A synopsis of UK and European cormorant and goosander dietary studies

Report No: 591

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Contents

Crynodeb Gweithredol

Mae poblogaethau adar pysgysol penodol, yn arbennig y fulfran (*Phalacrocorax carbo*) a'r hwyaden ddanheddog (*Mergus merganser*), wedi cynyddu yn y DU yn ystod y degawdau diwethaf, ac mae'r adar hyn bellach yn eang eu dosbarthiad ar hyd a lled Cymru. Dros gyfnodau tebyg o amser, gwelwyd gostyngiadau sylweddol yn statws stociau o bysgod dŵr croyw penodol yng Nghymru, yn arbennig yr eog (*Salmo salar*) a brithyll y môr (*Salmo trutta)*. Mae dosbarthiad 'mewn perygl' neu 'yn debygol o fod mewn perygl' bellach wedi'i bennu i'r mwyafrif o stociau o'r fath yng Nghymru. Mewn ymateb i'r dirywiadau hyn, gyda chefnogaeth cais Gweinidogol, cyhoeddodd Cyfoeth Naturiol Cymru y Cynllun Gweithredu ar gyfer Eogiaid a Brithyllod y Môr yng Nghymru ym mis Ebrill 2020. Mae'r cynllun gweithredu hwn yn cydnabod bod ystod eang o bwysau yn effeithio ar y stociau hyn ac yn nodi'r camau gweithredu angenrheidiol. Wrth geisio cael dealltwriaeth well o'r graddau y gall gwahanol bwysau fod yn effeithio ar stociau salmonid, un o'r camau a gymerwyd oedd cynnal adolygiad o ysglyfaethu ar salmonidau gan adar pysgysol.

I gefnogi'r cynllun gweithredu ac adolygiad ehangach o drwyddedu adar gwyllt, cymeradwyodd Bwrdd CNC ail sefydlu Grŵp Cynghori Cymru ar Adar sy'n Bwyta Pysgod o dan arweiniad CNC i asesu'r sefyllfa o safbwynt trwyddedu adar pysgysol yng Nghymru, cynghori ar y camau gweithredu posibl y mae angen eu cymryd, a datblygu polisi trwyddedu adar pysgysol.

Mae'r adolygiad hwn yn cwmpasu technegau dadansoddi deietegol a chyfyngiadau a rhagdybiaethau cysylltiedig, ac yn cynnig cyfuniad cyfoes o astudiaethau deietegol ar fulfrain a hwyaid danheddog a gynhaliwyd yn y DU ac Ewrop. Ar ben hynny, mae'r adroddiad yn cyflwyno data gwyddonol manwl am ddeiet adar pysgysol a faint o fwyd maent yn ei fwyta, ac yn nodi'r angen am ddata o'r fath, a'r angen am ei ddefnyddio mewn perthynas â'r ddadl gyhoeddus sy'n mynd rhagddi am effeithiau adar pysgysol ar bysgodfeydd.

Mae'r adroddiad hefyd yn disgrifio'r ystod o ddulliau (e.e. arsylwadau bwydo, dadansoddi peledi, cynnwys stumogau) sydd ar gael i asesu deiet adar pysgysol, ac yn rhoi gwybodaeth am y graddau y mae ysglyfaethu rhywogaethau o bysgod yn digwydd ar draws ystod eang o gynefinoedd dyfrol a mathau o bysgodfeydd. Mae'r adroddiad yn disgrifio rhinweddau a chyfyngiadau cymharol y dulliau gwahanol hyn.

Mae'r canfyddiadau allweddol fel a ganlyn:

- Nid yw dadansoddi deiet yn ddigon, ar ei ben ei hun, i bennu faint o bysgod o bwysigrwydd masnachol, neu rywogaethau o bryder cadwraethol sy'n cael eu bwyta gan adar pysgysol fel mulfrain a hwyaid danheddog. I gael gwybodaeth feintiol o'r fath, byddai angen data penodol i'r safle am (i) cyfansoddiad y deiet, (ii) nifer yr adar, a (iii) faint o fwyd y maent yn ei fwyta bob dydd.

- Mae nifer o wahanol dechnegau ar gael ar gyfer asesu deiet adar pysgysol, ond mae cyfyngiadau yn gysylltiedig â phob un. Y tri phrif dechneg yw: (i) arsylwi'n uniongyrchol ar adar wrth iddynt fforio ac ar yr ysglyfaethau y maent yn ei fwyta ar yr arwyneb; (ii) archwilio'r gweddillion caled (esgyrn pysgod ac ati) a geir mewn peledau y mae adar yn eu hailgyfogi (sylwer nad yw hyn yn berthnasol i hwyaid danheddog); a (iii) archwilio cynnwys stumogau adar sydd wedi marw.

- Mae data a ddarparwyd gan Ganolfan Gwyddorau'r Amgylchedd, Pysgodfeydd a Dyframaethu (Cefas) ar gynnwys stumogau mulfrain a hwyaid danheddog a laddwyd dan drwydded yng Nghymru rhwng 1993/94 a 2003/04 yn gyson ag astudiaethau eraill yn y DU. Mae'r data o Gymru yn cefnogi'r farn bod y ddwy rywogaeth o adar pysgysol yn bwyta ystod eang o rywogaethau ysglyfaeth a'r ddamcaniaeth bod y rhywogaethau hyn yn fforwyr oportiwnyddol, a bod eu deiet yn seiliedig ar yr ystod o ysglyfaeth sydd ar gael ar y pryd.

- Yn y DU a rhannau eraill o ogledd-orllewin Ewrop, un o'r problemau mynychaf ynghylch adar pysgysol yw'r ffaith eu bod yn ysglyfaethu ar leisiaid salmonidau. Ychydig o amcangyfrifon cyhoeddedig a geir o faint o leisiaid y mae adar pysgysol yn eu bwyta, ac maent yn amrywio'n fawr. Mae gwybodaeth am ddeiet mulfrain yng Nghymru a Lloegr yn ymwneud yn bennaf â misoedd y gaeaf a dyfroedd llonydd mewndirol. Mae'r data cyfyngedig ar gyfer afonydd yng Nghymru ar gyfer dechrau'r gwanwyn yn dangos bod eogiaid yn cael eu bwyta, ac er bod cyfran yr eogiaid yn y deiet yn parhau i fod yn isel, fe wnaeth gynyddu ar adeg rhedfa'r gleisiaid. Yn yr Alban, mae astudiaethau'n nodi bod ysglyfaethu blynyddol gleisiaid gan hwyaid danheddog yn cyfrif am 3-16% o'r gleisiaid a gynhyrchir. Mae amcangyfrifon o astudiaethau yn rhannau eraill o Ewrop yn amrywio'n fawr, gyda rhai'n adrodd am lefelau dibwys o ysglyfaethu gleisiaid gan adar pysgysol, ac eraill yn nodi colledion gweddol uchel (e.e. 47% o'r rhedfa gleisiaid ar gyfartaledd o amrywiaeth o archwiliadau yn Nenmarc).

- Mae yna gymhlethdodau amrywiol wrth geisio amcangyfrif effaith ysglyfaethu gan adar pysgysol ar stociau o bysgod. Mae dangos gwybodaeth o'r fath yn gymhleth am sawl rheswm ecolegol a thechnegol, ac oherwydd bod diddordeb dynol yn effaith adar pysgysol ar eu hysglyfaethau yn aml yn canolbwyntio ar rywogaeth benodol o bysgod, a hyd yn oed ar faint penodol (neu ddosbarth oedran). Mae ein gwybodaeth am ddewis/newid ysglyfaeth, a'r hyn sy'n cynyddu neu'n lleihau 'argaeledd' pysgodyn unigol i aderyn sy'n fforio am fwyd yn hynod gyfyngedig o hyd er gwaethaf ei phwysigrwydd o ran deall ac arddangos effaith. Ar ei symlaf, mae angen i ni ddeall y gymhariaeth rhwng: (i) amcangyfrifon o faint o fwyd y mae'r adar yn ei fwyta, a (ii) faint o fwyd sy'n bresennol (neu 'ar gael') yn yr amgylchedd ar yr adeg y mae ysglyfaethu'n digwydd. Mae casglu data 'adar' a 'physgod' o'r fath yn heriol, gydag anawsterau eraill yn deillio o ymdrechion i ddeall graddau unrhyw effaith ganlyniadol ar boblogaethau o bysgod neu ddaliadau pysgod.

- Mae llawer o fylchau yn y dystiolaeth o hyd o ran ein dealltwriaeth o'r rhyngweithiad rhwng adar pysgysol a physgodfeydd. Mae amcangyfrifon dibynadwy o effeithiau ar lefelau poblogaethau, neu o golledion economaidd cysylltiedig i bysgodfeydd o ganlyniad i ysglyfaethu yn brin, ac mae angen gwneud rhagor o waith. Er hynny, o gofio bod llawer o stociau eogiaid a brithyllod y môr yng Nghymru'n isel ar hyn o bryd, awgryma'r dystiolaeth sydd ar gael y gallai colledion i ysglyfaethwyr fod yn cael effaith gymharol fawr ar y stociau hyn ar hyn o bryd.

Executive summary

Populations of certain fish-eating birds, notably great cormorant (*Phalacrocorax carbo*) ("cormorant") and goosander (*Mergus merganser*), have increased in the UK in recent decades, and these birds are now widely distributed across Wales. Over similar timescales marked reductions have been observed in the status of certain freshwater fish stocks in Wales, particularly Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta)*. The majority of such stocks in Wales are now classified as being 'at risk' or 'probably at risk'. In response to these declines, supported by a Ministerial request, Natural Resources Wales published a Plan of Action for Salmon and Sea Trout in Wales in April 2020. This Plan of Action recognises there are a wide range of pressures affecting these stocks and sets out the necessary actions. In seeking to better understand the extent to which different pressures might be impacting on salmonid stocks, one of the actions was to undertake a review of predation by fish-eating birds on salmonids.

To support the Plan of Action and a wider wild bird licensing review NRW's Board endorsed the re-establishment of the NRW-led fish-eating birds Advisory Group to assess the fish-eating birds licensing position in Wales, advise on potential actions required and to develop a fish-eating birds licensing policy.

This review covers dietary analytical techniques and associated limitations and assumptions and provides a contemporary synthesis of dietary studies for cormorants and goosanders undertaken in the UK and Europe. Furthermore, the report presents rigorous scientific data on fish-eating bird diet and food intake and the need for, and use of, such data in relation to the ongoing public debate about fish-eating bird 'impacts' at fisheries.

The report also describes the range of methods (e.g. feeding observations, pellet analysis, stomach contents) that are available to assess fish-eating bird diet and provides information of predation levels on fish species across a broad spectrum of aquatic habitats and fishery types. The report discusses the relative merits and limitations of these different approaches.

Key findings are as follows:

- Dietary analysis alone is insufficient to quantify the consumption of commercially important fish, or species of conservation concern, by fish-eating birds, such as cormorant and goosander. Such quantification would require site-specific data on (i) dietary composition, (ii) bird numbers, and (iii) their daily food intake.

- There are a number of different techniques available for assessing the diet of fish-eating birds, but each has associated limitations. The three main techniques are: (i) direct observation of foraging birds and the prey they consume at the surface; (ii) examination of the hard remains (fish bones, etc.) recovered from pellets regurgitated by birds (N.B. not applicable for goosanders); and (iii) examination of the stomach contents of dead birds.

- Data provided by Cefas (Centre for Environment, Fisheries and Aquaculture Science) on the stomach contents of cormorant and goosander killed under licence in Wales between 1993/94 – 2003/04 are consistent with other UK studies. The Welsh data support the view that both species of fish-eating birds consume a wide range of prey species and the theory that these species are opportunist foragers, where their diet is based on the range of prey available at that time.

- In the UK and other parts of north-western Europe, one of the most persistent issues surrounding fish-eating birds is their predation on salmonid smolts. There are relatively few published estimates of smolt consumption by fish-eating birds and these vary widely. Information on cormorant diet in England and Wales relates mainly to the winter months and to inland stillwaters. The limited data for Welsh rivers in early spring indicate that salmon are consumed and that while the proportion of salmon in the diet remained low, it did increase at the time of the smolt run. In Scotland, studies report that annual predation of smolts by goosanders was estimated to account for 3-16% of smolt production. Estimates from studies in other parts of Europe vary widely, with some reporting negligible levels of smolt predation by fish-eating birds, while others indicate relatively high losses (e.g. averaging 47% of the smolt run from a range of investigations in Denmark).

- There are various complications when attempting to estimate the impact of predation by fish-eating birds on fish stocks. Such demonstration is complicated for several ecological and technical reasons and because human interest in the impact of fish-eating birds on their prey often focuses on a particular fish species, and even on a specific size (or age-class). Our knowledge of prey choice/switching, and what makes an individual fish more or less 'available' to a foraging bird is still remarkably limited despite their importance in understanding and demonstrating impact. At its simplest, we require an understanding of the comparison between: (i) estimates of how much food the birds consume and (ii) of how food much is present (or 'available') in the environment at the time when predation occurs. Collecting such 'bird' and 'fish' data is challenging, with further difficulties arising from efforts to understand the extent of any resulting impact on fish populations or catches.

- Numerous evidence gaps remain in our understanding of the interaction between fish-eating birds and fisheries. Reliable estimates of population level impacts, or associated economic losses to fisheries, as a result of predation are scarce and further work is required. Nonetheless, given that many salmon and sea trout stocks in Wales are currently at depressed levels, the available evidence suggests that losses to predators might be having a relatively large effect on these stocks at the current time.

1. Introduction

There have been large increases in populations of great cormorant (*Phalacrocorax carbo*) ("cormorant") across Europe over the past 40–50 years (van Eerden *et al*., 2012; Bregnballe *et al*., 2014). This increase has been mirrored in the UK (Chamberlain *et al*., 2013a), with birds also making increased use of inland fishery sites at which to feed and breed (Newson *et al*., 2013). Goosanders (*Mergus merganser*) have also increased in numbers across the UK in recent decades and spread to many parts of the country (Musgrove *et al*., 2013). The UK Breeding Bird Survey (Harris *et al*., 2020) suggests a gradual long-term (23 year) decline (-25%) in goosander breeding numbers, but with a 12% increase in the short-term trend (10 years). In Wales, the Wetland Bird Survey (WeBS) index for wintering goosander shows an increase of 184% over the long-term (25 years) and a 44% increase over the short-term (10 years) (Frost *et al*., 2021). For cormorants, the UK Breeding Bird Survey (Harris *et al*., 2020) suggests a gradual long-term (23 year) increase (24%) in breeding numbers, but with a 3% decrease in the short-term trend (10 years). In Wales, the WeBS index for wintering cormorants shows an increase of 62% over the long-term (25 years) and a 22% increase over the short-term (10 years) (Frost *et al*., 2021).

Both bird species are widely distributed in Wales and, as elsewhere in the UK, this has resulted in widespread conflicts with fishery interests. Principal concerns in Wales have centred on the potential impact of these fish-eating birds on river catchments supporting populations of salmonid species, mainly Atlantic salmon (*Salmo salar*), (hereafter salmon), and sea trout (*Salmo trutta*). However, concerns have also been raised about the potential impact of the birds on other riverine fish stocks and on stillwater fisheries, both stocked and 'natural', that all support important fisheries.

Salmon and many sea trout populations in Wales have been in decline for many years and the majority of stocks are currently classified as either 'at risk' or 'probably at risk' (Cefas, Environment Agency and Natural Resources Wales, 2020; Natural Resources Wales, 2019). In light of these declines, and in response to a Ministerial request, Natural Resources Wales (NRW) published a Plan of Action ("the Plan") for Salmon and Sea Trout in Wales (NRW, 2020). The overall objective for migratory salmon and sea trout stocks in Wales is: "*To protect, through the application of best-practice science and management, the sustainability of our natural resource of wild salmon and sea trout stocks in Wales."* The Plan details ongoing and new actions to address the many pressures affecting salmon and sea trout stocks in Wales, including catch control regulations, river habitat restoration and a renewed focus on water quality management. In seeking to better understand the extent to which issues might be impacting on stocks, and to better support delivery of their statutory responsibilities, the Plan also identified the need to undertake a review of the impacts of predation by fish-eating birds on fisheries in Wales.

In delivering the Plan's objectives, NRW have highlighted their statutory responsibilities to protect the designated status of fish species as listed on Annex II of the Habitats Directive (Council Directive 92/43/EEC) and also to ensure that any actions taken against fish-eating birds are compatible with the derogations permissible under the Birds Directive (Council Directive 2009/147/EC) on the conservation of wild birds. Although the UK is no longer an EU member state subject to the Wild Birds Directive, the terms of the Birds Directive are still relevant. Under Regulation 9(1) of the Conservation of Habitats and Species Regulations 2017 (as amended), NRW: "…*must exercise* [its] *functions which are relevant to nature conservation….so as to secure compliance with the requirements of the Directives*."

The Wildlife and Countryside Act 1981, as amended, (“the Act”) provides the legal framework in Wales for the protection of wild birds, their eggs and nests. The Act also establishes the framework under which the licensing authority may issue licences allowing the killing or taking of wild birds. Under section 16(1) of the Act, NRW (the licensing authority in Wales) may grant licences authorising activities which would otherwise be offences under section 1 and/or section 5. Licences may only be granted for the particular purposes listed in section 16(1) and may be, to any degree, general or specific. Before granting a licence for any purpose listed in section 16(1) NRW must be satisfied that, as regards that purpose, there is no other satisfactory solution.

In balancing these responsibilities, NRW seek to work towards the restoration and protection of a healthy and balanced biodiversity in Welsh aquatic ecosystems, extending to populations of both fish and birds. NRW have also recognised the need to protect populations of fish species other than migratory salmonids, including non-migratory brown trout and other fish species in rivers, lakes, and other stillwaters.

NRW’s Board endorsed the establishment of an NRW-led fish-eating birds Advisory Group to assess the position in Wales and advise on potential actions required. In January 2020, NRW started a wider, comprehensive review of its approach to the shooting and trapping of wild birds in Wales. The policy development to address the impacts of predation by fish-eating birds on Welsh fisheries falls within this wider review.

This report provides a review of cormorant and goosander dietary studies. Specifically, this report summarises the main techniques available for assessing the diet of cormorants and goosanders, as part of the evidence required to understand interactions between fish-eating birds and fish stocks. In addition, the report presents the relative merits and limitations of these different techniques and provides a brief overview of cormorant and goosander dietary studies in parts of the UK (including those for Welsh waters) and a number of other sites throughout Europe. The report also includes a consideration of how the impact of these birds might be determined through knowledge of their diet, feeding pressure (expressed as numbers x time present), and ‘bioenergetics’ (daily energy expenditure and food intake). Throughout, the report focusses on issues pertinent to the situation of cormorants and goosanders at Welsh fisheries, particularly those involving wild salmon and trout. The report provides a summary of implications and key points aimed at informing the NRW review and concludes with a section outlining current knowledge gaps.

2. Background to the study of cormorant and goosander diets

Throughout Europe there is often considerable concern about the potential impact of sawbill ducks *Mergus* spp. and the great cormorant (hereafter ‘cormorant’) on stocks and catches of fish of commercial, recreational and conservation value (Marquiss & Carss 1994, Russell *et al*., 1996, Carss 2003, van Eerden *et al*., 2012). This also holds true for Welsh waters, where the wildlife conflict between cormorant and goosander, and salmon and brown/sea trout is of licensing interest. Such interest is more than purely conservation, as there are significant fisheries for these salmonid species in Wales and, hence, also considerable commercial, public and political interest.

Given this - as well as the need for strong scientific rigour - political and public scrutiny also demands that the methodologies, interpretation, and presentation are of the highest quality and that any limitations are understood. This Evidence Report thus focusses on methods of assessing the dietary composition for goosanders and cormorants, and the interpretation and presentation of resulting data and analyses.

Importantly however, it should be noted that dietary analysis alone is insufficient to quantify the consumption of commercially important fish, or species of conservation concern, by birds. Such quantification would require site-specific data on (i) dietary composition, (ii) bird numbers, and (iii) their daily food intake. Further, demonstrating any impact based on such a knowledge of fish consumption by birds is likely, in turn, to require considerable site-specific data on the fish themselves (e.g. community structure, behaviour, age-structure, population dynamics, abundance and potential compensatory responses). These important factors are all outside the scope of the present Evidence Report but are covered in considerable detail elsewhere (e.g. Russell *et al*., 1996, Carss *et al*., 2012).

The question ‘What do cormorants and goosanders eat?’ is a deceptively simple one. The question itself is ecologically basic but the scientific, methodological, practical, spatial, temporal and financial constraints researchers inevitably face when trying to answer it are difficult and challenging. As a result, researchers have put considerable effort into understanding the inevitable limitations of their work and the level of confidence they have in their ‘results’. In parallel, there has also been a standardisation of methodological best practice in order to minimise bias, improve validity, and make dietary studies comparable.

Across Europe, the topics of fish-eating bird diet and food intake have been covered in considerable detail in two publications. The first, produced by the IUCN/Wetlands International’s Cormorant Research Group (Carss *et al*., 1997), sought to reach an international consensus on techniques for assessing diet and food intake and associated methodological limitations. The second (Carss *et al*., 2012) was part of the work of an EU-funded project - INTERCAFE (Conserving biodiversity – interdisciplinary initiative to reduce pan-European cormorant fishery conflicts) which developed the earlier work in terms of methodological standardisation, data interpretation, and attempts to integrate data on birds and fishes to better understand any ‘impact’ of the former on the latter.

For the sections in this review of evidence on dietary analytical techniques and associated limitations and assumptions, this report presents the salient parts of the Carss *et al*. (1997, 2012) overviews. Much, if not all, that is covered by them on the methods used to collect rigorous scientific data on fish-eating bird diet and food intake and the need for, and use of, such data in relation to the ongoing public debate about fish-eating bird 'impacts' at fisheries, is highly relevant to this evidence review. Given this, this report quotes sections of both publications verbatim, but always with the relevant citation where appropriate. One final point at this stage: whilst both overviews focussed on cormorants in particular, much of it is also directly relevant to goosanders (the few instances where this is not the case are highlighted).

3. Assessing the diet of cormorants and goosanders: techniques and limitations

The Carss *et al*. (2012) review determines there are several different techniques available for assessing fish-eating bird diet, each having associated limitations, primarily based on the 'freshness' of the material available for examination. Techniques fall into three categories. First, birds can be observed as they forage and the fish, they bring to the surface to ingest can be relatively easy to record. In other situations, some bird species produce oral pellets that contain hard, undigested prey remains, and these can be collected and analysed. Finally, the stomach contents of dead birds (usually shot as part of local, licensed management actions) can be examined, as can regurgitations (containing partially-digested 'meals') collected at roosts or usually from nestlings at colonies. These different methods are described here and the advantages and disadvantages of each are highlighted, following Carss *et al*. (1997, 2012). Full instruction on the use of these techniques is beyond the scope of this review of evidence but is, alongside species-specific identification and measurement guidance for prey remains, given in Carss *et al*. (2012).

It is important to note that, regardless of the method used to assess fish-eating bird diet, there will be limitations associated with any samples available. This is because samples will usually have been collected from locations where there are suspected conflicts with fisheries. As such, resulting dietary assessments might not be completely representative of more general diet. Similarly, there may well also be temporal differences between available samples and perceived conflict periods. For example, birds are commonly shot mostly in the winter months, which might not be the crucial period when bird numbers are greatest and when some fish species (or life-history stages) are thought to be most vulnerable to predation.

3.1 Feeding observations

Direct field observation of foraging birds to record the prey they eat has many advantages, the primarily benefit is that lethal measures are not required and provides data with little disturbance to the birds. A major advantage over other methods is that spatial and temporal variation in diet might be assessed with some accuracy (Davis & Feltham, 1996), as diet and feeding locations can be recorded together. Diet information usually comprises prey item identification (to species where possible) and an estimate of prey size (usually length). Feeding observations can also provide data on diving behaviour and rate, and of relative foraging performance.

There are a number of limitations associated with feeding observations. Samples of observations are usually related to a specific location and/or time period and care is needed because unless birds are individually marked (or naturally recognisable) the number of birds contributing to the observation sample is unknown. It may be difficult to get close enough to birds without disturbing them to identify all prey items caught. There will be additional biases if certain fish species are more, or less, easy to identify (particularly where the fish fauna is diverse) but this might be reduced by categorising fish on their type or body shape e.g. Cyprinid/flatfishes (Davies & Feltham, 1996). There may also be errors when estimating the size of fish caught, especially smaller ones that tend to be swallowed quickly. The sizes of fish caught by birds are usually estimated in relation to its bill or head length but there are few attempts to quantify observer bias in these length estimates experimentally, and prey is sometimes merely categorised (e.g. small, medium, large). Cormorants and goosanders also probably swallow prey items underwater but the frequency of this in the field is largely unknown. However, experiments have shown that captive cormorants do swallow fish underwater (up to 8cm in length in the study by Strod *et al*., 2003). It is almost certain that goosanders also swallow an unknown proportion of the smaller fish they catch underwater and that these fish will not be recorded during direct feeding observations. This potentially serious error in diet assessment, together with the possibility that birds may forage at more than one location, means that it is not possible to determine birds' daily food intake from direct observations, nor possibly the full prey composition in terms of species and size as smaller fish are likely to be disproportionately under recorded.

3.2 Pellet analysis

Oral pellets are produced by many bird species, including cormorants, but have not been recorded for goosanders (or any sawbill species) and so this method of diet assessment is only applicable to cormorants. The pellets regurgitated by cormorants contain the undigested 'hard parts' of their prey bound in mucus from the stomach lining. Cormorant pellets are relatively easy to collect from the ground at roosts or breeding sites and they may be the only available means of diet assessment in some situations, although there may be serious potential limitations (see below).

Samples

Once collected, pellets can be kept separately in a plastic bag and frozen for some time prior to examination. Thawed pellets are usually air died at room temperature for a few days before being 'crumbled' carefully into a Petri dish or are soaked individually in an enzymic washing powder to dissolve the binding organic mucus before the contents are rinsed through a fine sieve and dried prior to examination under a binocular microscope.

Analysis

Pellets (and also stomach contents, see below) usually contain the remains of several fishes and a number of recognisable 'key bones' that can be used to identify fish species, estimate minimum numbers, and estimate prey size. Prey fish body length is often derived from the measurement of these key bones, using either published equations or ones derived from local samples of reference fish. These fish size estimates can then be converted to estimates of fish weight (again using published or reference equations) and so the total estimated biomass of fish represented in the pellet sample can be assessed. The 'key bones' for pellet analysis include pharyngeal teeth, otoliths, chewing pads, lower jaws, opercular bones, vertebrae, and scales.

Pharyngeal bones are found in the mouths of Cyprinid (carp family) and Cobitid (loach family) fishes, and their shape, size, and tooth position are species-specific (published keys to aid identification and fish-length estimation are given in Carss *et al*., 2012). Each fish has two pharyngeal bones and measuring them allows an estimate of original fish length and pairing right and left bones of similar size provides a minimum number estimate for fish represented in pellets. All bony fishes have otoliths - pairs of structures in the inner ear which appear as small white 'stones' in pellets (and stomach contents). Again, otoliths can be used for species identification, measured to estimate original fish length, and can be paired-up to represent single fish, giving minimum number estimates. Cyprinid fishes also have a single 'chewing pad' that can similarly be used to identify fish species and estimate numbers of individuals and their original length, so too paired bones such as lower jaws (dentaires) and opercular bones in many other species. It is also possible to identify the species of fish prey (although not always their size or number) from other undigested hard parts such as vertebrae and scales.

Interpretation

Ultimately, the minimum numbers of each fish species can be recorded for each pellet. Thus, a cumulative total of individual fish of each different species can be recorded for each sample of pellets. The results of pellet analysis can be presented in several ways, each giving a slightly different picture of cormorant diet. At its simplest, diet can be assessed as the presence/absence of different fishes recorded. These data can be presented as frequency of occurrence, either 'percentage frequency' (the proportion of pellets containing a particular species) or 'relative frequency' (the number of occurrences of a particular species as a percentage of all recorded prey items). If estimated prey fish body length has been converted to estimated mass, the total estimated biomass of fish represented in the pellet sample can be assessed, and each species can be assigned a proportion of this and presented as relative frequency for a particular sample.

When interpreting the results of pellet analysis, it is wise to explore the size distribution of fish eaten, as well as to consider diet based on number and mass for each species. This is important when trying to compare the 'importance' of particular fish species because small (often young-of-the-year) fish may be most frequently eaten numerically but far fewer larger (i.e. older) fish may contribute most to overall diet in terms of biomass.

Limitations

There are a number of potential limitations to the use of pellets to assess fish-eating bird diet. These include the collection of only fresh (i.e. not partially decomposed) and intact pellets to ensure that no material is missing from them. Intact pellets of all sizes should be collected because there can be a bias towards collecting only larger pellets (perhaps containing the remains of larger prey) which tend to be easier to find. It is seldom possible to assign particular pellets to individual birds and so this method can rarely be used to compare individual meals of individual birds. Pellet analysis does not provide any information on where fish were actually caught by cormorants, but the mixed samples that are usually collected do give a qualitative description of the prey species and size composition of the wider 'population' of birds aggregating at the particular roost or colony where pellets were collected.

Pellet analysis can be a useful method of obtaining a description of diet in (at least) qualitative terms. Theoretically, it might be possible to estimate the daily food intake of birds by this method but only if the rate of erosion of material recovered from pellets can be quantified, which seems unlikely. Although, by their very nature, the hard parts contained in pellets must be relatively 'resistant' to digestion, a major limitation of this method of diet assessment is the erosion of material in pellets, as a result of the full digestion process. Although still recognisable, some bones may be eroded and so measuring them would underestimate original fish length, often to an unknown degree. An even more severe limitation is the fact that the hard parts from smaller fish - either smaller individuals or smaller species – may not be present in pellets at all having been completely digested. Another possible bias, which also applies to stomach contents analysis, is the possibility of secondary consumption – i.e. detecting the remains of prey consumed by a predatory fish subsequently eaten by a bird. Thus, when interpreting dietary data derived from pellet analysis, it must be remembered (Carss *et al*., 1997) that "*pellet analysis is a useful method of obtaining a rough index of cormorant diet in qualitative terms but there is serious doubt as to whether it can be used to derive quantitative information on, for example, the species composition or size-range of fishes taken. With reservation (in particular relating to the under-recovery of small fish), pellets may be used to investigate spatial or temporal variation in the relative frequencies of particular prey species of varying provenance. However, great care must be taken when interpreting the results of such studies as there are serious potential biases.*" Indeed, some published studies still use the results of pellet analysis to estimate total fish consumption by cormorants for instance, despite the erosion of otoliths and other hard parts being one of the main potential errors.

3.3 Stomach contents analysis

Carss *et al.* (1997) discuss stomach contents analysis and highlight that stomachs (and regurgitations – see below) often contain relatively fresh material whilst there are also well-established methods for dealing with more digested prey. Some of the more serious errors associated with well-digested material (e.g. as in pellet analysis above) can be avoided by examining stomach contents. Sometimes, these may be the only way of assessing bird diet if pellets cannot be collected (e.g. from those roosts where pellets fall directly into water) or direct observations are difficult. Stomach contents samples can be accompanied by age, sex, sub-species, and parasite infestation information for each bird, and site specific (i.e. the foraging location is usually known).

Samples

Licences can be issued to kill cormorants and goosanders in the UK but only for the purposes identified in section 16(1) of the Act, in this case to prevent serious damage to fisheries and for the conservation of flora and fauna. Birds are killed most commonly as part of 'shooting as an aid to scaring' management actions under licence. Nationally, 'scientific' licences are also occasionally issued to kill birds specifically for research purposes. In some places in Europe and elsewhere dead birds can also be obtained through cooperation with fishermen who use gill nets which sometimes kill (drown) foraging birds.

The sampling unit for stomach contents analysis is not the number of fish recorded in a stomach but the stomach itself. Sample size is important as it can affect the accuracy of diet assessments, with some fishes being 'missing' from smaller samples of dead birds (see Limitations below). In Scotland, where the freshwater fish community comprises relatively few species, it was concluded that 'adequate' estimates of diet were possible from samples of 12–15 goosander or cormorant stomachs containing food but more analysis is required from large samples of stomachs containing diverse fishes collected at different sites (Marquiss & Carss, 1997).

Regardless of the source, it is important that dead birds are labelled individually as soon as they have been killed, and that this information remains with the carcase at all times. The minimum information that should be recorded at the time of death is date, time, and location. Further information on sex, age, and body mass can be noted subsequently in the lab. The more information that can be recorded for each bird, the greater potential for interpreting the subsequent results of stomach contents analysis. Dead birds should be examined as soon after death as possible or stored frozen for subsequent analysis.

Analysis

After taking biometric measurements, the body cavity of dead birds can be opened down the length of the neck to the vent. The upper portion of the digestive tract – the mouth and much of the opened oesophagus – can be examined *in situ* and the stomach, and the foregut including the proventriculus and the gizzard severed from the hindgut can be lifted from the body cavity in its entirety and opened from the top to bottom.

Any whole, intact, undigested fish can be removed carefully, identified and measured (e.g. length and weight). Carss *et al*. (1997) report that all remaining partially digested material can be carefully flushed out into a storage jar. Adding a saturated solution of biological washing powder digests all the remaining flesh from partially digested fish after a few days. Then the contents of each jar can be poured into a fine sieve and thoroughly rinsed with cold water to clean the bones and other hard stomach contents remains. After rinsing, bones can be air dried on filter paper for 1–3 days. As with prey remains in pellets, biological washing powder does not appear to damage bones and air drying does not lead to significant shrinkage of material over time periods of a few days-weeks.

Dried prey remains can be examined under a low power binocular microscope and, as with pellet analysis, the same key bones can be identified to species level, counted (as pairs if necessary) and measured - bone lengths being converted to estimated fish lengths, and estimated fish lengths to estimated fish weights with appropriate regression equations. It is easy to recognise well-digested – and hence damaged and heavily eroded – bones at this stage of analysis and these can be ignored. Any data obtained from any whole, intact, undigested fish should be included with those determined from the examination of key bones from partially digested material. Interestingly, Feltham (1990) could not use otoliths from the stomach contents of red-breasted mergansers (*Mergus serrator*) because their presence did not correspond well with the presence (or size) of other bones from the same fish species (see also Limitations section below).

Interpretation

Ultimately, the minimum numbers of each fish species can be recorded for each stomach. Thus, a cumulative total of individual fish of each different species can be recorded for each sample of birds. At its simplest, as with pellets, diet can be assessed as the presence/absence of different fishes recorded in stomach contents and presented as frequency of occurrence, either ‘percentage frequency’ (the proportion of stomachs containing a particular species) or ‘relative frequency’ (the number of occurrences of a particular species as a percentage of all recorded prey items). If estimated prey fish body length has been converted to estimated mass, the total estimated biomass of fish represented in the sample of stomachs can be assessed, and each species can be assigned a proportion of this and presented as relative frequency for a particular sample.

When interpreting the results of stomach contents analysis, it is again wise to explore the size distribution of fish eaten as well as to consider diet based on number and mass for each species. This is important when trying to compare the ‘importance’ of particular fish species because small (often young-of-the-year) fish may be most frequently eaten numerically but far fewer larger (i.e. older) fish may contribute most to overall diet in terms of biomass.

Care must also be taken when interpreting the records of all the material (both intact/fresh and partially digested) recorded in stomach contents. As Carss *et al*. (1997) discuss, the more digested the food in stomach contents the greater the potential for bias, as those prey items less resistant to digestion may be digested relatively quickly. It is tempting to resolve this problem by examining only the freshest intact material. However, examination of goosander stomach contents has shown that smaller fish were under-represented by doing this, probably because small fish are quickly digested and disintegrate while larger ones remain intact for longer. Studies examining diet from these intact items alone will thus underestimate the proportion of small fish species and overestimate the mean size for some larger ones. As a result, it is necessary (see Analysis section above) to include data from whole, intact, undigested fish alongside those determined from the examination of key bones from the partially digested material to best assess diet from stomach contents.

Limitations

There are some limitations to stomach contents analysis, most obviously the necessity of killing birds. Licences are required to kill cormorants and goosanders in European countries and so, in most cases, the samples available for analysis are small and commonly from a wide range of different sites. The same is usually true for circumstances (e.g. gill net fisheries) where dead birds might be collected. Needless to say, time and place of shooting birds will determine their diet, and this can also lead to bias in assessing diet generally. For instance, diet assessments are often only available for locations where there are thought to be conflicts with fisheries and as noted previously, birds are typically only shot under licence in winter months.

The sampling unit for such analysis is an individual stomach, not the number of fish it contains. Sample size may be further reduced if stomachs are empty, but this might be reduced by shooting birds later in the day after they have had a chance to feed (although this adds a bias if some prey are digested quickly or if there are diurnal variations in the prey selected). As described above, at least for northern waters with generally low fish diversity, samples of 12-15 stomachs with food are considered necessary to obtain an ‘adequate’ estimate of diet for a particular site and time.

It is not clear why otoliths should be relatively less frequently recorded in red-breasted merganser stomach contents (see above) than in the more digested material available in pellets. Presumably this has something to do with differential digestion rates between otoliths and true bones and/or between sawbill ducks (that don’t produce pellets) and cormorants (that do).

Daily food intake should not be determined from stomach contents analyses because it is not known whether a bird had stopped feeding for the day when it was shot or died.

3.4. A note on regurgitations

When cormorants are disturbed, they often vomit whole or partly digested fish which can be collected in some situations. This is particularly true at colonies where well-grown nestlings will regurgitate meals as a reflex behaviour to divert the attention of predators (or human visitors). Goosanders seldom roost communally and nest ‘singly’ in very well protected sites, we do not know of any records of food regurgitation - unless from birds that are severely distressed, for instance after having been shot.

Where regurgitations are available, both intact and partially digested fish can be treated as described above for stomach contents but there are potentially serious problems with interpretation. Regurgitates collected from the ground tend to be larger specimens that are presumably more likely to be regurgitated and are generally easier to find. It is often also not possible to determine which fishes were regurgitated by which bird – and so which fish correspond to the same ‘meal’ (equivalent to a stomach containing food) – and this might compromise the sample size available. With regurgitations produced by nestlings, a further theoretical bias comes from the possibility that adults might eat low quality food themselves and feed higher quality food (of different species and/or size) to their young. However, data are currently unavailable to test this idea.

3.5 Other techniques

There are some less, common techniques that have also been used to examine the diet of fish-eating birds. These methods do not provide the same level of detail as those listed above but may have applications in certain situations.

One technique involves analysis of stable isotope ratios. The stable isotope ratios in proteins of consumers reflect those in their diets in a predictable manner and can applied to aid in the understanding of dietary inputs and trophic relationships. The use of stable isotopes has the advantage that the isotopic signature represents assimilated as opposed to ingested food, and thus represents the diet over an extended period. It can also be applied to bird feathers thus obviating the need for killing of birds. In one earlier study, Bearhop *et al*. (1999) used stable isotope ratios of carbon and nitrogen (δ13C and δ15N) in the feathers of wild cormorants to assess the extent of freshwater feeding. The study indicated that, when shot, nearly all of the cormorants had been feeding entirely on freshwater prey and appeared to have fed at freshwater sites throughout the autumn and winter. Stable isotope analyses do not typically provide information on prey species composition.

The other approach that can provide information on diet is the use of environmental DNA (eDNA). Techniques using eDNA have been developed that enable different prey species to be identified in samples such as pellets or bird faeces. Although the application of so-called ‘metabarcoding’ to dietary studies is now well established, there are still some important limitations to the method (de Sousa *et al*., 2019), one of the most important being the lack of a standardised method for quantitative assessment of prey items. Thus, quantifying the relative contribution of different prey to the overall diet remains a serious challenge. This is because using of the number of ‘reads’ from specific prey species as a proxy for their abundance (or biomass) is not straightforward (reviewed by Deagle *et al*., 2019). Perhaps even more pertinent to predation by fish-eating birds, eDNA techniques are unable to provide any information on the *size* of individual fishes eaten and so offer no insight into predation on salmonid smolts for example. Thus, for several reasons, the eDNA approach has not been widely adopted to date in studies of fish-eating bird diet.

4. A review of relevant dietary studies for cormorants and goosanders

Generally, there is a larger body of research concerning cormorant diet than there is for goosander, no doubt reflecting the differences in the geographic range and ‘intensity’ of perceived conflicts with fisheries interests. This section describes the general diets of both cormorants and goosanders across Europe, and within the UK where possible, in terms of species and sizes taken. There is little very recent information in the scientific literature pertaining to the diet of cormorants or goosanders on rivers. Given the particular focus of the review on the effects of predation on Welsh salmonid rivers, the section draws heavily on earlier work conducted in the UK. It also describes a meta-analysis of predation effects on fish populations and reviews specific research into the predation of salmonid smolts. Although these latter topics focus mostly on cormorants (all species globally and the *P. carbo* species, respectively), there are likely be elements that are equally applicable to goosanders, under certain circumstances at least.

4.1 Cormorant diet

A large number of European studies of diet show (e.g. Marquiss & Carss 1994) that the cormorant is almost entirely piscivorous and consistently feeds on relatively few species. This review indicated that at least 77 species of fish are recorded as cormorant prey in Europe but only about a third of these are regularly recorded, and within habitats different studies have shown similar prey spectra despite differing methods. In the sea, cormorants mainly feed on bottom-dwelling fishes, wrasses (Labridae) and codfishes (Gadidae) over rocky and weed covered substrates, flatfish over soft substrates and eelpout (Zoarcidae) and, previously the European eel (*Anguilla anguilla*) in a variety of areas. The major decline in the abundance of eel populations across Europe (ICES, 2020) means that eel are now relatively rare in cormorant diet (e.g. Russell *et al*., in press). On occasions small, shoaling, midwater fishes such as clupeids, capelin (*Mallotus villosus*) and even sandeels (Ammodytidae), are also taken. In estuaries, flounder (*Platichthys flesus*), trout (Salmonidae), eel and saithe (*Pollachius virens*) are most frequent prey, and sandsmelt (*Atherina presbyter*), mullet (Muglidae) and sea bass (*Dicentrarchus labrax*) are important in southern Europe. On European rivers, diet varies according to stream characteristics; trout, salmon and grayling (*Thymallus thymallus*) are the main prey in fast-flowing sections, cyprinids (roach and bream) in slower, deeper parts and flounder in the lowest reaches. In studies at freshwater lakes, by far the commonest recorded prey are roach (*Rutilus rutilus*), perch (*Perca fluviatilis*) and, previously, eel. Other cyprinid prey in 'rich' freshwaters include bream (*Abramis brama*), rudd (*Scardinius erythrophthalmus*) and tench (*Tinca tinca*), and other percids, notably ruffe (*Gymnocephalus cernua*) and zander (*Sander lucioperca*). In more 'acid' and/or species-poor waters, cormorants feed mainly on brown trout (*Salmo trutta*) or perch. Finally, cormorants frequently use waters artificially stocked for recreational angling, typically with brown and rainbow trout (*Oncorhynchus mykiss*) or carp (*Cyprius carpio*).

With such generalisations, it is likely that cormorant diet is predictable according to habitat and season, but this could only be confirmed unequivocally where the fish community (potential prey) has been quantified. Whilst the pan-European work coordinated by Carss (2003) did not assess cormorant diet, it did collate information on those fish species that stakeholders reported as being involved in over 200 ‘fisheries conflict’ cases. These cases involved lakes, rivers, freshwater aquaculture ponds, coastal aquaculture sites, and other coastal locations. Overall, 68 fish species were recorded from 24 Families and these were generally predictable from the broad habitats where conflict occurred. Overall, the highest proportion of fish species recorded in conflicts involving cormorants were Cyprinids (in rivers, aquaculture ponds, lakes), followed by Salmonids (in rivers), perch/pike (*Esox lucius*) (lakes), and a number of fishes, including mullets, eel, and flatfishes, associated with coastal aquaculture. A subsequent pan-European network then considered the broader ecology of cormorants (as opposed to focussing on conflict situations), producing a database characterising hydrological and ecological data from sites used by the birds. Data for nearly 100 species of prey fish, recorded at 117 sites across 26 countries were included in this analysis. At the landscape scale, large-scale waterbodies were generally shown to be favoured by the birds and, although most measures were of relative rather than absolute abundance, it also appeared that waters with the highest fish biomass attracted the greatest numbers of cormorants (Van Eerden *et al*., 2012).

The fish consumed by cormorants vary enormously in size. Stomachs from birds shot on Scottish rivers, for example, have contained tiny three-spined sticklebacks (*Gasterosteus aculeatus*), as well as a very large 'mended' salmon kelt of 1.53 kg (Carss & Marquiss, 1997). However, the majority of prey items are relatively small. The range of sizes of fish taken by cormorants, for a variety of prey species, are given in Table 1 alongside estimates of the most common sizes from various dietary studies from Marquiss & Carss (1994). Within some prey species or groups (e.g. eel, trout, roach and flatfish) there are similarities in the range of sizes taken in different habitats, but this does not apply to the size of average fish taken which varies between studies of the same habitat, as well as between habitats.

Table 1. The sizes (cm) of fish recorded in dietary studies of cormorants in Europe (modified from Marquiss & Carss, 1994).

Sea Coast

Fish species/Family	Range of recorded sizes (cm: min-max)	Most common sizes (cm: means, medians, modes – various studies)
Eel	10 - 65	23,26,40
Codfishes	3 - 35	15,18
Wrasses	10- 38	19,29
Sandeel	6 - 12	8
Flatfishes	7 - 21	11,14,18

Estuary

Fish species/Family	Range of recorded sizes (cm: min-max)	Most common sizes (cm: means, medians, modes – various studies)
Eel	14 - 56	18
Salmon	11 - 13	10
Trout	10 – 26	17
Flounder	7 – 18	8

River

Fish species/Family	Range of recorded sizes (cm: min-max)	Most common sizes (cm: means, medians, modes – various studies)
Salmon	6 - 16	9,10,11,13
Trout	7 - 47	10,15,18
Grayling	23 - 40	26,38
Roach	4 - 26	12

Lake

Fish species/Family	Range of recorded sizes (cm: min-max)	Most common sizes (cm: means, medians, modes – various studies)
Eel	12 - 60	19 - 25,25,33,37
Trout	13 - 46	25,25
Pike	13 - 42	-
Perch	3 - 30	5,7,8,10,14,15,15,17, 20

4.2 Overview of cormorant diet in England and Wales

Between 1993/94 and 2003/04, cormorants shot under licence in England and Wales were sent to Cefas for post-mortem examination (Russell *et al.*, in press). Licences to shoot birds typically covered the period between November and March, coinciding with the period when cormorant numbers on inland fisheries in the UK are highest. A small number of licences extended into April where a need was demonstrated to protect migratory salmonids. Most of the carcasses originated from stillwater fisheries (72%), with smaller numbers from river fisheries (23%) and fish farm sites (5%). Over the 11-year period, 1,412 cormorant carcasses were subject to analysis, this included birds from both the Atlantic race (*Phalacrocorax carbo carbo*) and the Continental race (*P. c. sinensis*).

In total, 6,749 separate prey items were identified from the stomach samples, comprising 32 different species. These were primarily freshwater fish species, consistent with the birds being shot at inland sites, although small numbers of estuarine and marine species were also recorded. The most common prey species recorded was roach, comprising 47% of all prey items identified and 27% by mass. Five species: roach, perch, bream, three-spined stickleback and minnow (*Phoxinus phoxinus*) together comprised almost 80% of the prey items recorded. Salmonid species - brown trout, rainbow trout and salmon collectively - made up just over 5% of the prey items by number. However, in view of their larger average size, the two trout species comprised 37% of the diet by mass. Rainbow trout were only recovered from birds shot at put-and-take trout fisheries and their large size reflects the size at which fish were stocked. Salmon comprised just under 1% of the prey items recorded and 0.3% by mass.

The median fork length of many of the more common species recorded was at or below 10 cm, as it was for the salmon recovered, but median lengths ranged between 15 and 35 cm for some other species, including brown trout, rainbow trout and grayling. The majority of prey items identified were < 50 g in weight and for many of the more common prey items were well below this (e.g. three-spined stickleback 1.4 g; minnow 2.5 g; perch 17.8 g; roach

21.6 g; bream 34.4 g). For some other species, particularly some of the salmonid species, mean weights were substantially higher (e.g. grayling 173.3 g; brown trout 201.1 g; rainbow trout 450.5g). On rare occasions, individual fish in excess of 1 kg were recorded.

The study confirmed that cormorants are versatile and adaptable predators capable of foraging in a range of fishery types and taking a wide range of species on an opportunistic basis, albeit with a relatively small number of species predominating in the diet. The study also demonstrated broad overlap in the diet of the different subspecies and sexes foraging at inland fisheries, However, the relative composition of different prey items in the diet and the size of the fish consumed did vary with the size of the birds – male birds are larger than female birds and birds of the Atlantic race are larger than the Continental race. Further details on these differences are provided in Russell *et al.* (in press).

4.3 Goosander diet

The diet of goosanders is diverse (e.g. Marquiss & Carss, 1994) and comprises mainly small fish taken from rivers and occasionally lakes. In spring goosanders can feed on carrion, and frogs can also be important then. In summer, small ducklings feed on large insects as well as small fish, and at times adults have been known to take freshwater crayfish. In common with cormorant diet studies, it should be remembered that most investigations of goosander diet derive from shot birds, with licensed shooting typically taking place where there are concerns about impacts on particular fish stocks and in the winter months. As such, information on diet may we'll not be representative of other places and at other times.

In Europe (see Marquiss & Carss, 1994), goosander diet on rivers includes salmonids, eel, lamprey, bullhead (*Cottus gobio*), grayling and perch, with ducklings consuming minnows, salmonids and stoneloach (*Barbatula barbatula*). On lakes outside the breeding season, the diet mainly comprises cyprinid and percid fish, and three-spined stickleback. In winter and spring, in shallow coastal waters, eel, eelpout (*Zoarces viviparus*), three-spined stickleback, gobies (Gobiidae), sandsmelt, butterfish (*Pholis gunnellus*), and cottids are taken. In northern European rivers, where the fish community commonly contains relatively few species, goosanders diet includes trout, salmon and arctic char (*Salvelinus alpinus*) in spring and summer. In general terms, the diet of goosander consists of the most easily caught small fish, and those most abundant in the various habitats used by the birds.

In general, goosanders consume smaller fish than do cormorants, reflecting their smaller body size. Thus, goosanders eat mostly small fish between 5 and 11 cm and the range of sizes, for a variety of prey species, are given in Table 2 alongside estimates of the most common sizes from various dietary studies (from Marquiss & Carss, 1994).

Table 2. The sizes (cm) of fish recorded in dietary studies of goosanders in Europe (modified from Marquiss & Carss, 1994).

River

Fish species/Family	Range of recorded sizes (cm: min-max)	Most common sizes (cm: means, medians, modes – various studies)
Eel	12 - 37	19
Salmon	3 - 13	6,7,7,7,8,8,9,10
Brown Trout	3 - 33	10,13
Cottid spp.	4 - 12	6
3-spined s'back	2 - 7	5
Lamprey spp.	9 - 33	12,26

Lake

Fish species/Family	Range of recorded sizes (cm: min-max)	Most common sizes (cm: means, medians, modes – various studies)
Roach	10 - 20	9,14
Perch	4 - 20	5
Brown Trout	12 - 51	25
Dace	3 - 6	-
Bleak (*Alburnus alburnus*)	5 - 9	-

4.4 Cormorant and goosander diet studies in Scotland

The foregoing sections provide a broad overview of cormorant and goosander diet across a wide range of different European aquatic habitats. In the context of this review, there are particular concerns about the potential impact of these fish-eating birds on migratory salmonids in Welsh rivers. The following sections therefore aim to focus on the available information from diet studies primarily undertaken on river systems in the UK and other parts of Europe.

In a comprehensive investigation into fish-eating birds and salmonids in Scotland, (Marquiss *et al.*, 1998) examined the stomach contents of birds from 21 river systems and 7 lochs between 1991-96. A total of 1676 birds were examined: 186 red-breasted mergansers, 1099 goosanders, and 391 cormorants. The numbers of stomachs containing food being 159, (merganser), 1005 (goosander), and 293 (cormorant). The study found that brown trout, salmon, minnow, three-spined stickleback, and eel and were the most widespread and common prey (see Tables 3 & 4 for a subset of samples). The dietary patterns found were consistent with the hypothesis that cormorants and goosanders take the commonest and largest prey available to them, but also that they are opportunist generalist predators, eating what is most available locally.

Table 3. The number of goosander stomach samples from Scottish rivers containing particular prey species/types. Rivers are listed south (left, four rivers) to north (right, three rivers) and the number of samples for each is given in brackets. This is a subset of samples presented in Marquiss *et al*. (1998) – those with the largest numbers of stomachs containing food. Carrion* includes parts of large salmonids, unidentified fish, a grayling, pheasant/chicken feet, rabbits, and a vole.

Prey species/type	Nith (3)	Annan (2)	B. Esk (5)	Tweed (23)	Dee (3)	Deveron (4)	Spey (1)
B. trout	3	2	5	22	3	4	1
Salmon	3	2	5	23	3	4	1
Minnow	3	2	5	22	3	4	1
3-spined s'back	3	2	4	21	2	4	-
Eel	3	2	4	23	-	2	-
Stoneloach	3	2	5	17	-	-	-
Gudgeon (*Gobio gobio*)	2	2	-	10		-	-
R. Lamprey (*Lampetra fluviatilis*)	-	-	4	8	-	-	-
Grayling	-	2	-	9	-	-	-
Frog	1	-	3	2	-	1	1
Carrion*	-	-	-	6	1	-	-
Invertebrates	-	1	3	3	-	-	-
B. Lamprey (*Lampetra planeri*)	-	-	-	4	-	1	-
Flounder	-	1	-	4	-	-	-
Lamprey spp.	1	-	-	1	-	-	-
R. trout	1	-	-	1	-	-	-
Perch	1	-	-	-	-	-	-
Dace (*Leuciscus leuciscus*)	-	-	1	-	-	-	-
Chub (*Leuciscus cephalus*)	-	-	1	-	-	-	-
No. prey species	**11**	**10**	**11**	**16**	**4**	**7**	**4**

Table 4. The number of cormorant stomach samples from Scottish waters containing particular prey species/types. Waters are listed south (left) to north (right) and the number of samples for each is given in brackets. This is a subset of samples presented in Marquiss *et al*. (1998) – those with the largest numbers of stomachs containing food. Large sea trout were also recorded in stomachs from the Tweed (one stomach) and the Deveron (two stomachs), and large salmon kelts from the Deveron (two stomachs).

Prey species/type	R. Tweed (4)	L. Fad (3)	R. Deveron (4)
Brown trout	4	2	4
Salmon	3	-	4
Eel	3	2	1
Rainbow trout	1	3	-
Flounder	2	1	1
Grayling	4	-	2
3-spined stickleback	2	-	-
Minnow	1	-	2
Perch	-	3	2
Roach	-	2	-
Dace	1	-	-
Gudgeon	1	-	-
Brook lamprey	1	-	-
No. prey species	**11**	**6**	**7**

One focus of this work was to assess predation on juvenile salmonids, particularly salmon, with most birds sampled in the 'spring' (March/April), although some cormorants were collected in the winter. Most salmon eaten by goosanders and cormorant were less than 140mm long and the average sizes were estimated to be 92mm and 101mm, respectively. Cormorant diet varied according to habitat, with grayling, trout, and salmon being common prey on fast-flowing rivers, flounders in the lowest reaches and estuaries, and rainbow trout, perch, and roach from birds shot at stillwaters (see Table 3 for a subset of samples). Relatively large samples (> 10 cormorant stomachs) were collected from the rivers Nith, Annan, Tweed and Deveron and indicated that juvenile salmon were a minor component of the diet (< 95g by mass in samples). Only stomachs from the Beauly contained a high proportion of young salmon, although the sample size was relatively small.

Across Scotland, latitudinal trends were also apparent in the diet, being more diverse, and including fewer salmon, on rivers in the south (see Tables 3 & 4 for a subset of samples). More fish species occur in the rivers of southern Scotland; some 17-18 species are present in Border rivers, around ten species in the Findhorn and Spey, and even fewer farther north and west (Maitland & Campbell, 1992). Moreover, with fewer species in the north, trout and salmon increasingly dominated the fish communities there. The investigations found that salmon comprised <1% of the winter / spring diet (by mass) of cormorants feeding in southern rivers and 18% in northern rivers. For goosander it was estimated that salmon comprised 9% of the winter / spring diet (by mass) in southern rivers and 41% in northern rivers (Marquiss *et al*., 1998). The rivers where goosanders consistently consumed fewer fish species and more salmon were mainly fast-flowing Highland rivers such as the Dee, Deveron, Spey, and Beauly.

4.5 Cormorant and goosander dietary data from Welsh rivers

Background

This section is based extensively on data collected by Cefas (Defra's executive agency the Centre for Environment, Fisheries and Aquaculture Science), kindly made available to us to inform this Evidence Report. For eleven years (1993/94 – 2003/04), fish-eating birds shot under licence in England and Wales were subject to post-mortem examination by Cefas primarily to determine their diet and to help inform management and policy decisions. Stomach contents analysis was conducted following the methods described above and the diet of the birds assessed in terms of both the relative number of different prey species consumed and the relative mass. A detailed evaluation of the diet data arising from this work explored variability in the winter diet for different sub-species and sexes of cormorant from fishery sites in England and Wales (Russell *et al*., in press) and has been summarised in section 4.2 above. This section provides a brief overview of diet data for both cormorants and goosanders from birds that were shot on rivers in Wales, including the cross-border River Wye.

Results – cormorants

In total, 111 cormorants shot on Welsh rivers were examined. Of these, 36 birds were shot on the upper reaches of salmonid catchments (upper Wye: 27, Usk: 5, and Clwyd: 4), with 77 birds from the lower Wye. Prey composition (by mass) was determined collectively for the upland rivers (Figure 1) and for the lower Wye (Figure 2). Data from upland rivers was pooled because of the small sample sizes from the Usk and Clwyd.

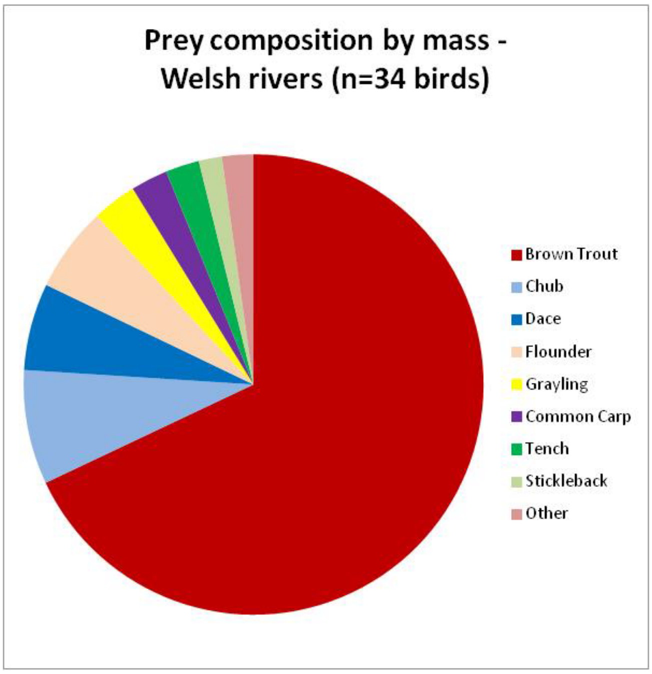

Figure 1. Winter diet of cormorants (proportion by mass) from upland Welsh rivers (Wye = 27 birds, Usk = 5, Clwyd = 4.

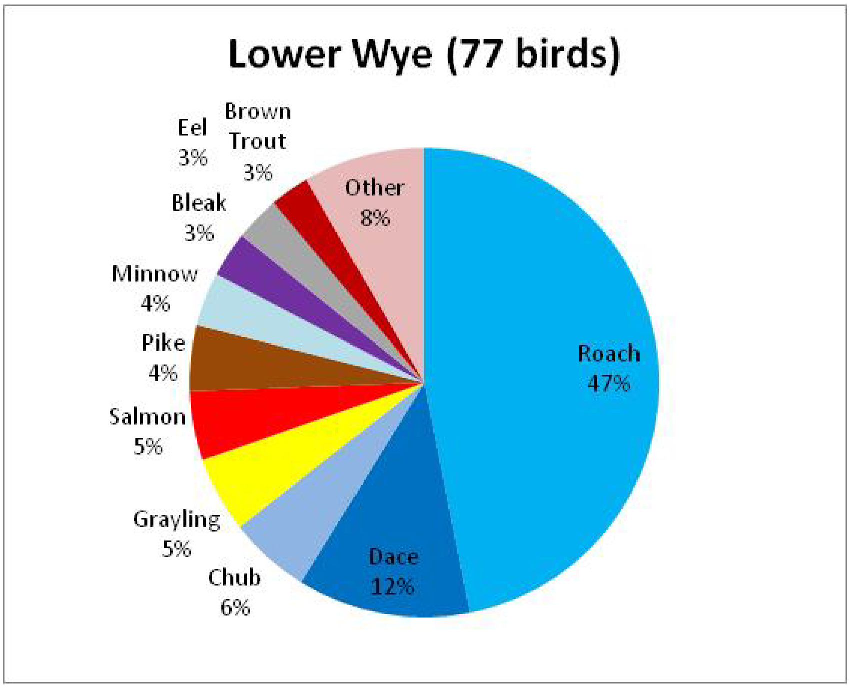

Figure 2. Winter diet of cormorants (proportion by mass) from the lower Wye.

The larger sample size on the lower Wye enabled some comparison of the prey composition of cormorants over time, specifically in relation to consumption of salmon (Figure 3). Licences on the Wye usually extended into March but in some years they were extended into April to help protect the salmon smolt run.

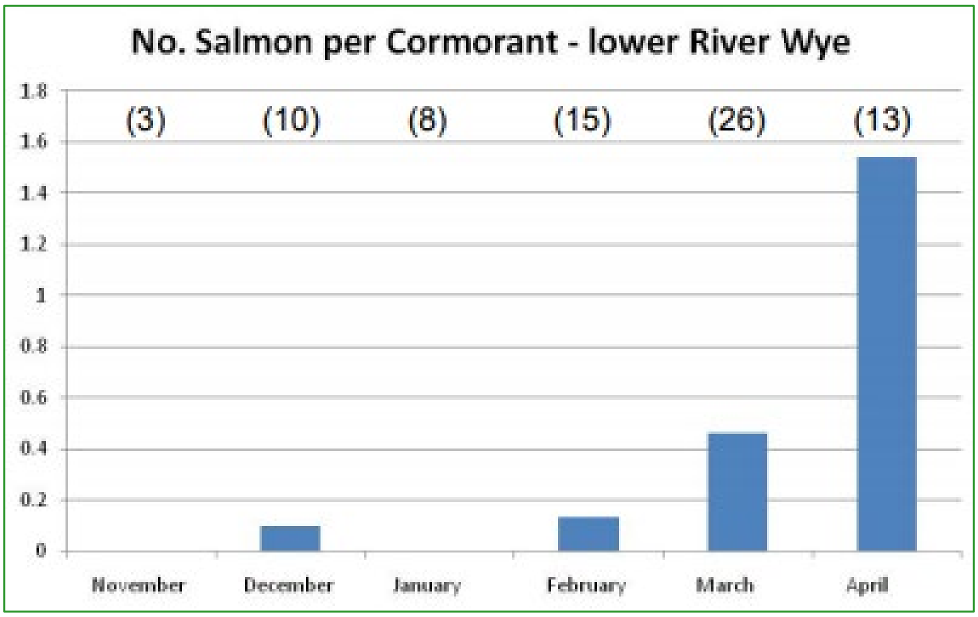

Figure 3. Average number of salmon recovered from cormorants feeding on the lower Wye by month (Number of birds examined given in parentheses).

Key findings

- The data are consistent with cormorants being opportunistic predators feeding on locally abundant species. A wide range of fish species was recorded from birds feeding on both the upper and lower reaches of these Welsh rivers. Brown trout represented the main prey item (by weight) for birds feeding on upland rivers in winter. In contrast, roach and dace were the predominant prey on the lower Wye.

- Salmon comprised a small part of cormorant diet, contributing <1% of the diet (by weight) for the birds feeding on upland rivers and 5%, on average, for birds from the lower Wye. However, diet composition varied over time and, for birds on the lower Wye, the proportion of salmon in the diet increased in the spring consistent with the onset of the salmon smolt run.

Results – goosanders

In total, 54 goosanders shot on upland salmonid river catchments in Wales were examined. These were predominantly from the upper Wye (33 birds) and Dyfi (18) with a small number from the Clwyd (3). Table 5 provides details of all the fish species recorded in these birds, their mean length and the relative proportion each species contributed to the overall sample in terms of both numbers and mass. The prey composition (by mass) was determined separately for the upper Wye and Dyfi (Figure 4).

Table 5. The prey composition for 54 goosanders shot on upland salmonid river catchments in Wales (upper Wye, Dyfi and Clwyd) over the winter period.

Species	Percentage by mass	Number	Percentage by number	Mean weight (g)
Brown trout	44.6	34	4.9	57.4
Trout spp.	17.0	3	0.4	247.6
Salmon	3.8	11	1.6	15.3
Unidentified salmonid	3.0	8	1.2	16.7
Minnow	10.7	376	54.2	1.2
Perch	3.6	118	17.0	1.4
Grayling	2.6	1	0.1	113.1
Roach	2.6	3	0.4	48.7
Chub	2.4	2	0.3	58.8
Common carp	2.3	5	0.7	14.5
Dace	1.9	13	1.9	6.5
Bullhead	1.5	18	2.6	3.6
3-spined stickleback	1.4	37	5.3	1.7
Gudgeon	0.8	2	0.3	16.7
Flounder	0.8	4	0.6	8.4
Stoneloach	0.5	18	2.6	1.3
Unidentified fish remains	-	22	3.2	x
Unidentified cyprinid	-	15	2.2	x
Lamprey spp.	-	2	0.3	x
Pike	-	1	0.1	x
Amphibian remains	-	1	0.1	x

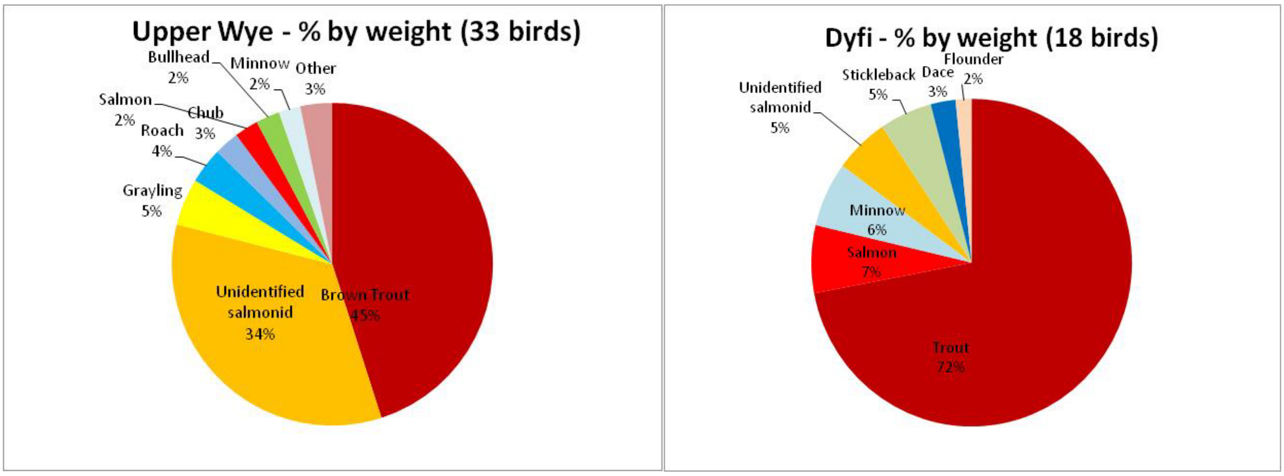

Figure 4. Winter diet of goosanders (proportion by mass) from the upper Wye and Dyfi.

Key findings

- As with cormorants, a wide range of prey species was recorded in the diet of goosanders. Similarly, data are consistent with goosanders being opportunist foragers, and that the prey species consumed broadly reflect the range of species available at particular sites/times of year.

- While minnows and perch fry were by far the most numerous prey items recorded in the goosander diet (minnows comprised 54% of all the prey items recorded), these fish comprised only a relatively small portion of the overall diet in terms of biomass. Brown trout were estimated to comprise ca. 62% of the winter diet by mass. [N.B. this assumes that all records of 'trout' refer solely to brown trout].

- On average, salmon parr comprised only ca. 4% of the diet by mass in this combined sample of goosanders, although the proportion of salmon was greater for the Dyfi (7%) than for the upper Wye (2%), possibly reflecting a more diverse fish fauna.

- The identification of some individuals of the common carp in the sample, a species unlikely to occur in these upland catchments, may indicate that birds had recently foraged at locations other than the river.

Clearly both cormorants and goosanders have diverse winter diets on Welsh rivers, at least based on the samples available to Cefas from 1993/4 to 2003/4. However, it should be noted that cormorant diet assessments are only likely to be robust for the Upper and Lower Wye, as samples for the Usk and Clwyd are too small. Similarly, robust goosander diet assessments are available for the Upper Wye and the Dyfi, again those from the Clwyd being too small.

The only other comparable data available on fish-eating bird diet for Wales is also restricted to the Wye where Feltham *et al*. (1999) examined a sample of 11 goosanders shot on the upper Wye in July/August 1996. Here, it was estimated that the bird's diet comprised 63% juvenile salmon on average by mass (range 16-97%). These salmon were mostly from the smaller (0+, young-of-the-year) age group of parr.

Feltham *et al*. (1999) were unable to reliably assess the potential impact of this level of predation on the salmon stock as a whole, as the estimated losses to birds (based on counts of feeding birds) exceeded the estimated standing stock of salmon (derived from fish surveys) by almost 7 times. Similar apparent discrepancies between calculated losses to goosanders and estimated impacts on salmonid stocks have been reported from studies in Scotland (Marquiss *et al*., 1998).

Quantitative comparisons between the Cefas and Feltham *et al*. (1999) studies are difficult without access to the raw data (and the summer 1996 sample is relatively small) but these results suggest that goosander fish diet may change during the year, particularly when females have broods in summer and birds shift between upper and lower river sections in response to fish availability and life cycle aggregations. This behavioural shift is what you would expect in an opportunist, generalist predator. Young-of-the year salmon may feature more prominently in the diet of goosanders in the summer (Feltham *et al*.'s data from 1996) than during the winter months (Cefas data) because these fish are most abundant then. As well as changes in prey abundance, these differences may also be related to the age-class of the birds in Feltham *et al*.'s sample from 1996 which may have included growing ducklings (as well as full-grown adults/immatures) at that time of year.

Diet samples from cormorants and/or goosanders on Welsh waters were last collected some 15-16 years ago. Moreover, knowledge of cormorant and goosander diet in Wales is largely restricted to just two rivers: the River Wye for both species with the addition of the River Dyfi for goosanders. Similarly, there is a paucity of dietary information for birds at many times of the year, particularly outside the 'traditional' licensing period of November-mid March. This despite the fact that diet is expected to vary markedly throughout the year as a result of changes in fish abundance and 'availability', and the distribution and abundance of the birds. Little is known about the diet of cormorants or goosanders during the period of the smolt run (likely to be April-May) for instance. Thus, more up-to-date dietary samples from a wider number of Welsh rivers, and other waters, at various times of year would be useful to provide evidence to inform policy on the management of fish-eating bird: fisheries interactions. Clearly the more finely tuned sampling efforts can be to the specific times and locations where particular fishes are considered vulnerable to predation, the more informative and robust the evidence may be.

4.6 Predation of salmonid smolts

In the UK and other parts of north-western Europe, one of the most persistent issues surrounding fish-eating birds is their predation on salmonid smolts. In recent years, these concerns have increased as consensus has built that, by this stage in the life cycle of salmon and sea trout, fish have become density-independent and their populations cannot compensate for losses to predation. Thus, for smolts, there is thought to be some form of relationship between the numbers of them that go to sea, and the number of adult fish that return in subsequent years to spawn. The extent to which compensatory factors might offset losses at various stages of the salmonid life-cycle and under different scenarios is discussed in more detail in subsequent sections. Given the potential particular importance of losses at the smolt stage, a number of studies have focussed on trying to derive estimates of losses. These differ widely, as illustrated by the following examples from the literature.

Kålås *et al*. (1993) investigated goosander foraging on the River Halselva in northern Norway in relation to the seaward migration of smolts in 1987-1989. Birds aggregated in the estuary during the smolt migration (June), spending about a third of their time feeding. Subsequent stomach contents analysis found about 25% of prey was salmonids. Goosanders appeared not to select for fish size for hatchery-reared salmon smolts released in the estuary but took smaller individuals than were available for wild Arctic char smolts. In 1989, it was estimated that goosanders took 1% of the hatchery-reared smolts released in the estuary, and 2% of wild smolts migrating through it. Kålås *et al*. (1993) suggested it was likely that less fit smolts (e.g. sick, injured, small) were most prone to predation, and argued that such a level of predation on migrating smolts would have only a minor impact on salmonid production.

Elsewhere in northern Norway, Svenning *et al*. (2005) investigated goosander predation and its potential impact on Atlantic salmon smolts in the River Tana, which at the time had the largest wild stock in the world. In the summers of 1981 and 2000, the stomach contents of 288 goosanders sampled in the estuary were examined and, based on the 2308 otoliths recovered, sandeels were found to be the dominant prey. Only one pair of salmon otoliths was found, suggesting that goosanders were not significant predators on salmon smolts, probably because of the high abundance of sandeels and other marine prey fishes, at least in the particular study years.

In contrast to these studies, Jepsen *et al*. (2018a) reviewed a number of Danish studies carried out over an extended period to estimate losses of salmon and trout to cormorants in a number of locations. Most investigations were performed in the estuary of the River Skjern but included four other rivers and one lake. The Skjern is the focus of one of the largest riverine restoration projects in northern Europe. There was a colony of some 1,200–2,500 pairs of breeding cormorants in the Skjern estuary and most Danish salmonid rivers and coastal areas are within 25 km of colonies holding 100s or 1000s of breeding pairs. At the time of writing, the authors reported that the Danish cormorant breeding population was approximately 30,000 pairs, a decline of over 10,000 pairs since the peak numbers of the mid-1990s.

In the majority of the studies presented by Jepsen *et al*., (2018a), wild trout and salmon smolts were captured in screened traps, rotary screw traps or fyke nets in the lower reaches of rivers or by electrofishing in shallow upper reaches and tagged. Some studies also involved hatchery-reared fish that were stocked following tagging. A range of tagging investigations were conducted using both radio and acoustic telemetry, Passive Integrated Transponder (PIT-tagging), and the use of coded wire tags. This was combined with checks for tags at cormorant colonies and in pellets, and weekly counts of birds to calculate the total number of individual fish eaten in each weekly interval.

In all 24 individual studies, cormorant predation was consistently estimated to be over 20% of the estimated total smolt run, with a mean of 47%. Environmental factors (e.g. water flow, turbidity, wind, temperature) during the few weeks of the smolt run may have played an important role in determining the risk of predation for these fish. Considering this, the variation between 23% and 88% in estimated predation from cormorants was considered "*modest across species, years and systems, leading to the conclusion that cormorant predation on smolts generally is an important factor in lowland rivers."* The authors also suggested that such smolt losses should be taken into account in areas where cormorants are abundant before calculating return rates and applying population models for salmon and trout populations.

All of the Danish studies reviewed that involved wild smolts required that these had been captured, handled, and tagged during their migration to sea. Jepsen *et al*. (2018a) acknowledge that the question of whether this treatment increases the probability of being eaten by a cormorant is relevant. However, they also state that it is hard to resolve but that the findings suggested that this was not a major problem in these studies because a range of different methods provided similar predation estimates. An alternative explanation is that these different methods generally affected the smolts' probability of being eaten by cormorants equally, but this is perhaps unlikely given the widely differing sizes and attachment methods of the tags used. Nonetheless, further work is clearly needed on the effects of catching, handling and tagging smolts (and on the types and sizes of tag used) in relation to their possible effects on the survival and vulnerability of smolts to predation during their migration to the sea.

In another Danish study, Källo *et al*. (2020) assessed the impact of cormorants on migrating sea trout. In this investigation, over 31,000 wild sea trout were caught and PIT tagged over four separate years (2008, 2009, 2015, and 2016) in the River Villestrup, the main tributary flowing into Mariager fjord. Levels of cormorant predation were evaluated by repeat scanning for tags at nearby cormorant colonies and roosting sites. The minimum predation rate on smolts was reported to be 27%, but rates varied among years. A negative correlation was identified between the body length of the tagged fish and predation risk.

There are relatively few documented estimates of losses of salmon smolts to cormorants for rivers in the UK. One study was carried out on the River Bush, a small salmonid river in Northern Ireland, in 1986 (Kennedy and Greer, 1988). A cormorant breeding colony situated on the coast close to the river mouth, resulted in large numbers of birds feeding on the catchment, particularly during the spring smolt migration. Based on counts of bird numbers, published estimates of the daily food requirements of cormorants and a sample of birds (N = 10) shot for stomach analysis, it was estimated that cormorant predation during May accounted for 51-66% of the wild smolt run, and 13-28% of the hatchery smolt releases in that year. These estimates of smolt depredation are likely to be atypical, as the river is situated near one of the largest cormorant breeding colonies in the British Isles. It should also be noted that the sample size was relatively small.

A subsequent study (Warke and Day, 1995) reported lower levels of predation on the Bush and that the level of predation on fish stocks in the river appeared to be strongly influenced by the abundance of cyprinid and percid prey at alternative feeding sites.

As noted above, information on cormorant diet in England and Wales relates mainly to the winter months and to inland stillwater sites (Russell *et al*., in press). The limited data for Welsh rivers in early spring indicate that salmon are consumed and that while the proportion of salmon in the diet remained low, it did increase at the time of the smolt run. Harris *et al.* (2008) noted that there is a paucity of information to estimate possible population level impacts for salmon stocks in Scotland as a result of cormorant predation. However, they reported that annual predation of smolts by goosanders was estimated to account for 3-16% of the smolt production for one river in eastern Scotland; while another study on the River Spey predicted a loss of 3-5% of the smolt run as a result of sawbill duck predation.

5. Knowledge of diet to estimates of 'impact'

Used and interpreted carefully, the diet methods described in Section 3 (and applied to field situations, reviewed in Sections 4 and 5) can provide good assessments of what cormorants or goosanders eat, in terms of the species, numbers, and sizes of fish. However, this knowledge of diet - almost invariably for a specific location at a particular time of year, and often derived from a relatively small sample of birds - does not allow us to conclude anything about the 'impact' that such predation might have on fish communities, populations, stocks, or catches. Much of the information in this section is summarised from Cass *et al.* (2012) where these issues are covered in greater detail.

Knowledge of bird diet is only part of what is needed to demonstrate (or estimate/quantify) impact. Such demonstration is complicated for several ecological and technical reasons and because human interest in the impact of fish-eating birds on their prey often focuses on a particular fish species, and even on a specific size (or age) classes.

Cormorants and goosanders are opportunistic 'generalists' and their diets are generally diverse, consisting of those foods most available to them locally. There is often concern over these birds eating juvenile salmon for instance but any impact on these fish will be mediated through all the other alternative species that are eaten. Consumption of these alternative species might well influence the quantity of the 'target' species eaten and hence the likely impact of such predation and/or the circumstances under which it occurs. In theory, generalist predators could have considerable impact on their 'preferred' prey species because their numbers are buffered against declines in these prey - to some degree – by their ability to switch to other prey species (Marquiss *et al*., 1998). Similarly, it is also theoretically possible that a generalist predator could have a negative impact on a prey species which, although scarce, is nevertheless still consumed opportunistically when encountered (see also mortality Section in 5.2 below). Consequently, some knowledge of the temporal and spatial abundance and distribution of *all* prey species in the diet is likely to be needed to understand impact, not just that relating to the species of concern to people.

There are also technical complications because our knowledge of prey choice/switching, and what makes an individual fish more or less 'available' to a foraging bird is still remarkably limited despite their importance in understanding and demonstrating impact. At its simplest, this requires comparison between (i) estimates of how much food the birds consume and (ii) of how food much is present (or 'available') in the environment at the time when predation occurs. These quantities are generally not easy to estimate in the field. Furthermore, our ability to (iii) make direct comparisons between 'bird' and 'fish' data more generally in an attempt to quantify impact is also often similarly difficult. These important issues are discussed briefly in the remainder of this section in relation to estimating the impact of fish-eating birds on fisheries.

5.1 How much food is eaten?

The question "how much food do cormorants or goosanders eat?" is deceptively simple and requires a lot of information to answer in a useful way. At the very least, information is required on (1) the diet of the birds – proportions of different species and sizes of fish, (2) the number of birds involved over the relevant time period (so-called 'bird days'), and (3) the amount of fish (by species and size/age class) likely to be consumed by a bird over a specific period of time. Methods for assessing bird diet are described elsewhere (Section 3) and the issues of assessing bird numbers and their food intake are covered here.

Given that human interest in fish-eating bird predation is commonly focussed on particular species (or size-/age-classes), the following discussion can be read as relating to a specific fish species. However, it must be remembered that, in all but the simplest systems (e.g. fish farm ponds or possibly single-species put-and-take trout fisheries), birds prey upon a community of fish species and that there will be interrelationships between these fishes, although most are poorly understood. Similarly, although predation by cormorants and goosanders is the issue of interest here, it must be remembered that these birds are unlikely to be the only predators the fish have to contend with. Moreover, predation itself is only one factor in a complex array of biotic and abiotic factors that will affect the fish throughout their life-cycle (see diagrams in Feltham *et al*., 1999, Carss *et al*., 2012).

Counting birds and estimating 'predation pressure'

At a small site, counting birds can be relatively straightforward, if systematic and cumulative counts are made from a good vantage point overlooking the whole site. Several systematic counts will be needed to arrive at a biologically meaningful count because, at any time, some birds will be arriving, some leaving, and others diving underwater and so potentially excluded from counts. As waterbodies increase in size, counting becomes more difficult and several observers are needed. Counts have to be coordinated and care taken to note the numbers and directions of birds moving within the site in order to accommodate these in the final 'best estimate' of bird numbers. Even such basic counts can be time consuming (taking several hours) and the time of day they are undertaken should also be considered. One UK study showed that some counts at one time of day were up to 40% higher than counts made at different times on the same day (Wright, 2003). An important requirement is thus that multiple counts, made over a specified time period at a specific site, are always undertaken at the same time of day.

Overall, the total number of birds counted at a particular fishery or stretch of river is not necessarily the same as the actual number that feed there. This is because of the (potentially large) movement of birds in and out of sites. Intensive work at Loch Leven in Scotland showed that the number of cormorants visiting the fishery was probably ten times the mean number counted there at any one time (Wright, 2003). Another study estimated that a cormorant roost was actually used by 66% more birds over the season than the peak count recorded there (Frederiksen *et al*., 2003). This so-called 'turnover' of birds is difficult to capture in most counts but, as it might be an important factor in relation to impact, it is important to acknowledge it even if it is difficult or impracticable to calculate.

In most situations, counts will never give the true 'total' number of birds involved at any particular site - in effect, they are just snapshots of what is actually happening. Nevertheless, with careful planning counts can be standardised and made comparable in most situations.

In relation to determining impact at a fishery, the next step is to convert an accurate bird count to some measure (or index) of cormorant or goosander 'use' of the site. This can be thought of as a measure of 'predation pressure' and, at its simplest, can be derived from the number of birds counted each consecutive day and the number of days that they feed. This is an important point: just because a bird is counted at a site it does not mean it will take all – or any – of its daily food there. This integration of counts and feeding observations provides a number of 'bird-days'. There are several ways to calculate bird-days' and each has its limitations, usually dependent on both the frequency of counts made during the period of interest and how bird numbers are inferred or estimated on those days when counts are not made (Carss *et al*., 2012). Here, worked examples show that, at best, the number of bird-days are still either under- or over-estimated by more than 10% and so, much like bird counts themselves, calculations of bird days are always no more than best estimates but can nonetheless help us understand interactions between fish-eating birds and their prey.

Estimating consumption

Given realistic estimates of the number of birds and the scale of their occupancy at a fishery - in terms of bird-days for instance - the final issue to consider when estimating impact is the amount of food likely to be consumed by this number of birds over the time period of interest. How much food these birds eat is yet another deceptively simple question that, to be biologically meaningful, depends on a number of interacting factors. Inevitably, these factors have to be calculated for an individual bird and aggregated to the ‘population’ level. As a consequence, overall estimates of consumption are usually an ‘average’ value, and often of unknown accuracy (but likely to be the appropriate order of magnitude).

The *amount* of food that a bird eats depends on many things, often considered under the term ‘bioenergetics’ – which encapsulates how the act of feeding, and the type and ‘quality’ of prey contributes to (i) the general behaviour and ecology of the birds and (ii) how much energy an individual bird uses capturing food and how much it obtains from digesting and assimilating it. The necessity to obtain food (as a source of energy) drives both foraging behaviour and foraging site choice. The foraging choices of a bird in relation to location, duration of visit, and how far it is ‘prepared’ to fly when switching to a new foraging site are all important to understanding the likely impact birds might have at specific times and places.

Bioenergetics are thus crucial to an understanding of any impact of predation on prey species because of the complex inter-relationship between the ‘daily energy expenditure’ (DEE) costs of birds following their normal routine and the ‘daily food intake’ (DFI) required to fuel it. Once an estimate of DEE is established, it can be converted to an estimate of DFI if information on diet, calorific content, and digestive efficiency are available. Most investigations into the food consumption of fish-eating birds in the wild have focussed on cormorants and their energetic requirements as the basis for estimating quantities of food consumed. Such findings are likely to be applicable to goosanders too, as they are morphologically similar pursuit-divers.

It is beyond the scope of this Evidence Report to discuss all aspects involved in estimating the DEE of birds but it includes basal metabolic rate (BMR, the energy used to keep the body functioning at rest) plus the energy that free-living birds also spend (and for how long) for thermoregulation, digestion, moult, and locomotion (e.g. flying, diving). There are numerous environmental factors which can modify these costs (e.g. dive depth, air and water temperatures and wind exposure), and DEE also varies during the annual cycle. For example, it might be greatly increased during breeding and chick-rearing as a result of increased foraging effort. Similarly, in winter, low air and water temperatures greatly increase the energy required to keep warm, or the amount of time spent flying if some foraging sites are no longer available, due to ice cover for instance.

Estimating the energy requirement of any free-living animals is difficult, and fish-eating birds like cormorants and goosanders are no exceptions. Methods to assess energy consumption are complex, rely on a number of assumptions, and are often limited by small sample size (see Carss *et al*. 2012). Converting DEE to DFI then requires detailed information on (a) the fish species composition of the diet, (b) the calorific content of the fish species eaten (which can vary substantially between seasons and regions), and (c) the efficiency with which birds 'absorb' the energy contained in the fish. Estimates of energy conversion are known to vary between fish species and based on double-crested cormorants (*P. auritus*), only about 75–80% of the energy content of the fish may be absorbed by the birds through digestion (Brugger, 1993). Studies involving the two races of great cormorant (summarised in Carss *et al*., 2012: see Tables 4.3 and 4.4) show large variation in both the body mass of birds and their estimated daily food intake, illustrating the degree of variation in derived estimates of DFI resulting from the different energy (and hence food) demands on the birds when undertaking different activities throughout the year.

In many cases calculations of DEE and DFI are ultimately just 'best guesses' that try to take into account the degrees of variation associated with key parameters and methodological assumptions to derive a figure for the amount of food eaten per bird per day. Most studies then convert this to a proportion of 'average' body mass for the bird species under investigation and use the resulting figure as a means of calculating the number of fish consumed. From previous studies, Marquiss *et al*. (1998) concluded that the most likely published estimates of DFI were in the order of 15-25% of lean body weight and chose the upper value of 25% in their consumption calculations (see below) when examining predation on salmonids by cormorants and goosanders on rivers in North-East Scotland.

It is clear that consumption is difficult to measure, and this is reflected in the wide range of published estimates, derived from a number of techniques. At best, there is necessarily a range of potential values for DFI – they are probably in the 'right ball-park' but are of unknown accuracy. When making comparisons with the food available to these birds (see below), authors thus tend to use DFI values at, or towards, the upper end of this range - perhaps 25-30% of body mass/day (see Carss *et al*., 2012 for synthesis).

5.2 How much food is 'available'?

In the context of this Evidence Report, interest in fish populations is related to the general concern over the potential 'impact' of cormorant and goosander predation on freshwater fisheries, and on populations of migratory salmonids in particular. Carss *et al*. (2012) offer an overview of some of the well-established field methods (and their associated limitations) available for assessing fish numbers in appropriate habitats in relation to fish-eating bird predation. Based on this, here we provide an insight into the complexity (in both time and space) of the ecology of fishes, their behaviour, and relationships with the diverse habitats in which they live. This is pertinent because of the obvious consequences on our ability to quantify fish populations, and the likelihood of identifying and/or quantifying any *impact* that cormorants or goosanders might be having on fish at a specific location.

Fish distribution, ecology, and behaviour

The fish fauna of Europe is not particularly rich, and that of the UK even less so. Across Europe, westwards and northwards, the freshwater fish fauna gradually becomes more impoverished in terms of species numbers. Against this, the diversity of fish species everywhere is closely linked to specific habitats and environmental conditions. A range of factors influence the distribution and abundance of these fish populations (in both space and time), including seasonal factors and life-history characteristics (e.g. migration, habitat requirements of different life stages, etc.). For instance, many adult fish have specific spawning requirements, and many juvenile fish occupy a specific habitat but switch to others as they grow older. All fish are mobile to some extent because of the need to forage and to avoid predators, and in response to changing environmental variables such as light levels and water temperature.

Often, several different species may have broadly similar habitat requirements (at least at some time in their life-cycles), resulting in assemblages that are associated with particular broadly-defined habitat types. In freshwater, such broad-scale distribution is chiefly controlled by climatic, topographical and hydrological differences. Each individual fish lives in a defined area within a ‘community’ – a complex web of interactions and processes with others of the same and different species.

Compensatory or additive mortality?

The interactions between fish and their predators are also complex. While the impact of predators might, on the face of it, seem obvious – predators remove individuals from the population resulting in a decline in abundance – determining the actual effect on a population is problematic and potentially misleading. For example, the stage of the life-cycle on which predation occurs is likely to be an important consideration in assessing the scale of any impact. In many prey populations, including Atlantic salmon and trout, strong compensatory processes can operate to ameliorate the effect of losses to predators. In simple terms, such compensatory processes will tend to be strongest for the earliest life stages. Thus, in a healthy population, the number of fry and small parr in freshwater normally exceed the available resources (the carrying capacity) and levels of natural mortality are high. As such, fish eaten by predators tend to be replaced by others that would otherwise have died of another cause, such as starvation.

However, while juvenile recruitment in these early freshwater stages can often be strongly density-dependent (i.e. compensation expected to apply), recruitment of older life stages in freshwater and of salmon during the marine phase of the life cycle is considered to be density-independent and not subject to compensation (Jonsson *et al*., 1998; Milner *et al*., 2003). Typically, therefore, as the intensity of compensatory processes reduces with age, so the relative importance of random factors such as environmental extremes or predation increases. Of course, the relative vulnerability of populations to predation will also vary between populations, dependent on other factors such as the role of other limiting factors and the population size. The impact that predators have on a stock will therefore depend on the relative size of that stock, the timing and extent of the predation, and the influence this has on the potential for compensation.

Based on a review, Ward and Hvidsten (2011) suggested that there were two general situations where predators are likely to have strong, negative effects on salmon populations. Firstly, where predation takes place on older parr, smolts and marine life stages, based on the fact that recruitment of these older life stages is density independent (Jonsson *et al*., 1998; Milner *et al*., 2003). As a consequence, predation mortality for older stages is likely to be more additive in nature, directly reducing recruitment and population growth, with little scope, if any, for compensatory mechanisms to operate. Ward and Hvidsten (2011) further note that this may be a particular problem where other human impacts increase the vulnerability of older salmon to predators.

The second situation where strong, negative effects may be expected is on populations that are at low levels of abundance, because predation may have a disproportionate impact on such stocks (Ward and Hvidsten, 2011). The proportion of a prey population consumed by predators depends on the predator response. If predators take a particular prey even when it is relatively rare, typical of opportunistic predators, then predators will have a disproportionate impact on populations at low levels. If predators tend to ignore relatively rare prey, then predation may have a small impact on such populations. Both types of response have been reported for interactions between Atlantic salmon and different predators (Middlemas *et al*., 2006; Ward *et al*., 2008). Given that the majority of predators preying on Atlantic salmon are considered to be opportunistic, Ward and Hvidsten (2011) consider that these are more likely to have major impacts on low-abundance populations, greatly increasing the risk of extinction when population size declines due to other factors. They highlight, however, that any extrapolation from such general guidelines to specific stocks needs to be undertaken with caution, since the effects of predation are typically context-dependent (Mather *et al*., 1998).

Recent studies in the United States serve to highlight the difficulties of assessing whether predation on fish stocks is additive or compensatory. Two investigations into predation by fish-eating birds on ‘steelhead’ (anadromous rainbow trout *Oncorhynchus mykiss*) in the Columbia River basin in the north western United States have reached differing conclusions on whether predation constituted an additive or compensatory source of mortality. The assessments focused on predation from colonies of double-crested cormorants (*Phalacrocorax auritus*) and Caspian terns (*Hydroprogne caspia*) in the Columbia river estuary.

In their assessment, Haeseker *et al*. (2020) found that average predation rates on steelhead smolts were 3.3% for the double-crested cormorant colony and 17.0% for the Caspian tern colony, but that mortality due to avian predation was compensatory. Other variables including river flow, juvenile migration timing, and an index of forage biomass in the ocean accounted for the majority of the variation in survival rates in their model, whereas predation rates accounted for <1%. Conversely, Payton *et al*. (2020) concluded that predation by Caspian Terns may have represented a super-additive source of mortality during the smolt life stage and a partially additive source of mortality to the adult life stage. Super-additive mortality was taken to mean that more smolts died than the numbers estimated to be consumed by bird predators due to sources of additional undetected mortality, such as: deposition of PIT tags at locations other than the colony, smolts being stolen by gulls, wounding or injury that results in mortality but not capture by the predator, or consumption by birds that occupy areas other than the colonies monitored for PIT tags.

These apparently conflicting conclusions have been the subject of a subsequent comprehensive review (Carothers *et al*., 2021). This noted that there were important differences in definitions and underlying models used to distinguish additivity and compensation that could partly account for differences in conclusions between the studies. A number of other differences were identified including the specific populations investigated, the time periods covered, and the life cycle periods evaluated. The review also made a number of recommendations for further investigation. The detailed discussions surrounding these investigations is beyond the scope of this review, but further highlights the challenges posed in assessing the significance of avian predation on migratory salmonids.

Fish populations, stocks, and catches

As Carss *et al*. (2012) discuss, the relationship between fish populations, fish stocks and, ultimately, fish catches are likely to be extremely complicated and usually very difficult to quantify. Furthermore, predation by birds on a fish *stock* may not have the same biological meaning as predation on a fish *population*. When considering the impact of generalist predators like cormorants and goosanders, it is also particularly important to understand that, in almost all habitats, several fish species will be living and interacting directly with each other and so it is extremely difficult to consider any fish species in isolation in any ecologically meaningful way.

In order to properly understand the population dynamics of a specific fish stock, Carss *et al* (2012) recommended that the following information is ideally required:

- Estimates of population abundance (fish numbers) for all stages of the life-cycle;
- Measures of the rate of change of abundance for these stages;
- Mortality, growth and fecundity (potential reproductive capacity) rates — which are all size- (age) related and which may also be functions of the density of the population;
- The relationship between the abundance of the sexually mature portion of the population and recruitment to a defined age (or size) class — i.e. the stock-recruitment relationship;
- The amount of fish flesh generated by a cohort as the fish grow and die, applied to assess production.

Deriving such information is both challenging and expensive, and typically requires a continuous process of monitoring and assessment (often over many years). In addition, the relationship between fish populations, stocks and, ultimately, catches are likely to be extremely complicated and very difficult to quantify in many cases.

In the context of Welsh migratory salmonid stocks, fish counters or traps on some rivers enable numbers of returning adults to be determined and, taking account of catches, the resulting spawning stock and egg deposition rates can be estimated. On other rivers spawning stocks are estimated from catches and exploitation rates. Widespread juvenile surveys are conducted on a regular basis to provide information on the distribution and abundance of salmonid fry and parr. Further, smolt trapping investigations on a small number of rivers can provide information on smolt abundance. However, despite these investigations the available data fall well short of what might be regarded as ‘ideal’, even for the most intensively studied river catchments. The available information on the status of fish stocks in most stillwater fisheries is substantially more limited.

The information (e.g. stock size and composition, catches, etc.) available for fisheries subject to bird predation is thus likely to vary enormously and it cannot be assumed that parallel fisheries data will be available alongside that of fish-eating birds. Indeed, Carss *et al*. (1997) concluded that “*attempts to fine-tune particular aspects of our cormorant diet/food intake methods must be seen against a background of the huge variability often associated with current fisheries assessments*.” The situation is essentially unchanged today and so the type and quality of fisheries data is important to consider because, despite its likely limitations, it is probably all that is available for any investigation into cormorant or goosander impact at fisheries. The subject of attempting to quantify such impact, through the integration of both bird and fishery data, is discussed below.

5.3 Difficulties in quantifying/estimating 'impact'

Cormorant or goosander 'impact' can be understood or interpreted differently by different people, depending on their values, attitudes and expectations. Obviously, if there *is* an impact, it should be measurable - but what should be measured? How? By whom? Over what period of time? What information would be required to demonstrate impact?

Impact also has spatial and temporal elements. Smaller water bodies (particularly 'closed' ones within well-defined spatial limits) and the fish in them often react more quickly to changes in environmental factors than do larger ones which can have greater capacity to buffer any impact, to some degree at least. Temporal scale is also important because many issues related to potential impact on fish populations (e.g. compensation, lack of population effects) actually occur over the long-term, probably on a generational scale. From a biological perspective, long-term population resilience to predation might thus be equated with no negative impact. However, this view is unlikely to be shared by fisheries interests whose catches (income or amenity values) can be depressed in the short-term. Conversely, long-term impact might be an important conservation concern if predation occurs on a particularly 'important' fraction of the population that relates directly in some way to the size of the breeding population (perhaps a situation with little, or no, density dependence e.g. salmonid smolts), or affects stocks that are already depleted (Ward and Hvidsten, 2011).

There are also many issues and interactions that will influence the scale (if any) of impact and which require consideration when trying to measure any ecological relationship between predator and prey. For instance, fish abundance can be greatly influenced by fish mortality - the sum of all deaths in the fish population regardless of their cause. Causes will include things like the harvest of adult fish by people; starvation of fry as they compete for space in a habitat; predation; the effects of diseases or parasitism; and deaths caused by one or more abiotic factors. Clearly, it is a major challenge for researchers to quantify the relative proportions of each of these causes of mortality, to tease apart the mortality caused by predators, then calculate the proportion of this that is caused by cormorants or goosanders and the ultimate effects of this portion of overall mortality on the fish population (stock, or subsequent catches).

A meta-analysis of cormorant predation effects on fish populations

There is clearly considerable interest predation by fish-eating birds at fisheries, but demonstrating impact appears very difficult, even for particular locations at specific times. Recently, Ovegård *et al*. (2021) took a different approach, examining relevant literature at a global level to search for any patterns to predation effects and undertaking the first meta-analysis of the impact of predation on fish by cormorants (*Phalacrocoracidae* – all species, all over the world). This analysis was based on a systematic literature search of titles and abstracts, and covered those studies using significance-based hypotheses tests on the relationships between cormorant abundance and various fish parameters. The analysis reinforced the message that few studies have quantified cormorant impact at fisheries, confirming that despite extensive research on diet, few studies use statistical hypothesis testing to examine the consequent effect on fish populations. Thus, although 603 publications were identified as relating to interactions between cormorants and fish, only 27 of these tested fish population parameters against cormorant predation. Of these, 22 could be included in the meta-analyses, where effect size (i.e. “impact”) was defined as being ‘negative’ in cases where cormorant numbers or presence reduced fish numbers or biomasses, or when individual fish-sizes decreased, and *vice versa* for a ‘positive’ effect.

Ovegård *et al*.’s (2021) modelling showed that the combined effect of cormorant predation on fish was negative, but that this overall effect was not significant at the 95% confidence level. Their analysis also showed that cormorant predation effects differ between fish species and that species in the Cyprinidae (Carps) and Percidae (Perches) families appeared “*most vulnerable to cormorant predation, which may be a result of prey selection”* (Salmonidae figured very little in the analysis). Whilst not demonstrating the impact of cormorants, this meta-analysis did reveal the complexity of interaction between cormorants and fish. The authors concluded that it also “[added] *to the consensus on the importance of considering cormorant predatory effects in research, conservation actions, ecosystem-based management, and environmental monitoring*.”

In the context of much of this discussion on impact, it is revealing that Ovegård *et al*. (2021) urge researchers to focus on effects on fish populations, rather than merely conducting diet analyses. They also stress the importance of focusing future research on studies that includes a design with statistical hypothesis testing to further add to the knowledge of the predatory effects of birds. Finally, they note the paucity of studies investigating the effects of fish-eating predation in natural ecosystems, presuming this is “*probably due to the difficulty in isolating the effects of cormorant predation among all the other biotic and abiotic pressure variables acting on fish populations in a variety of challenging habitats and complex systems*”.

5.4 Predation: inferences for Welsh salmonid populations

The ecological relationships between fish-eating birds and fishes, including any impact of the predators on their prey, are complex and usually poorly understood. Researchers and those faced with managing conflicts are clearly faced with a major problem: complete understanding of the dynamics of even the simplest predator-prey relationship is likely to be unrealistic. As well as significant limitations in the available data, there are also demonstrable difficulties in ‘marrying’ fisheries data with those on the birds, as these are seldom collected for the purposes of quantifying impact. Acknowledging these problems is important, and allows us to appreciate the limitations of our knowledge and the likely confidence limits around any assessments we make. A pragmatic approach is thus needed both in assessing cormorant or goosander impact at fisheries and this clearly requires some simplification.

In most circumstances, the term ‘impact’ is implicitly used to describe a situation where cormorants or goosanders are consuming sufficient fish in a system so as to affect it negatively from a human perspective. This almost invariably equates to a reduction in fish catches, fish value, or to a specific portion of the fish stock (e.g. a particular species or age/length class of individuals). In the Welsh situation, the most common areas of interest in terms of cormorant and goosander predation at, primarily, freshwater fisheries are likely to be their consumption of fish of a size that could also be taken by anglers and losses of juvenile salmonids (salmon and sea trout, large parr and smolts) prior to and during their migration to sea.

Harris *et al*. (2008) reviewed the impacts of piscivorous birds on salmonid populations and game fisheries in Scotland, and this was updated by Humphreys *et al*. in 2016. Interestingly, the later review of post-2008 studies did not alter the conclusions of earlier ones. Humphreys *et al*. (2016) reported two primary conclusions from studies undertaken to date. First, there was substantial evidence that, at a site level, piscivorous birds can take large numbers of fish from natural and stocked fisheries. In Scotland, the highest levels of concern have been raised for: (a) wintering cormorants foraging at stillwater fisheries where wild (and farmed) trout species are consumed, and also in rivers where salmon parr (large) and smolts are taken; (b) sawbill species in the early winter period and March/ April foraging on salmon (small) smolts and, to a lesser extent, parr. Grey herons did not appear to be a major concern in Scotland.

Second, there was a lack of evidence that such predation impacts affect fish species at the population level or cause direct economic losses. However, this cannot be interpreted as a lack of the existence of an effect, rather that it is very difficult to measure (Humphreys *et al*., 2016).

These reviews also highlighted that the lack of accurate assessments of fish consumption rates by piscivorous birds, in combination with the lack of evidence available for key parameters of fish populations (e.g. overall fish abundance and mortality rates caused by other factors), had hindered any attempts to demonstrate a reduction in numbers or productivity of fish species caused by piscivorous birds (Harris *et al*., 2008). The conclusions from these reviews are also very likely to be applicable to salmonid fisheries in Wales.

As noted previously, a key scientific issue in any consideration of predation is whether the different mortality factors are additive or whether compensatory factors operate in the system under consideration. In other words, whether different mortality factors are cumulative, or whether when one factor increases another inherently decreases. The majority of salmon and sea trout populations in Wales are currently in a depleted state, with insufficient numbers of returning adults for optimal production. Thus, in many cases there is likely to be lower potential for compensation and the impact of any factor that removes fish will, proportionally, be greater than in a healthy population. Predation may therefore be playing an important part in the dynamics of these wild salmonid populations in Wales. Such issues of compensation are not really relevant to put-and-take fisheries where, in theory at least, losses to predators are merely compensated for by additional stocking.

Relevant case studies

Compensatory mechanisms were one of the alterative explanations offered by Marquiss *et al*. (1998) for problems with their attempt to quantify fish-eating bird impact on juvenile salmon from the sort of bird and fish data obtained by methods discussed above. These authors compared consumption rates of birds (cormorant, goosander, red-breasted Merganser, *Mergus serrator*) with the best available scientific estimates of fish abundance (estimated as numbers of fish per 100 m^2 in relation to river width). They discussed a number of potential sources of error in their calculations and these are listed here to highlight difficulties in estimating impacts, even in a relatively simple system.

- Bird density — data from the study river;
- Bird diet — data from the study river;

- Bird daily food intake — upper limit derived from literature;
- Salmon standing crop — not measured directly. Based on data from four other rivers. Likely to be underestimated because of methodological limitations and does not take into account the seasonal movement of fish within the catchment.

Studies by both Marquiss *et al*. (1998) in Scotland and Feltham *et al*. (1999) on the River Wye in Wales showed that the highest estimated consumption rates for cormorants and sawbill ducks on their study rivers were those for goosander duckling broods in summer. It was further concluded that at certain times and places, the fish consumption of the birds (estimated as specified in the bullets above) suggested that the birds would remove all fish from the river within a relatively short period of time. This clearly did not happen, implying that some of the procedures for estimating losses were invalid or inaccurate or the salmon population was somehow able to compensate.

Either estimates of consumption were too high and/or the estimates of salmon standing stock were too low (as noted in Section 5.2, there may be huge variability associated with current fisheries assessments). One of the main problems highlighted by Marquiss *et al*. (1998) was that birds take most fish from mainstem pools, whilst estimates of fish density on wider streams are mainly available for shallow riffle rather than deeper habitats. Similarly, there was virtually no direct information on the abundance and distribution of juvenile salmon living in the mainstem, all good long-term data come from narrower streams. Alternatively, as Marquiss *et al*. (1998) point out, the figures and calculations could be realistic, but the fish population might somehow be able to compensate for the recorded levels of predation. Clearly, such cases show the difficulties in moving from estimates of fish consumption by predators to their impacts on prey populations. Fish losses to birds can be substantial, albeit impossible to quantify in population terms using commonly collected data.

Another method of attempting to quantify cormorant impact on fisheries has been to try to follow the fate of tagged fish. Skov *et al*. (2014) used data from recovered PIT tags to explore species- and size-specific annual predation rates by cormorants on three common fishes in a Danish lake. Based on three years of PIT tagging in lake Viborg, and subsequent recoveries of tags from nearby cormorant roosting and breeding sites, they showed that cormorants were major predators of roach, bream and perch within the size range (120-367mm) investigated and, for all species, larger individuals had higher predation rates. Perch appeared to be the most vulnerable species and based on a comparison with mortality estimates from lakes without significant avian predation, it was suggested that cormorant predation could induce age/size ‘truncation’ in the lake, resulting in very few larger individuals there. These authors thus claimed that anglers were less likely to catch larger perch and that there may also be an influence on lower trophic levels, and thus turbidity, because large piscivorous perch often play an important structuring role in lake ecosystem functioning.

Jepsen *et al*. (2018b) used radio-telemetry, PIT-tagging, and traditional fish surveys to estimate the impact of cormorant predation in Danish lowland rivers. This work was undertaken because a combination of cold winters and low availability of coastal prey fish apparently triggered birds to seek new foraging areas. The appearance of cormorants on rivers and streams coincided with an observed massive decline of fish, particularly brown trout and grayling. Recovery of PIT-tags revealed that cormorants ate an estimated 30% of wild trout and 72% of wild grayling tagged in a small river. In another medium-sized river, 79% of radio-tagged adult grayling were lost, presumably by cormorants during winter. The authors thus suggested that the level of cormorant predation appeared to be enough to explain the observed collapse of grayling and brown trout populations in many Danish streams.

These findings from tagged fish do suggest that cormorants might be consuming a large proportion of tagged fish. However, it is possible that their previous capture, handling, and tagging might have increased their vulnerability to predation and further work is needed to validate such studies (see also section 4.6 concerning smolts).

6. Key points and recommendations

Background to this Evidence Report

- There is growing concern in Wales about the potential impact of cormorants and goosanders on stocks and catches of fish of commercial, recreational and, conservation value. These concerns relate particularly to migratory salmonid species – salmon and sea trout – but have also been raised in relation to other freshwater fish stocks.

- Salmon and many sea trout populations in Wales have been in decline for many years and the majority of stocks are currently classified as either ‘at risk’ or ‘probably at risk’.

- NRW have published a Plan of Action for salmon and sea trout in Wales with the aim of: “*protecting, through the application of best-practice science and management, the sustainability of our natural resource of wild salmon and sea trout stocks in Wales*.” The Plan details ongoing and new actions to address the many pressures affecting these stocks, but also identified a need to undertake a wider review of predation by fish-eating birds on fisheries in Wales.

Diet assessment techniques and limitations

- Generally, there is more research and information available concerning cormorants than there is for goosanders, reflecting the differences in the geographic range and ‘intensity’ of perceived conflicts with fisheries interests. Whilst some of the information presented here is thus derived solely for cormorants, much of it is also directly relevant to goosanders.

- There are a number of different techniques available for assessing the diet of fish-eating birds, but each has associated limitations. The three main techniques are: (i) direct observation of foraging birds and the prey they consume at the surface; (ii) examination of the hard remains (fish bones, etc.) recovered from pellets regurgitated by birds (N.B. no applicable for goosanders); and (iii) examination of the stomach contents of dead birds.

- The principal limitations associated with observation of foraging birds include the difficulties of prey identification, of watching particular birds over extended periods and the fact that some prey is consumed below the water surface. With pellets and stomach contents analysis, limitations include sample collection and the difficulties of identifying prey from digested and partially digested remains.

- Other approaches that can provide information on diet are the use of stable isotopes and environmental DNA (eDNA). Stable isotopes do not enable detailed appraisal of diet content but can provide an indication of the relative contribution of prey derived from marine and freshwater environments. More recently, techniques using eDNA have been developed that enable different prey species to be identified in samples such as pellets or bird faeces. However, quantifying the relative contribution of different prey to the overall diet remains a challenge.

- Regardless of the method used to assess diet, there will be limitations associated with any samples available. This may arise due to temporal differences between available samples and perceived conflict periods, for example, birds are commonly shot in the winter months, but this might not be the time when potential impacts on fish stocks are manifest. Similarly, samples will usually derive from locations where there are suspected conflicts with fisheries and may not be representative of bird diet in general.

Cormorant diet

- There is an extensive literature on the diet of cormorants in Europe. This confirms that the birds are almost entirely piscivorous and have a diverse diet consisting of those species most readily available to them locally – i.e. they are opportunistic generalists.

- Cormorants are able to consume relatively large fish, exceptionally up to around 1.5 kg in weight. However, the majority of fish consumed are relatively small, typically in the range 10-20 cm.

- Diet investigations in the UK primarily relate to the winter period, coinciding with the time when licences are issued to allow shooting. Results are consistent with the prey species available in different habitats. Thus, cyprinids and perch typically predominate in stillwater coarse fisheries and lowland rivers, while rainbow trout are common prey at put-and-take fisheries. For upland, faster flowing rivers, salmonids (trout, salmon and grayling) are commonly consumed.

- Investigations in Scotland found that salmon comprised <1% of the winter / spring diet of cormorants (by mass) feeding in southern rivers but 18% in northern rivers, reflecting the lower diversity of the fish communities in the northern river.

- Available data for Welsh rivers indicated that brown trout represented the main prey item (by mass) in upland rivers in winter, with roach and dace the predominant prey on the lower Wye. Salmon comprised a small part of the diet, contributing <1% (by mass) for birds feeding on upland rivers and 5% for birds from the lower Wye.

- Little information exists on the diet of cormorants at other times of the year and this remains an important evidence gap.

Goosander diet

- Goosanders have been less extensively studied than cormorants. However, the available information on diet indicates that the birds are also opportunistic 'generalists' feeding on species most readily available locally. The birds are largely piscivorous, but can consume carrion, and frogs and juveniles also feed on large insects.

- In general, goosanders consume smaller fish than cormorants reflecting their smaller body size. Prey are mostly small fish in the range 5-11 cm, although larger prey items can be consumed.

- Investigations in Scotland indicated similar latitudinal trends in the abundance of prey in goosander diet as with cormorants, reflecting the diversity of the riverine fish communities. Thus, salmon were found to comprise 9% of the winter / spring diet of goosanders (by mass) feeding in southern rivers but 41% in northern rivers.

- Available data for Welsh rivers found that brown trout represented the main prey item (62% by mass) in winter; salmon comprised just 4% of the diet. In contrast, a small sample of birds shot on the River Wye in the summer (July/August) estimated that the bird's diet comprised 63% (range 16-97%) juvenile salmon on average by mass.

- Diet investigations in the UK primarily relate to the winter period, coinciding with the time when licences are issued to allow shooting. Relatively little information exists on the diet of goosanders at other times of the year and this remains an important evidence gap.

From knowledge of diet to estimates of 'impact'

- The interactions between fish and their predators are complex. While the impact of predators might, on the face of it, seem obvious – predators remove individuals from the population resulting in a decline in abundance – determining the actual effect on a population is problematic.

- Knowledge of bird diet is only part of what is needed to demonstrate or estimate impact. In addition to knowledge of the relative proportions of different prey species in the diet, information is needed on the numbers of birds feeding at a site and their daily food intake requirements. While this might provide realistic estimates of the amount of fish consumed, this then needs to be related to how food much is thought to be present (or 'available') in the environment at the time that the predation occurs.

- In addition, concerns about potential predator impact commonly focus on particular species, but consumption of other 'non-target' fish species is very likely to influence the quantity of the 'target' species eaten and hence the likely impact. As a consequence, at least some knowledge of the abundance and distribution (in time and space) of all prey species in the diet is likely to be needed to understand impact, not just that relating to the species of specific human interest.

- The stage of a fishes life-cycle at which predation occurs is also likely to be an important consideration in assessing the scale of any impact. In many prey populations, including salmon and trout, strong compensatory processes can operate to ameliorate the effect of any losses, including those to predators. Typically, such compensatory processes will tend to be strongest for the earliest life stages.

Inferences for migratory salmonids in Wales

- The recruitment of salmon and trout in the early freshwater stages of their life-cycle is often strongly density-dependent meaning that losses (e.g. to predators) may be fully compensated. However, the strength of such compensatory processes decreases as the fish grow and numbers in a cohort decline. During the marine phase of the life-cycle of salmon and sea trout, recruitment is believed to be density-independent. Any losses of these species at the smolt stage, when the fish migrate to sea, would therefore be expected to result in a proportional reduction in numbers of returning adults. Predation on salmonid smolts is thus one of the most persistent issues surrounding fish-eating birds.

- A study on the River Wye indicated that the diet of goosanders in the summer months (July/August) comprised 63% juvenile salmon on average by mass (range 16-97%). Estimated losses to birds over this period (based on counts of feeding birds) exceeded the estimated standing stock of juvenile salmon (derived from fish surveys) by almost 7 times. Similar discrepancies between calculated losses to goosanders and estimated impacts on salmonid stocks have been reported from Scotland. The extent to which goosanders may be impacting salmonid stocks during the summer period, while broods are being reared, remains an important evidence gap.

- There are relatively few published estimates of smolt consumption by fish-eating birds and these vary widely. Studies on goosander in Norway have suggested low levels of predation on salmonid smolts. In contrast, cormorant predation in a number of Danish investigations has been consistently estimated to account for over 20% of the estimated total smolt run, with a mean of 47%. Another similar study calculated the minimum cormorant predation rate to be 27% of the smolt run, but this varied between years. The Danish estimates were based on tagging investigations; the extent to which capture, handling and tagging might affect a fish’s vulnerability to predation remains unclear.

- In the UK, a study on the River Bush in N. Ireland estimated that cormorant predation accounted for 51-66% of the wild salmon smolt run, and 13-28% of the hatchery smolt releases in that year. This estimate was based on a relatively small sample of shot birds and was perhaps atypical, as the river is situated near one of the largest cormorant breeding colonies in the British Isles. In Scotland, goosanders have been estimated to account for 3-16% of the smolt production for one river in eastern Scotland; while another study on the River Spey predicted a loss of 3-5% of the smolt run as a result of sawbill duck predation.

- The limited data for Welsh rivers in early spring indicate that salmon are consumed by cormorants and that although the proportion of salmon in the diet is low, it does increase at the time of the smolt run.

- There are two general situations where predators are likely to have strong, negative effects on migratory salmonid populations. Firstly, as noted above, where predation takes place on older parr, smolts and marine life stages. The second situation where strong, negative effects may be expected is on populations that are at low levels of abundance, since predation may have a disproportionate impact on such stocks.

- The majority of salmon and sea trout populations in Wales are currently in a depleted state, with insufficient numbers of returning adults for optimal production. Thus, in many cases there is likely to be lower potential for compensation and the impact of any factor that removes fish will, proportionally, be greater than in a healthy population.

- Recent investigations in the United States serve to highlight the difficulties of assessing whether predation on fish stocks is additive or compensatory. Here, differing conclusions have been reached based on two alternative approaches examining the interactions between stocks of steelhead (anadromous rainbow trout) and colonies of double-crested cormorants and Caspian terns in the Columbia river estuary.

- Numerous evidence gaps remain in our understanding of the interaction between fish-eating birds and fisheries. Reliable estimates of population level impacts, or associated economic losses to fisheries, as a result of predation are scarce and further work is required. Nonetheless, given that many salmon and sea trout stocks in Wales are currently at depressed levels, the available evidence suggests that losses to predators might be having a relatively large effect on these stocks at the current time.

7. Knowledge gaps

Given the complex nature of the interactions between fish-eating birds and fisheries, and how best to manage these, there are numerous areas where uncertainties remain, and additional evidence would be welcome. There are clearly significant challenges in addressing these uncertainties, but options for further study might include:

Further studies to elucidate the diet of fish-eating birds in Wales

There is a relative paucity of information on bird diet specific to Welsh fisheries and more up-to-date dietary samples from a wider number of Welsh rivers, and other waters, at various times of year would be useful to provide evidence to inform policy on the management of fish-eating bird: fisheries interactions. Clearly, the more finely tuned sampling efforts can be to the specific times and locations where particular fishes are considered vulnerable to predation, the more informative they may be. In particular, there is a need for further information on the diet of goosanders during the summer months when broods are being reared, commonly on the upper stretches of rivers. There is also a particular need for further information on the diet of both cormorants and goosanders around the time of the salmon and sea trout smolt migration in spring.

Improving estimates of impact

Researchers have highlighted that a major problem in calculating the proportion of fish standing crop consumed by birds has been collecting accurate data for all the necessary parameters at a specific site. The main priorities to facilitate more accurate estimates would rely on better matching of data sets on birds and fish at specific foraging sites. Information requirements would include:

- Reliable estimates of the daily food intake of birds;
- Knowledge about prey switching by birds and the role of alternative foraging habitat;
- Estimates of bird densities at foraging sites where there are dietary data;
- Direct estimates of fish standing crop (abundance) at foraging sites and of fish movement patterns.

Quantifying smolt predation

Given the particular concerns about losses of salmon and sea trout at the smolt stage, and the paucity of available estimates on the levels of smolt predation in the UK, there is a clear need for further work to improve understanding in this area, particularly for salmonid stocks in Wales.

The common usage of tagging techniques to evaluate the extent of smolt losses (often based on the recovery of tags from cormorant roosts) has also raised questions about the extent to which catching, handling and tagging fish (and on the types and sizes of tag used) might affect subsequent vulnerability of the fish to predation. Further work to explore this issue would be of value, although the practicalities of objectively testing this in the field should not be under-estimated.

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