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The Impact of Predation on the Atlantic Salmon (*Salmo salar*) and Brown Trout (*Salmo trutta*) Stocks of the Lough Foyle Catchment A Bioenergetics Modelling Application

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Non-technical Summary

THE IMPACT OF PREDATION ON THE ATLANTIC SALMON (SALMO SALAR) AND BROWN TROUT (SALMO TRUTTA) STOCKS OF THE LOUGH FOYLE CATCHMENT. A BIOENERGETICS MODELLING APPLICATION

Quantifying the impact of cormorant predation on fish stocks to apply an appropriate management response

BACKGROUND

There has been an overall reduction in the Atlantic salmon (*Salmo salar*) commercial fisheries catch within the Foyle catchment since the late 1960's. Predation pressures have been identified as a key source of population depletion in salmonid stocks. The great cormorant (*Phalacrocorax carbo*) is an opportunistic predator with the potential to remove large numbers of Atlantic salmon smolts and brown trout (*Salmo trutta*) during the smolt run, ultimately influencing the number of individuals available to recreational and commercial fisheries. Modelled results based on best estimates and available data for the Foyle catchment suggested that cormorants could potentially remove up to 48% of the total number of migrating salmon smolts. This value must, however, be put into context and considered alongside the accuracy of input data, as the model used incorporates a large number of assumptions. The quantitative results of this study provide a tentative estimate of the impact of cormorant predation on salmonid stocks, and suggest predation levels during the smolt run are significant enough to merit further scientific investigation. A number of recommendations can be made to increase the validity of the model output and facilitate the implementation of effective managerial tactics:

Cormorant Population Survey

An accurate estimate of the number of cormorant individuals foraging within the Foyle catchment is essential. Visual surveys around the Foyle and its tributaries should be conducted. Simultaneous counts of individuals within different areas would be most accurate, but apparent occupied nest (AON) measurements would also provide a useful estimate. Long-term survey data would also allow the efficacy of any implemented management technique to be studied.

Cormorant Stomach Content Analysis

The model incorporated data from a 1998 study of cormorant diet in the River Bush during the smolt run. A more up-to-date study of dietary composition during the smolt run in the Foyle catchment would improve the validity of the model. This would require a short-term study, sampling the stomach contents of a few cormorant individuals shot whilst foraging during the smolt run.

Cormorant Removal techniques

The results of other studies, summarised within the report, suggest that the most effective cormorant deterrent strategy involves the implementation of acoustic and visual scaring devices. Shooting individuals appears to be useless and will simply result in the influx of others to replace those shot. Placing visual and acoustic scaring devices along the banks of rivers used by smolts during the six-week smolt run would provide an available management window and should minimise the number of smolts lost to cormorants. Moving the devices and altering their frequency, sound or shape would improve their effectiveness.

Further Predator Surveys

Studies suggest that harbour and grey seals could potential prey upon salmon completing their return migration through estuaries. Population surveys and feeding observations in the Foyle estuary would indicate if this was a potential source of significant removal from the population.

ABSTRACT

Perhaps the most documented conflict between piscivorous bird predation and human resource use pressures in Europe is that of the Great Cormorant and the fishing industry. Through direct stock removal by consumption and injury of individuals during foraging, cormorants are perceived to be responsible for significant economic losses incurred to the fishing fleet and recreational angling industry. The fishery of Lough Foyle in Northern Ireland has seen a dramatic decrease in catch, in what were once extremely productive fishing grounds. Cormorants were suggested to be a key predator in this area and play a particularly important role in stock removal during the Atlantic salmon smolt run. The impact of cormorant predation on the Atlantic salmon and brown trout stocks of the Foyle catchment was investigated, using a bioenergetics modelling approach. Cormorants resident at the Inishowen coastal nesting colony were modelled to be responsible for the removal of 196.98Kg of brown trout and 84.5Kg of Atlantic salmon smolt daily. This established quantity of smolt consumption equated to a removal of 48.32% of the total migrating Atlantic salmon smolt population of the Foyle catchment during the six week smolt migration. This value was compared with a similar study conducted in Northern Ireland and discussed in the content of other published literature. Managerial implications arising from this result were considered in view of the current decrease in fisheries catch within the Foyle catchment.

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1 INTRODUCTION

Populations are dynamic and shaped by both self-regulating mechanisms and external influences. The delicately-balanced relationships that exist in nature have evolved in response to these interactions and place constraints upon a species' life history strategy and survival. These limitations can be either density-dependant, related specifically to the number of individual of the same species in a set space, or density-independent, determined by factors that will influence individuals in a population regardless of population size. Density-independent factors are generally random abiotic events such as extreme weather or disease outbreak, and dependant-dependant factors include disease spread, food availability and predation.

Successful predator-prey interactions are sustainable. Long-term survival of the predatory species relies on the availability of prey such that the removal of mass quantities of a prey item to unrecoverable limits would be self-damaging. Natural food webs are, however, dynamic, involving multiple interconnected species. Prey-switching often occurs, either seasonally or opportunistically, and adds further complexities to the study of natural predator/prey relationships. Field observations are often restrictive in only producing a one-dimensional, static representation of a bionetwork involving multiple levels of foraging dynamics. More reliable information can be gained through directly analysing the stomach content of predatory species, but this is a highly intrusive sampling method requiring accurate identification of decomposing prey items. As such, alternative methods of modelling natural predator/prey interactions are desirable to gain insight into the feeding ecology of scientifically, economically or commercial important species. The use of bioenergetics has provided significant advances in the management of such species (e.g. review given in Hansen *et al.* 1993).

The fisheries sector is one such industry for which stock monitoring and management is vital to ensure continued success. Natural predation effects are exacerbated by intensive commercial and recreational fishing action and can consequently reduce the standing stock of a population significantly, if not closely monitored. The Lough Foyle region of Ireland has been a successful fishery for generations and is of great economic importance to the local community. Previous annual commercial catch in the mid 1960's reached almost 150,000 fish (figure 1.2) and the area is extremely popular with recreational anglers. Situated in the north of the island, the lough straddles the border of Northern Ireland and the Republic of Ireland and opens directly into the Atlantic Ocean (Figure 1.1). The streams and rivers of the Foyle catchment are popular recreational fishing sites, with the upper reaches providing ideal spawning grounds for Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*). Migratory Atlantic salmon and sea trout are also permitted direct access to the rich feeding grounds of the Atlantic Ocean, via the Lough Foyle estuary.

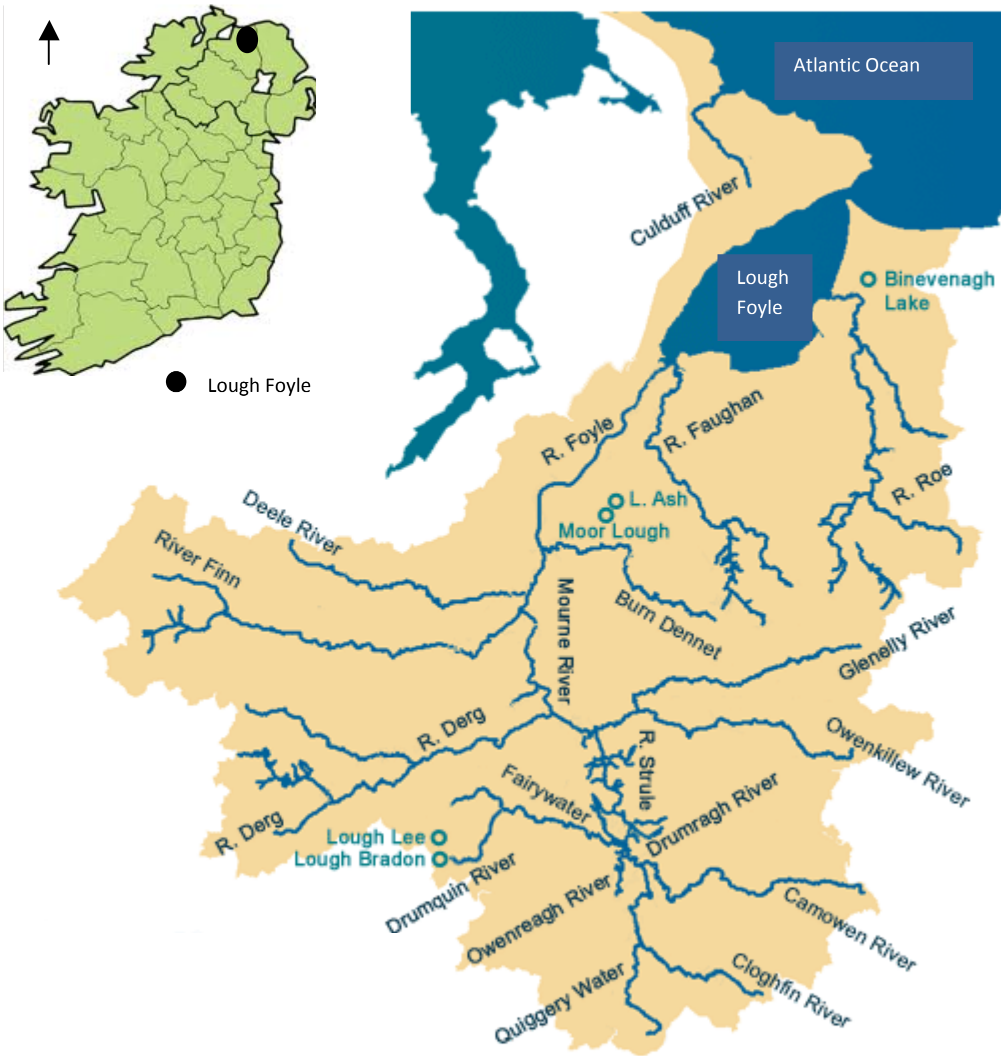

Figure 1.1: Location of Lough Foyle in Ireland and the extensive spawning and recreational fishing ground of the Lough Foyle catchment.

Since the late 1960's there has been, overall, a dramatic decline in the catch success of the commercial Atlantic salmon fishery of Lough Foyle (Figure 1.2). The highest recorded value for annual fisheries catch was 149,635 in 1964, but the 2006 catch yielded only 12,176 fish (Loughs Agency, unpublished data). Fisheries catch and the number of redd nests present in the upper tributaries of the Foyle catchment have been carefully monitored by the Lough's Agency since 1952. Although an accurate count of standing stock is near impossible to achieve, these data have allowed for general population trends to be observed on a long-term basis. A large decline in standing stock is clearly apparent, thus providing the physical evidence necessary to propose the short-term cessation of commercial fishing in Lough Foyle to allow the population of Atlantic salmon sufficient time to recover. This ban was enforced in 2010 and is still in-place for the 2012 fishing season.

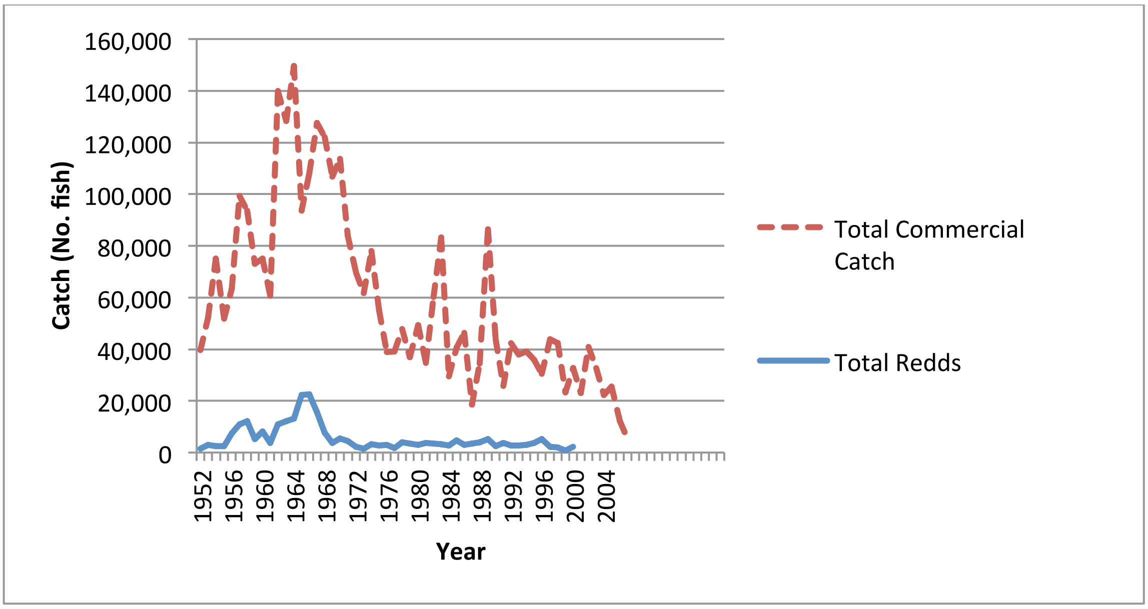

Figure 1.2: Total Commercial Atlantic salmon catch (1952-2007) and redd production (1952-2000) in the Lough Foyle area (Loughs Agency, unpublished data).

The justification for such drastic managerial intervention is clearly evident in the supplied fisheries data. The dynamic nature of the natural world does, however, suggest that additional ecological influences may also be affecting the Atlantic salmon population. Natural predators provide a source of removal from the standing stock and may intensify the effects of long-term fishing pressures. It is therefore logical to explore these relationships further, in order to test this hypothesis and, if necessary, suggest managerial implications for minimising this source of stock depletion.

In looking at multi-species interactions and how these in turn affect one species in particular, it is imperative to first look at the basic biology and life history strategies of the individuals in question. By understanding the underlying processes that drive an organism and influence its daily functions, it is possible to gain insight into how changing dynamics will influence overall species success. Basic biological information was gathered for two economically important fish species in the Lough Foyle catchment, the Atlantic salmon and its salmonid relative the brown trout. The importance of the Atlantic salmon to commercial fishing has already been discussed above and the brown trout is a popular commercial and recreationally-fished species that makes use of similar upstream habitats for spawning and juvenile feeding territories. The main predatory species' thought to be important consumers of each fish species were also considered and the information used to model the potential impact of predation inflicted by one key predatory species.

1.1 Salmon life history

The migratory nature of the Atlantic salmon and brown trout life cycles adds further complexities to stock management considerations. Salmon are anadromous and only found in freshwater systems during juvenile (fry, parr and smolt) or reproductive adult phases. The majority of their life is spent in the marine habitat, where feeding and most growth occur. For sexually mature individuals, migration to freshwater spawning grounds is necessary. Individuals undertaking this journey may have been at sea for just one winter ('grilse') or upwards of two years. The distance from Atlantic salmon feeding grounds off the coast of Greenland or the Faroe Islands to natal spawning rivers can be anywhere from a 10km to 1,000km journey, depending on the river system in question (Lucas and Baras 2001).

Fish can enter the freshwater system during any month of the year but a mass upstream migration towards spawning areas occurs in autumn. A correlation has been found between upstream movements and several environmental factors, namely; river flow, light level, temperature and tide (Banks 1969). During periods of low flow, river entry is mostly nocturnal, with faster flowing rivers promoting daytime migration (Potter 1988). Higher air temperature and ebb tides also increase upstream movement, although conflicting results have been published concerning the influence of tidal patterns in different geographic regions (Smith and Smith 1999, Erkinaro *et al.* 1999). Individuals fast during this process so must exert minimal effort to preserve energy stores and ensure reproductive success.

Spawning occurs between autumn and winter. Females dig spawn pits, termed "redds," within the gravel substrate before laying their eggs, which are then fertilised and covered-over. The eggs hatch-out whilst still buried in the gravel and alevins begin to emerge in late spring. Once all of the yolk sac has been consumed they live as fry, with related individuals feeding and growing in the same stretch of river where they were spawned (McCormick *et al*. 1998). During the parr growth phase each fish takes on a defendable territory, although individuals can temporarily occupy other areas seasonally (Cunjack *et al.* 1989). Fish can remain as parr for a number of years before joining the mass migration out to sea in spring. Some male parr, termed "precocious males," mature early and move up or downstream to spawning sites where they perform last-minute fertilisation on laying females (Buck and Youngson, 1982). Although these individuals have not had the benefit of marine feeding to build up energy-rich stores for reproduction, they have been found to consume salmon eggs during this period which is thought to replace energy lost during gametogenesis and spawning (Cunjack and Therrien 1998). The larger of these males and remaining large parr then undergo the physiological changes necessary to participate in the spring smolt run.

Smoltification is a period of morphological enhancement arising from changes in photoperiod that prepare salmon for seaward migration (McCormick *et al.* 1998). It involves a window of increased olfactory sensitivity and learning, during which each individual imprints a permanent sensory memory of site odours specific to the rivers in which they spawned (Jordan *et al*. 2003). These environmental cues are retained in periphery sensory neurons in order to provide navigational guidance during the return migration to freshwater natal spawning grounds. Smolt adopt a silvery colour and undergo physiological changes to allow for osmoregulatory capabilities in the marine environment. A shift from territorial to schooling behaviour occurs due to the collective change in buoyancy resulting from these physiological changes and associated change in preferred water velocity (Gibson 1983). A mass movement of individuals then follows, as smolt migrate down through rivers to estuaries and eventually out to sea. Salmon will then remain in the marine environment, feeding and growing in large schools until such a time as they feel compelled to respond to their biological clock and return to spawn in the very rivers in which they were born.

1.2 Trout life history

The *Salmo trutta* trout species has three distinct ecotypes: the sea trout, the lake trout and the riverine brown trout (Lucas and Baras 2001). Ecotypes can be categorized by their migratory pattern, with the anadromous sea trout migrating to sea in a similar pattern to the Atlantic salmon, and the lake trout and brown trout opting for a purely freshwater existence, remaining in the larger freshwater bodies or faster flowing river and streams. A small migration to suitable spawning grounds does occur in both the lake and brown trout. These different morphologies are thought to occur from different individual responses to environmental conditions and related individuals can opt for alternative migratory strategies (Luca and Baras 2001). Ecotypes can all interbreed, with documented examples of the eggs of female sea trout being fertilised by the sperm of male riverine trout (Elliot 1989).

Each morphology follows a different life history strategy, which can also vary based on geographic location. River trout remain in the relatively nutrient poor upland rivers where mortality rates are lower but growth occurs more slowly, and will achieving a much smaller size than those that migrate to loughs or out to sea (Fahy 1989). There is clearly a pay-off between the relative safety and consistency of freshwater residence and the greater feeding opportunities but higher mortality rates that come with seaward migration. The energy budget of sea, estuary and lough migrant fish can be four times greater than that of the same year-class individuals remaining in freshwater streams (Forseth *et al*. 1999). These migratory individuals also allocate more energy to growth and have total metabolic costs up to five times greater than those of resident fish.

Autumn migration occurs between October and November for all *Salmo trutta* and riverine residents will gather with sea-run and lough or estuarine individuals in the same upstream gravel spawning grounds. Individuals can travel at speed of up to 5km/night in the early stages of migration, covering long distances and slowing down as water temperatures decrease in the upper reaches of spawning rivers (Ovidio *et al.* 1989). Factors promoting the return to spawning grounds are similar to those of

Atlantic salmon and include changes in water or air temperature, river flow characteristics or a combination of environmental factors.

Females from all ecotypes will gather and dig redds for egg deposition before spawning. As with other salmonid species, the eggs will develop and hatch out as alevins within the gravel beds. Fry will emerge in the warmer late spring months and juveniles will move downstream to nursery areas. Juveniles undergoing seaward, estuarine or lough migration have been shown to leave this habitat earlier than those remaining in rivers and tributaries, despite being of smaller body size. It has been suggested that these individuals are energetically constrained by the limited food resources available in nursery areas and their more energetically-demanding life history strategy requires earlier movement to richer feeding grounds (Forseth *et al.* 1999). The movement of brown trout within a river system has been found to follow a distinct pattern of migratory movement at distinct key life stages (Thorpe 1974, Solomon and Templeton 1976). Following the initial downstream movement of all juveniles to nursery habitats from hatching to six months old, riverine brown trout will move further downstream to find a suitable habitat for maturation and growth between the ages of 6 to 15 months of age, feeding on molluscs, worms, insects and larvae. They will then remain in this habitat territorially until they return to upstream spawning grounds, continuing to grow to sexual maturation and altering their time budget to suit variations in local prey abundance (Giroux *et al.* 2000).

1.3 Predatory Influences

The life history strategies of the Atlantic salmon and brown trout species bring with them their own survival implications, as discussed above. Predation stresses also vary between species and ecotype, as each exposes individuals to different predatory influences at different locations and different life stages. Populations are most vulnerable when individuals are present in large densities, for example during the annual smolt run, migration to spawning grounds or at spawning time. Opportunistic predators have evolved to take advantage of the predictable nature of seasonal fish life cycles and can alter their foraging behaviour to exploit this window of opportunity. In addressing the impact of predation on vulnerable Atlantic salmon and brown trout stocks in the Lough Foyle catchment, the basic biology and feeding ecology of key predatory species should first be considered.

Mills (1971) lists the grey seal (*Halichoerus grypus*) as the most significant predator of salmon during their marine phase. In freshwater residence, the European otter (*Lutra lutra*) and American mink (*Neovison visa*)are indicated as important mammalian predators, alongside the great cormorant (*Phalacrocorax carbo*), heron (*Ardea cinerea*), osprey (*Pandion haliaetus*) and several other bird species found foraging at coastal and inland waters. Predatory piscine species are also of importance, and include pike (*Esox lucius*), perch (*Perca fluviatilis*), eel (*Anguilla anguilla*), chubb (*Squalius* *cephalus*) and trout (*Salmo trutta*). Of these, predation from the otter, cormorant, osprey and pike were listed as the main sources of removal from brown trout populations. The grey seal was selected for further study as its large size and consequently high energy demands require it to consume large quantities of prey, and it was suggested to be a key predator of the Atlantic salmon. The harbour seal (*Phoca vitulina*) was also chosen as it was found to utilise similar resources and has attracted a certain infamy as a result of considerable interactions with fisheries throughout its range. The European otter was identified as a species meriting further investigation owing to its suggested predatory impact on both the brown trout and Atlantic salmon, as with the great cormorant for which land-use conflicts with fisheries have also been well documented.

1.4 Seal life histories and their role as salmonid predators

Seals are a marine species tied to the land, commonly found along sheltered rocky shores and in sandy estuaries. Both harbour and grey seals live in territorial colonies, termed 'haul-outs,' to which they return periodically to rest, rear young and perform social activities (Cronnin *et al.* 2004). They are not social creatures but generally tolerate the presence of others during key life-stages. These follow a defined annual cycle, with harbour seals pupping in June, mating in July and moulting shortly after, and grey seals pupping earlier in the year, mating in spring and moulting three to five months after reproducing (Anderson, 1990). The predictability of this annual cycle facilitates observations of seal behaviour and allows more accurate measurement of colony size to be obtained at specific life stages.

Both common and grey seals are protected under the Conservation of Seals Act 1970 and are listed on the schedules of the Berne Convention and Bonn Convention (Anderson 1990). As such, seal habitats are protected and shooting is not permitted during the breeding season. A license can be issued outside of this time, however, for justifiable shooting for the purposes of hunting, scientific research and fisheries protection. UK seal populations have historically faced routine culling and individuals are still frequently shot around fishing nets and fish farm areas. A 2004 publication by the National Parks and Wildlife Service in Ireland published estimates from the most recent census taken in 2002 and 2003, and put the minimum population of grey seals in the Republic of Ireland at approximately 1,287 and harbour seals in the whole of Ireland at approximately 4,153 individuals (Cronin *et al* 2004). As these values are now ten years old, they should be treated as a very rough indication of population size. The same survey also recorded the presence of harbour seals at haul-out sites within Lough Foyle and both harbour and grey seals around the mouth of the estuary and nearby rocky shores. Haul-out sites are selected as areas providing optimum seal territories and, although these can change over time as population structures change, it is realistic to expect that a site considered favourable in a recent survey may still be in use a present.

As opportunistic predators, seals generally exploit the high density of prey species present in the foraging area. Grey seals can consume up to 5kg prey/day and harbour seals 3.5kg/day of fish, squid, shellfish and crustaceans, depending on prey availability (Anderson 1990). Over the short time that salmonids participate in the mass migratory return to freshwater spawning grounds, they are therefore extremely vulnerable. Carter *et al*. (2001) conducted a study into the predation of salmon by harbour seals and grey seals in two Scottish estuaries and found the density of seals within each estuary correlated with the seasonal fluctuations in salmon availability. Larger numbers were recorded in winter and early spring when salmon are known to return from their oceanic feeding grounds and are resident in their estuarine waters. The study also showed that seals were virtually absent during the summer months, when resident salmon stocks were lower. Scat analysis was conducted on samples collected at haul-out sights and showed no evidence of salmonid prey species, yet observed feeding data showed seals to predominantly prey upon salmon and brown trout. Observations of seal feeding shows that they often do not consume salmon heads, and thus otoliths may be missing in scat samples despite salmon being ingested, providing a plausible explanation for the discrepancies between the two sampling methods. Observational data was used to give a minimum estimate of large salmon consumption by resident seals over a monthly period, which the authors concluded to be an order of magnitude less than the number of salmonids removed by recreational anglers within the same area. Conflicting results have been published in literature detailing seal diet preference. Other studies into harbour seal predation have shown varied prey composition and only limited consumption of salmonid species (e.g. Wilson *et al.* 2002, Pierce and Santos 2003, Kavanagh *et al*. 2010). This variance is also evident in the available grey seal literature (e.g. Matthiopoulos *et al*. 2008). Parsons et al. (2005) described a DNA-based prey identification technique which yielded conflicting results to traditional otolith counting methods and was considered to be a more accurate representation of prey composition, due to the fragility of otolith bones and individuals not always consuming fish heads. It has further been suggested that estimates of the length of individual fish consumed can be inaccurate, depending on the digestive coefficient used in analysis (Grellier and Hammond 2006). This can therefore yield a false value for estimated proportion by weight of species diet composition. Such analytical discrepancies can be important sources of error in diet analysis and foraging ecology studies.

Evidence detailing high levels of salmonid consumption by grey or common seals is lacking, although it is probable that seal diet varies based on seasonally available prey species. Seals may, therefore, exploit the short window of availability when Atlantic salmon and sea trout are present around estuarine waters in high densities during their inland migration to spawning grounds. As the dietary preference and current number of grey and harbour seals utilising this area as foraging grounds in unknown, other predatory species in the Foyle catchment should be considered.

1.5 European otter life history and its role as a salmonid predator

Otters reside in predominantly coastal areas, living in and around underground “holts” that are commonly found along the coastal strip. Several individuals can utilise the same holt, which are dispersed along the coastline at up to a kilometre apart (Kruuk and Hewson 1978). Otters are, however, dependant on the freshwater environment, requiring constant access to a freshwater source in which to wash their fur following marine foraging activities (Lovett *et al*. 1997). Their habitat is listed under parts II and IV of the Habitats Directive so all areas utilised by otters must be carefully managed.

The species itself is an “Internationally Important Species” categorised as “vulnerable” on a worldwide scale under IUCN Red Book listing (1990). Otters are also listed as a UK Biodiversity Action Plan priority species and are currently managed under a Northern Ireland Species Action Plan. There is currently no direct count or Irish population estimate. Sites have been surveyed for otter presence in on-going monitoring programmes since 1980 and, after showing an initial decline of 13% occupancy in 2004, 88.6% of sites sampled in 2010 showed the presence of otters, an increase of 23.2% since the 2004 survey (Preston and Reid 2011). Of these sampled sites, five were directly on the banks of Loch Foyle and numerous more were located throughout the Foyle catchment (National Biodiversity Network).

Otter diet is found to vary with sex, age, seasonal availability and location (Carss 1995). Gorman (1997) found that salmonid species dominated the diet of otters located in the north-east of Scotland, as traces of salmonid prey were found in 88% of all faecal samples analysed. Trends in brown trout and salmon species distribution were reflected in otter diet, with foraging individuals consuming prey species in relation to local abundance. Watt (1995) found a similar pattern of location-dependant foraging, with little prey selectivity seen in otter populations residing in a sea loch on the isle of Mull. Again, individuals were found to primarily consume the prey species present in the highest local abundance, although butterfish and cottids were found to dominate otter diet in this study. Seasonal variations in prey composition, complimenting local abundance, have also been documented. In a study analysing dietary preference of the otter population resident in a Scottish sea loch, Mason and MacDonald (1980) found brown trout to comprise only two percent of the total prey consumed during winter. Their data also found the large majority of otter prey species to be of no commercial value, suggesting populations in the Wester Ross area of Scotland were not in direct competition with local fisheries.

The Lough Foyle catchment provides an ideal habitat for otter populations, owing to the range of salinities resulting from freshwater discharge in the upper reaches and marine connectivity at the mouth of the lough. Although an exact population count has not been conducted, numerous holts have been found throughout the Foyle catchment and numbers in Northern Ireland are known to be increasing. Dietary composition and prey selection of the Lough Foyle otter population is undocumented but it is logical to assume their foraging activities follow a similar pattern to those of the studies conducted in Scotland. Their preference for selecting locally abundant prey species suggests otters to be opportunistic feeders that will generally forage for the most accessible prey item. As such, it seems likely that Atlantic salmon and brown trout would feature heavily in otter diet when present in large numbers locally, such as during migratory periods or in nursery, feeding or spawning areas. Owing to the present conservation status of the European otter, populations must be managed with care. The species is afforded protected status in Ireland as a result of their low overall global population, and resource management strategies affecting Lough Foyle population must consequently receive careful consideration. Until accurate local dietary analysis and population counts have been conducted, the significance of otter consumption on local salmon and trout stocks can only be hypothesised. Although their presence may scare fish making them more difficult to catch, otters seem unlikely to have a sustained significant impact on angling success and invasive managerial tactics to prevent salmon and trout consumption would be conflicting with current conservation efforts.

1.6 Great cormorant life history and its role as a salmonid predator

The great cormorant is an efficient fish predator found to utilise both coastal and inland habitats, depending on seasonality. Irish populations have been found to generally inhabit inland freshwater bodies over the winter months before moving to coastal nesting sites from spring to autumn (MacDonald, 1987). Breeding occurs at these coastal colonies and clutches of three to four eggs are laid, incubating for about 30 days (British Trust for Ornithology). Geographical and relatively local discrepancies in seasonal habitat shift are apparent, as Warke *et al.* (1994) noted year-round stability in the local density of feeding cormorants in the Bann estuary, Ireland.

The UK breeding population has seen a considerable increase over the last forty years; a likely result of the protection of breeding sites (an indirect result of Atlantic salmon habitat listing under the habitats directive), improved breeding success, increased food supply in inland waters (resulting from eutrophication) and a reduction in control measures (potentially aided by the Wildlife and Countryside Act 1981) (Hughes *et al.* 1999). A government study, executed by the Joint Nature Conservation Committee, recently estimated the total UK and Irish cormorant population to comprise approximately 7,100 breeding pairs (Mitchell *et al*. 2004). Of this total value, 451 available occupied nests (AON) were located at Strangford Lough, the second largest breeding colony in Ireland, and 225 were recorded at Inishowen, a colony situated at the mouth of Lough Foyle. Both locations have shown just over a nine percent increase in AON since a previous survey was conducted in 1985-1988. Larger population increases have been reported throughout the British Isles (Callaghan *et al.* 1998). In autumn 2004, the large-scale expansion of UK cormorant populations and their perceived threat to fisheries prompted the government to change their policy for population management and increase the number of cormorants legally allowed to be shot under licence (Robertson 2004).

Understanding the foraging strategies utilized by cormorants can aid the implementation of effective predation control strategies. A study into cormorant feeding behaviour in England and Wales, conducted by the WWT Wetland Advisory Service, recorded solitary foraging, foraging in pairs and a high incidence of flock-feeding in observed colonies (1999). Flock-feeding was characterised by synchronised group diving and was associated with higher densities of feeding birds. Adult breeding birds appear more likely to conduct solitary feeding, possibly due to improved technique and foraging efficiency such that they don't require the assistance of others. Cormorants have been found to opportunistically feed upon the highest density local prey. This is reflected in the literature as dietary composition studies show the exploitation of a wide range of prey sources (review in Kirby *et al.* 1996). West and Cabot (1975) investigated cormorant diet composition through analysing regurgitates at seven breeding sites distributed around Ireland's coastline. Most sites showed representation from freshwater, brackish and marine fish in cormorant diet, suggesting individuals foraged in a range of habitats. Overall, salmonid species accounted for less than 1% of the total prey of all areas studied, with wrasse comprising 60% by weight. Discrepancies between study sites were, however, apparent, with one site yielding 9% salmonid dietary preference by weight, and another only 2%. Such opportunistic foraging means that seasonal fluctuations in fish density will consequently affect their vulnerability to cormorant predation. Kennedy and Greer (1988) looked at the diet of cormorants foraging on a river during the annual salmon smolt run by shooting individuals, collecting their stomach contents and quantifying the percentage composition of prey. They found that smolt consumption amassed to almost 30% of total cormorant diet at an upstream site, the rest comprising brown trout (69.5%) and a singular stickleback (<0.5%). Samples from a site downstream of a large smolt hatchery showed, unsurprisingly, that cormorants fed exclusively on the high density hatchery reared smolt. Cormorants accounted for the removal of 51-66% of the wild Atlantic salmon smolt participating in seaward migration and a large number of resident brown trout in the upper reaches of the River Bush, close to the Foyle Catchment.

Numerous studies have been conducted to assess the impact of cormorant predation on fisheries. Stewart *et al.* (2005) calculated brown trout to comprised 70% by mass of total cormorant diet in Loch Leven. The removal of brown trout by feeding cormorants amassed to approximately ten times the mean annual fisheries catch over the same five year period. The likelihood of direct competition between cormorant predation and recreational anglers was therefore considered to be high in this region. In other locations throughout Britain, no such relationship has been found. Despite large rates of fish removal by feeding cormorants, Callaghan *et al.* (1998) found little evidence of a relationship between increasing cormorant density and recreational angling success in their five year study encompassing 45 different water bodies throughout England and Wales. The need for localised cormorant feeding studies is therefore apparent.

The opportunistic nature and seasonal shift in cormorant prey selection is a similar foraging strategy to those of the grey and harbour seal. Cormorants have the potential to produce more of an impact of salmonid stocks in the Foyle catchment, owing to their exploitation of marine, brackish and freshwater foraging grounds. They also have the ability to move up/downstream with a desirable and energetically-favourable prey source, such as juveniles and smolt, increasing the window of vulnerability for these prey items. Cormorants foraging in the North of Ireland have been shown to remove brown trout and a large percentage of salmon smolt during the annual smolt run. The potential for regional conflict with fisheries could be demonstrated by modelling salmon smolt and brown trout removal in a given area, and thus quantifying the influence of cormorant predation on the Atlantic salmon and brown trout stock available to fisheries. The use of bioenergetics to model the impact of avian predation on commercially or biologically important fishing stocks has been well documented (e.g. Glahn and Brugger 1995, Madenjian and Gabrey 1995, Roby *et al.* 2003). Gremillet *et al.* (2003) conducted fieldwork, laboratory research and behavioural studies to produce a detailed bioenergetics model for wintering cormorants, intended as a wildlife management tool for the fisheries sector. This study uses the model by Gremillet *et al*. (2003) to investigate the potential impact of predatory great cormorants feeding on commercially important Atlantic salmon and brown trout in the Lough Foyle catchment.

2 MATERIALS AND METHODS

An extensive literature search was carried out to establish the current state of knowledge of the role played by natural predators on the depletion of Atlantic salmon and brown trout stocks. Four predatory species were then chosen for further study; the grey seal (*Halichoerus grypus*), common seal (*Phoca vitulina*), the European otter (*Lutra lutra*) and the great cormorant (*Phalacrocorax carbo*). Of these, the great cormorant was perceived to have the highest level of impact in the Foyle catchment study site and was therefore selected for more intensive bioenergetics analysis.

2.1 Estimates of feeding cormorants in the Foyle catchment

The 2000 Joint Nature Conservation Seabird Survey located a cormorant breeding colony at Inishowen (Grid ref. C 685437) (Mitchell *et al.* 2004). Northern Ireland cormorants have been known to travel up to 58km to reach foraging grounds (Warke *et al.* 1994), so the Inishowen colony, at a distance of 5km from the Foyle estuary and 30km from the mouth of the River Foyle, is a likely source of incoming predatory cormorants foraging within Lough Foyle and its tributaries (Figure 2.1). The survey recorded 225 apparently occupied nests (AON) at this site, suggesting a population of approximately 450 cormorants.

Figure 2.1: Location of Inishowen nesting colony of great cormorants in the North of Ireland, shown by green square (National Biodiversity Network).

2.2 Bioenergetics analysis

The bioenergetics model for wintering cormorants described in Gremillet *et al*. (2003) was used as a template for calculating the daily food intake (DFI) of 450 cormorants nesting at the Inishowen coastal colony. The model incorporated published literature, data from intensive laboratory studies and the results of radio-tagging behavioural fieldwork to obtain basic metabolic parameters and establish a daily activity budget for an individual cormorant. A published interactive programme was produced in which regionally-specific input values and other known parameters could be altered to suit the needs of a particular study, producing unique output values relative to a specific colony or study site.

In the present study, the impact of cormorant predation on salmonid populations during the six week annual smolt run was modelled. Dietary composition data from a 1988 study in Northern Ireland indicated that cormorants would maintain a diet of 69.65% brown trout and 29.88% salmon smolt during the smolt run in this region (Kennedy and Greer, 1988). Salmon smolt in the River Faughan, a large river within the Foyle Estuary catchment, were found to weigh 26g on average (Loughs Agency, 2008). This equates to approximately 4.625 kJ g^{-1} of energy available to consumers (Jonsson and Jonsson, 1988). Published values for the brown trout suggest each individual would yield 5.92 kJ g^{-1} of energy. These quantities were therefore used to calculate the proportional mass of each prey species in cormorant diet based on the known percentage composition, producing a value for the average calorific value of fish consumed by cormorants. This was then incorporated into the model, alongside, surface water temperature and bird mass to allow regionally appropriate results (Appendix one).

An estimate of the daily food intake (DFI) of a generic cormorant foraging in the Foyle catchment during the smolt run was produced. This value was then scaled-up to represent the 450 cormorants located at the Inishowen coastal colony to produce a population DFI. The proportional feeding detailed in Kennedy and Greer (1998) was applied to this population DFI value, to gain the mass of smolt and brown trout consumed daily. The mass value was then divided by the published weight of Atlantic salmon smolt and brown trout described above, producing a quantitative measure of smolt and trout removal. The smolt run in the Foyle catchment lasts for approximately six weeks, so the number of fish consumed by the population daily was then multiplied by 42. Finally, the potential impact of this level of predation on the overall population of Atlantic salmon was hypothesised, by comparing this number to the known population of smolt in the Foyle catchment. The total number of smolt moving through the Foyle catchment was calculated by obtaining the number of smolt recorded in the River Faughan and multiplying proportionally by the percentage of total redd production in the whole Foyle catchment known to stem from the River Faughan and its tributaries (Loughs Agency Catchment report, 2008).

3 RESULTS

An individual cormorant feeding in the Foyle catchment during the smolt run would require a predicted daily food intake of 628g. Of this, 187.79g would be assigned exclusively to smolt and 437.74g designated to brown trout. 450 cormorants would therefore consume 84.5Kg of salmon smolt and 196.98Kg of brown trout daily, equating to 3,246 smolt and 2,196 brown trout. Over the course of a six week smolt run, the predatory cormorant population would be responsible for removing 136,326 individual smolt and 92,232 individual brown trout from the waterways of the Foyle catchment. This level of predation would result in the removal of 48.32% of the total population of migrating smolt.

4 DISCUSSION

The modelled value of 48.32% removal of the total Atlantic salmon smolt in the Foyle catchment is comparable to the results of other studies in the same geographical region. Kennedy and Greer reported cormorant consumption of 51- 66% wild smolt during their 1988 study. Their work involved the direct measurement of prey consumption by analysing the stomach contents of cormorants shot whilst actively foraging. The 51% lower estimate of smolt population removal on the River Bush is extremely close to the modelled value of 48.32% found in the current study. Although the model utilises the same dietary composition observed in previous research, current site-specific values were used for the average calorific value of fish and the final number of smolt removed by predation was compared directly with a calculated value of the smolt population within the Foyle catchment. The similarity in results obtained indicated the efficiency of the model in predicting natural cormorant predation levels and suggested cormorants to be a significant source of removal of Atlantic salmon smolt during the seasonal smolt run.

The model used in the present study was designed for use with wintering cormorants and may not, therefore, provide a true representation of cormorant predation. The energy budget assigned to individuals and incorporated into the model would differ with seasonal fluctuations in energy demand. In particular, the smolt run coincides with the approach of cormorant breeding season and the arrival of warmer spring weather, which would likely alter cormorant behaviour and dispersal patterns. Model input values for activity budget and foraging efficiency were those of Gremillet *et al*. (2003) taken from laboratory and fieldwork observation in Loch Leven, Scotland. It was assumed that these values would not differ significantly for a population of cormorants in a region of Ireland similar in climate and topography, and that birds used in this study were of similar size and morphology. The estimated value of 450 individuals foraging in the Foyle catchment is based on data collected from a breeding colony in 2000. The reliability of this value in relation to a present-day study is contingent upon the stability of feeding cormorant populations around Irish estuaries observed in Warke *et al.* (1994). The accuracy of the proportion of smolt removed by feeding cormorants in relation to the total number of smolt migrating through Lough Foyle is also based on assumption. Calculated overall population values were done so assuming equal probability of smolting from each of the rivers within the Foyle catchment, as the value for smolt population was calculated using the proportion of total Foyle catchment redds present in the River Faughan, where smolt number were actively censused. Bioenergetics models encompass massive assumptions and the accuracy of results is dependent on reliable input data. Wherever possible in this study, regionally-specific factors were applied and, where these values could not be obtained, estimates were taken from literature published from similar study sites.

The modelled impact of cormorant predation on the Atlantic salmon smolt population in the Foyle catchment is sufficiently large to warrant further investigation. In order to provide the most accurate estimate achievable, the implementation of regional monitoring and population studies is essential. An accurate count of individual cormorants foraging throughout the Foyle catchment is of high importance. Wherever possible, studies should coincide with the timing of the smolt run. Cormorants are known to feed opportunistically on readily available prey items and a decline in Atlantic salmon or brown trout fishing stocks within the study area may be reflected in cormorant diet. A review of dietary composition studies showed great variation in prey consumed in relation to location and seasonality (Kirby et al. 1996). The current study modelled results based on the work of Kennedy and Greer (1988), which concluded that cormorants assign almost 30% of their diet to smolt during the smolt run, but Warke and Day (1995) found limited smolt consumption in their Northern Irish study and suggested individuals were more likely to have an impact on salmon parr. The need for local data collection is therefore apparent.

The potential for management of foraging European Otters was discounted as a result of their conservation status. The population of the Foyle catchment is suggested to be small and therefore unlikely to have a significant impact on Atlantic salmon or brown trout stocks in this region. Bioenergetics analysis of the impact of the other two key predators identified, grey and harbour seals, was discounted due to a lack of regionally-specific population and diet information. Seal population data for Ireland published in Cronin *et al.* (2004) provides only minimum population values as studies were conducted by aerial survey and do not take in to account individuals that were in the water, and therefore not visible, at the time of survey. The data available in the study is also ten years old and unlikely to give an accurate reflection of the present population size and distribution of individuals around the coastline of Ireland. A current estimate of the number of individual seals utilising the Foyle Estuary as foraging grounds, and seasonal fluctuations in this value, would also been an important management resource. Enhanced methods of local prey identification and predation rate (such as DNA analysis of prey, physical observations of feeding and the use of appropriate dietary analysis models) could also be utilized, wherever economically and physically possible, to ensure an accurate estimate of seal prey composition. Such combined local data would allow for further studies incorporating bioenergetics models specifically designed to analyse the conflict between seal predation and fisheries, such as the model produced by Butler *et al.* (2006).

The suggested seasonality of seal and cormorant predation upon Atlantic salmon provides a window of opportunity for managerial intervention during the smolt run. Cormorant predation on brown trout stocks has the potential to experience seasonal shift, but this effect would likely show a more gradual fluctuation in prey consumption, suggesting effective short-term managerial intervention would be more difficult. The routine culling or scaring of apex predators is a tactic that has been traditionally used in fisheries where large predators have been found to significantly interfere with fish stocks. The efficacy of these methods is variable, with conflicting results presented in scientific literature, depending on site-specific considerations. Methods of controlling seal predation upon important fishing stocks range from non-invasive tactics such as physical barriers, to scaring with acoustic deterrents, capture and relocation of individuals or even lethal shooting (Butler et al. 2006). Of the various seal-scaring tactics tested by Yurk and Trites (2000), acoustic deterrents were found to be the most effective non-lethal tactic employed. Wiese *et al*. (2008) found that the most effective control tactic to improve salmonid survival from hatching to adulthood involved deterring cormorants from feeding during the annual smolt run, but allowing them back to feed post-migration. This option allowed for cormorant predation on Northern-pike minnow also present in the study area, which were found to also be predators of local salmonid species. Such a tactic could be a more effective compromise in cormorant control, but would rely on anglers in the Foyle catchment accepting the potential decrease in population of other recreationally fished local species. Wight (2002) conducted a study into the potential impacts of shooting cormorant as a method of population control to protect local fishing stocks in Loch Leven. The study found no evidence to suggest an increase in angler's catch or correlation between wintering cormorant numbers and the implementation of culling tactics. Despite routine culls being widely considered an effective control mechanism, this study suggests this tactic to be of little benefit to improving fishing stocks or angling success. Management options that limit cormorant foraging would also need to take into account the importance of food availability during key life stages and important periods in the reproductive cycle. The persistent removal of a specific age-class of individuals could have catastrophic consequences for the long-term survival of a population, but non-specific management strategies applied to an entire population may be ineffective and redundant in terms of predatory control (Matthiopoulos *et al.* 2008).

If such extreme control measures are to be justified, conclusive evidence must be obtained to show that the level of cormorant predation within a given area has a negative and inhibitory impact on the longevity of local salmonid stocks. The present study suggests that cormorant predation on smolt during the seasonal smolt run may remove almost 50% of the entire migrating population in the Lough Foyle catchment. Further specific regional studies into the distribution and diet selectivity of cormorants would improve the validity of these results. When these parameters have been established, an informed management plan detailing predator removal options can be implemented, and directed specifically towards the individuals having the largest impact on fish stock depletion.

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6 APPENDICES

Appendix 1: Input parameters for the bioenergetics model, calculated values used in the study and data source information.

Parameter	**Value**	**Source**
Body Mass (kg)	3.2	Gremillet *et al.* (2003)
Time resting at night (min.d-1)	958	Gremillet *et al.* (2003)
Time resting daytime (min.d-1)	337	Gremillet *et al.* (2003)
Time flying (min.d-1)	5	Gremillet *et al.* (2003)
Time wing-spreading (min)	10	Gremillet *et al.* (1995)
Time in water (min.d-1)	130	Gremillet *et al.* (2003)
Assimilation Efficiency %	77.6	Brugger (1993)
Calorific value of smolt (KJ g-1)	4.625	Kennedy and Greer (1988), Elliot (1976), Jonsson and Jonsson (1988), Loughs Agency Faughan catchment status report
Swim speed (m/s)	1.35	Gremillet et al. (2003)
Dive/pause ratio	3.46	Gremillet et al. (2003)
Water temperature (degrees Celsius)	10.5	Loughs Agency website
Dive depth (m)	5	Gremillet et al. (2003)
Dive cost (w)	121.83	Gremillet et al. (2003)
Flight costs (w)	252	Pennycuick (2001)
Resting costs (day; w)	22.72	Storch (1997)
Resting costs (night; w)	19.2	Storch (1997)
Wing spreading costs (w)	20.48	Hennemann (1983)