involved in fish interactions. Efforts were made to acquire images of individual seals in the river Moy on a monthly basis between August 2011 and July 2012, in particular near the weir in Ballina where seals apparently aggregate. Efforts were also made in the Slaney estuary during seal surveys, but the main effort for this element of the study was initially focused in the Moy, based on feedback from IFI representatives, NPWS rangers, anglers. Based on information provided by anglers in Spring 2013 the survey area was extended beyond Wexford Harbour to include the section of the Slaney river adjacent to and below Enniscorthy town where grey seals have been observed predating on salmon. Monthly surveys of this area were conducted from May to August 2013 from shore and zodiac boat to capture images of individual seals in the river.

Photographs of individual seals were taken using a digital SLR camera (Canon EOS-IDS) with a 600mm telephoto auto-focus image stabilising lens (Canon 600mm f/4L EF IS USM lens). A Manfrotto tripod with a Wimberley Head (WH-200), a gimbal-type design of the tripod head to allow rotation of the lens around its centre of gravity and bear the combined weight of the camera body and lens (approx. 6.3kg) was used. When light conditions were suitable shutter speed were set to at least 1/1000th second to minimise image blur if the subject moved. Patterns of individual seals pelages are usually assessed using photo-viewing software to identify individuals and ascertain re-sighting rates. When sample size is low however there is no requirement for using the automated photo-matching software and matching can be done by eye, which was the case in the present study.

Fishers perception of seal predation on salmon in recent years

A questionnaire/damage logsheet was circulated to regional IFI representatives and commercial fishermen in 2012 and 2013 (distributed by IFI) to gather information on perceived levels of seal predation on salmon in the study areas (see Appendix C).

Results

Estimating seal abundance at the two study sites

Moy

Seal counts and haul-out patterns

Seals observed during monthly surveys of sandbars in the Moy estuary between August 2011 and December 2012 were mainly harbour seals, with the occasional grey seal. Maximum numbers were observed during August and September 2011 when up to 100 harbour seals were observed. This period coincides with the species' annual moult (Cronin et al. in press). Lowest numbers were observed in December 2011 and November 2012 (less than 20 individuals). Numbers were generally higher in early Spring in 2012 and declined towards the start of Winter (Fig 3)

The site is primarily used by harbour seals. Grey seal presence in the estuary is sporadic. Between 1-3 grey seals were observed on most surveys and a maximum of 11 grey seals observed in October 2011. The small group was made up of mainly juvenile males, 3-4 females and 2 large adult males. Grey seals tended to haul-out on sandbars away from the harbour seals and leave after low water.

Surveys were conducted during a 4 hour period, 2 hours either side of low tide. When looking at seal haul-out behaviour over the entire 17 month period, highest numbers of seals hauled out after low tide (Figure 4). As the sandbars in the mouth of the Moy generally remain exposed for up to 3.5 hours after low tide, seals may remain hauled-out until these sandbars become completely submerged. The lowest numbers of seals occurred 2 hours before low tide. When grey seals are present they tended to haul-out earlier than the harbour seals but also left the sandbars sooner.

Slaney

Seal counts and haul-out patterns

Grey seal abundance in this area appears to be relatively high throughout all months of the year (Figure 5). The highest count of grey seals in the Slaney occurred during July 2013 with 780 seals hauled-out. Lowest counts of grey seals were observed in December 2012-January 2013. In general grey seals use of the area is relatively high (>100 seals) all year round, primarily at the Raven Point haul-out site. Harbour seal presence in this region appears minimal. The highest abundance recorded was in January 2012 when 5 seals were present.

Aerial surveys of the site were conducted in February and October 2012 and February 2013 (see Fig 6). A total of 215, 213 and 355 grey seals were observed from aerial images captured on those dates respectively. A total of 169 and 332 grey seals were observed during simultaneous boat based counts in October 2012 and February 2013, respectively. The counts taken from the boat during the October survey are under-estimated due to disturbance caused by the aerial survey. There was no disturbance caused during the February survey and direct comparison of boat and aerial count suggests boat based counts were under-estimated by approximately 6%.

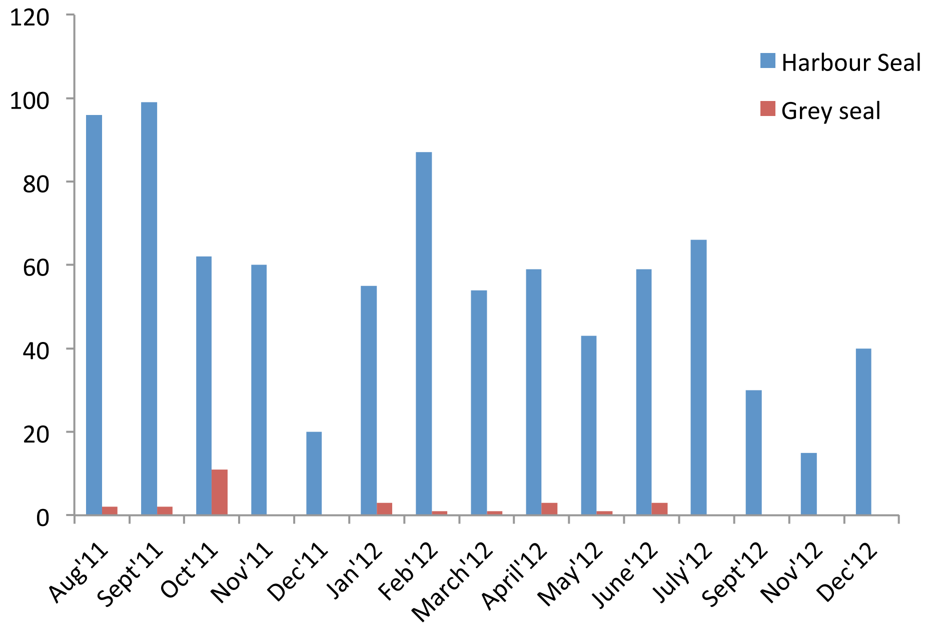

Fig 3. Counts of seals at the Moy Estuary

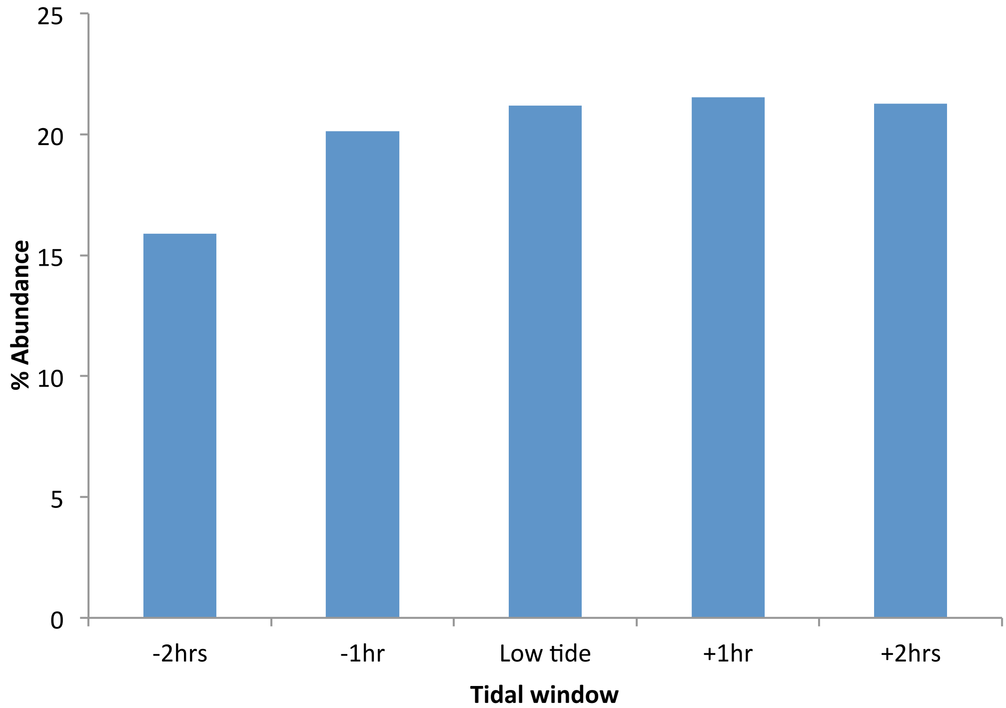

Fig 4. Overall percentage of harbour seal abundance around low tide in the River Moy

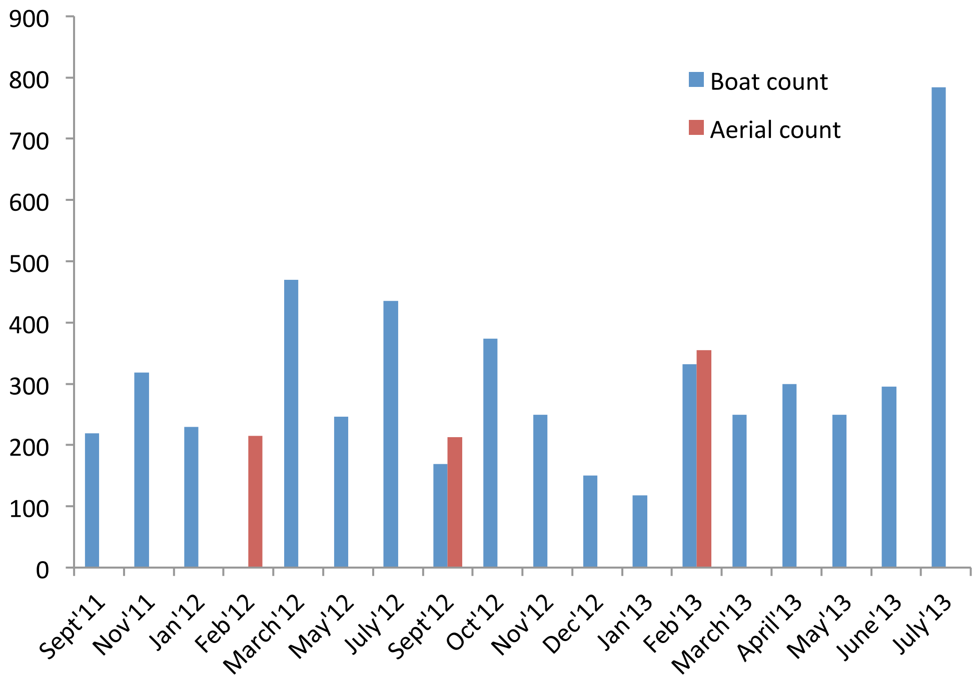

Fig 5. Counts of grey seals at Wexford Harbour (Slaney)

Fig 6. Aerial image of grey seals at Raven Point Wexford Harbour

Assessing diet of grey seals and harbour seals at the two study sites

Scat collection

A total of 67 scats from the Moy and 80 from the Slaney were collected and processed (Table I). No scats were found at the Moy site during the months of November, December 2011, and May, June 2012. Between the months of April – July 2012 very few scats were found on the sandbars although harbour seal presence was relatively high with an average count of 46 seals hauled-out per month. As the number of scat samples from the Moy estuary were relatively low (compared to the Slaney) due to lower numbers of seals and the intertidal nature of the sites (where scat is washed away), effort was continued until December 2012 at the Moy site. Sample size of scat collected at the Slaney site was higher than the Moy, due to the higher numbers of seals present at the site.

Table I Number of seal scat samples collected and processed from the 2 study sites

Month	Moy	Slaney
Aug-11	7	-
Sep-11	9	9
Oct-11	5	-
Nov-11	2	15
Dec-11	0	
Jan-12	4	6
Feb-12	0	-
Mar-12	7	19
Apr-12	2	-
May-12	0	6
Jun-12	0	-
Jul-12	1	15
Aug-12	-	-
Sep-12	7	10
Oct-12	-	-
Nov-12	1	-
Dec-12	3	-

Recovery of prey remains

In total 1,459 otoliths were recovered from the scats; 346 from the Moy and 1,113 from the Slaney; 72% of the prey items from the Moy, and 52% from the Slaney, were identified by otoliths. The remaining 28% and 48% respectively were identified by other diagnostic prey remains (see Table II), giving a total of 1,761 individual prey items identified (to varying taxonomic levels). The diagnostic features in Table II are ranked in order of use. That is, premaxillae were used to quantify prey in the absence of otoliths; vertebrae were used preferentially to dentaries. Individuals quantified by fish eyes alone were excluded from subsequent calculations. As these individuals could not be assigned to any of the prey species, their inclusion would have provided little insight into diet composition and could have skewed results.

Table II: The number of prey items identified from harbour seal (Moy) and grey seal (Slaney) scats, and the prey remains which were used to identify/quantify them.

Prey remains	Moy	Slaney
Otoliths	239	737
Premaxillae	23	51
Preopercula	0	93
Vertebrae	16	36
Dentaries	0	4
Cephalopod beaks	5	23
Cephalopod eyes	7	17
Crustacean chelae	9	384
Fish eyes	32*	85*

* Individuals quantified by fish eyes alone were excluded from subsequent analysis as they could not be assigned to prey species.

Harbour seal diet in the Moy

The harbour seals from the Moy fed on a wide variety of species and these are summarised in Appendix A. At least 24 species of fish, one species of cephalopod, and one species of crustacean were consumed (Figs 7, 8). Gadidae species were recovered from a large proportion of the scats. Of these, Pouting/Bib/Poor cod (*Trisopterus* species) were recovered most frequently, occurring in 29% of the scats. Haddock/Pollock/Saithe *(Melanogrammus aeglefinus/Pollachius* spp.) were other important Gadidae species in the harbour seals diet.

Pleuronectidae (flatfish) species occurred in the highest numbers (21.3%). Otoliths from this family were particularly difficult to distinguish; however, at least four species were identified in the harbour seal scats. These were plaice (*Pleuronectes platessa*), flounder (*Platichthys flesus*), dab (*Limanda limanda*), and long rough dab (*Hippoglossoides platessoides)*. Of these species, plaice appeared to be the most important.

Sandeels (Ammodytidae) also occurred in high numbers (18.2%). Herring (*Clupea harengus*) and Allis Shad (*Alosa alosa*) were the only pelagic species found in the harbour seal scats. Herring occurred in 13% of scats, and comprised 5.3% of prey numbers. Only two Allis shad were recovered. Some unusual or noteworthy species that occurred in low numbers included one eel (*Anguila anguila*), two tadpole fish (*Raniceps raninus*), and one venomous greater weever fish (*Trachinus draco*). In total, 12 cephalopod individuals were identified in seven harbour seal scats. However, only one could be identified as a species of octopus. In addition, a small number (n = 9) of crustaceans were found in eight scats.

Salmonids (salmon/trout, *Salmo* spp.) represented less than 5% of the number of prey items consumed (Fig. 7) and 16% of the total prey weight consumed (Fig 8). The majority of the biomass consumed comprised of Gadoids (bony fish of the cod family including cod, haddock, whiting and pollock) and flatfish species (together amounting to 50% of total biomass). Salmonids recovered from the harbour seal scats ranged in length from 283-374mm, with an average length of 325mm (+/- 28mm). The low size range may reflect both consumption of sea trout and an underestimate of salmonid length using published regression equations (see Discussion).

Grey seal diet in the Slaney

The grey seals in the Slaney consumed a wider range of prey items than the harbour seals from the Moy (Appendix B). These included at least 33 species of fish, two species of cephalopods, two species of crustaceans, and one species of skates/rays (Rajidae species) (Figs 9, 10).

Gadidae species occurred in a very high proportion of scats (86.3%). Of these, Pouting/Bib/Poor cod species were the most common. Other important Gadidae species groups included haddock/pollock/saithe (*Melanogrammus aeglefinus*/*Pollachius* spp.) and whiting/blue whiting which occurred in 37.5% of scats. Gadidae species in general comprised 27% of prey numbers and 47% of prey biomass (Fig 9,10). Dragonets (*Callionymus* spp.) occurred in 37.5% of scats, and were the most numerous fish species recovered (12.8%) although the relatively small dragonets only contributed 4.1% to the total prey biomass. Pleuronectidae species occurred in 38.8% of grey seal (Slaney) scats and after Gadidae species, they had the next highest important contribution to overall prey biomass (17%). Of the identified Pleuronectidae species, plaice seemed to be the most important

Similar to the harbour seals in the Moy, salmonids (*Salmo* spp.) were recovered in relatively low numbers (1.6% of all prey remains), but contributed 14% of the total prey biomass consumed by the grey seals in the Slaney. Salmonids recovered from the grey seal scats ranged from 278-488mm in length with a mean length of 352mm (+/- 52mm), which may reflect both consumption of sea trout and underestimation of fish lengths using published regressions.

In contrast to the harbour seals in the Moy, sandeels were of little importance. Crustaceans occurred most frequently (55.0%) in the grey seal scats, and were recovered in the highest numbers (26.7%). Two species of crustacean were identified as *Nephrops norvegicus* and *Cancer pagarus*. *Nephrops norvegicus* in particular appeared to be of some importance. Based on the size of the recovered chelae, it is likely that these were juvenile *Nephrops*. Skates and rays (Rajidae species) occurred in 38.8% of scats. However, as these could only be identified by denticles, these species could not be identified or quantified. For this reason, a minimum of one skate/ray was assumed for every scat containing any number of denticles. A total of 40 cephalopods were recovered from 22 scats. Of these, seven were identified as species of octopus, and two were identified as squid. Some unusual or noteworthy species that occurred in low numbers included two eels (*Anguila anguila*), two conger eels (*Conger conger*), two bull-rout (*Myoxocephalus scorpius*), two hooknose (*Agonus cataphractus*), one eelpout (*Zoarces viviparous*). Fifteen gurnard (*Triglidae* spp.) were found in one scat, and another grey seal had consumed at least five venomous, lesser weevers (*Echichthys vipera*).

Comparative diets of harbour seals from the Moy and grey seals from the Slaney

Overall Gadidae was the most important family of prey species in the diets of both the harbour and grey seals. Of these, Pouting/Bib/Poor cod species occurred the most frequently in both species' diets. Haddock/pollock/saithe and whiting/blue whiting also occurred in both species' diets. While Gadidae were important for both species, they were twice as important to grey seals as they were to harbour seals. Sandeels and flatfish were particularly important to harbour seals (Fig 7,8) but rarely occurred in the diet of grey seals (Fig 9,10). Conversely, only two dragonets were recovered from the harbour seal scats, whereas dragonets represented one of the most numerous and important prey groups to the grey seals.

In the diets of both harbour seals and grey seals, salmonids comprised a small proportion of the diet by number, and approximately 15% of the total prey biomass consumed (Figs 7 -10). Harbour seals relied almost entirely on teleost prey species, whereas a larger proportion of grey seal diet was comprised of non-teleost prey. Crustaceans comprised only 2.4% of prey numbers consumed in the harbour seal diet, but comprised 26.7% of prey numbers in the grey seal diet. Grey seals also commonly consumed skates and rays.

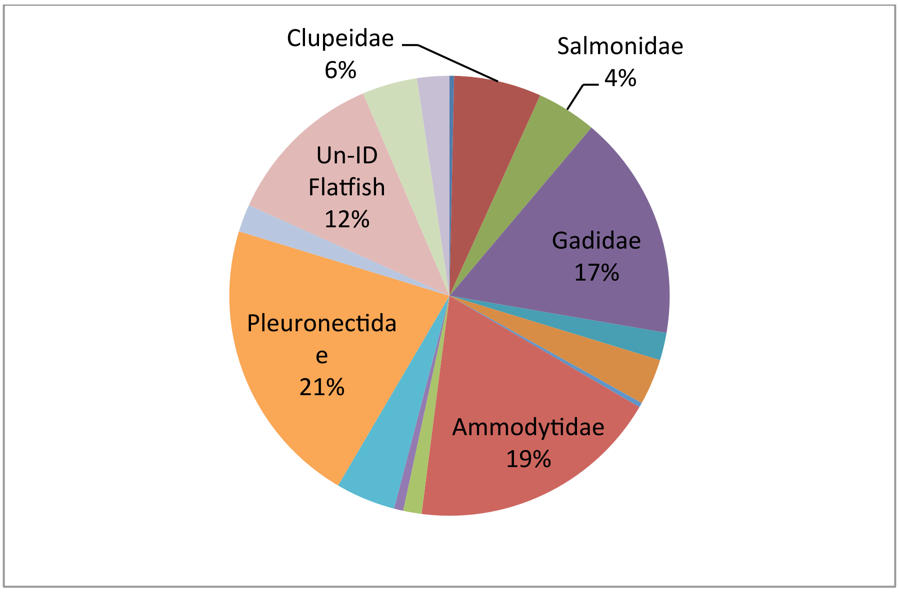

Figure 7: The % by number of prey families recovered from harbour seal scats from the river Moy, highlighting the more important species.

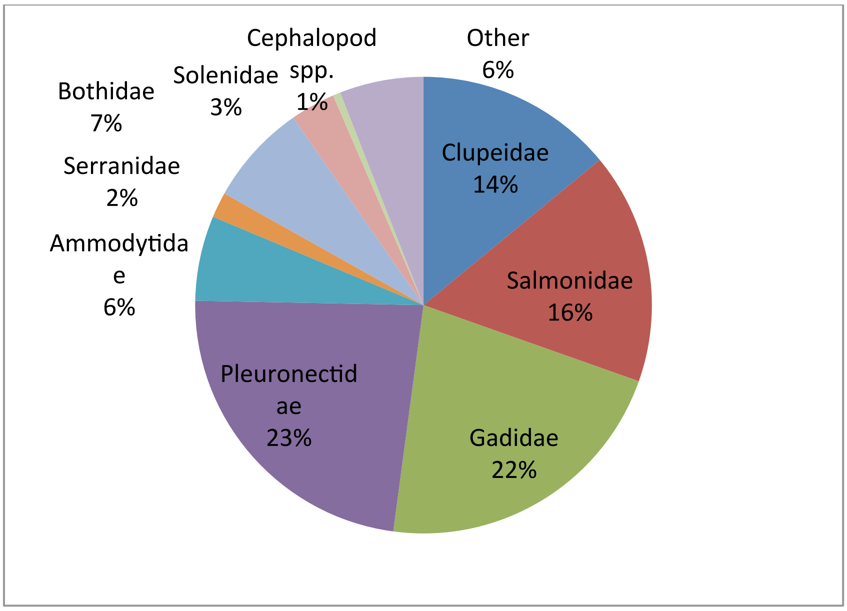

Figure 8. The % by weight of prey families recovered from harbour seal scats from the river Moy, highlighting the more important species. The application of digestion correction factors (CFs) to the otoliths and bones altered prey biomass significantly (Appendix A); corrected values are presented here.

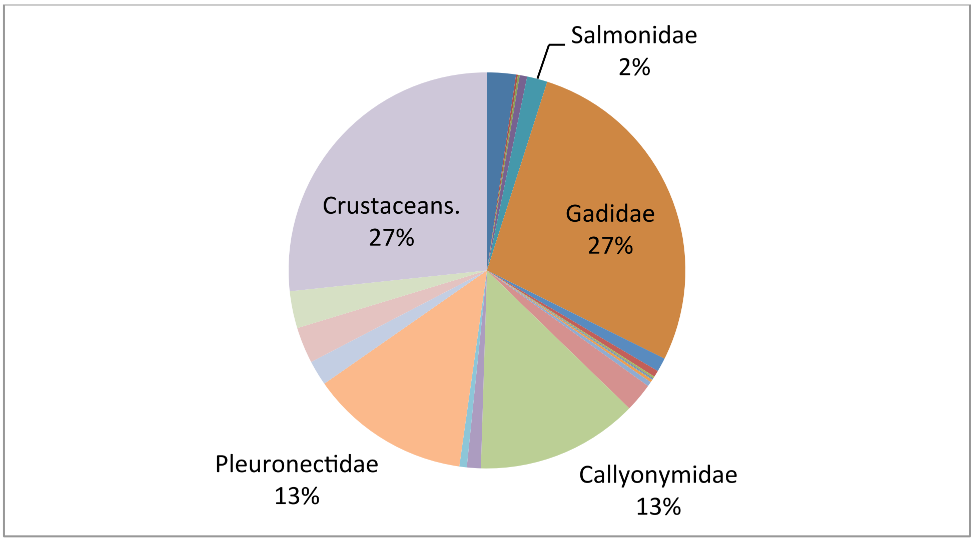

Figure 9. The % by number of prey families recovered from grey seal scats from the river Slaney, highlighting the more important species.

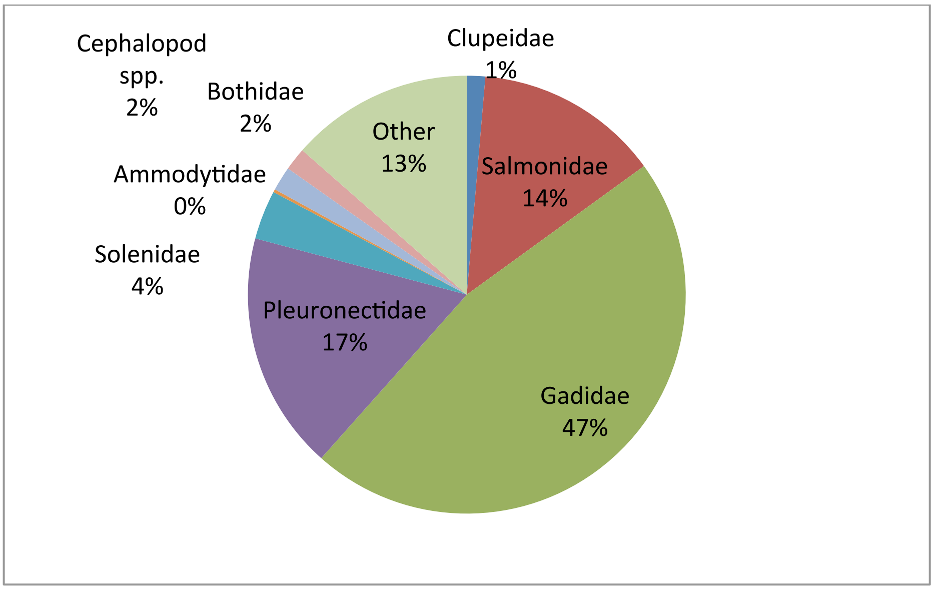

Figure 10. The % by weight of prey families recovered from grey seal scats from the river Slaney, highlighting the more important species. The application of digestion correction factors (CFs) to the otoliths and bones altered prey biomass significantly (Appendix B); corrected values are presented here.

Comparative analysis of prey abundance in the seal diets

Multi-dimensional scaling (MDS) plots based on Bray-Curtis similarity showed an apparently high level of overlap between the harbour seals (Moy) and grey seals (Slaney) with regard to the numbers of each prey species identified from scats (Figure 11). Samples from the Slaney were more tightly grouped, indicating more similar prey assemblages than in the Moy. This may be a consequence of the larger sample size from the Slaney, resulting in more overlap between scats.

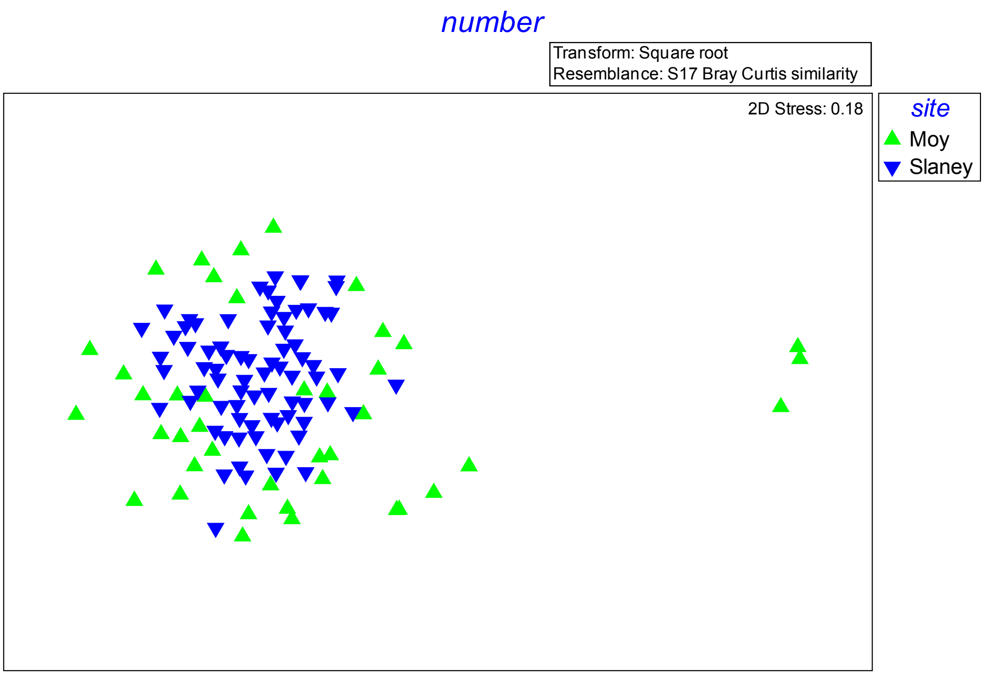

Figure 11. Multi-dimensional scaling (MDS) plot of Bray Curtis similarity of prey numbers recovered from harbour seal scats (Moy) and grey seal scats (Slaney). Outliers excluded from plot. Symbols represent individual scats from each site.

A two-way PERMANOVA was run to test for differences in prey assemblage structure between sites and seasons, with a significant difference (PERMANOVA, t = 2.199; P = 0.001) found between both sites. Significant differences between sites existed across all seasons (see Table III). SIMPER two-way analysis was used to identify which prey species were contributing most to the inter-site differences in prey numbers. More crustaceans, *Trisopterus* species, dragonets, and whiting/blue whiting were consumed in the Slaney, while more sandeels were consumed in the Moy.

In the Moy, a significant difference in species assemblages was found (PERMANOVA, t = 1.7552; P = 0.002). Pairwise tests showed that differences in assemblage structure occurred only between spring and autumn seasons (see Table IV). No significant differences were found between seasons in species assemblages in the Slaney (see Table V).

Table III: Results of PERMANOVA, testing for inter-site differences in prey numbers recovered from scats during each season. PERMANOVA was carried out following a square root transformation of prey abundance data. Values in bold signify significance at least at the P=0.05 level.

Season	Spring	Summer	Autumn	Winter
P	**0.002**	**0.046**	**0.001**	**0.003**
T	1.8829	1.4781	1.6967	1.5899

Table IV: Results of PERMANOVA test for inter-seasonal differences in prey numbers found in scats from the river Moy. Values in bold signify significance at the P = 0.01 level.

Seasons		t	P
Spring	Summer	1.284	0.193
Spring	Autumn	1.755	**0.002**
Spring	Winter	1.291	0.118
Sumer	Autumn	1.022	0.616
Summer	Winter	0.945	0.747
Autumn	Winter	0.997	0.436

Table V: Results of PERMANOVA test for inter-seasonal differences in prey numbers found in scats from the river Slaney.

Seasons		t	P
Spring	Summer	1.382	0.079
Spring	Autumn	0.729	0.821
Spring	Winter	1.294	0.098
Sumer	Autumn	0.675	0.858
Summer	Winter	1.045	0.340
Autumn	Winter	0.843	0.694

Comparative analysis of prey biomass in the seal diets

Multi-dimensional scaling plots based on Bray-Curtis similarity also showed an apparently high degree of overlap between sites with regard to prey biomasses, although the spread of samples from the Moy appears to be broader (Figure 12).

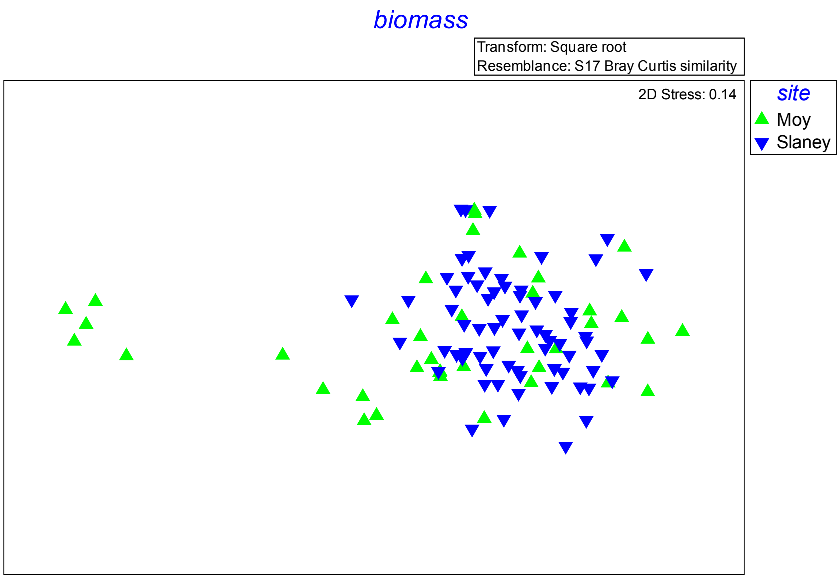

Figure 12. Multi-dimensional scaling plot of Bray Curtis similarity of prey biomass recovered from harbour seal scats (Moy) and grey seal scats (Slaney). Outliers excluded from plot. Symbols represent individual scats from each site.

A significant difference (PERMANOVA, t = 1.6612; P = 0.002) was found in the species assemblages determined by biomass of prey items between the harbour seals (Moy) and the grey seals (Slaney). Further PERMANOVA analysis on the site*season interaction (Table VI) showed significant inter-site differences in prey assemblages based on biomass only during summer and autumn. In relation to inter-seasonal variation within each site, no significant differences in prey assemblages based on biomass between seasons were found in either the Moy or the Slaney (Tables VII, VIII).

Table VI: Results of PERMANOVA, testing for inter-site differences in prey biomass recovered from scats during each season. PERMANOVA was carried out following a square root transformation of prey abundance data. Values in bold signify significance at the P = 0.05 level.

Season	Spring	Summer	Autumn	Winter
P	0.281	**0.047**	**0.009**	0.558
t	1.0908	1.3664	1.5188	0.93151

Table VII: Results of PERMANOVA test for inter-seasonal differences in prey assemblages based on biomass in the river Moy.

Seasons		t	P
Spring	Summer	0.919	1.000
Spring	Autumn	0.751	0.893
Spring	Winter	0.755	0.901
Sumer	Autumn	0.981	0.637
Summer	Winter	1.206	0.222
Autumn	Winter	0.990	0.467

Table VIII: Results of PERMANOVA test for inter-seasonal differences in prey assemblages based on biomass in the river Slaney.

Seasons		t	P
Spring	Summer	1.124	0.266
Spring	Autumn	0.641	0.910
Spring	Winter	1.183	0.180
Sumer	Autumn	1.210	0.142
Summer	Winter	1.265	0.122
Autumn	Winter	1.125	0.240

Length-frequency distributions of salmonids recovered in seal scat at both sites

The reconstructed length-frequency distributions of salmonids recovered from harbour seal (Moy) and grey seal (Slaney) scats were compared. The grey seals in the Slaney fed on a wider size range of salmonids (279-488mm) than the harbour seals in the Moy (283-374mm) (Fig 13). There was no significant difference in length (Mann-Whitney U test; P = 0.149) or weight (Mann-Whitney U test; P = 0.139) of salmonids consumed at each site. Table IX shows the months in which salmonids were recovered from scats collected from each site. The highest number of salmonids was recovered from the harbour seal (Moy) scats in September (n = 8) and from the grey seal (Slaney) scats in July (n = 10) and September (n = 6).

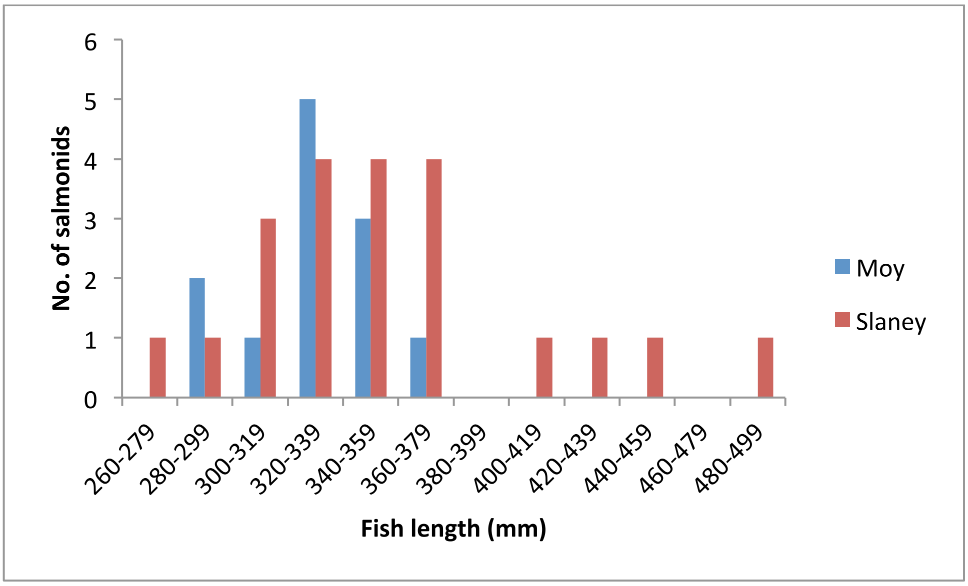

Figure 13. Length-frequency distribution of salmonids recovered from harbour seal scats collected from the Moy and grey seal scats collected from the Slaney.

Table IX: Number of salmonids recovered from scats of harbour seals (Moy) and grey seals (Slaney) collected from each month.

Season	Moy	Slaney
January	1	0
February	0	-
March	2	3
April	0	-
May	0	3
June	0	-
July	0	10
August	0	-
September	8	6
October	2	-
November	0	-
December	0	0

Genetic analyses of seal scat for evidence of salmonids

A total of 76 samples (296 subsamples) were processed to test for evidence of salmonid DNA, 50 from the Slaney site and 26 from the Moy site. Of these, only five scat samples tested positive for salmonids, two samples for salmon DNA, two for trout DNA, and one sample tested positive for both salmon and trout DNA. The samples that were tested for salmonid DNA were also 'blind' tested for prey hard part remains (salmonid bones). Subsamples from these scats were sent to the genetics laboratory and the remaining samples were processed for prey hard part remains. Of 76 samples tested 74% were in agreement, 54 samples tested negative for both salmonid bones and DNA and 2 samples tested positive for both salmonid bones and DNA (Table X). 22% of samples had salmonid bones yet tested negative for salmonid DNA and 4% that tested positive for salmonid DNA had no salmonid bones.

No salmon DNA was detected in the 24 samples from the Moy, however sea trout DNA was evident in a sample from June 2012. Salmonid bones were detected in samples from September 2012 (n=3), which equates to approximately 25% of the samples.

Salmon DNA was detected in 3 samples from the Slaney (March, May and July) and trout in 2 samples (May, September). Salmon bones were also detected in May, July and September and November samples. There was a relatively high detection rate in the July and September samples in particular, where salmon bones were detected in 46% and 36% of samples respectively.

Note that the results above only relate to scat samples that were simultaneously tested for both salmonid DNA as well as salmonid hard part remains. Salmonid bones were also detected in months other than those listed above.

Overall there was general agreement between the two methods in the detection of salmonids (73% of the samples). Of the samples that were not in agreement, the traditional technique of prey hard part remains appears to be superior to the genetic technique (Figs 14, 15).

Of the five scat samples that tested positive for salmonid DNA, three had salmon DNA (all from the Slaney) and three had sea trout DNA (one sample from the Moy and two from the Slaney). It suggests seals are taking both salmon and sea trout.

Table X: Evidence of salmonids in scat samples from seals at the study site using two different techniques

Salmonids detected by bone ID	Salmonids detected by genetics	Number of samples
-	-	54
+	+	2
+	-	17
-	+	3

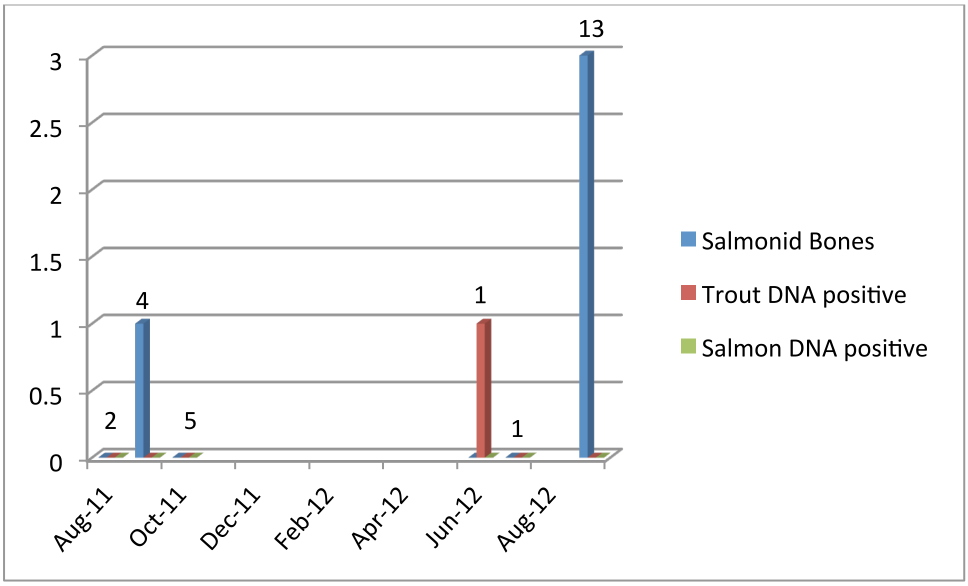

Fig 14. Number of scat samples with evidence of salmonids at the Moy site (sample size shown)

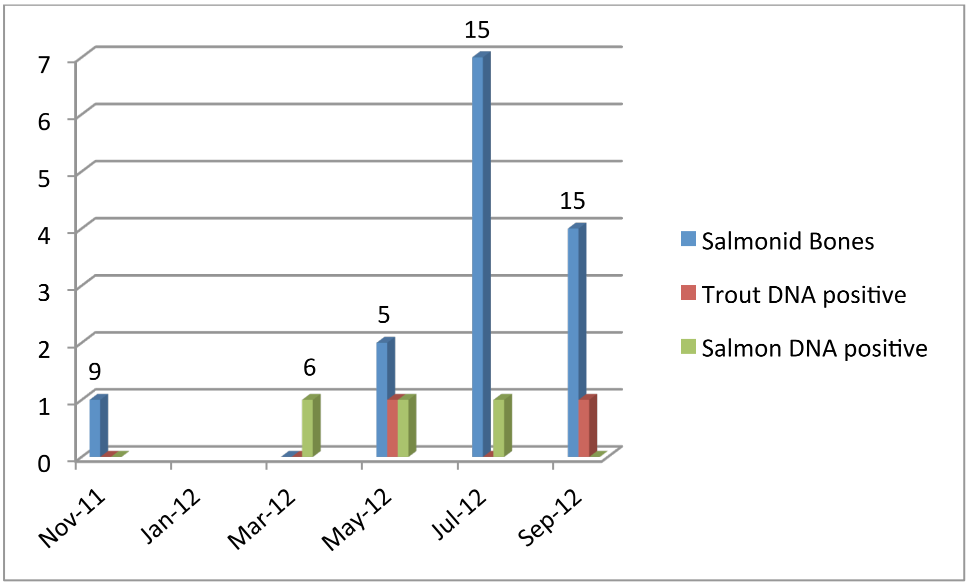

Fig 15. Number of scat samples with evidence of salmonids at the Slaney site (sample size shown)

Consumption estimates of prey by seals at both sites

Species-specific energy values were combined with information on the average grey and harbour seal daily energy requirements and the proportion of biomass that the main prey contributed to the diet over the 12 months of sampling, to estimate the average daily prey consumption per seal (Table XI). The average daily consumption of prey of a grey seal (Slaney site) was estimated at 4.64kg. Average daily consumption of prey of a harbour seal (Moy site) was estimated at 4.04kg. It should be noted that this is a very crude estimate which does not account for differences in size between individual seals or reflect seasonal changes in seal diet.

Table XI: Prey consumption estimates of a) Grey seals in the Slaney and b) Harbour seals in the Moy. %W represents the percentage contribution of each prey group to the diet of seals by weight seals

a) Grey seals in Slaney

Prey	%W	Prey energy content $kJ\ g^{-1}$ +	Ave daily prey consumption* (kg)
Clupeidae	1.4	10.2	**0.03**
Salmonidae	13.7	4.0-5.0	**0.66**
Gadidae	46.6	4.2-5.0	**2.33**
Ammodytidae	0.2	4.9-7.5	**0.01**
Pleuronectidae	17.6	5.8	**0.70**
Solenidae	3.6	5.0	**0.13**
Bothidae	1.7	5.4	**0.07**
Cephalopod spp.	1.8	4.8	**0.09**
Other	13.5	5.0	**0.62**
			Total=4.64kg

b) Harbour seals in Moy

Prey	%W	Prey energy content $kJ\ g^{-1}$ +	Ave daily prey consumption* (kg)
Clupeidae	14.0	10.2	**0.31**
Salmonidae	16.4	4.0-5.0	**0.82**
Gadidae	21.7	4.2-5.0	**1.06**
Pleuronectidae	23.2	5.8	**0.90**
Ammodytidae	6.0	4.9-7.5	**0.21**
Serranidae	1.8	6.0	**0.07**
Bothidae	7.2	5.4	**0.30**
Solenidae	3.2	5.0	**0.14**
Cephalopod spp.	0.5	4.8	**0.02**
Other	5.9	5.0	**0.22**
			Total=4.05kg

*Based on an average daily energy requirement for grey seal 5,497 Kcals (Sparling & Smout, 2003) and harbour seal 4680Kcals (Härkönen & Heide-Jørgensen 1991) + Energy content values from Spitz et al., 2010; Demson et al., 2004; Hislop et al., 1991

Grey seal requirements of 4.64kg/day and harbour seal requirements of 4.05kg/day were multiplied by seal counts (average per season) at each site to give estimates of the total weight of prey consumed by the population of seals in the region each season (Table XII). These seasonal estimates are based on aggregated diet data over the study period, as sample size was too low to derive season-specific prey biomass estimates. It is therefore inappropriate to calculate seasonal estimates of specific prey types as their availability and contribution to the diet varies between seasons. Overall, total estimated prey consumption by grey seals at the Slaney site varied from 988 kg/day in winter to 1865 kg/day in Summer, and for harbour seals in the Moy from 152 kg/day in Winter to 288kg/day in Autumn. As illustrated in Table IX, salmonid consumption is likely to reflect seasonal availability in the two areas, so seasonal estimates of salmonid consumption based on aggregated data would be inappropriate.

Table XII: Estimates of total daily prey consumption by seals at each site by season

Site	Slaney		Moy	
	Mean seal count	Est daily prey consumption kg	Mean seal count	Est daily prey consumption kg
Spring	338	1568	67	268
Summer	402	1865	56	224
Autumn	254	1178	72	288
Winter	213	988	38	152

Photo identification

Moy

Grey seals have been observed swimming up-river near Ballina town (just below the first bridge) during January & February 2012. Head shots were taken using a digital SLR camera (Canon EOS-ISD) with a 600mm telephoto autofocus image stabilising lens (Canon 600mm f/4L EF IS USM lens), however photo-id from these pictures is not possible. The seal was observed in this area approximately 3 hours after low tide and remained up-river for 2 hours. On one occasion (February 2012) the same male which had been observed the previous day caught & ate a large salmon before swimming back down-river. A smaller female was also observed further down river from the male, however she did not remain in the area for long and did not swim up as far as the town.

No grey seals have been observed up-river during other survey months. However, anglers and IFI staff have reported seeing grey seals up-river sporadically during Summer months, swimming around near the first bridge in Ballina town. Unfortunately we have been unable to capture any images of grey seals up-river that could be used for photo-identification purposes. Furthermore, no grey seals were observed up-river during the months of June & July 2012.

Slaney

Images were taken of seals in the water near the haul-out site following disturbance during scat collection. For these images to be used in mark recapture models to asses population parameters high sampling effort would be necessary and as outlined in the proposal, is outside of the scope of the present study. No individual seals were observed predating on salmon in the river during the initial months of the study so effort related to this aspect of the study was focused on the Moy site. From May 2013-August 2013 the study area was extended to include the upper Slaney near Enniscorthy town in response to reports from anglers of grey seals predating in the river (see Fig 16). Monthly surveys of the river were made at Edermine and Kilcoole (with advice from anglers and IFI staff) in an attempt to photograph individual seals but the outcome was disappointing. Only 1-2 seals were observed at the sites in May and June 2013, no seals were observed in July, and one seal was observed in August 2013. A small number of images were taken from the shore in May, June and August and attempts made to ascertain if these were the same individuals using the pelage markings on the seals head (see Fig 17). The images in May and June suggest the same individual is re-visiting the area, however the quality of the images was not sufficiently high enough to be 100% certain; this was because the seal appeared at the surface very infrequently as it travelled back down the river on a falling tide. The pelage images of the individual seal taken in August were of higher quality, however it was only possible to photograph the left side of the head and therefore potential matches with images in May/June could unfortunately not be made.

Fig 16. Atlantic salmon with evidence of predator damage (source: IFI)

Fig 17. Grey seal in river Slaney, markings on pelage of head are unique to each individual seal

Discussion

Seal counts and haul-out patterns

Seals using haul-out sites in the Moy estuary are mainly harbour seals, with the occasional grey seal. Numbers of seals at the site were generally higher in early Spring and declined towards the start of Winter. Lowest numbers were observed in November/December. Maximum numbers of seals were observed during August and September 2011 when up to 100 harbour seals were observed. This period coincides with the species' annual moult (Cronin et al. 2013). Grey seal presence in the Moy estuary is sporadic and generally consisted of a small group of between 1-11 seals.

There was a tidal influence on seal haul-out behaviour evident at the Moy estuary. Highest numbers of seals hauled out after low tide and lowest numbers of seals were observed 2 hours before low tide. As the sandbars in the mouth of the Moy generally remain exposed for up to 3.5 hours after low tide, seals may remain hauled-out until these sandbars are completely submerged. When grey seals are present they tended to haul-out earlier than the harbour seals but also leave the sandbars sooner. Other harbour seal sites in the vicinity of the Moy estuary include Ballysadare Bay Co. Sligo, approx. 20 km from the Moy, where a larger colony of harbour seals occur; 260 harbour seals were observed there during a national census in 2003 (Cronin et al. 2007).

Seals using haul-out sites in the Slaney estuary or Wexford harbour, in contrast to the Moy, are predominately grey seals. Grey seal abundance in the harbour appears to be relatively high throughout all months of the year. The highest count of grey seals occurred during July 2013 when 780 seals were observed. Lowest counts of grey seals were observed in December 2012-January 2013. This coincides with the end of the grey seal breeding season. Wexford harbour is not one of the primary breeding sites for grey seals although there have been pups recorded at the site. It is likely that mature seals move to nearby breeding colonies at this time e.g. Saltee Islands, Co. Wexford. Numbers increase again from February 2013 and this could relate to the species' annual moult (Jan-April), where large numbers of grey seals remain ashore for extended periods of time. Wexford harbour appears to be an important site for grey seals during the annual moult in the Spring (Ó Cadhla & Strong 2007) but also during the Summer months. In general grey seals use of the area is relatively high all year round, primarily at the Raven Point haul-out site. Harbour seal presence in this region appears minimal. The highest abundance recorded was in January 2012 when 5 seals were present. Other grey seal haul-out sites in the vicinity of Wexford harbour include the Saltee Islands Co. Wexford, approx. 40km from Wexford harbour, which is a grey seal breeding and moulting site of national importance (Ó Cadhla & Strong 2007, Ó Cadhla et al. 2007).

Overall at both study sites seal abundance was highest in the Spring and Summer periods and lowest in Winter months. This is possibly influenced by prey availability and potentially the run of salmon at the study sites. The Slaney has a peak salmon run from March to May, and a smaller run of grilse in the summer months, peaking July/August. The Moy, has a later salmon run than the Slaney, May to September with peak run occurring around June/July. However, seasonal patterns in abundance of both seal species at the two sites are more likely related to the species' annual cycles. The presence of seals in two salmon rivers in Scotland was also highly seasonal and appeared to be related to the breeding and moulting behaviour of the seals rather than the abundance of salmonids (Carter et al. 2001).

It is important to note that counts of seals at both sites can be considered only as minimum estimates, as a certain fraction of the 'local population' will be at sea and unavailable for counting.

However as both sites were inter-tidal and the surveys were conducted at low tide, it is likely that the majority of the population was ashore and counted during this period. Previous studies on seal haul-out behaviour in southwest Ireland suggest that factors other than tide also influence haul-out patterns, these include season, time of day, weather and disturbance (Cronin 2007, Cronin et al. 2009, Cronin et al. 2010). As much as possible these factors were considered in the planning of surveys. Aerial surveys of the grey seal haul-out site at the Raven Point in Wexford harbour were conducted and direct comparison of boat and aerial count suggests boat based counts were under-estimated by approximately 6% only.

Diet of grey seals and harbour seals at the two study sites

Harbour seals in the Moy estuary were found to feed on a wide variety of prey species, and almost exclusively on teleost fish; flatfish species (primarily plaice), sandeels, and *Trisopterus* species were the most commonly consumed prey items, occurring in over 20% of scats. Pelagic species, herring and allis shad represented only 6% of the prey numbers consumed by the harbour seals. Considering that harbour seals typically do not travel far to forage (< 60km in the Moray Firth; (Thompson et al. 1996); <20km in southwest Ireland, (Cronin et al. 2013), a high percentage of demersal and benthic prey in the diet of the Moy harbour seals is not surprising. Scat analysis is often considered biased towards meals consumed relatively close to haul-out sites, as scats typically represent prey which has been consumed within the last day or two. However, given the relative short range of harbour seal foraging trips, this should not heavily bias results of the harbour seal diet in the Moy.

Similarities exist between the diet composition of harbour seals studied off the west (Co. Clare) and southwest coast (Co. Cork) by Kavanagh *et al.* (2010) and this study. Gadidae was the family most frequently occurring in the scats in both studies. Of these, *Trisopterus* species were the most commonly recorded in both studies. Kavanagh et al. (2010) however found sandeels to be the most numerically important species at the west coast site in Co. Clare, and in greater quantities than in the Moy. While diet composition varied across the species range of harbour seals in Europe, overall harbour seals have been described as opportunistic, generalist feeders (Härkönen 1987, Pierce & Santos 2003, Andersen et al. 2004).

While the grey seal diet in the Slaney comprised predominately teleost fishes, non-teleost fish and invertebrate species occurred regularly in the diet including skates and rays, octopus and squid, and at least two species of crustaceans. Among the teleost fish consumed, it was evident that Gadidae was the most important prey family, occurring in 86.3% of scats. Of the gadoids, *Trisopterus* species were the most important. In contrast with a number of grey seal diet studies in other parts of their range, sandeels were of relatively minor importance to grey seals in the Slaney. The most comparable study on grey seal diet was that of Gosch (2010) who studied the diet of grey seals on the Blasket Islands, Co. Kerry in Spring 2009 and 2010, through scat analysis and found that sandeels were of considerable importance, representing 18.8% of total prey biomass consumed. Considering the apparent differences in sandeel importance in grey seal diets between the south west (Blasket Islands, Co. Kerry) and south east (river Slaney, Co. Wexford) of Ireland, sandeel importance to grey seal diets may well be site specific.

Around the south-western North Sea, Prime & Hammond (1990) found grey seals to feed almost exclusively on demersal and benthic prey. This was also evident with the grey seals in the Slaney. Jessopp et al. (2013) studied the dive-behaviour of grey seals tagged in southwest Ireland and found that, in water deeper than 50m, 69% of foraging dives were to the benthos. The remaining 31% of foraging dives were categorised as pelagic. Because pelagic dives were not sequentially repeated, it was suggested that the seals were opportunistically feeding on pelagic prey that they encountered *en route* to the benthos (Jessopp et al. 2013). The diet of the grey seals in the Slaney did not suggest that pelagic species were important to seals in this area. However, as scat analysis tends to be biased towards those seals feeding closest to the haul-out site (Thompson et al. 1996), this may reduce the likelihood of pelagically feeding grey seals being accurately represented in the scats. So despite the capacity of grey seals to regularly travel large distances over several days (Cronin et al. 2013), it is likely that most prey items found in the scats were consumed relatively near the Slaney.

Some interesting insights were gained by comparing the diet compositions of each species based on prey numbers and prey biomass consumed. Based on the differences in prey numbers, it was clear that the harbour seals in the Moy were relying more heavily on teleost fish, whereas the grey seals in the Slaney were consuming more non-teleost prey, particularly crustaceans (of which *Nephrops norvegicus* was the most important species). This may be related to the proximity of the Slaney to "the Smalls"; an important *Nephrops* fishery to the south-east of the Slaney. Based on prey biomass, more gadoids were consumed by the grey seals in the Slaney when compared to harbour seals in the Moy, but more flatfish as well as sandeels and herring were consumed by the harbour seals.

The diet of harbour seals in the river Moy and grey seals in the river Slaney were likely subject to both species and site effects. However, given the geographical separation of each site, and the predominance of harbour seals in the Moy, and grey seals in the Slaney, these two effects could not be distinguished from one another. A number of studies suggest that the diets of both seal species are influenced by prey availability and differ with sites and available foraging habitats (e.g. Thompson et al. 1996, Hauksson & Bogason 1997, Tollit et al. 1998). Thompson *et al.* (1996) compared the foraging activity and diets of harbour seals and grey seals in the Moray Firth, and found that, although grey seal scats may not have reflected the diets of individuals feeding further offshore, there was a remarkable similarity between the diets of both seal species. Grey seals foraged over a wider range and consequently had more foraging habitats available to them, and also appeared to show more intra-specific variation in preferred foraging areas (Thompson et al. 1996). Therefore, while scat analysis will typically reflect more local foraging, inter-specific differences in foraging behaviour would likely have an effect on diet composition.

Harbour seal scats contained fewer prey items than those of grey seals. No significant differences were found in the weights of prey items from each site, but this comparison would be influenced as much by species composition as prey size. Nonetheless, it appears that the grey seals were, on average, consuming more prey items than the harbour seals in the Moy.

Salmonids in the diet

In the diets of both harbour and grey seals in the present study, salmonids were recovered in relatively low numbers, representing only 1.6% of the total prey numbers in the Slaney and less than 5% in the Moy, however due to the large size of individual salmonids, they comprised approximately 15% of the total prey biomass consumed. A number of diet studies that focused on hard parts recovered from grey seal digestive tracts have detected salmonids in grey seal diets in other parts of their range (Rae 1960, Rae 1968, 1973, Pierce & Boyle 1991). However, until recently, salmonids had not been detected in grey seal scats from Irish sites. Gosch et al. (in review) was the first study to detect salmonids in the scats of grey seals in Ireland; salmonids comprised 33% of prey biomass in the diet of grey seals on the Blasket Islands, Co. Kerry during Spring 2009 and 2010. While salmonids did not account for quite so high a proportion of prey weight consumed by the grey seals in the rivers Moy and Slaney in the present study they were still of importance.

Salmonid bones were recovered from seal scats in the Moy in January, September, and October. The salmon season in the Moy runs from the beginning of February to the end of September. The highest number of salmonids were recovered from scat in September (n=8) and likely included Atlantic salmon (*Salmo salar*). These ranged from 285-373mm in length. The length-frequency range of salmon in the Moy is 450-605mm, with a mean of between 550-600mm (P. Gargan, IFI, Pers comm). The calculated salmonid lengths are consistent with sea trout, however, salmon were likely to have been consumed. This suggests that the regression equation available in the literature is underestimating fish lengths, possibly due to erosion of the premaxillae recovered in scats. The salmonids recovered in January and October were either Atlantic salmon or sea trout (*Salmo trutta*). These salmonids ranged from 283-356mm in length, and again, total lengths may be underestimated. Genetic analyses of scat samples to detect the presence of salmonid DNA conducted in September and October did not confirm the presence of either salmon or trout DNA. Genetic analysis of three salmonid premaxillae recovered from scats confirmed that they belonged to salmonids, although whether they were from salmon or trout was not determined. Further genetic work to reliably determine whether premaxillae are from salmon or trout, and possibly whether salmon are wild or farmed would provide more detailed insight into seal-salmon interactions.

The possibility that common seals are removing farmed salmon from enclosures cannot be ruled out. Seal predation was considered a problem at 81% of marine salmon farms in Scotland (Quick et al. 2004), and seal predation on farmed salmon has been reported in Ireland (Cronin et al. 2010). However, the nearest sea salmon farms to the Moy, are located at Clew Bay, Co. Mayo, and Clare Island, Co. Mayo; approximately 110km and 150km away respectively. These are likely outside the core foraging range of harbour seals feeding in the Moy.

The highest numbers of salmonids in the Slaney were recovered from scats collected in July (n=10), but salmonid bones were also detected in March, May, and September. The main run of MSW salmon in the Slaney is from March to May. The salmon stock in the Slaney is currently under conservation limits, and therefore only catch and release angling occurs there. The salmonids recovered from March and May ranged from 280-357mm in length, and are likely to include adult Atlantic salmon (*Salmo salar*) consumed during the spring salmon run. However, DNA tests on scat samples from May suggest trout DNA was also present. In the Slaney, after the Spring salmon run, a run of grilse occurs in the Summer months, and sea-trout tend to run from June to August. Salmonids recovered from scats in July may be a combination of salmon grilse and sea-trout (*Salmo trutta*). In July scat samples sent for genetic testing only one was positive for salmon DNA and none for trout DNA. These salmonids ranged from 295-440mm in length. Salmonids recovered in September could represent either salmon or sea-trout. Indeed genetic tests on September scat samples confirmed one positive for trout DNA. These salmonids included the largest recovered, ranging from 305-490mm in length. Overall, calculated lengths are appear to be more consistent with sea trout as Slaney salmon tend to be larger than those in the Moy, with a mean size exceeding 600mm P. Gargan, IFI, pers comm.). However, genetic tests did confirm the presence of salmon in the diet of seals, and the smaller calculated lengths likely represents an underestimate due to erosion of premaxillea recovered from scats. Further studies to produce more realistic salmonid regression equations for premaxillae than are currently available is certainly warranted.

It is unlikely that the salmonids recovered in grey seal scat at the Slaney site were farmed as there are no salmon/trout farms on the southeast or east coasts of Ireland and even though grey seals can potentially forage over distances of hundreds of kilometres, the scat samples should represent recently consumed prey, so within general proximity to haul-out sites. Overall it appears that seals fed opportunistically on salmonids whenever they occurred.

Detection issues and biases

Given that salmon had been found in a number of seal diet studies by identifying otoliths from digestive tracts (e.g. Rae 1960, Rae 1968, 1973, Pierce & Boyle 1991), but had not been identified by otoliths in scat analysis, it was clear that salmon were being overlooked in scats by using otoliths alone. The fragility of salmonid otoliths and their apparent tendency to being completely eroded during digestion makes the inclusion of alternative salmonid prey remains vital. Salmonids would have been completely overlooked in both harbour seal and grey seal diets had only otoliths been used. Otoliths provided only a partial insight into the harbour seal and grey seal diets. Without the use of additional prey remains no salmonids, crustaceans, skates/rays, and 53% less dragonets would have been accounted for in diet reconstructions of both seal species; these omissions would have biased the results and further inflated the importance of other species.

Biomass estimates were not possible for all species that were found to occur in the diet due to a lack of regressions for diagnostic features such as eyes, dentaries, and vertebrae. These species will be under-represented in the data. In addition to this, scat analysis generally is subject to a number of other well-documented biases. "if the biases were constant across species, the relative importance of different prey (which is how the data are usually expressed) would be accurate" (Grellier & Hammond 2006). Species-specific digestion correction factors are intended to equalise the effect of digestion on otoliths across all species. While only some of the remains could be used to estimate prey weights, a published numerical correction factor for salmonid bones (Tollit et al. 2007a) was used to estimate salmonid biomass contribution to diet. To not have done so would have introduced a potentially large error in estimating the relative contribution of salmonids to the overall prey biomass. Applying correction factors for otolith erosion, while not accounting for erosion of salmonid premaxillae, would have underrepresented the importance of salmonids in the diets of both species of seal. While it is apparent that reconstructed salmon lengths are less than those reported by IFI for both the Moy and the Slaney, by not applying digestion coefficients to other prey items, the potential bias is reduced. More extensive experimental seal feeding trials, on a wider range of prey species, and focused on otoliths and non-otolith bones would go some way to making correction factors more refined and robust so that they can be applied across all prey groups.

Another potential source of bias is the possibility that seals may not consume the heads of large prey (Pitcher 1980) and in that case both otoliths and premaxillae will not be present, and salmonids and other species will remain undetected. However this may be more of an issue when salmon are available to seals at unusually high densities, for example, in salmon nets and at salmon farms where heads may be discarded. This may be less of an issue in rivers with freely swimming salmonids and particularly with smaller (juvenile and sub-adult) salmonids. However, the potential bias suggests that traditional techniques using prey hard part remains should be supplemented with other techniques, including genetic analysis, to detect salmonids.

Genetic analyses and salmonid detection

Analyses of seal scat using quantitative PCR has confirmed the presence of salmonid DNA in seal scats which went undetected using just bones or otoliths in a Scottish study (Matejusová et al. 2008). Considering the aforementioned issues associated with the detection of salmonids in seal scat, the genetic technique was employed in this study. Random samples of scat were tested in an independent laboratory with expertise in detecting salmonid DNA. Out of a total of 76 samples tested for evidence of salmonid DNA over the study period, only five scat samples tested positive for salmonid DNA; two samples for salmon DNA, two for trout DNA, and one sample tested positive for both salmon and trout DNA. The samples that were tested for salmonid DNA were also 'blind' tested for salmonid bones. Of 76 samples tested, 74% were in agreement with the genetic test results, with the majority negative for both salmonid bones and DNA. Two samples tested positive for both salmonid bones and DNA. However, 17 samples (22%) contained what were identified as salmonid bones, yet tested negative for salmonid DNA, while three samples (4%) that tested positive for salmonid DNA had no salmonid bones.

Of the samples that were not in agreement, the traditional technique of prey hard part remains appeared to be superior to the genetic technique in its ability to detect salmonids in the scat samples. This is in contrast to findings of Matjusova et al. (2008) where salmonid DNA was detected in a greater number of grey seal scats than hard parts were, including positive results from areas and months where otoliths and bones were absent. The 17 scats that had salmonid bones, but tested negative for salmonid DNA in our study, may be due to the way the scat was sub-sampled for the genetic analyses (3 subsamples taken from an intact scat before the washing process). Homogenisation of the scat sample prior to taking sub-samples for DNA testing would be useful for future sampling, as the reproducibility of DNA detection is superior in homogenized samples than those without homogenization (Matejusová et al. 2008).

Estimation of seal prey consumption.

Estimates of prey consumption by seals in the study areas were derived using a method similar to that of Hammond & Grellier (2006a). Species-specific energy values along with information on the daily energetic requirements for grey and harbour seals and information on the seals diet at both sites enabled us to estimate the average daily prey consumption per seal. The average daily consumption of prey of a grey seal at the Slaney site was estimated at 4.64kg. This is in line with estimated per capita fish consumption of grey seals in the North Sea and western Scotland of 4.7-5.0 kg d^{-1} (Hammond & Grellier 2006b, a). Average daily consumption of prey by a harbour seal at the Moy site was estimated at 4.05kg. This concurs with estimates from Norwegian harbour seal populations of approximately 4 kg (Härkönen & Heide-Jørgensen 1991, Bjørge 2002). Estimated values of prey consumption by grey seals varied from 988 kg/day to 1865 kg/day in Winter and Summer respectively at the Slaney site, and between 152 kg/day to 288kg/day for harbour seals in Winter and Autumn respectively at the Moy site. The seasonal patterns in prey consumption observed (lowest in Winter at both sites, highest in Summer in the Slaney and Autumn in the Moy) are a result of seasonal patterns in seal abundance as the diet data were aggregated across the entire study period. Grey seal numbers were highest in the Summer in the Slaney and harbour seals highest in the Autumn in the Moy, likely due to the timing of the annual moult in harbour seals and that Wexford harbour appears to be an important Summer haul-out site for grey seals. Sample size of scats was too low to derive season specific biomass estimates based on diet data; it is difficult to get a robust sample size of scat from haul-out sites used by low numbers of seals (e.g. Moy) and at inter-tidal sites (both study sites) as scat is usually washed off by tides.

Local stock size of salmon in the river Slaney is below conservation limits, and estimated to be 785 individuals in 2013, comprising of 608 multi-sea Winter individuals (MSW, run Jan-May) and 177 grilse or one-sea Winter individuals (ISW, run from June onwards), based on the previous five years of count data. No commercial fishery operates in the area, but some salmon are consumed by a range of predators, including seals. Feedback from fishers also noted damage caused by otters (*Lutra lutra*), cormorants (*Phalacrocorax carbo*) and lamprey. The Moy is above conservation limits for salmon and supports a large rod fishery. Local stock size of salmon in the river Moy is currently estimated to be 42,717 individuals (run May-Sept, peak July) (P. Gargan IFI *pers comm*).

It is important to note that estimates of salmonid consumption should be treated with considerable caution. The biomass estimate used for salmonids assumes this is comprised solely of salmon, not sea trout. It is practically impossible to differentiate between sea trout and salmon premaxillae by eye. Genetic analyses provides us with more information, with tests suggesting that sea trout DNA was indeed present in seal scat at both sites – in fact 50% of scat samples that tested positive for salmonid DNA were sea trout. The detection rate overall of salmonid DNA was low, as was the sample size (scat was sub-sampled for genetic testing), but it provides conclusive evidence that salmonids taken by seals at the sites also include sea trout. The estimates provided therefore are 'worse-case scenario' estimates based on the assumption that salmonid biomass estimated in the diet consisted entirely of Atlantic salmon. A more comprehensive genetic study with a larger sample size of homogenized scat may also provide more robust estimates of the proportion of salmon versus sea trout in the seal diet.

Daily consumption estimates of salmonids (Table XI) are based on aggregated diet data across the entire study period, and multiplying by the seasonal abundance of seals to derive salmonid consumption within each site/season is inappropriate given that salmonids were not recovered in all sampling months and their contribution to diet varied greatly. Sample size was too small to enable a more detailed diet analyses by season, but the low contribution of salmonids to frequency of occurrence suggests that salmonids are taken infrequently by the seal population. It is also important to note that estimates of total consumption of prey (including salmonids) are only approximate estimates as they are based on averaged seal counts (not exact population estimates), an average value for daily energetic requirements of adult seals (not accounting for gender/age/season heterogeneity in energetics) and diet information based on samples of scat from each site (assuming these scat samples are representative of the diet of the local seal populations). The estimates also assume that the seal 'populations' in each study area are foraging exclusively within the study areas, which although possible for harbour seals (due to their small foraging range) is highly unlikely for grey seals. These consumption estimates therefore should be treated with considerable caution. Telemetry data from grey seals that will be tagged in Wexford harbour in 2014 will provide useful insights into the foraging distribution and habitat use of grey seals using terrestrial sites in Wexford harbour and will help refine consumption estimates of salmonids at the Slaney site; it is very likely that the estimates will be significantly reduced once the foraging distributions of grey seals in Wexford harbour are established.

Photographic identification to determine the number of individual seals involved in fish interactions

Photo identification of individuals based on unique pelage markings can be used to examine fidelity of individuals to a particular location and, with sufficient survey effort and data, population size. It can also be used to ascertain how many seals are involved in interactions with the salmon fishery in the estuaries. This is dependent on the acquisition of high quality images of seals in the water actively predating on salmon. To ensure a robust sample size of images this would require significant sampling effort on the estuary and river mouth and was outside the scope of the current study. However efforts were made to acquire images of individual seals during monthly seal counts and scat collection, with initial efforts focused in the river Moy near the weir in Ballina, where seals apparently aggregate. Although small numbers (1-2) of grey seals were observed occasionally, one actively predating on salmon, it was not possible to capture any images that could be used for photo-identification purposes. In the Slaney, similarly small numbers (1-2) of grey seals were observed foraging upriver near Enniscorthy town and a small number of images of these individuals were acquired between May and August. The images in May and June suggest the same individual re-visiting the area, however the quality of the images were not sufficiently high enough to be 100% certain.

Overall it appears a small number of seals (primarily grey seals) travel upriver at both sites to forage. However, whether these are the same individuals remains inconclusive. Photo identification of individuals proved to be extremely difficult due to infrequent surfacing of seals, small numbers of seals (therefore lower probability of 'capture' of images) and infrequent sampling, as this was not a core objective of the project. A dedicated study with frequent (daily) observations of seals upriver during salmon runs would greatly increase the potential for acquiring images suitable for photo-identification. Furthermore using a boat to get closer access to the individuals would be advised, as despite using a 600mm telephoto lens it was difficult to impossible to capture high quality images from the river bank if seals were on the far side of the river from the photographer. Involving IFI staff and/or anglers (who report frequent sightings of seals in the rivers) in the capture of images of individual seals would also be worth exploring further. Photo-identification has successfully been used by Graham et al. (2010) in a dedicated study on Scottish rivers (with over 500 days of survey effort) to demonstrate that only a small number of individual seals repeatedly visit rivers, as opposed to occasional visits by a larger sector of the population.

Changes in seal predation on salmon

A qualitative assessment was made of the perception of anglers and other stakeholders of seal damage in the two study sites by way of a questionnaire distributed via IFI. Only seven returns were received, with records of damaged salmon attributed to seals ranging from 9% in Loughross, to over 50% in in the river Nore (12% in Gweerbarra Doochary, 17% in the Boyne Estuary, 22% in Inver Bay). There was a general perception that seal damage to salmon has increased since the 2006 drift net ban in all areas except the Boyne, where damage was perceived to be similar to before the driftnet ban, despite anglers reporting more seals hauled out upstream of fishing areas. When seals were sighted in the area, they tended to be grey seals.

To place this in national context, feedback from a questionnaire distributed to IFI representatives in 2010 provided qualitative information on interactions between seals and salmon fisheries from 7 regions nationally. Information compiled nationally suggested that seal damage to line and snap-net caught salmon varied geographically from less than 1% in the Shannon estuary to 40% in the Moy estuary. Damage levels were reported to have increased since the 2006 drift netting ban in the Moy Estuary and Killary Harbour. However, damage levels were reported to have decreased in Galway Bay and the Shannon Estuary. When combined with the reported increase in damage levels sustained by the gill net and tangle net fisheries since the drift-netting ban, this may suggest displacement of seal activity to alternative sources of prey (Cronin et al. 2010).

Seal-Salmon interaction management considerations

The perceived contribution of seals to declines of salmon populations has led to calls from fisheries stakeholders for seal predation to be controlled. The majority (81%) of salmon fisheries stakeholders in the Moray Firth, Scotland believed that seals had a significant or moderate impact on stocks and catches, 77% believed that all seals were responsible and 47% supported seal culling (Butler et al. 2011). However, the management of marine mammal interactions with fisheries is challenging, and particularly when both predator and prey populations are protected, as is the case with Atlantic salmon and seals. The Atlantic salmon (in freshwater), harbour and grey seals are all listed in Annex II of the EU Habitats Directive (92/43/EC). An important step in the management of seal–salmon interactions is to determine accurately the occurrence of salmonids in the seal diet. Using conventional techniques, it is not possible to determine for certain whether a low occurrence of salmonid remains is due to their scarcity in the diet or the fragility of their hard parts compared with those of other prey species (Boyle et al. 1990). However our findings, using bones other than the fragile otoliths, together with results from the DNA analysis, supports suggestions that salmonids are in fact rare in the diet of seals in the two study sites, as has been found also in Scottish estuaries (Pierce & Boyle 1991, Tollit & Thompson 1996, Middlemas et al. 2006, Matejusová et al. 2008). Salmonids were found in 19% of all scat at the Slaney and 11% of scat in the Moy, and in small numbers; 1.6% of total prey numbers in the Slaney and less than 5% in the Moy. There may well be 'specialist' seals at both estuaries i.e. a small number of seals predating on salmon in the rivers further upstream of the main haul-out sites. In many cases populations where the feeding strategy may be that of a generalist, can be made up of individuals with a narrower, more specialised, diet than the whole population. Telemetry studies have shown individual seals repeatedly returning to the same foraging locations at sea (Bjørge et al. 1995, Tollit et al. 1998), and the same is likely to occur in rivers. Indeed survey effort in the rivers at both sites observed small numbers of individuals predating on salmon. Whether or not they were the same individuals observed on each survey remains inconclusive. Management practices that focus on the control of a small number of seals that move into key salmonid rivers will be far more effective, and preferable to targeting the larger groups of animals that haul-out in nearby estuaries (Butler et al. 2008). However, the current uncertainty around seal habitat use and level of individual specialization in salmonid consumption in Irish salmon rivers, must be addressed before an effective management strategy can be developed.

In a recent review of marine mammal culling programmes, Bowen & Lidgard (2012) examined many of the issues surrounding predator removal, especially as a potential mechanism to recover fish stocks. The idea that fewer seals will directly result in more fish being available to the fishing industry is an over-simplistic argument as the marine ecosystem is a complex one and indeed the argument has been disproved with the development of complex ecosystem models (Holt & Lavigne 1982, Punt & Butterworth 1995, Yodzis 2001). In relatively intensive seal/salmon interactions studies in the UK, scientific evidence indicates that salmon and sea trout contribute a minor component of these species' diet in the Moray Firth, Scotland and population reduction may not result in a direct compensatory increase in stocks and catches of salmon and sea trout (Butler et al. 2011), in common with other marine mammal–fishery interactions (Yodzis 2001).

The approach taken in Scotland to deal with controversial seal/salmon interactions is one that might be worth considering in the Irish context. The Moray Firth Seal Management Plan (MFSMP), introduced in 2005 to manage seal/salmon conflict, provides a 'useful adaptive co-management framework for balancing seal and salmon conservation with the protection of fisheries and/or fish farms and tourism for application in the UK and internationally' (Butler et al. 2008). Management Areas were established to cover rivers and river mouths to allow the targeting of 'problem' animals preying on salmon. The Potential Biological Removal (PBR) method (Wade 1998) is used in the MFSMP to estimate the number of seals (harbour seals in the case of the Moray Firth) that can be removed without causing a population decline, based on knowledge of the size and maximum rate of increase for the Moray Firth population. The Scottish Executive stipulates a maximum permitted limit of seals to be shot in each Management Area and by trained licensed marksmen. Although seals are protected under the EU Habitats Directive and Wildlife Act in Ireland, derogations are permissible and predator control mechanisms for seals are operational in Ireland, but on an individual rather than a population or management area basis. Permission to control by scaring or killing individual seals may be issued by the regulatory authority, the National Parks and Wildlife Service (NPWS) of the Department of Arts, Heritage & the Gaeltacht, under Section 42 of the Wildlife Act, to control damage to fishing gear and fish stocks. Permissions are given where economic damage has occurred or is likely to occur as set out in the Wildlife Act 1976. The onus is on the applicant to demonstrate that the damage has occurred or is likely to occur and permission granted only when all reasonable non-destructive methods have been considered and rejected as unsuitable (Cronin et al. in press).

The management measures of removing individual seals is more likely to be effective if only a small number of individuals repeatedly visit rivers than if the seals found in rivers are a larger part of the freely-mixing seal population. Dedicated studies over a 3 year period using photo-identification helped to determine whether or not specific individual seals were repeatedly using three rivers in the Moray Firth and the evidence suggests a small number of individual seals were shown to repeatedly visit rivers rather than simply a larger sector of the population using those areas more occasionally. This provided support for the management strategy of focussing control within rivers (Graham et al. 2010). Evidence of such in the current study remains inconclusive and a more comprehensive and focused study would be necessary to assess this is more detail than the current study allowed. Data on the growth rates of the local seal populations are necessary for calculating the Potential Biological Removal quotas. This would involve long-term (multiple year) studies of seal populations at both sites for robust site-specific estimates. However, in the absence of such data a precautionary approach could be used and conservative rates of population increase based on seal studies elsewhere could be considered.

Non-lethal, Acoustic Deterrent Devices (ADDs) are another management/mitigation measure worth exploring further. Used mainly at aquaculture sites, the effectiveness of these devices to deter seals appears to vary (Jefferson & Curry 1996, Quick et al. 2004, Fjälling et al. 2006) and evidence suggests that whilst generally their effectiveness in the longer term appears to decline there are some exceptions. Acoustic devices had a positive effect in the Baltic salmon-trap net fishery by way of larger landed catches (less damaged) and less gear damage (Fjälling et al. 2006). ADDs have been effective at deterring seals from a specific area of river in trials in Scotland reducing seal movement upstream by approximately 50% in two rivers over a 4-month period (Graham et al. 2009). Although only partially effective as a barrier, these studies suggest that ADDs, once sited appropriately, might be a useful conservation tool in the management of seal-salmon conflicts in estuaries and rivers where the potential for adversely impacting cetaceans is limited, as the devices can have potentially negative impacts on cetaceans.

Conclusion

The study has established that salmonids have been found in the diet of both grey and harbour seals in the rivers and possibly estuaries of the Moy and Slaney. Estimates of the daily consumption of Atlantic salmon by seals at the study sites (Table XI) need to be treated with caution until estimates are refined further using telemetry data from tagged seals, but overall results suggest that salmonids contribute 11 – 19% of the biomass consumed by the local seal populations. Salmonids were found in 19% of seal scat at the Slaney and 11% of scat in the Moy, but in small numbers, indicating that not all seals from local haul-out sites are predating on salmonids. Smaller salmon population units, and spring salmon sub-stocks and fisheries in particular, are most vulnerable to predation (Butler et al. 2006) and even with low predation of salmon by "specialist" seals (or other predators), they could have disproportionately large effects on small population units such as in the river Slaney.

Any management framework for Irish salmon rivers needs to be based on robust scientific data, and the removal of salmonids by seals (or other predators) must also be placed into context of the amount removed by fisheries; in the rivers Don and Dee in Scotland, the number of adult salmon consumed annually by seals is an order of magnitude lower than that removed by rod fisheries (Carter et al. 2001). In the Moy 6,564 salmon were caught (non-release) by rod fisheries (5 year average, P Gargan IFI *pers comm*) which is likely to be far higher than that removed by seals in the area. Any proposed mitigation framework should include a suite of management measures with clear and measureable objectives to be evaluated during planned follow-up monitoring. Management frameworks would require participation of the relevant regulatory authorities such as the National Parks & Wildlife Service, as well as Inland Fisheries Ireland, and long-term success is more likely if adaptive co-management includes all stakeholders including anglers and netsmen, a lesson learned from the MPFMP initiative (Butler et al. 2011). Since rivers may contain genetically-distinct populations which differ in the timing of their return migration, and hence their seasonal availability to fisheries (Stewart et al. 2002, Jordan et al. 2005), any management plan would also need to ensure management is targeted at the scale of such sub-stocks (Youngson et al. 2003) and timing of the run.

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Appendix A

Frequency of occurrence (O), number (N), corrected and uncorrected biomass (W) of prey species found in seal scats from the **river Moy**

						Uncorrected		Corrected	
Prey family	**Prey species**	**O**	**%O**	**N**	**%N**	**W**	**%W**	**W**	**%W**
Anguilidae	*Anguila anguila*	1	2.2	1	0.3	NA	NA	NA	**NA**
Clupeidae	*Clupea harengus*	6	13.0	16	5.3	1240.0	6.6	7116.4	**14.0**
	Alosa alosa	2	4.3	2	0.7	NA	NA	NA	**NA**
Salmonidae	Salmonidae spp.	5	10.9	13	4.3	5160.0	27.3	8307.6	**16.4**
Gadidae	*Pollachius pollachius*	3	6.5	7	2.3	864.7	4.6	3558.8	**7.0**
	Pollachius spp.	4	8.7	12	4.0	1174.5	6.2	3944.0	**7.8**
	Melanogrammus aeglefinus/Pollachius spp.	2	4.3	3	1.0	45.1	0.2	151.5	**0.3**
	Merlangius merlangus	1	2.2	1	0.3	35.0	0.2	143.4	**0.3**
	M.merlangus/Micromesistius poutassou	3	6.5	3	1.0	87.7	0.5	377.6	**0.7**
	Trisopterus esmarki	2	4.3	2	0.7	18.7	0.1	53.6	**0.1**
	Trisopterus luscus/Trisopterus minutus	3	6.5	4	1.3	125.0	0.7	282.0	**0.6**
	Trisopterus spp.	12	26.1	17	5.7	324.3	1.7	635.8	**1.3**
	Ciliata mustella	1	2.2	1	0.3	1.3	0.0	5.6	**0.0**
	Molva molva	2	4.3	4	1.3	72.5	0.4	347.0	**0.7**
	Raniceps raninus	2	4.3	2	0.7	430.3	2.3	1513.0	**3.0**
	Gadidae spp.	3	6.5	3	1.0	NA	NA	NA	**NA**
Serranidae	*Dicentrarchus* spp.	2	4.3	5	1.7	600.6	3.2	915.5	**1.8**
Carangidae	*Trachurus trachurus*	2	4.3	10	3.3	403.6	2.1	925.6	**1.8**
Trachinidae	*Trachinus draco*	1	2.2	1	0.3	7.1	0.0	15.1	**0.0**
Ammodytidae	Ammodytidae spp.	7	15.2	52	17.3	1028.1	5.4	3051.9	**6.0**
Callyonymidae	*Callionymus* spp.	2	4.3	2	0.7	262.0	1.4	2072.0	**4.1**
Gobidae	Gobidae spp.	1	2.2	2	0.7	1.0	0.0	2.4	**0.0**
Bothidae	*Psetta maxima/Scophthalmus rhombus*	1	2.2	1	0.3	336.9	1.8	697.5	**1.4**
	Phryonorhombus norvegicus	1	2.2	2	0.7	38.9	0.2	78.4	**0.2**
	Bothidae spp.	5	10.9	10	3.3	1477.4	7.8	2876.3	**5.7**
Pleuronectidae	*Pleuronectes platessa*	7	15.2	18	6.0	934.0	4.9	2034.3	**4.0**
	Platichthys flesus	2	4.3	2	0.7	157.3	0.8	266.9	**0.5**
	P.platessa/P.flesus	3	6.5	5	1.7	897.0	4.8	1789.4	**3.5**
	Limanda limanda	3	6.5	11	3.7	499.3	2.6	1517.6	**3.0**
	Hippoglossoides platessoides	1	2.2	1	0.3	14.3	0.1	14.3	**0.0**
	H.platessoides/Glyptocephalus cynoglossus	1	2.2	2	0.7	51.5	0.3	113.3	**0.2**
	Pleuronectidae spp.	8	17.4	24	8.0	1742.5	9.2	3704.6	**7.3**
Solenidae	*Solea solea*	1	2.2	1	0.3	37.7	0.2	81.2	**0.2**
	Solenidae spp.	4	8.7	5	1.7	712.5	3.8	1536.5	**3.0**
	FLX	6	13.0	3	10.	1073.1	5.7	2321.4	**4.6**

				2	7				
	Unknown fish	1	2.2	1	0.3	NA	NA	NA	**NA**
Cephalopod	Octopus	1	2.2	1	0.3	256.6	1.4	271.5	**0.5**
	Cephalopod spp.	7	15.2	11	3.7	NA	NA	NA	**NA**
Crustacea	Crustacean spp.	8	17.4	9	3.0	NA	NA	NA	**NA**

Appendix B

Frequency of occurrence (O), number (N), corrected and uncorrected biomass (W) of prey species found in seal scats from the **river Slaney**

						Uncorrected		Corrected	
	Prey species	**O**	**%O**	**N**	**%N**	**W**	**%W**	**W**	**%W**
Rajidae	Rajidae spp.	31	38.8	31	2.3	NA	NA	NA	**NA**
Anguiliformes	*Anguilia anguila*	2	2.5	2	0.1	0.8	0	2	**0**
Congridae	*Conger conger*	2	2.5	2	0.1	19.5	0	42.3	**0**
Clupeidae	*Clupea harengus*	2	2.5	5	0.4	315.3	0.6	1809.4	**1.3**
	Sprattus sprattus	2	2.5	3	0.2	22.6	0	33.9	**0**
Salmonidae	Salmonidae spp.	15	18.8	22	1.6	11540	23.3	18579.4	**13.7**
Gadidae	*Melanogrammus aeglefinus*	4	5.0	12	0.9	1605.9	3.2	7488.1	**5.5**
	Pollachius spp.	9	11.3	22	1.6	4343.1	8.8	14584.8	**10.7**
	M. aeglefinus/Pollachius spp.	10	12.5	32	2.3	4751.7	9.6	15957.2	**11.7**
	Merlangius merlangus	4	5.0	4	0.3	138.3	0.3	566.1	**0.4**
	M.merlangus/Micromesistius poutassou	26	32.5	83	6.1	2077.7	4.2	8385.2	**6.2**
	Trisopterus esmarki	1	1.3	1	0.1	72.2	0.1	72.2	**0.1**
	Trisopterus minutus	3	3.8	3	0.2	75.1	0.2	134.4	**0.1**
	Trisopterus luscus	2	2.5	5	0.4	75	0.2	188.9	**0.1**
	T. luscus/T.minutus	9	11.3	14	1.0	658.3	1.3	1531.9	**1.1**
	Trisopterus spp.	38	47.5	139	10.2	3087.2	6.2	5957.3	**4.4**
	Ciliata mustella/Gaidopsaurus vulgaris	2	2.5	5	0.4	179.1	0.4	877.6	**0.6**
	Molva molva	1	1.3	1	0.1	454	0.9	2172.2	**1.6**
	Rockling spp.	1	1.3	1	0.1	NA	NA	NA	**NA**
	Gadidae spp.	28	35.0	47	3.4	972.7	2	5447.8	**4**
Triglidae	Triglidae spp.	1	1.3	15	1.1	590.9	1.2	1324.1	**1**
Cottidae	*Myoxocephalus scorpius*	1	1.3	2	0.1	130.2	0.3	284	**0.2**
	Taurulus bubalis	3	3.8	5	0.4	120.3	0.2	168.8	**0.1**
Agonidae	*Agonus cataphractus*	1	1.3	2	0.1	12.9	0	12.9	**0**
Labridae	Labridae spp.	1	1.3	1	0.1	NA	NA	NA	**NA**
Zoarcidae	*Zoarces viviparus*	1	1.3	1	0.1	14	0	36.4	**0**
Pholidae	*Pholis gunnellus*	3	3.8	3	0.2	5.1	0	6.9	**0**
Trachinidae	*Echichthys vipera*	1	1.3	5	0.4	45.3	0.1	89.5	**0.1**
Ammodytidae spp.	Ammodytidae spp.	11	13.8	31	2.3	100.3	0.2	297.8	**0.2**
Callyonymidae	*Callionymus* spp.	30	37.5	175	12.8	2124.2	4.3	16361.3	**12**
Gobidae	*Pomatoschistus pictus*	2	2.5	2	0.1	5.1	0	23.6	**0**
	Gobidae spp.	4	5.0	9	0.7	27.7	0.1	67.9	**0**
Bothidae	*Psetta maxima*	1	1.3	1	0.1	384.2	0.8	755.5	**0.6**
	P.maxima/Scophthalmus rhombus	1	1.3	2	0.1	418.1	0.8	872.7	**0.6**
	Lepidorhombus whiffiagonis	1	1.3	1	0.1	120.9	0.2	120.9	**0.1**
	Bothidae spp.	2	2.5	4	0.3	276.8	0.6	544.6	**0.4**
Pleuronectidae	*Pleuronectes platessa*	18	22.5	32	2.3	3852.6	7.8	8035	**5.9**
	Platichthys flesus	4	5.0	14	1.0	631.4	1.3	1084.7	**0.8**
	P.platessa/P.flesus	10	12.5	29	2.1	1715.4	3.5	3474.8	**2.6**
	Limanda limanda	7	8.8	18	1.3	440.7	0.9	1286.1	**0.9**
	Hippoglossoides platessoides	6	7.5	7	0.5	191.7	0.4	580.8	**0.4**
	L.limanda/P.flesus	2	2.5	3	0.2	1.9	0	1.9	**0**
	L.limanda/H.platessoides	5	6.3	14	1.0	129.5	0.3	2778.7	**2**
	Microstomus kitt	2	2.5	2	0.1	192.8	0.4	192.8	**0.1**
	Pleuronectidae spp.	10	12.5	51	3.7	2085.4	4.2	4483.8	**3.3**
Solenidae	*Solea solea*	8	10.0	9	0.7	1440.4	2.9	3106.2	**2.3**

	Buglossidium luteum	2	2.5	2	0.1	45.6	0.1	89.2	**0.1**
	Solenidae spp.	8	10.0	16	1.2	806.4	1.6	1739	**1.3**
	FLX	16	20.0	48	3.5	891.9	1.8	1974.6	**1.5**
	Unknown fish	1	1.3	1	0.1	NA	NA	NA	**NA**
Cephalopds	Octopus	7	8.8	17	1.2	1734.4	3.5	1835.1	**1.3**
	Squid	2	2.5	2	0.1	568.8	1.1	606.5	**0.4**
	Cephalopod spp.	16	20.0	21	1.5	NA	NA	NA	**NA**
Crustaceans	*Nephrops norvegicus*	19	23.8	184	13.5	NA	NA	NA	**NA**
	Cancer pagarus	7	8.8	20	1.5	NA	NA	NA	**NA**
	Crustacean spp.	36	45.0	180	13.2	NA	NA	NA	**NA**

Appendix C

Example of seal damage logsheet

Seal Damage Logsheet for IFI Seal Predation Survey

Name [ ]

Location [ ]

Date	Time	Number of fish caught	Number of seal damaged fish	Number 'scrape' damage	Number 'bite' damage	length of damaged fish	length measurements undamaged fish (sample of 5-10)	Photos taken? y/n	Seals sighted nearby? y/n	Species of seal?	Do you consider seal damage has increased since drift net ban?	On a scale of 1-5 (1=low 5=high) please rate seal damage PRIOR to drift net ban	On a scale of 1-5 (1=low 5=high) please rate seal damage SINCE drift net ban	Comments

For further details please contact Martha Gosch 021 4703125 or e mail: m.gosch@gmail.com

Logsheet to be returned to Martha Gosch, Coastal & Marine Research Centre, Naval Base Haulbowline, Cobh, Co. Cork

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