Analysis of Bird Stomach Contents

Final Report: Goosander and Cormorant diet on four Scottish rivers (2019-2020)

October 2022

Scottish Government
Riaghaltas na h-Alba

Analysis of Bird Stomach Contents
Goosander and Cormorant diet on four Scottish rivers (2019-2020)

Final Report – June 2022

David N Carss

Published by Marine Scotland

This report presents the results work carried out for Marine Scotland under external commission.

Marine Scotland is the directorate of the Scottish Government responsible for the integrated management of Scotland's seas. Marine Scotland Science provides expert scientific and technical advice on marine and fisheries issues. These reports are not subject to formal external peer review.

While every effort has been made to make this publication accessible to all, some sections may remain inaccessible due to the nature of the content. If you are unable to access any content you require, please contact salmonandrecreationalfisheries@gov.scot

UK Centre for Ecology & Hydrology

Analysis of Bird Stomach Contents

Final Report: Goosander and Cormorant diet on four Scottish rivers (2019-2020)

Client Ref: CASE/208582
Issue Number V.4
David N
Carss June
2022

Client	Scottish Government
Client reference	CASE/208582
Confidentiality, copyright and reproduction	As per contract
UKCEH reference	NEC07206
UKCEH contact details	David N Carss UK Centre for Ecology & Hydrology Bush Estate, Penicuik, Midlothian EH26 0QB t: 0131 445 8473 e. dnc@ceh.ac.uk
Author	David N Carss
Approved by	Richard Pywell
Signed	R. Pywell
Date	4 June 2022

Contents

Summary

Background

Assessments using best available scientific evidence to assess the potential impacts of fish-eating birds on prey populations require information on diet, numbers and behaviour of birds, and population dynamics processes of both birds and their prey fishes. This study considers aspects of the diets of fish-eating birds in some Scottish salmon rivers.

UKCEH was commissioned by the Scottish Government to assess whether there was evidence of substantial changes in diets of Goosanders (*Mergus merganser*) and Cormorants (*Phalacrocorax carbo*) since the 1990s. Samples collected under scientific licence organised by the Scottish Government, NatureScot and Fisheries Management Scotland, were available from two times of year during 2019: 1st March - 31 May 2019 (the smolt run period, a so-called “spring” sample) and from 1st September 2019-29 February 2020 (the “autumn-winter” sample).

In total, four rivers were studied- the Aberdeenshire Dee, Nith, Tweed and Spey. A total of 180 birds were examined, 108 Goosanders and 72 Cormorants. Birds were sampled from a variety of locations throughout each river catchment and all sampling locations are detailed, alongside accompanying maps. The main parameters of interest were the estimated proportions (by mass and by number) of Salmon and other fish species in the stomach contents, and the estimated length frequencies of Salmon consumed.

Diet composition

During the smolt run period, the proportions of Salmon (by relative mass) in Goosander stomach contents from 2019 varied between each of the four rivers sampled: 50% (Dee), 36% (Spey), 16% (Nith), and 15% (Tweed). This broad latitudinal trend of higher dietary proportions of Salmon in birds from northern rivers is consistent with earlier work (Marquiss *et al*. 1998). There were insufficient data to make the same comparison for Cormorants, or for Goosander diets in autumn/winter.

Comparisons of diet between 2019 and 1990s were made in cases where at least 12 individual birds with stomach contents were sampled. Relative mass of Salmon in the diets of Goosanders in all four rivers in spring was broadly similar between the two sampling periods, as it was for a sample of birds from the Tweed collected during autumn/winter.

There was evidence that Minnow (*Phoxinus phoxinus*) was significantly more commonly recorded (by mass) in the spring Goosander diet on the Tweed in 2019 than in the 1990s. A similar trend was evident in spring Goosander samples from the Dee and Spey and in spring Cormorant samples from the Tweed. Three-spined Stickleback (*Gasterosteus aculeatus*) also comprised a greater mass by proportion in the Tweed spring goosander sample in 2019 than in those from the 1990s.

Inadequate numbers of Cormorants were available to ensure spring 2019 samples were representative of general diet in terms of the relative proportions (by mass) of the different prey species consumed. Adequate samples, available from the 2019-20 autumn and winter for the Nith and Tweed, contained high proportions (by mass) of Grayling (*Thymallus thymallus*) and adult Salmon, which along with large Trout (*Salmo trutta*) were also recorded in the smaller number of birds sampled from the Dee and Spey.

Salmon size distribution

As yet there is no way that Salmon smolts can be differentiated from parr in the partially digested remains of most fish in stomach contents of birds. Although this and previous research does not explicitly categorise individuals as either smolts or parr, “larger” Salmon greater than 89mm in length are considered more likely to be either smolts or parr prior to smoltification. In autumn- winter 2019-20, Salmon >90mm were frequently recorded in samples of Goosanders from the Dee, Spey, and to a lesser extent on the Tweed, and Salmon > 90mm were also common in the Tweed Cormorant samples. In spring 2019, Salmon >100mm were much scarcer than they had been in the 1990s in Goosander samples from the Dee and Tweed, and spring Cormorant samples for the Tweed. Goosanders and Cormorants are considered to be ‘generalist’ foragers, taking the most easily available (often most abundant) local prey items. The data presented are thus consistent with evidence from other Scottish rivers of a steady, long-term (1963-2003) reduction in mean river age, and hence size, for juvenile Salmon. The results also indicate that on all rivers where there were adequate samples, predation on pre-smolts by Goosanders and Cormorants during autumn and winter could influence the strength of the smolt run in the following spring, although further research is needed to confirm and quantify this.

1. Introduction

Throughout Europe there is often considerable concern about the potential impact of sawbill ducks Mergus spp. and the Great Cormorant (*Phalacrocorax carbo*, hereafter 'Cormorant') on stocks and catches of fish of commercial value (e.g. Marquiss & Carss 1994, Russell *et al*. 1996, Carss 2003, van Eerden *et al*. 2012). This also holds true for Scottish rivers, where Goosanders (*Mergus merganser*) and Cormorants, and Atlantic Salmon (*Salmo salar*) and Brown Trout (*S. trutta*) are the bird and fish species of most interest. This is more than purely biological, as there are world-renowned fisheries for these Salmonid species in Scotland and, hence, also considerable commercial interest. Angling and netting activities here are associated with 4,300 full-time jobs and contributed a total of £79.9 million to Scotland's economy in GVA, there are about 250 listed angling clubs across Scotland, and an estimated 125,000 river anglers (*An Analysis of the Value of Wild Fisheries in Scotland* (www.gov.scot).

Reviews in the past have concluded that there is generally a lack of unequivocal scientific evidence for the impact of piscivorous birds on fisheries (e.g. Carss in press), not necessarily because there is no impact, rather because impact is notoriously difficult to quantify (Carss *et al.* 2012). Furthermore, there are often limitations in the quality of available fish data, for example in terms of their abundance and behaviour particularly in deeper, wider sections of rivers, the vulnerability and responses of fish to predation in mainstems compared to tributaries (e.g. Marquiss *et al.* 1998, Carss *et al.* 1997, Wires *et al.* 2003). However, there are credible concerns that the potential for predation impact might well be exacerbated if a prey population is declining for other reasons. Such declines are certainly the case for Atlantic Salmon (hereafter 'Salmon') stocks in rivers in Scotland and elsewhere in Europe and Scandinavia (e.g. *SalmonBusiness* 2018, Ward & Hvidsten 2011).

Both Goosanders and Cormorants are so-called 'generalist' predators that appear to consume prey in relation to their abundance and availability in particular habitats, rather than being 'specialist' on particular prey species and/or specific foraging habitats. In certain places, at certain times of year, these birds undoubtedly prey upon juvenile Salmon (both parr and smolts) as reported in Marquiss et al.'s (1998) previous intensive research on these issues in Scottish freshwaters undertaken some 20 years ago. In the meantime, stocks of Salmon and European Eel (*Anguilla Anguilla*), both species eaten by these birds (Marquiss *et al*. 1998), have declined (e.g. Hindar *et al.* 2011 for Salmon, Correia *et al*. 2018 for Eel). The precise causes of these declines are unclear but include habitat loss, pollution, or overexploitation and changes in growth and survival, and in the distribution of predators or prey, often during the 'at sea' phase of the life- cycle and likely operating, to some degree at least, in a cumulative manner. There are thus likely to have been changes in the community structure of fishes in Scottish rivers in recent years and so it is timely to collect new comparative dietary information for two of the most abundant and widespread avian predators in these habitats.

Dietary analysis alone is insufficient to *quantify the consumption* of commercially important fish by birds. This would require site-specific data on (i) bird numbers, (ii) their daily food intake, and

(iii) dietary composition. Further, *demonstrating any impact* based on such a knowledge of fish consumption by birds is complicated by the numerous other biotic and abiotic factors interacting to affect fish populations (e.g. Carss *et al*. 2012) but teasing out the role of predation is likely, in turn, to require considerable site-specific data on the fish themselves (e.g. behaviour, age-structure, population dynamics, abundance, potential compensatory responses).

The present research does not set out to quantify the impact of these birds, but to document the diet of Goosanders and Cormorants, and make comparisons with previous work. Much of this research was undertaken during the International Year of the Salmon's (IYS) 5-year initiative (*Year of the Salmon.org)*. All of it was carried out against the background of possible changes in fish abundance and/or community structure in Scottish rivers and heightened concern over the decline of the nation's wild Salmon and the environmental and man-made pressures faced by this iconic and economically important species.

Four Scottish Salmon rivers were included in this research: the Nith, Tweed, Aberdeenshire Dee, and the Spey. The overall aim of the work was to derive the proportion (by mass and by number) of each fish species in the diet of Goosanders and Cormorants, collated in a form directly comparable (and equivalent) "*as contained in appendix 5.1 and 5.3, for Goosanders and Cormorants respectively*, of [Marquiss *et al.* 1998] the '*Fish-eating Birds and Salmonids in Scotland*' report published in November 1998 (ISBN 0 7480 7232 2)" (7.1 of contract requirements).

In the present study, a maximum of 36 Goosanders and 36 Cormorants with food in their stomachs were to be collected from each study river, with a minimum of 12 Goosanders and 12 Cormorants (with sufficient food in their stomachs) to be sampled during the smolt run period. Samples were collected under a scientific licence arranged between Marine Scotland, Scottish Natural Heritage (now NatureScot) and District Salmon Fishery Boards prior to the award of this contract. Arrangements were made to collect Goosander and Cormorant samples from the four study rivers in two periods:

(a) 1st March - 31 May 2019 - the smolt run period, and

(b) from 1st September 2019 – 29 February 2020

The latter period thus covered the autumn (Sep-Nov) and winter (Dec-Feb) and throughout the report information is generally presented separately for the smolt run period and the autumn/winter period.

2. Methods

Stomach contents analysis

Full details of the stomach contents analysis and diet assessment methodology used in the present study are given in **Appendix 1** and published sources (Marquiss *et al*. 1998 and references therein, Feltham 1990, Carss & Ekins 2002, Carss *et al.*, 1997).

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 birds. In Scotland (where the fish community comprises relatively few species) it has been concluded that 'adequate' estimates of Goosander and Cormorant diet (i.e. relative proportions of different prey species by mass) were possible from samples of 12-15 stomachs containing food (Marquiss & Carss, 1997). An important consideration for the present work was thus acknowledging that a sample of fewer than 12 stomachs with food is likely to be too small to ensure it is representative of general diet. The full process of carcase dissection and stomach contents analysis is described and illustrated in Carss *et al.* (2012) but is described briefly here.

After taking biometric measurements (**Appendix 2**), the body cavity of the bird was opened, following the digestive tract, down the length of the neck to the vent. Any whole, intact, undigested fish were removed, identified and measured (length, mass) whilst all remaining partially-digested material were carefully flushed out into a storage jar. A saturated solution of biological washing powder was added for a few days in a warm oven in order to digest all the remaining flesh from partially-digested fish. Then the contents of each jar were sieved and thoroughly rinsed with cold water before being air dried on filter paper for 1–3 days. There is no evidence that exposure to biological washing powder damages bones nor that air drying leads to significant shrinkage over periods of at least a few months.

The resulting dried prey remains were examined under a low power binocular microscope and 'key' bones identified to species level. These key bones included the atlas vertebra (for Salmonids), paired pharyngeal teeth (*Cyprinids*) and pelvic bones (3-Spined Stickleback), and other vertebrae and lower jaws (*dentaries*). Key bones were counted (as left/right pairs if necessary) and measured - bone lengths being converted to estimated fish lengths using regression equations, and estimated fish lengths to estimated fish mass, also with appropriate regression equations. Extremely well-digested - and hence heavily eroded and damaged - bones were excluded from analysis at this stage. Any data obtained from whole, intact, undigested fish were included with those determined from the examination of key bones from partially-digested material.

Ultimately, the minimum numbers of each fish species were recorded for each stomach and a cumulative total produced for each sample of birds. At its simplest, general diet can be assessed as the presence/absence of different prey species and presented as frequency of occurrence (e.g. 'percentage frequency' - the proportion of stomachs containing a particular species). Estimated prey fish body masses were summed for conspecifics in each sample of stomachs. Finally, the contribution each species makes to the total mass was calculated and presented as relative frequency for a particular sample.

Importantly, the material examined during this stomach analysis process was 'fresh', having usually been consumed no more than hours before birds were sampled. Whilst Goosanders and Cormorants have different digestive tracts, both digest fish quickly and in distinct stages.

Cormorants regurgitate an oral pellet each day and these contain the hardest, indigestible parts from prey, covered in mucus produced from the stomach lining. Consequently, any stomach contents found in Cormorants can only have been consumed in the previous 24 hours. Goosanders do not produce oral pellets but instead have a muscular proventriculus, often containing grit and small pebbles which help to grind prey items, thus aiding digestion and reducing the residence time of stomach contents. For both birds species, careful examination of any visibly damaged and/or eroded (i.e. well-digested) key bones from stomachs, and the exclusion of these from analysis, further ensures that diet assessments are tightly associated with the date of sampling. It is thus highly likely that such dietary assessments are derived from the prey consumed by birds on the day of sampling or possibly the previous day, but seldom – if ever – any longer ago than that.

Following Marquiss *et al*. (1998), general diet as assessed from stomach contents is reported here for each prey species in terms of (i) numbers, (ii) estimated mass, and (iii) frequency (% by mass). In Section 4, these data are tabulated and a graphical comparison is made (by river stretch and/or time of year) with any available relevant historical (1990s) samples from Marquiss *et al.* (1998). In Section 5, the estimated length frequency distributions for Atlantic Salmon (*Salmo salar*) from both the 2019 smolt run and autumn-winter 2019/20 sampling periods are compared with relevant historical data and with each other. It should be noted that historical fish length frequency distribution data were never digitised and so the length frequency comparisons presented here are limited to those still available for individual fish as hard copy.

Additional fish identification and biometrics methods

In addition to the published sources for diet assessment cited above, the bone to fish length and length:mass equations of Hájková *et al*. (2003) were used here for Grayling, and those of Britton & Shepherd (2005) for Gudgeon and the largest Minnows. To estimate the mass of the single (fresh, intact) Grey Mullet, the length:mass equation for Salmon was used, as this is a species of similar body shape. Throughout the report, any Salmonid more than 30cm in length was arbitrarily categorised as being “large” to differentiate it from juvenile individuals. Such fish were identified as either adult Salmon or large Trout (either resident, or migratory ‘Sea Trout’) where possible, based on the pattern of teeth on the vomer – with Trout having a well-developed double row of teeth and Salmon a less developed single row. Where species identification was not possible, fish were recorded as ‘large Salmonid’. The lengths of these large Salmonids were determined by averaging the length estimates derived from measurements of the atlas vertebra, lower jaw (dentary), and caudal vertebrae (cf. Carss & Brockie, 1994) and from direct measurements and comparison to the body proportions (i.e. tail to anterior edge of dorsal fin vs anterior edge of dorsal fin to snout) of the ingested fish and reference photographs of live Salmon. In one case, body length was estimated from the circumference of the caudal penduncle (Carss *et al.*, 1990).

Statistical methods and a note on presentation

The estimated Salmon length frequencies for different samples of birds (Section 5) were compared using the Kolmogorov-Smirnov test, adapted for data sets following discrete or mixed distributions (Arnold & Emerson 2011, Dimitrova *et al*. 2020). This is a non-parametric statistical analysis with a null hypothesis stating that there is no difference between the two length frequency distributions. The test has no restrictions on sample size and so small sample sizes are acceptable (Siegel & Castellan 1988). The test was chosen because it is distribution-free, adapted for discretised data with repeated measurements, and is applicable to data with bi/multi-modal distributions. The test statistics was specified by:

D = supx | F1 (x) – F2 (x)|

where F1 (x) is the empirical distribution function of the data samples from one sampling period and F2 (x) is the empirical distribution function of a second data sample.

Reported p-values were estimated by Monte Carlo simulations with 10,000 replicates, and those were then compared to the exact p-values obtained using the Fast Fourier Transform method (FFT). The threshold of probability was taken to be 0.05 and p-values (exact KS-FFT method) are presented. Full details of the methodology are given in Arnold & Emerson (2011) and Dimitrova *et al.* (2020), respectively. Tests were performed using the ks.test function in R (dgof library) and the disc_ks_test function in R (KSgeneral library).

Salmon length frequency distributions are presented graphically in three ways in Section 5. First, histograms of estimated length frequency (% by number) for 10mm length categories are given. Many of these show that the Salmon have bimodal or skewed length distributions, hence the need for non-parametric statistical testing as detailed above. Second, boxplots are presented to show the distribution of the length data, its skewness and non-Normality. For comparative samples of estimated Salmon lengths, these boxplots give median values (the middle value of the dataset), the 25th and 75th percentiles (medians of the lower and upper halves of the dataset, respectively) and the minimum and maximum estimated length values within a distance equal to the interquartile range x 1.5. The dots show the points that are beyond this distance. Finally, plots of empirical Cumulative Distribution Functions (ecdf) are presented for the estimated Salmon length frequency comparisons. These are plots of the distribution functions associated with the empirical Salmon length measurements for different samples. Length differences between samples are apparent from ecdf plots but they also provide some summary statistics. For example, Figure 1 is an ecdf plot of the proportions (Y-axis) of Salmon lengths (X-axis) for three annual samples and shows the proportion of fish with estimated lengths of 60mm or less was 45% in 2019, 19% in 1995, and 8% in 1996.

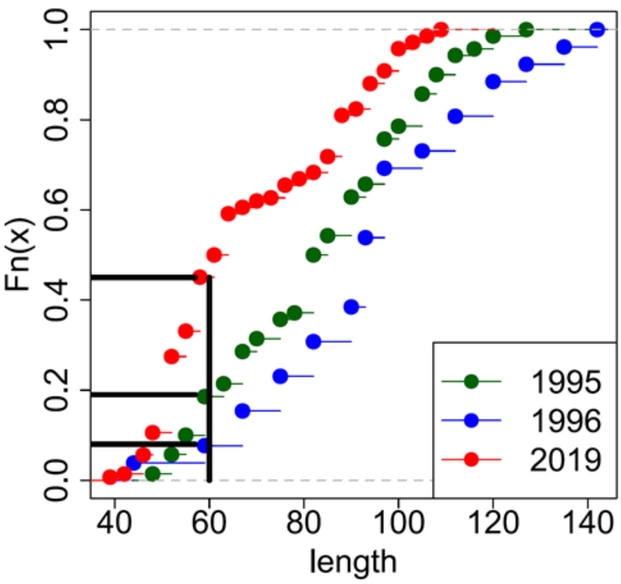


Figure 1. Plots of Empirical Cumulative Distribution Functions (ecdf) for the estimated Salmon lengths in the study year and two historical years. As an example of interpretation (see text), heavy black lines show the proportion of fish with estimated lengths of 60mm or less was 45% for 2019, 19% for 1995, and 8% for 1996.

Statistically, this ecdf plot is the distribution function associated with the empirical measure of a sample set against a cumulative probability on the Y-axis that ranges from 0 (0%) to 1.0 (100%) and with Salmon lengths on the X-axis sorted (left to right) from shortest to longest. The ecdf is a step function represented by a series of dots with tails. Each dot represents a (sorted) fish length with a tail extending to the right until the next (sorted) length is reached whereby the distribution steps up to this next point. The cumulative distribution function value at any specified point of the measured variable is the fraction of observations of the measured variable that are less than or equal to the specified point.

The ecdf is an empirical (step) function, where 'empirical' means that it represents the observed values and the corresponding data percentiles. The step function increases by a percentage equal to 1/"Sample size" for each observation in the data set. As an example, the 2019 season (Figure 1) has 142 observations and the step function increases by 0.007 for each observation. Thus, the probability of fish with length of 46mm or below would be 0.007 multiplied by 8 observations, which is 0.056 (or 5.6%).

Statistical analysis for stomach contents samples

For a limited number of samples, it was possible to investigate statistically any differences in diet assessments using K-S tests and following the same procedure as described above but comparing the estimated mass of each fish species recorded in each stomach that contained food.

Such data were recorded for all stomachs examined in the present study, although comparisons were limited by the numbers of stomachs containing food in each 'paired' seasonal sample. On occasion, Marquiss *et al.* (1998) made dietary comparisons (their p. 38) or estimated species 'intake rates' per 100g of food (their p. 54) based on samples of at least five or ten stomachs with food, respectively. Given this, in order to be able to include data from late autumn 2019, samples with 11 or more stomachs with food were deemed 'valid' in the following statistical analysis. Historical data in the required form (i.e. mass of each prey species per stomach with food) were only available for a single previous sample (Tweed Goosanders, April 1992, N = 55 birds containing food). Consequently, statistical comparisons of general diet were made between samples of Tweed Goosanders in the smolt run period 2019, spring 1992, autumn 2019, and both early and late autumn 2019 separately.

Within each sample of stomachs containing food, the mass of each fish species recorded will either be zero or a positive value, with zero values counting towards the total sample size for statistical tests. Simulation studies to understand what sample size and what number of positive values within a sample might be appropriate was outwith the scope of the present study. Therefore, a threshold sample size of five stomachs was chosen subjectively (D. Sadykova, pers. comm.) in order to reduce the 'uncertainty' of diet estimates for samples where a particular fish species is only recorded in a small number of stomachs. Thus, to increase confidence in the interpretation of the statistical tests, any samples of stomachs with records of a particular prey fish in none, or only 1, 2, 3, or 4 of them, were excluded from analysis.

As before, K-S tests are reported as D-statistics and p-values (KS-FFT method), and data are presented as boxplots and ecdf plots. For each fish species within a sample of birds, plots were determined from all stomachs containing food, and so they include zero values whenever a particular fish species was absent from a stomach. For boxplots, median values were calculated for the full sample of stomachs (including zero values) and so show the median estimated mass (g) of a particular fish species in any particular sample of birds. Statistical comparisons of the general diet estimates between pairs of samples could not be made if all of the stomachs in either sample contained no records of a particular species.

3. Samples

Samples: numbers of birds

In many instances, smaller numbers of birds were collected than the sampling protocol requested. The numbers collected are detailed below for (a) the smolt run period (Table 1), and (b) the following autumn-winter period (Table 2).

River	Species	Total	Empty	With food	Months
(1a) R. Dee	Goosander	20	1	19	Mar/May
(2a) R. Nith	Goosander	15	2	13	Apr/May
(3a) R. Tweed	Goosander	14	2	12	Apr/May
(4a) R. Spey	Goosander	15	2	13	Mar/Apr
(5a) R. Dee	Cormorant	0	0	0	-
(6a) R. Nith	Cormorant	6	3	3	Mar/Apr
(7a) R. Tweed	Cormorant	9	3	6	Apr/May
(8a) R. Spey	Cormorant	1	0	1	April

Table 1. The numbers of Goosanders and Cormorants sampled during the 2019 smolt run sample period in relation to river and bird species. Also included is the time period of sampling, the numbers of empty stomachs and those containing food.

River	Species	Total	Empty	With food	Months
(1b) R. Dee	Goosander	2	0	2	Nov
(2b) R. Nith	Goosander	10	0	10	Oct-Feb
(3b) R. Tweed	Goosander	24	0	24	Sep-Nov
(4b) R. Spey	Goosander	8	1	7	Sep-Dec
(5b) R. Dee	Cormorant	4	1	3	Dec-Jan
(6b) R. Nith	Cormorant	12	0	12	Nov-Feb
(7b) R. Tweed	Cormorant	27	3	24	Sep-Nov
(8b) R. Spey	Cormorant	13	5	8	Dec-Feb

Table 2. The numbers of Goosanders and Cormorants sampled during the autumn-winter 2019/20 period in relation to river and bird species. Also included is the time period of sampling, the numbers of empty stomachs and those containing food.

Samples: chronology

(1) Goosanders

During spring 2019, most Goosanders were sampled in April, with some in May, and a few in March. Later in the year, most Goosanders were sampled in the autumn (Sep-Nov) and relatively few in the winter (Dec-Feb). The monthly numbers of Goosanders collected throughout the study period is shown in Figure 2.

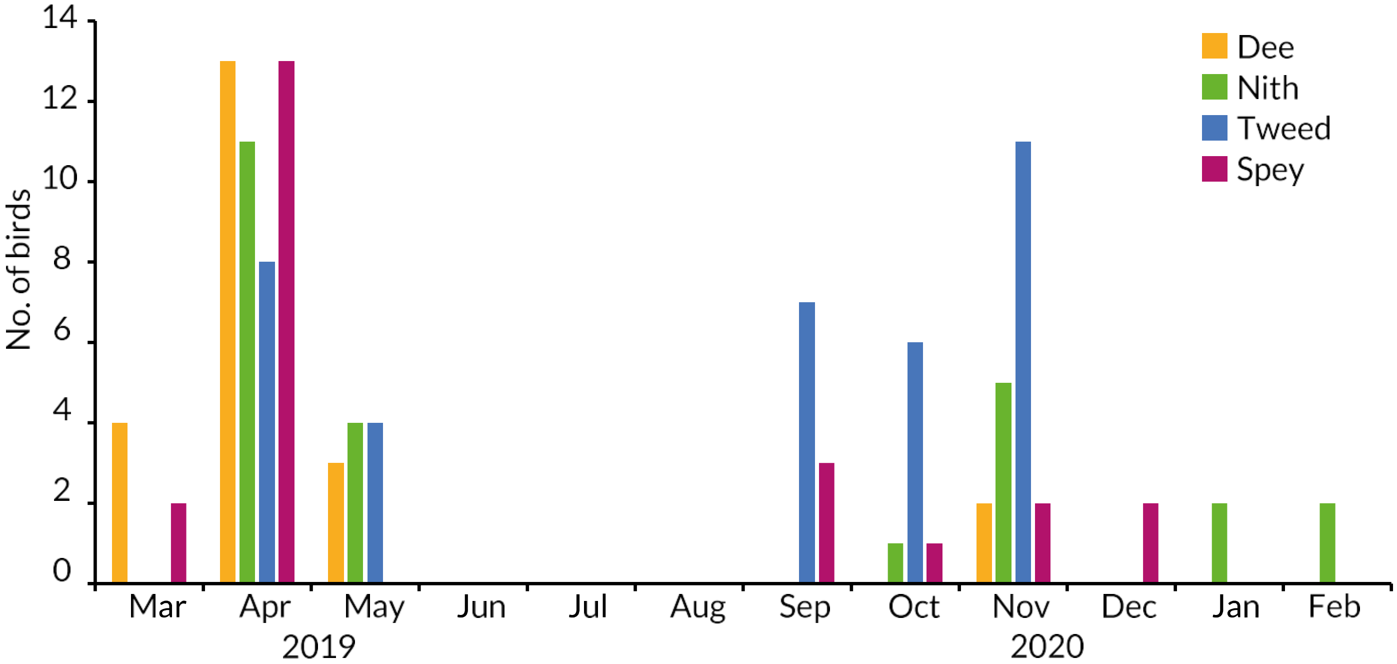


Figure 2. The monthly numbers of Goosanders sampled on each river during the study period (March 2019 - Feb 2020).

(2) Cormorants

During spring 2019, only a small number of Cormorants were sampled in April and in May. Later in the year, all R. Tweed Cormorants were sampled in the autumn (Sep-Nov), and most birds from other rivers were collected in the winter (Dec-Feb). The monthly numbers of Cormorants collected throughout the study period is shown in Figure 3.

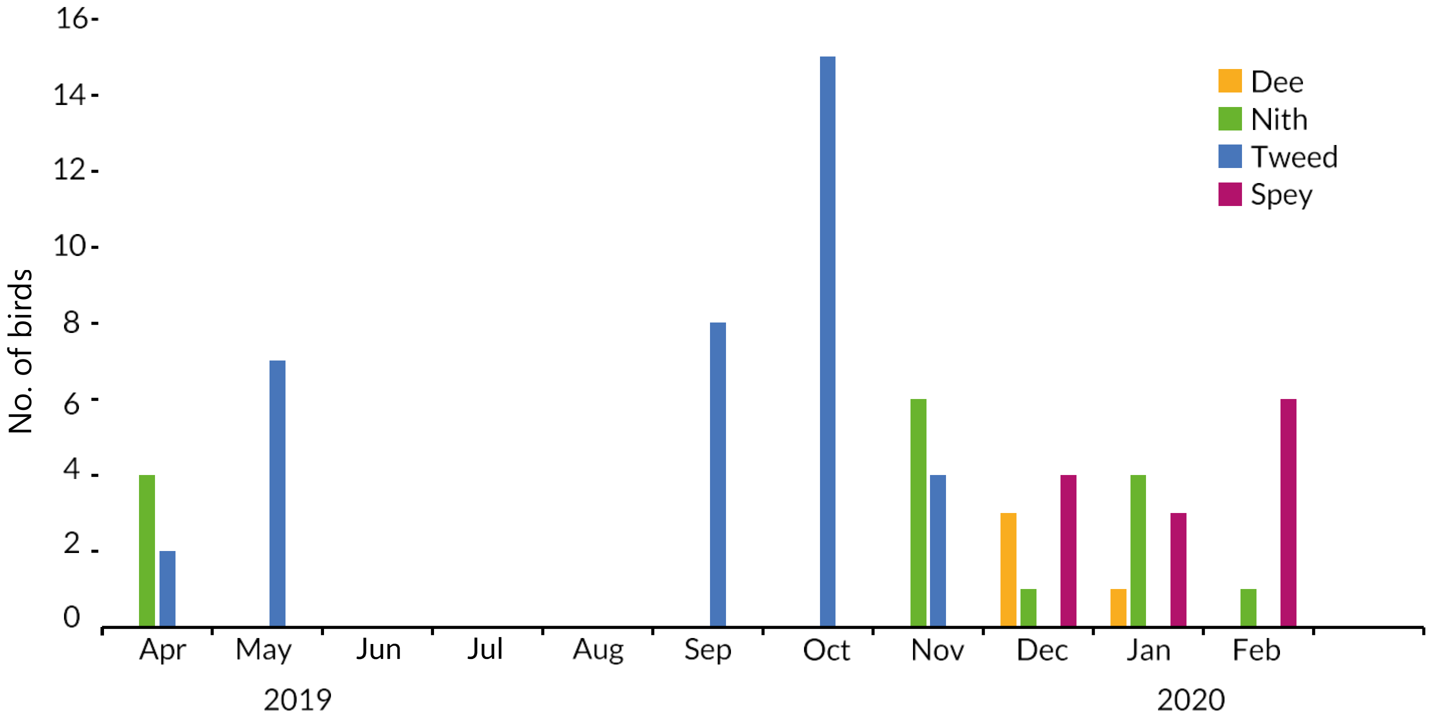


Figure 3. The monthly numbers of Cormorants sampled on each river during the study period (March 2019 - Feb 2020).

Full details of the chronology of samples received are given in **Appendix 3**.

Samples: location

In the lists below, the sampling locations (by fishing beat) are given in bold and ordered downstream to upstream, with any other available information in parenthesis. Fishing beats are also shown in maps for each study river (Figures 4 to 7).

(a) smolt run period

During spring 2019, Goosanders from the R. Dee were collected from **Lower Crathes, Woodend, Commonty** (Cattie Burn), **Sluie, Borrowston** (Sands Pool), **Dess**, and **Crathie** (Polmonier). Goosanders from the R. Nith came from **Cowhill, Blackwood** (including Auldgirth), **Barjarg** (including Cleughfoot), **Buccleuch**, and **Upper Nithsdale** (Dalpeddar). Goosanders from the R. Tweed were sampled from the **Lees, Lower Floors, Markestoun, Rutherford**, and **Bemersyde**. Those from the R. Spey were sampled at **Easter Echlies** (including Orn's Beat and Inverfiddich), **Pitchroy, Ballindalloch Tulchan** (B and D), and **Castle Grant**.

No Cormorants were sampled on the R. Dee in spring 2019. Birds from the R. Nith were taken from **Cowhill, Boatford** (Newhole), **Buccleuch** (**Lower**) (Doctor's Pool), and Buccleuch (Mid) (Whitehill). Cormorants from the R. Tweed came from the **Lees, Rutherford**, and **Bemersyde**, and the single Cormorant available from the Spey came from **Kinchurdy**.

(b)autumn-winter period

During the autumn winter 2019/20, Goosanders from the R. Dee were collected from **Lower Crathes** (including Greenbanks). Goosanders from the R.Nith came from **Dalswinton, Blackwood, Boatford** (including Kirkbog), **Buccleuch**, and **Buccleuch** (**Mid**) (including Whitehill). Goosanders from the R. Tweed were sampled from the **Lees, Hendersyde, Lower Floors, Markestoun** (**Upper and Lower**), **Middle Mertoun**, and **Bemersyde**. Those from the R. Spey were sampled at **Low Water** (**Groynes**), **Arndilly, Easter Elchies, Pitchroy**, and a single bird had no location provided.

Cormorants from the R. Dee were collected from only **Lower Crathes**. Cormorants from the R. Nith came from **Cowhill, Blackwood, Boatford** (Kirkbog), and **Buccleuch** (**Mid**) (Whitehill). Cormorants from the R. Tweed were sampled from **Ladykirk**, the **Lees, Hendersyde, Lower Floors, Rutherford, Middle Mertoun**, and **Bemersyde**. Those from the R. Spey were sampled at **Brae Water** (including Intake, Beat 5, Flats Pool), **Delfur, Arndilly, Easter Elchies** (including Inverfiddich), **Knockando Tulchan** (D), and **Kinchurdy**.

Full details of the locations of all samples received are given in **Appendix 3**.

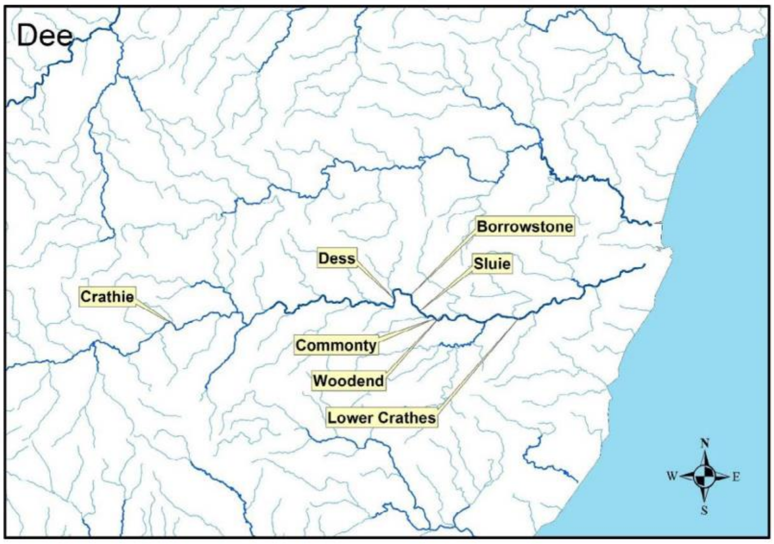


Figure 4. Map of the River Dee showing locations where samples were collected for inclusion in the present study.

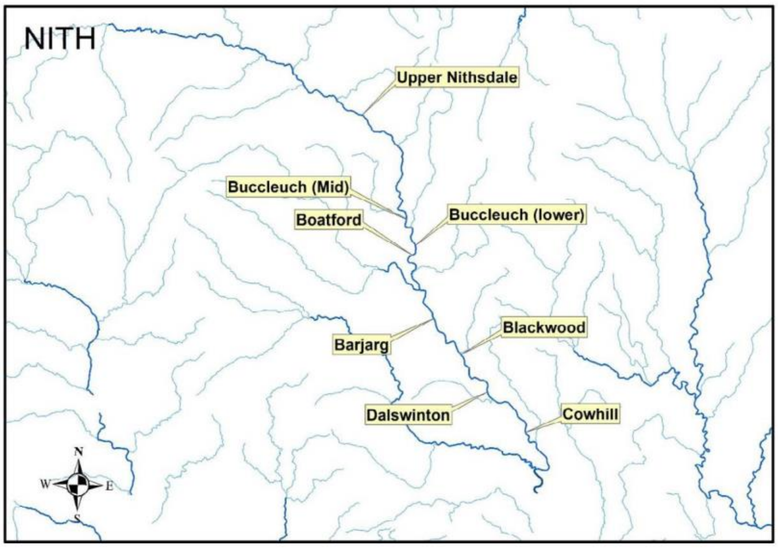


Figure 5. Map of the River Nith showing locations where samples were collected for inclusion in the present study.

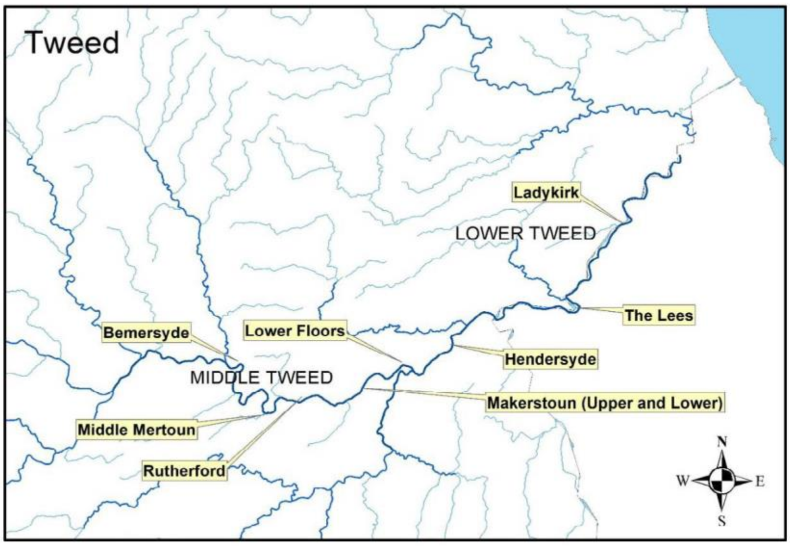


Figure 6. Map of the River Tweed showing locations where samples were collected for inclusion in the present study.

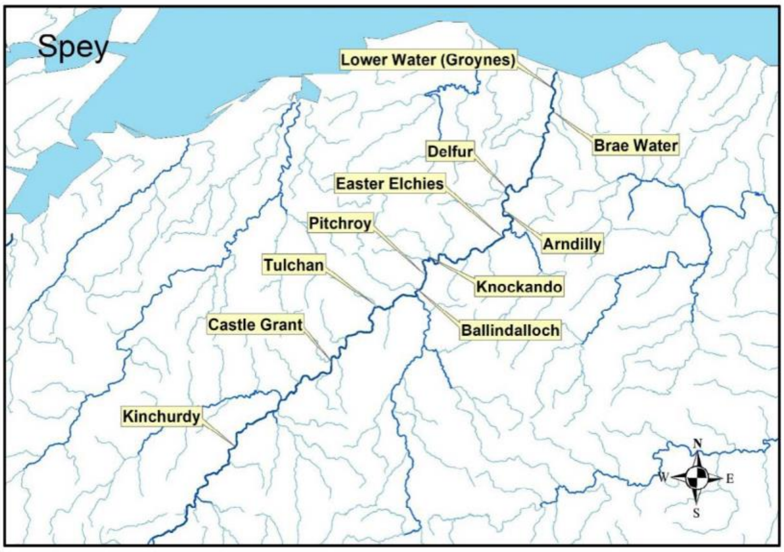


Figure 7. Map of the River Spey showing sampling locations for the present study showing locations where samples were collected for inclusion in the present study.

Comparable historical datasets (Marquiss *et al*. 1998)

(a) smolt run period

For the R. Tweed, knowledge of the sampling locations allowed comparison with specific stretches mentioned in Appendices 5.1 and 5.3 of Marquiss *et al.* (1998). All Goosanders sampled in spring 2019 were within the ‘Melrose-Coldstream’ section used by Marquiss *et al.* (1998). Comparable 1990s samples from this section of river were available for April 1991 (Appendix 5.1, table 22f), April 1992 (5.1, table 22p), April/May 1994 (5.1, table 22y), and April 1995 (5.1, table 22bb – which DNC found to be wrongly dated as ‘March’ in the original report). This same river section was also appropriate for the R. Tweed Cormorants and the relevant comparable samples were March/May 1994 (no locations given, 5.3, table 22i), and March/April 1995 (no locations given, 5.3, table 22j).

Previous analysis for the other rivers did not differentiate between specific river sections and so comparisons could only be made with samples collected in similar months. For R. Dee Goosanders, comparable samples were in March/April 1995 (Appendix 5.1, table 9f), and “spring” 1996 (5.1, table 9i). For R. Nith Goosanders, comparable data were March/April 1993 (5.1, table 17d), April 1994 (5.1, table 17e), and March/April 1995 (5.1, table 17f). For R. Nith Cormorants, only very broad comparisons could be made (because samples of birds were small) with February/April 1991 and March/April 1992 (Appendix 5.3, 14a and 14b, respectively). For
R. Spey Goosanders, comparable samples were April 1993 (Appendix 5.1, table 20a), March/April 1994 (5.1, table 20b), and April 1996 (5.1, table 20c), although only the latter sample was large enough to provide an adequate estimate of diet. Little meaningful comparison could be made for the single R. Spey Cormorant from 2019, samples from “spring” 1993 and March/April 1994 (Appendix 5.3, 19a and 19b, respectively) were relevant but samples of birds were again very small.

(b)autumn-winter period

Unlike the smolt run samples detailed above, only two possible comparisons could be made between the current autumn-winter 2019/20 samples and those from a similar period in earlier years (i.e. Tweed Goosanders, Tables 22[k] and 22[v] of Appendix 5.1 in Marquiss *et al*. 1998). This was because either no samples were available in most cases, or sample sizes were very small (i.e. three samples each with only 3-4 stomachs containing food).

4. Assessments of general diet

Monthly details of smolt run and autumn-winter period samples are show in Figures 2 and 3 and a full chronology is given in **Appendix 3**. The scientific names of all prey species are given in **Appendix 4**.

(a) Smolt run period

4a.1 River Dee Goosanders

Twenty carcases were available, 19 of them had stomach contents. Of these, all but one stomach contained Salmon (95%) and three quarters contained Trout (74%). Over half of stomachs contained Minnow (61%) and about a quarter contained 3-Spined Stickleback (28%). Two stomachs contained Eel (11%) and single stomachs each contained Lamprey and Pike (6% each, Table 3).

No. (%) of Goosander	Fish species	No. fish	Estimated mass (g)	% by mass
18 (95%)	Salmon	142	588	50
14 (74%)	Trout	44	313	26
12 (61%)	Minnow	161	176	16
2 (11%)	Eel	2	85	7
1 (6%)	Pike	1	15	1
5 (28%)	3-Spined Stickleback	22	7	<1
1 (6%)	Brook Lamprey	1	2	<1
N = 19 birds	**Totals**	**373**	**1186**	

Table 3. The diet of Goosanders (n = 19) from the R. Dee (March-May 2019) as determined by stomach contents analysis.

Comparisons with relevant historical samples (by time of year) from Marquiss *et al*. (1998) are given in Figure 8.

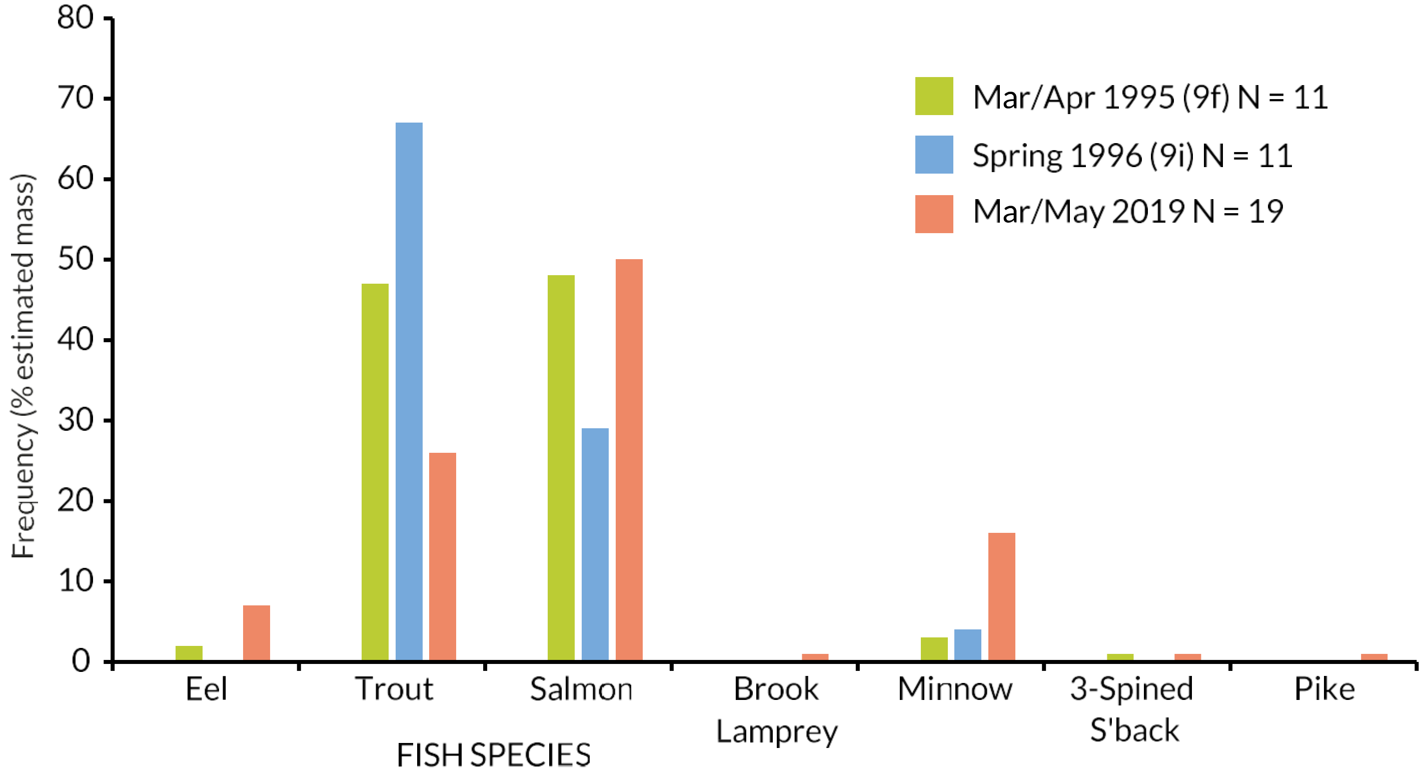


Figure 8. Diet comparisons for R. Dee Goosanders: smolt run sample period 2019 and three other broadly comparable samples (legend indicates relevant table numbers and sample sizes of stomachs with food from Appendix 5.1 of Marquiss *et al.* (1998).

4a.2 River Nith Goosanders

Fifteen carcases were available, 13 of them had stomach contents. Of these, all stomachs contained Stone Loach and most contained Minnow (92%), Trout and Salmon (85% each). Just under half of stomachs contained 3-Spined Stickleback (46%) and single stomachs contained Eel and Lamprey (8% each), Table 4.

No. (%) of	Fish species	No. fish	Estimated mass (g)	% by mass
11 (85%)	Trout	21	207	31
13 (100%)	Stone Loach	59	174	26
12 (92%)	Minnow	117	136	20
11 (85%)	Salmon	22	105	16
1 (8%)	Eel	2	36	5
1 (8%)	River Lamprey	1	7	1
6 (46%)	3-Spined Stickleback	9	3	<1
N = 13 birds	**Totals**	**231**	**668**	

Table 4. The diet of Goosanders (n = 13) from the R. Nith (April-May 2019) as determined by stomach contents analysis.

Comparison with relevant historical samples (by time of year) from Marquiss *et al.* (1998) are given in Figure 9.

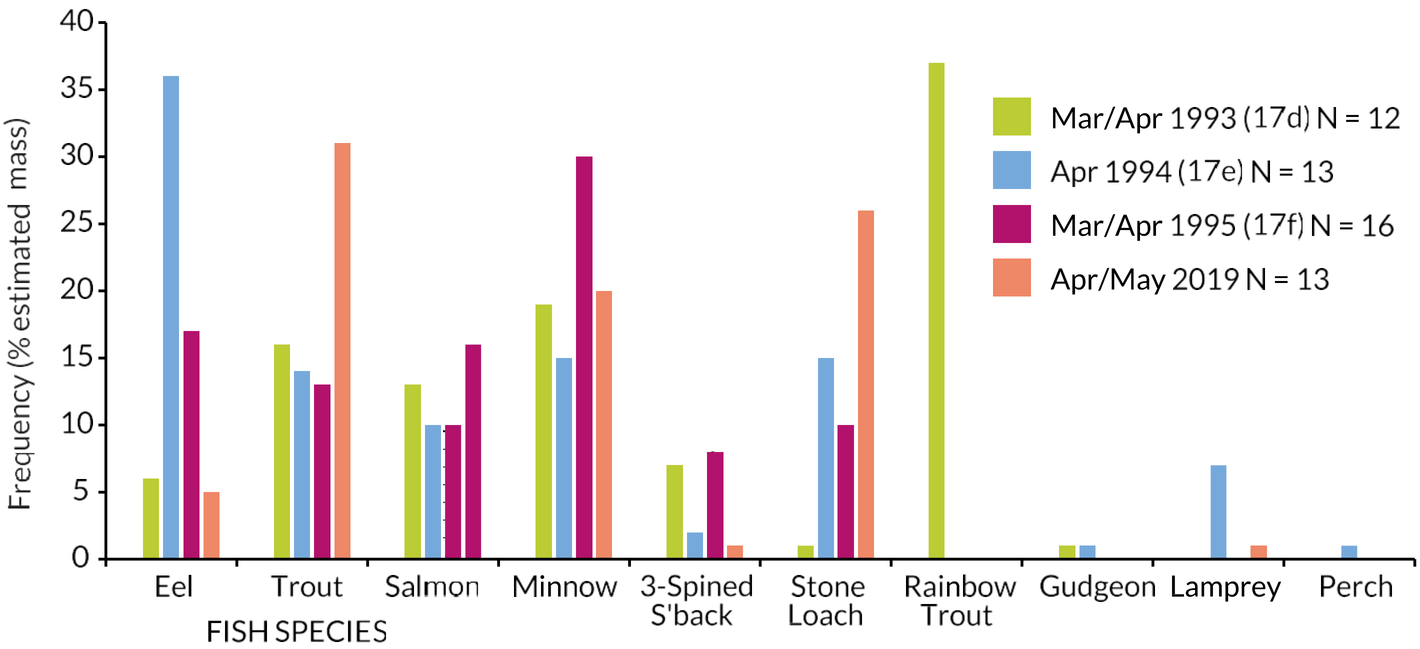


Figure 9. Diet comparisons for R. Nith Goosanders: smolt run sample period 2019 and four other broadly comparable samples (legend indicates relevant table numbers and sample sizes of stomachs with food from Appendix 5.1 of Marquiss *et al.* (1998).

4a.3 River Tweed Goosanders

Fourteen carcases were available, 12 of them had stomach contents. Of these, all stomachs contained Minnow, three-quarters contained Salmon (75%), and half contained Trout. Under half the stomachs contained 3-Spined Stickleback (42%), and around a third each contained Eel and Stone Loach (33% each, Table 5).

No. (%) of	**Fish species**	**No. fish**	**Estimated mass**	**% by mass**
12 (100%)	Minnow	155	305	38
4 (33%)	Eel	6	174	22
6 (50%)	Trout	15	147	19
9 (75%)	Salmon	21	120	15
5 (42%)	3-Spinedd Stickleback	45	26	3
4 (33%)	Stone Loach	5	22	3
N = 12 birds	**Totals**	**224**	**794**	

Table 5. The diet of Goosanders (n = 12) from the R. Tweed (April-May 2019) as determined by stomach contents analysis.

Comparison with relevant historical samples (by time of year) from Marquiss *et al*. (1998) are given in Figure 10.

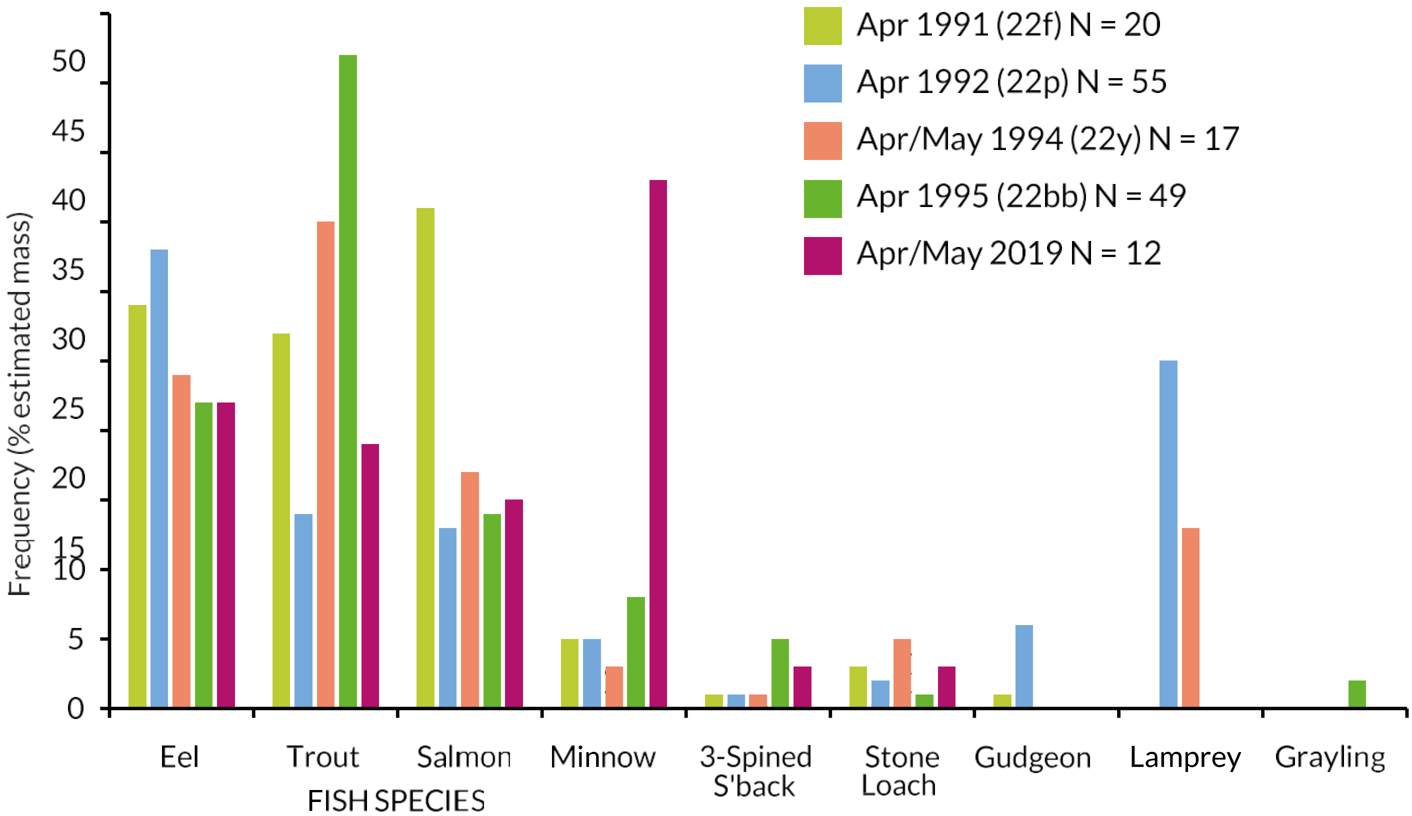


Figure 10. Diet comparisons for R. Tweed Goosanders: smolt run sample period 2019 and four other broadly comparable samples (legend indicates relevant table numbers and sample sizes of stomachs with food from Appendix 5.1 of Marquiss *et al*. (1998).

4a.4 River Spey Goosanders

Fifteen carcases were available, 13 of them had stomach contents. Of these, most stomachs contained Salmon (92%) and Trout (92%), just less than half contained Minnow (46%), just less than a third each contained Eel and 3-Spined Stickleback (31% each), and one stomach contained Lamprey (8%, Table 6).

No. (%) of Goosander	Fish species	No. fish	Estimated mass (g)	% by mass
12 (92%)	Trout	31	245	40
12 (92%)	Salmon	33	219	36
4 (31%)	Eel	4	87	14
4 (31%)	3-Spined Stickleback	42	34	6
6 (46%)	Minnow	32	27	4
1 (8%)	Brook Lamprey	4	3	<1
N = 13 birds		**146**	**615**	

Table 6. The diet of Goosanders (n = 13) from the R. Spey (March-April 2019) as determined by stomach contents analysis.

Comparison with relevant historical samples (by time of year) from Marquiss *et al.* (1998) are given in Figure 11.

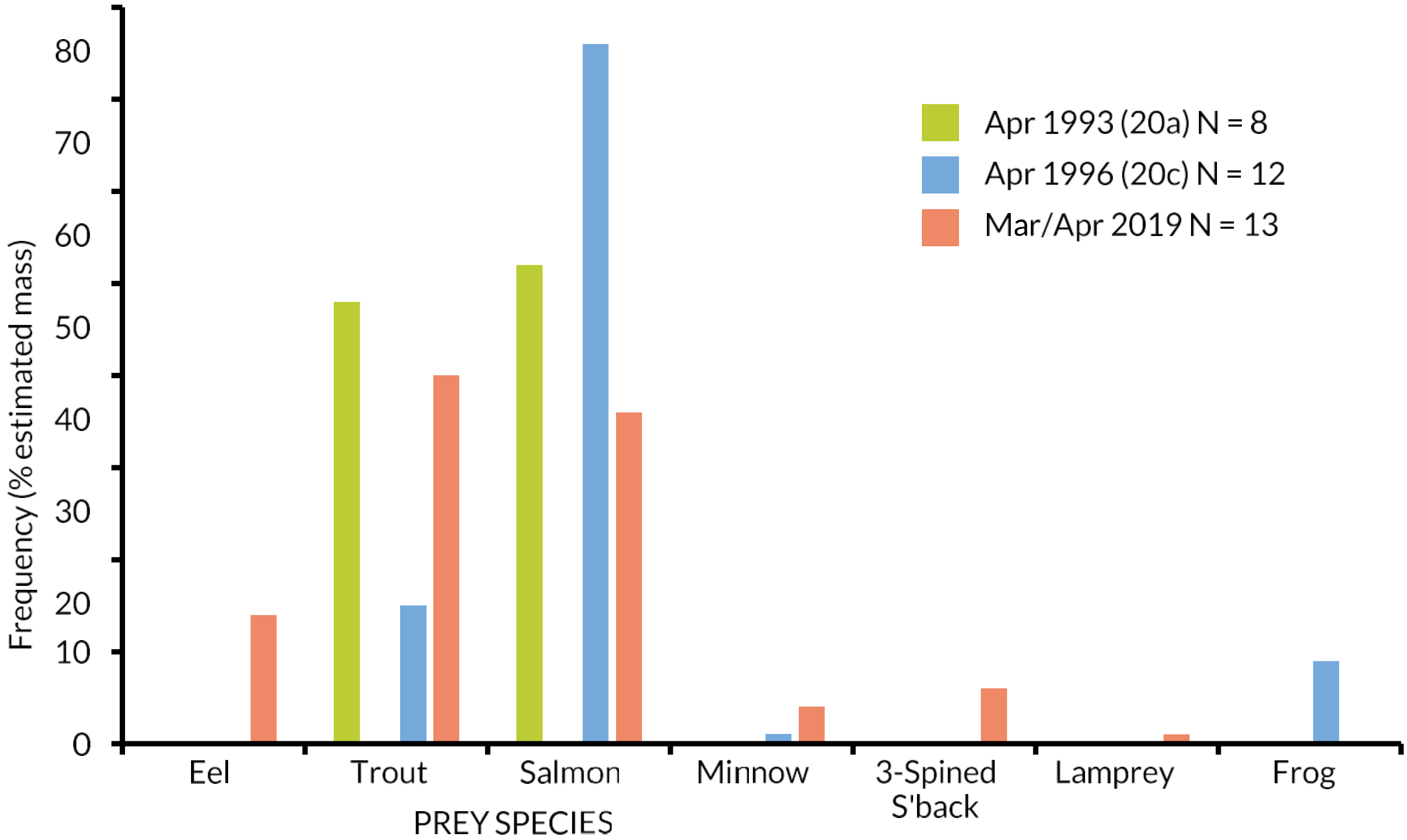


Figure 11. Diet comparisons for Spey Goosanders: smolt run sample period 2019 and three other broadly comparable samples (legend indicates relevant table numbers and sample sizes of stomachs with food from Appendix 5.1 of Marquiss *et al*. (1998).

4a.5 River Dee Cormorants

No birds sampled in spring 2019.

4a.6 River Nith Cormorants

March/April 2019

Six carcasses were available, one was likely to have regurgitated its stomach contents (only a single [32mm/0.3g] 3-Spined Stickleback was found in the gullet), and two were categorised as ‘empty’ containing only a few, very eroded bones (sea fishes in one stomach and probably a large Salmonid in the other). The remaining three stomachs with food contained:

3 Perch (42% by mass), 12 Trout (20%), 22 Salmon (19%), 1 unidentified Flatfish sp. (11%), 2 Grayling (6%), 1 Stone Loach (<1%), and 2 Minnow (<1%). All three stomachs contained Trout and Salmon, two stomachs contained Minnow (66%), and one stomach each contained Perch, Flatfish, Grayling, and Stone Loach (33% each).

Due to the constraints of small samples (current and historical), no comparison is possible with previous data.

4a.7 River Tweed Cormorants

April/May 2019

Nine carcasses were available, 6 of them had stomach contents. Of these, most contained Trout and Salmon (83% each), two-thirds contained Minnow, and single stomachs each contained Grayling and 3-Spined Stickleback (17% each, Table 7).

No. (%) of	Fish species	No. fish	Estimated mass (g)	% by mass
5 (83%)	Trout	27	323	45
5 (83%)	Salmon	39	289	40
4 (67%)	Minnow	41	71	10
1 (17%)	Grayling	1	42	6
1 (17%)	3-Sp Stickleback	2	1	<1
N = 6 birds	**Totals**	**110**	**726**	

Table 7. The diet of Cormorants (n = 6) from the R. Tweed (April-May 2019) as determined by stomach contents analysis.

Some samples of Cormorants with food from the R. Tweed were small (including the April/May 2019 one) and therefore too small to be sure they are representative of general diet. Nevertheless, the comparison with historical samples is of interest (Figure 12).

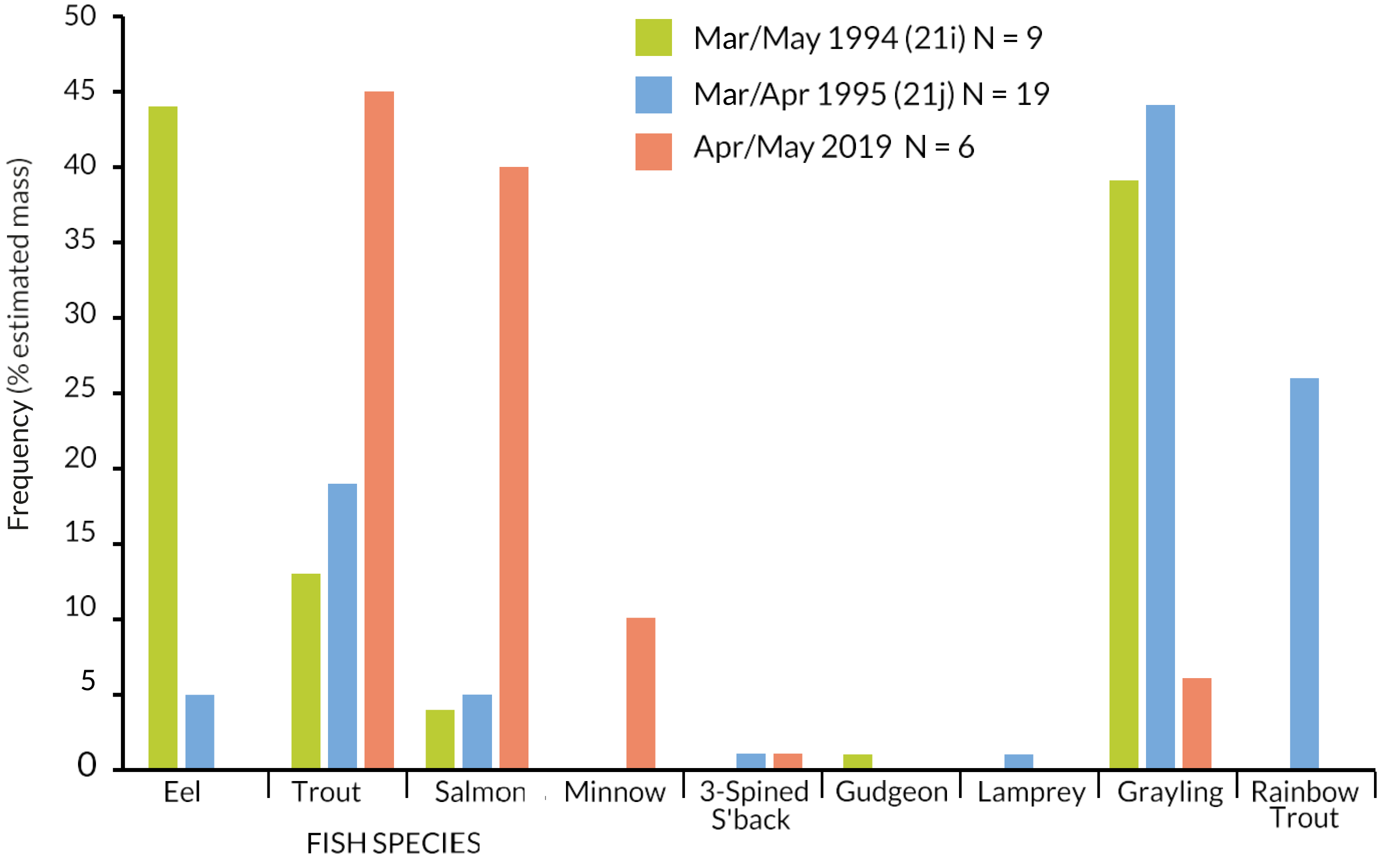


Figure 12. Diet comparisons for Tweed Cormorants: smolt run sample period 2019 and three other broadly comparable samples (legend indicates relevant table numbers and sample sizes of stomachs with food from Appendix 5.3 of Marquiss *et al*. (1998). Note: apart from the 1995 sample, others are too small to be sure they are representative of general diet.

4a.8 River Spey Cormorants

April 2019

One carcase contained:

1 Salmon kelt (estimated FL = 47.5cm, estimated wt. = 907g).

(b)Autumn-winter period

4b.1 River Dee Goosanders

Two carcases during autumn 2019, 2 with stomach contents contained:

33 Salmon (estimated mass 259g, 72% by biomass), 8 Trout (93g, 26%), and 3 Minnow (7g, 2%).
Both stomachs contained Salmon and Trout, one of them contained Minnow.

Due to the constraints of small samples (current and historical), no comparison is possible with previous data, including that from the 2019 smolt run period.

4b.2 River Nith Goosanders

Ten carcases during autumn-winter 2019/20 were available, 10 of them had stomach contents. Of these, all contained Trout and most contained Salmon (80%), followed by Minnow and 3-Spined Stickleback (70% each). Over half the stomachs contained Grayling (60%) under half contained Stone Loach (40%), and two contained Common Frogs (20%, Table 8).

No. (%) of Goosander	Fish species	No. fish	Estimated mass (g)	% by mass
10 (100%)	Trout	81	546	41
6 (60%)	Grayling	20	458	34
2 (20%)	Common Frog	3	111	8
8 (80%)	Salmon	11	98	7
7 (70%)	Minnow	74	54	4
4 (40%)	Stone Loach	10	37	3
7 (70%)	3-Sp Stickleback	64	25	2
N = 10 birds	**Totals**	**200**	**1329**	

Table 8. The diet of Goosanders (n = 10) from the R. Nith (October 2019/February 2020) as determined by stomach contents analysis.

Due to the constraints of small samples (current and historical), no comparison is possible with historical data. Although the autumn-winter stomachs containing food is <12, a comparison is nevertheless made with data from the 2019 smolt run period (presented in Table 4) in Figure 13.

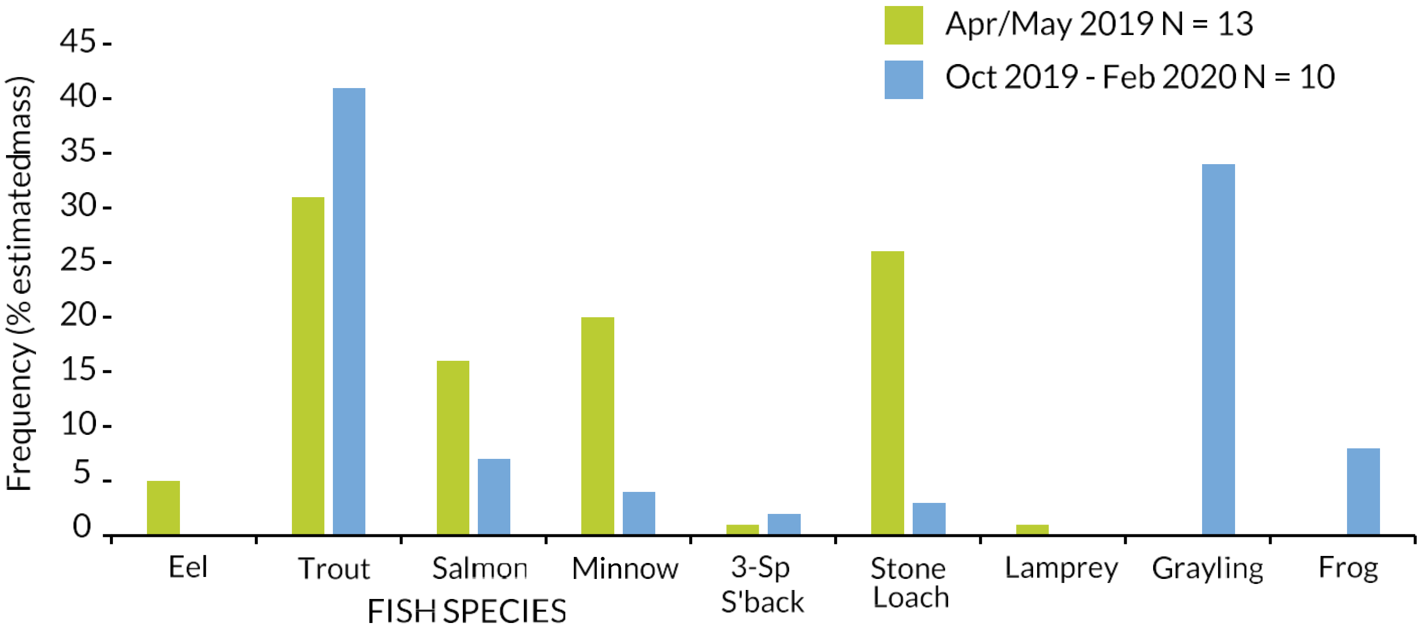


Figure 13. Diet comparisons for R. Nith Goosanders: smolt run sample period 2019 and subsequent autumn-winter (Oct 2019 – Feb 2020) sample (legend indicates sample sizes of stomachs with food).

4b.3 River Tweed Goosanders

Twenty-four carcases during autumn 2019 were available, 24 of them had stomach contents. Of these, almost three-quarters contained 3-Spined Stickleback, and rather fewer contained Minnow (62%), and Trout and Salmon (58% each). Fewer than a third of stomachs (29%) contained Grayling, even fewer contained Stone Loach (21%), and one stomach (4%) contained Flatfish (Table 9).

No. (%) of Goosander	Fish species	No. fish	Estimated mass (g)	% by mass
14 (58%)	Trout	37	699	40
7 (29%)	Grayling	18	606	34
14 (58%)	Salmon	36	229	13
5 (21%)	Stone Loach	22	99	6
17 (71%)	3-Sp Stickleback	177	75	4
15 (62%)	Minnow	40	47	3
1 (4%)	Flatfish	2	7	<1
N = 24 birds	**Totals**	**332**	**1762**	

Table 9. The diet of Goosanders (n = 24) from the R. Tweed (Sep/Nov 2019) as determined by stomach contents analysis.

Comparison with relevant historical samples (by time of year) from Marquiss *et al*. (1998) are given in Figure 14.

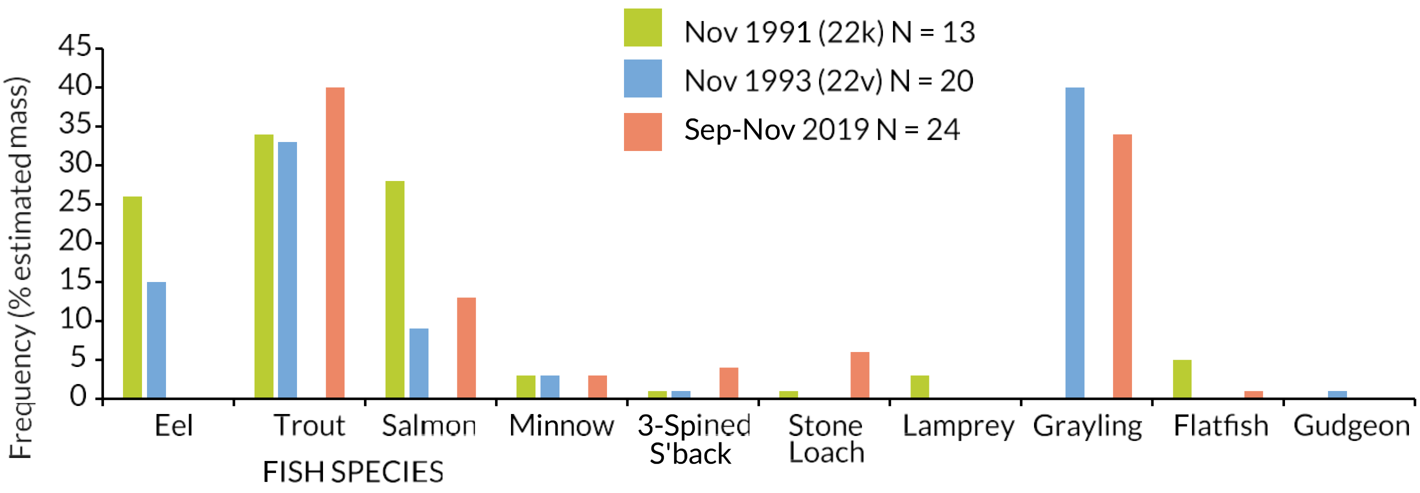


Figure 14. Diet comparisons for R. Tweed Goosanders: autumn sample period 2019 and two other broadly comparable samples (legend indicates relevant table numbers and sample sizes of stomachs with food from Appendix 5.1 of Marquiss *et al*. (1998).

For the sampling periods of the current study, it was also possible to compare the autumn diet of Goosanders on the R. Tweed with data from previous smolt run period (presented in Table 7) in Figure 15.

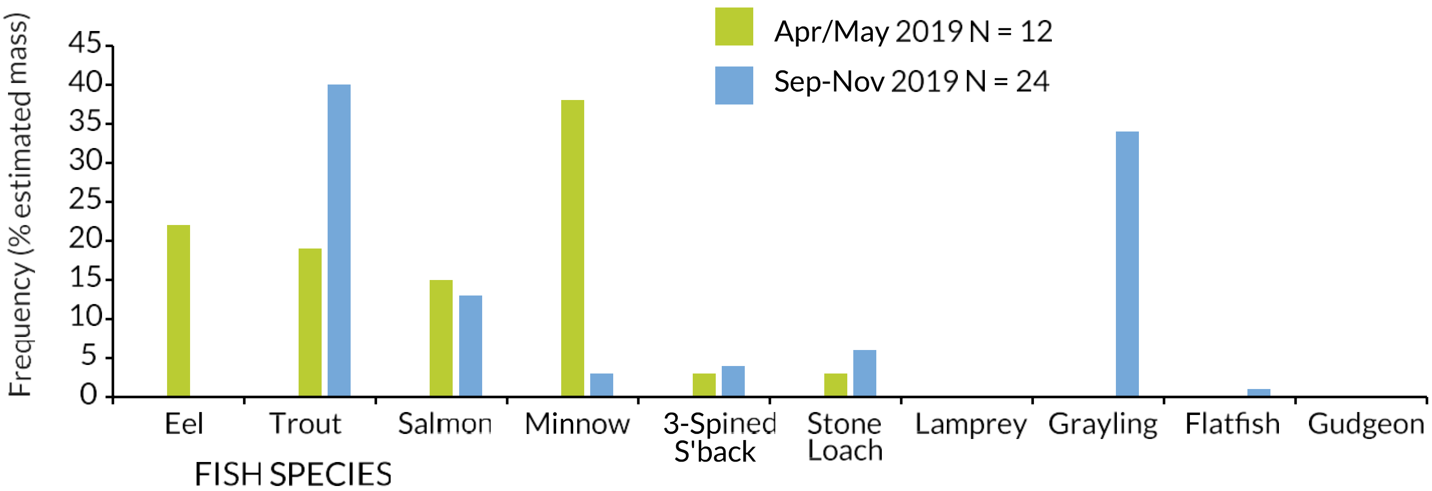


Figure 15. Diet comparisons for R. Tweed Goosanders: smolt run sample period 2019 and subsequent autumn (Sep-Oct 2019) sample (legend indicates sample sizes of stomachs with food).

Sample sizes of Goosanders from the R. Tweed were large enough in the current study to look for differences in diet between early and late autumn (Sep-Oct vs Nov 2019, respectively), as shown in Figure 16.

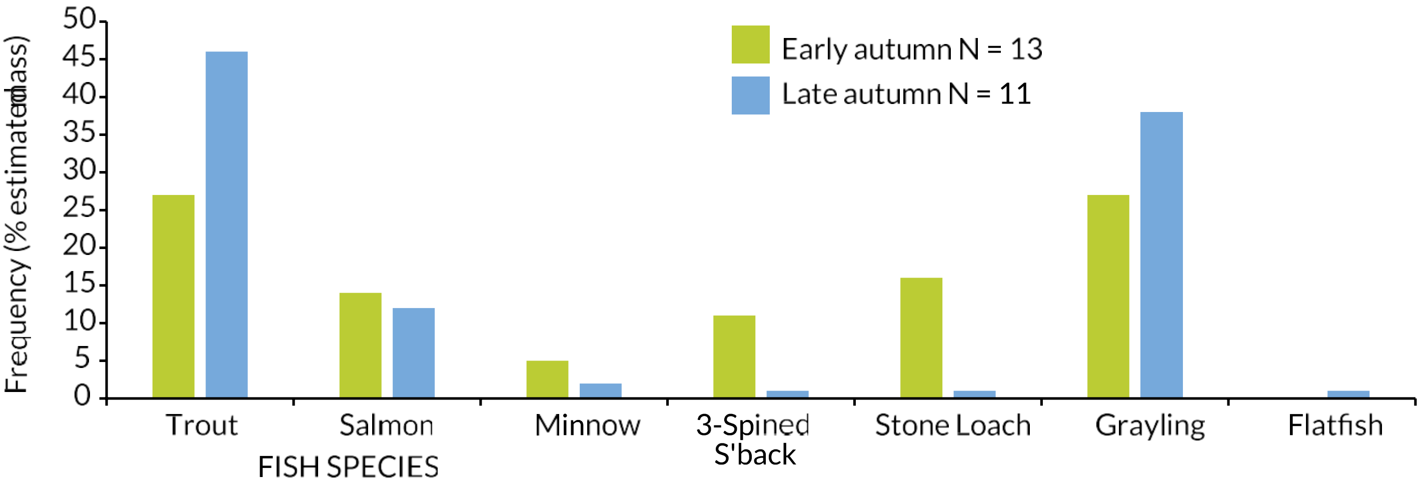


Figure 16. Diet comparisons for R. Tweed Goosanders: early autumn (Sep-Oct 2019) and late autumn (Dec 2019) samples (legend indicates sample sizes of stomachs with food).

4b.4 River Spey Goosanders

Eight carcases were available, 7 of them had stomach contents contained:

57 Salmon (estimated mass 450g, 64% by biomass), 23 Trout (240g, 34%), and 13 Minnow (17g, 2%). All stomachs contained Trout, most contained Salmon (89%), and around a third contained Minnow (29%, 2 birds).

Due to the constraints of small samples (current and historical), no comparison is possible with previous data, including that from the 2019 smolt run period.

4b.5 River Dee Cormorants

Four carcases during winter 2019/20 were available, 3 of them had stomach contents

contained: 1 adult Salmon (estimated mass 1020g, 60% by biomass), and 2 Pike (668g, 40%).

One stomach contained an adult Salmon and the other two each contained a single Pike.

Due to the constraints of small samples (current and historical), no comparison is possible with previous data, including that from the 2019 smolt run period.

4b.6 River Nith Cormorants

Twelve carcases during autumn-winter 2019/20 were available, 12 of them had stomach contents. Three quarters of stomachs contained Grayling and most contained Minnow (58%). Half the stomachs contained Trout and Salmon, and a third contained 3-Spined Stickleback and adult Salmon. Single Rainbow Trout, Grey Mullet, and Stone Loach were each found in one stomach (8%, Table 10).

No. (%) of Cormorants	Fish species	No. fish	Estimated mass (g)	% by mass
4 (33%)	Adult Salmon	4	1748	37
9 (75%)	Grayling	48	1599	34
6 (50%)	Trout	22	753	16
1 (8%)	Rainbow Trout	1	432	9
6 (50%)	Salmon	8	111	2
7 (58%)	Minnow	24	54	1
4 (33%)	3-Sp Stickleback	21	8	<1
1 (8%)	Grey Mullet	1	8	<1
1 (8%)	Stone Loach	1	3	<1
N = 12 birds	**Totals**	**130**	**4716**	

Table 10. The diet of Cormorants (n = 12) from the R. Nith (Nov 2019/Feb 2020) as determined by stomach contents analysis.

Due to a lack of historical samples and a small sample from the 2019 smolt run period, no comparisons are possible with previous data.

4b.7 River Tweed Cormorants

Twenty-seven carcases during autumn 2019 were available, 24 of them had stomach contents. Most stomachs contained Trout (58%) and just over half contained 3-Spined Stickleback. Just less than half of the stomachs contained Salmon and Minnow (46% each) or Grayling (42%). A single large Salmonid, adult Salmon, large Trout, Flatfish, and Gudgeon were each found in one stomach (4%, Table 11). Due to a lack of historical samples, no comparisons are possible with previous data.

No. (%) of Cormorants	Fish species	No. fish	Estimated mass (g)	% by mass
14 (58%)	Trout	35	1292	26
1 (4%)	Large Salmonid	1	1020	20
1(4%)	Adult Salmon	1	694	14
10 (42%)	Grayling	20	572	11
1 (4%)	Large Trout	1	481	10
11 (46%)	Minnow	215	446	9
11 (46%)	Salmon	26	401	8
1 (4%)	Flatfish	1	108	2
13 (54%)	3-Sp Stickleback	54	18	<1
1 (4%)	Gudgeon	1	18	<1
N = 24 birds (100%)	**Totals**	**355**	**5050**	

Table 11. The diet of Cormorants (n = 24) from the R. Tweed (Sept/Nov 2019) as determined by stomach contents analysis.

For the sampling period of the current study, it was possible to compare the autumn diet of Cormorants on the R. Tweed with data from the previous smolt run period (presented in Table 6), as shown in Figure 17. However, any interpretation must be made with caution as the latter sample (n = 5 stomach with food) is likely to be too small to be representative of general diet.

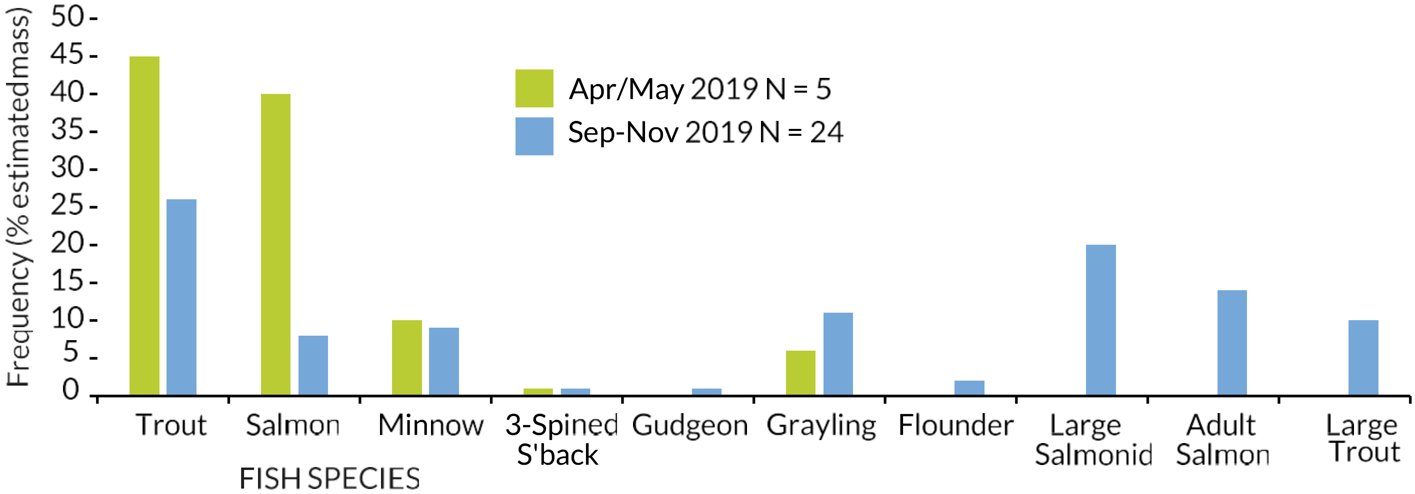


Figure 17. Diet comparisons for R. Tweed Cormorants: smolt run sample period 2019 and subsequent autumn (Sep-Oct 2019) sample (legend indicates sample sizes of stomachs with food). Note the sample size in April/May is likely to be too small to be representative of general diet.

Sample sizes of Goosanders from the R. Tweed were large enough in the current study to look for differences in diet between early and late autumn 2019 (Sep-Oct vs Nov, respectively), as shown in Figure 18.

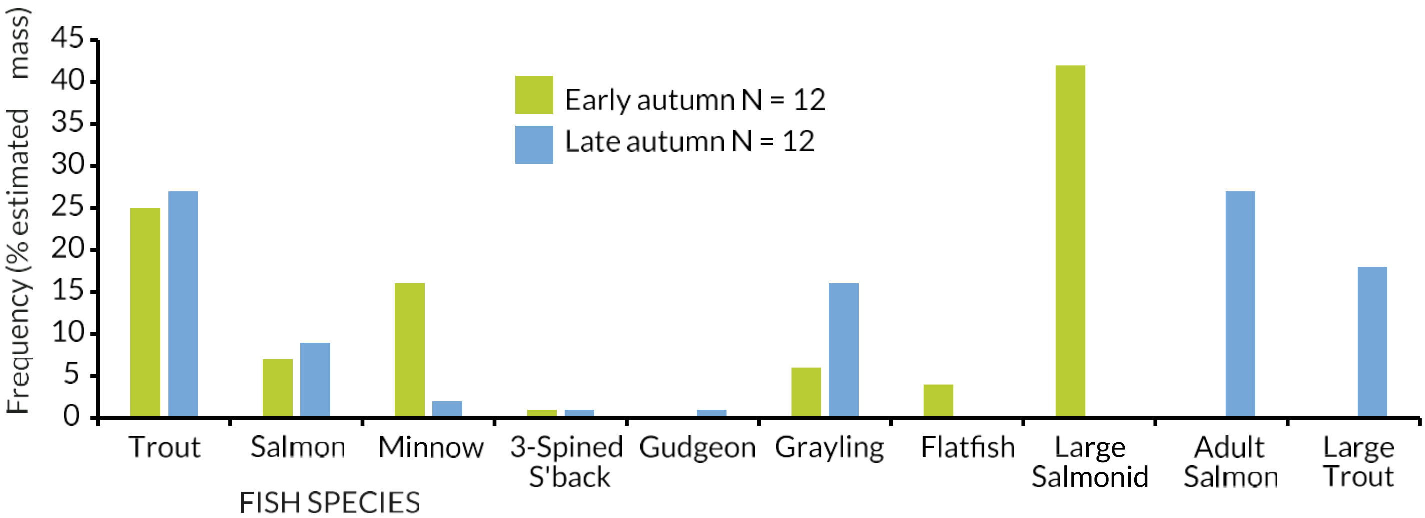


Figure 18. Diet comparisons for R. Tweed Cormorants: early autumn (Sep-Oct 2019) and late autumn (Dec 2019) samples (legend indicates sample sizes of stomachs with food).

4b.8 River Spey Cormorants

Thirteen carcases during winter 2019/20 were available, 8 of them had stomach contents contained:

7 large Trout (estimated mass 4856g, 59% by biomass), 2 adult Salmon (2245g, 27%), 1 large Salmonid (1148g, 14%), 1 Salmon (7g, <1%), and 1 Minnow (3g (<1%). Most stomachs contained large Trout (88%), two (25%) contained adult Salmon, and single stomachs (12.5%) each contained a single large Salmonid, Salmon, and Minnow.

Due to the constraints of small samples (current and historical), no comparison is possible with previous data, including that from the 2019 smolt run period.

(c) Statistical analysis for some stomach contents samples

For a limited number of samples, it was possible to investigate statistically any differences in diet assessments (using K-S tests as described in section 2) with the dietary data under comparison being the estimated mass of each fish species recorded in each stomach that contained food. Historical data in the required form (i.e. mass of each prey species per stomach with food) were only available for a single previous sample (Tweed Goosanders, April 1992, N = 55 birds containing food). Consequently, statistical comparisons of general diet were made between samples of Tweed Goosanders in the smolt run period 2019, spring 1992, autumn 2019, and both early and late autumn 2019 separately.

Statistical comparisons between pairs of samples could not be made if all of the stomachs in either sample contained no records of a particular species: this was the case for Lamprey, Gudgeon, Flatfish and Grayling. Statistical comparisons were possible for one of the pairs of Eel samples and some of the Stone Loach ones but none were significant. In this necessarily restricted analysis, significant dietary differences were found for Salmon, Trout, Minnow, and 3-Spined stickleback (Table 12).

Tweed Goosander		**Salmon**		**Trout**		**Minnow**		**3-Sp s'back**	
Sample1	Sample2	D	p	D	p	D	p	D	p
April 1992	Apr/May 2019	0.24	0.24	0.11	0.87	0.72	**1.9e-7**	0.27	0.03
Apr/May 2019	Autumn 2019	0.17	0.37	0.21	0.13	0.71	**6.3e-13**	0.29	0.01
Apr/May 2019	Autumn 2019 E	0.37	**0.02**	0.13	0.64	0.76	**1.0e-8**	0.35	0.02
Apr/May 2019	Autumn 2019 L	0.20	0.51	0.47	**3.8e-3**	0.75	**4.8e-7**	0.24	0.17

Table 12. Comparisons (D-statistics, KS-FFT p-values) between general diet assessments for a variety of Tweed Goosander samples in different seasons, details of which are given for either Sample 1 or 2. Statistically significant differences are highlighted. The large Autumn 2019 sample could be split in to an early (E) and a late (L) one. The only biologically meaningful comparison that could be made with the April 1992 sample was with that from the same time of year (Apr/ May) in 2019.

Salmon

The only significant difference for the Salmon component of the Tweed Goosander diet samples was between those from Apr-May 2019 and early Autumn 2019 (Table 12).

Boxplots for the mass (g) of Salmon in stomachs for the Tweed Goosander samples are shown in Figure 19a and ecdf plots in Figure 19b. As can be seen in the boxplots, the Salmon component of the diet in the Apr-May 2019 sample had a median mass of 5.5g, higher than the median mass of the early Autumn 2019 sample which was 0g.

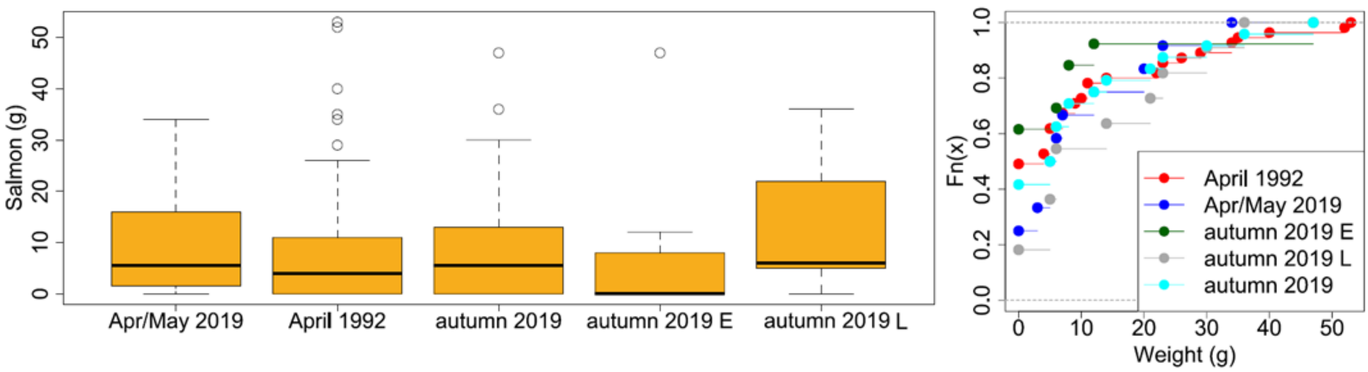


Figure 19. Boxplots for the mass of Salmon from the stomach contents of R. Tweed Goosanders from various samples (a, left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (b, right). Further sample details in text, note on boxplot presentation in Methods.

Trout

The only significant difference for the Trout component of the Tweed Goosander diet samples was between those from Apr-May 2019 and late Autumn 2019 (Table 12).

Boxplots for the mass (g) of Trout in stomachs for the Tweed Goosander samples are shown in Figure 20a and ecdf plots in Figure 20b. As can be seen in the boxplots, the Trout component of the diet in Apr-May 2019 sample had a median mass of 3g, lower than the median mass of the late Autumn 2019 sample which was 46g (see also Figure 15).

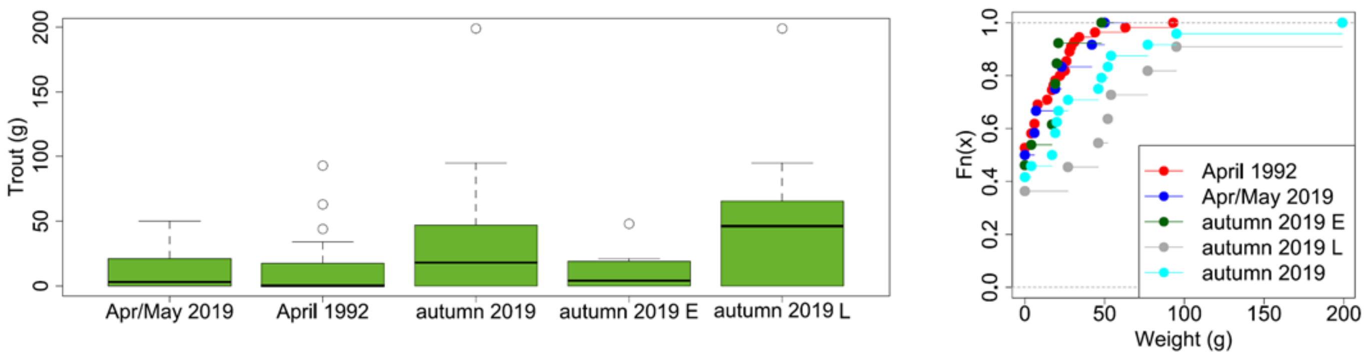


Figure 20. Boxplots for the mass of Trout from the stomach contents of R. Tweed Goosanders from various samples (a, left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (b, right). Further sample details in text, note on boxplot presentation in Methods.

Minnow

There were significant differences for the Minnow component of the Tweed Goosander diet samples for all comparisons (Table 12).

Boxplots for the mass (g) of Minnow in stomachs for the Tweed Goosander samples are shown in Figure 21a and ecdf plots in Figure 21b. As can be seen in the boxplots, the Minnow component of the diet in the Apr-May 2019 sample had a median mass of 22.5g, higher than the median mass of the April 1992 sample which was 0g (see also Figure 10), and of the Autumn 2019 sample when it was 1g (see also Figure 15), as it was in both early and late autumn samples.

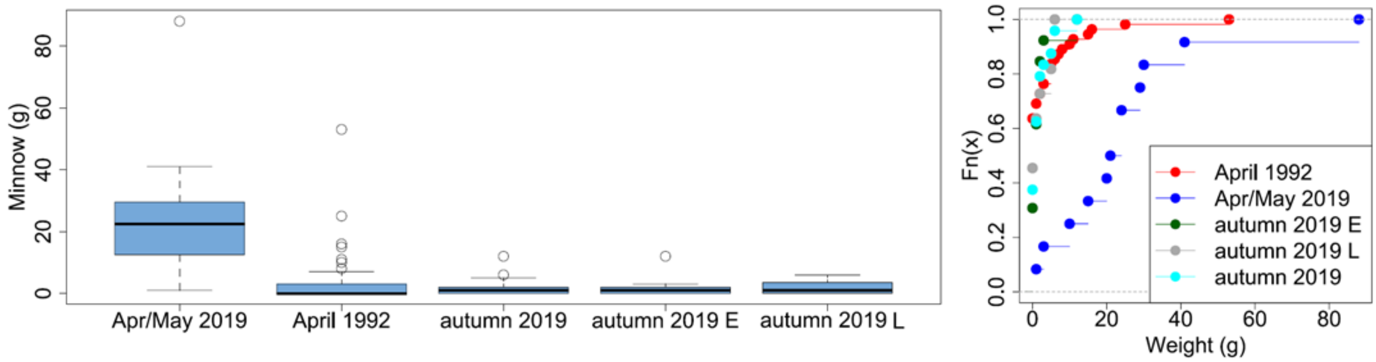


Figure 21. Boxplots for the mass of Minnow from the stomach contents of R. Tweed Goosanders from various samples (a, left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (b, right). Further sample details in text, note on boxplot presentation in Methods

3-Spined stickleback

There were three significant differences for the 3-Spined stickleback component of Tweed Goosander diet samples (Table 12).

Boxplots for the mass (g) of 3-Spined stickleback in stomachs for the Tweed Goosander samples are shown in Figure 22a and ecdf plots in Figure 22b. As can be seen in the boxplots, the 3-Spined stickleback component of the diet in both the smolt run period 2019 and April 1992 samples had a median mass was 0g, the median mass in Autumn 2019 was 1g, and in early autumn 2019 sample it was 2g.

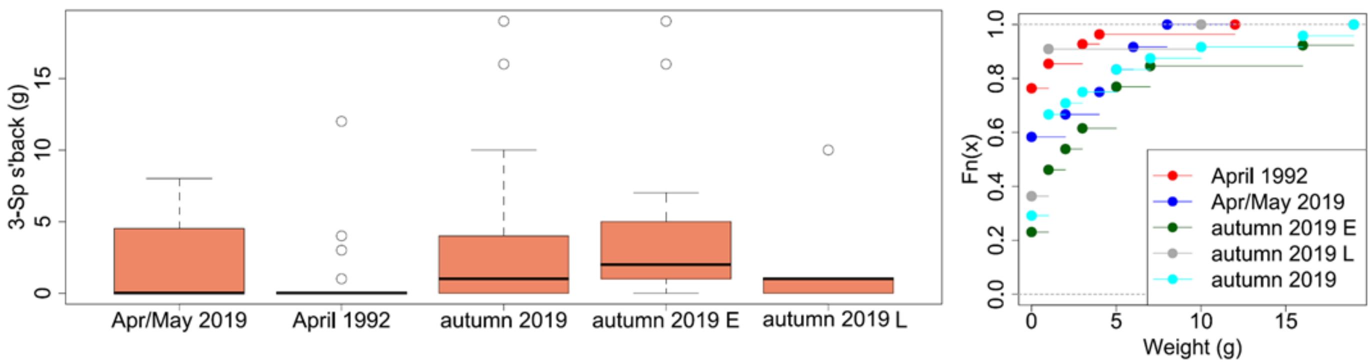


Figure 22. Boxplots for the mass of 3-Spined stickleback from the stomach contents of R. Tweed Goosanders from various samples (a, left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (b, right). Further sample details in text, note on boxplot presentation in Methods

(d) Broad summary: proportions of Salmon in the diet

Overall, samples for the two bird species on each of the four study rivers, collected over two time periods (the smolt run and autumn-winter), give a total of 16 samples (Table 13). However, three 'samples' (3/16 = 19%, indicated in red in Table 13) were void, either because there were no birds sampled (N/a) or no Salmon were recorded in those birds that did contain food (None).

Fewer than half of these samples (7/16 = 44%, indicated in green in Table 13) were large enough to be confident that they were representative of general diet (i.e. at least 12 stomachs with food, Marquiss & Carss, 1997). This proportion was highest for diet assessments during the smolt run period for Goosanders from all study rivers, and the autumn-winter period for both Goosanders and Cormorants from the R. Tweed, and Cormorants from the R. Nith. Some dietary information was available for the remaining samples (6/16 = 38%, indicated in amber in Table 13) and, although samples were small, it appeared to follow the patterns described below for other samples.

From Table 13, the proportions of Salmon in Goosander stomach contents from the smolt run period sample were highest from the Dee (50% by mass), followed by the Spey (36%), Nith (16%), and Tweed (15%). At this time of year, Salmon comprised the highest proportion of diet by mass on the Dee, and the second highest after Trout (36%) on the Spey. On the Nith and Tweed, four species were taken in higher proportions than Salmon (Trout, Stone Loach, Minnow on the Nith; Minnow, Eel, Trout on the Tweed).

Proportions of Salmon were low in the autumn-winter samples of Tweed Goosanders (13% by mass) and Cormorants (8%), and of Nith Cormorants (2%). In none of these samples were Salmon the main species in the diet by mass. Two species (Trout, Grayling) were taken in higher proportions by Tweed Goosanders, six others (Trout, large Salmonid, adult Salmon, Grayling, large Trout, Minnow) by Tweed Cormorants, and four others (adult Salmon, Grayling, Trout, Rainbow Trout) by Nith Cormorants.

Clearly, Cormorant diet in autumn-winter was often dominated by large Salmonids – presumably adult Salmon and Trout around the spawning period. In general, apart from the Dee sample in the spring and those (albeit with small sample size) from the Dee and Spey in autumn, the proportions of Salmon in Goosander stomach contents in either the smolt run or autumn-winter periods were not particularly high, and Salmon seldom comprised the highest proportion of the diet, other species often being consumed in larger proportions by mass. The same was true for the two autumn-winter Cormorant samples from the Tweed and Nith.

River and bird species	Smolt run period		Autumn-winter period	
	Proportion of Salmon in diet assessment			
	By mass	**In relation to other species**	**By mass**	**In relation to other species**
Dee Goosander	50%	Highest proportion	72%	Highest proportion
Nith Goosander	16%	4th after Trout, Stone Loach, Minnow	7%	4th after Trout, Grayling, Common
Tweed Goosande	15%	4th after Minnow, Eel, Trout	13%	3rd after Trout, Grayling
Spey Goosander	36%	2nd after Trout	64%	Highest proportion
Dee Cormorant	N/a	-	None	-
Nith Cormorant	19%	3rd after Perch, Trout	2%	5th after adult Salmon, Grayling, Trout, Rainbow Trout
Tweed Cormorant	40%	2nd after Trout	8%	7th after Trout, large Salmonid, adult Salmon, Grayling, large Trout, Minnow
Spey Cormorant	None	-	1%	4th after large Trout, adult Salmon, large Salmonid

Table 13. The estimated proportion of Salmon in the diet assessments of 16 samples of Goosanders and Cormorants from four study rivers in the smolt run and autumn-winter periods 2019/20. For each sample, the proportion of Salmon in the diet by percentage biomass and in relation to other prey items is given.

Samples of 12 or more stomachs with food
Samples with fewer than 12 stomachs with food
Samples with either no birds or no Salmon

5. Estimated Salmon length frequencies

(a) Smolt run period

Not all historical length frequencies for Salmon were available and so comparisons were made between the current smolt run period samples from spring 2019 and those from similar times of year in 1991, 1995 and 1996 (see Table 14).

River	Bird species	Sample date	No. Salmon	Fish length:
Dee	Goosander	Mar/May 2019	142	39 - 109
		Spring 1996	26	44 – 142
		Mar/Apr 1995	70	48 – 127
Nith	Goosander	Mar/May 2019	22	52 – 112
		Mar/Apr 1995	17	52 – 127
Tweed	Goosander	Apr/May 2019	21	64 – 148
		April 1995	56	52 – 142
		April 1991	44	72 - 144
Spey	Goosander	Mar/Apr 2019	33	52 – 133
		April 1996	41	36 – 127
Tweed*	Cormorant	Apr/May 2019	39	70 – 112
		Mar/Apr 1995	19	59 – 142

Table 14. Descriptive statistics for Salmon recovered from fish-eating birds in relation to sample river, bird species and sampling date. For each sample, values are given for the numbers of Salmon recorded and the range of estimated fork lengths (mm). *Note: although numbers of Salmon recorded from Tweed Cormorants in Apr/May 2019 are reasonable, these come from a small number of stomachs (N = 5) and so may not be representative.

5a.1 River Dee Goosanders

Salmon from the 2019 R. Dee Goosander sample were significantly smaller than those recorded from the spring 1996 sample (K-S test, D = 0.45, P = 1.26e-13). These Salmon from the 2019 R. Dee Goosander sample were also significantly smaller than those recorded from the Mar-Apr 1995 sample (K-S test, D = 0.32, P = 1.12e-13).

The frequency distributions of the estimated Salmon lengths for these three Dee Goosander samples are shown in Figure 23, boxplots for them in Figure 24a, and ecdf plots in Figure 24b. As can be seen in the boxplots, Salmon in the stomachs of Dee Goosanders in 2019 had a median length of 63mm, the median length of the Mar-April 1995 sample was 2cm longer at 83mm, and that for the spring 1996 sample was 3cm longer at 93mm.

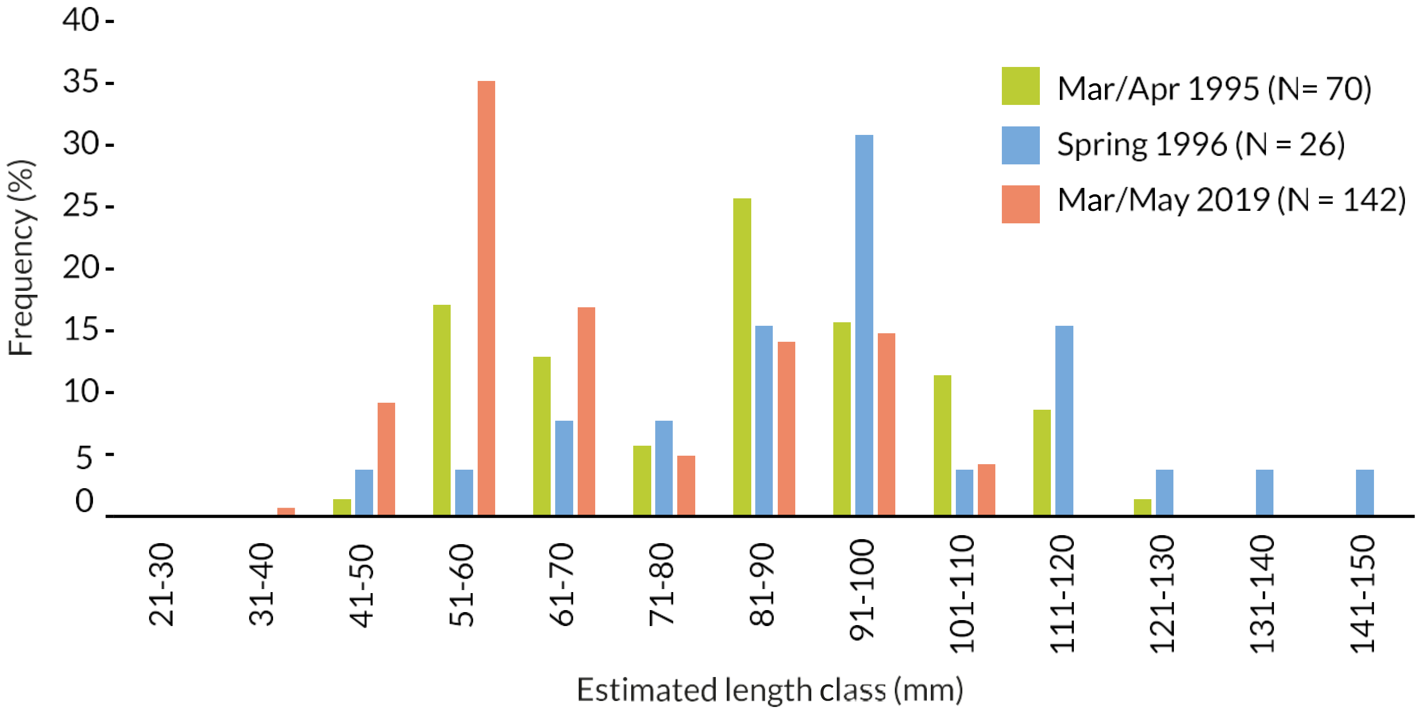


Figure 23. Estimated Salmon length frequency distribution from the stomach contents of R. Dee Goosanders: smolt run sample period 2019 and two other broadly comparable samples (legend indicates date of sampling and number of Salmon for each sample).

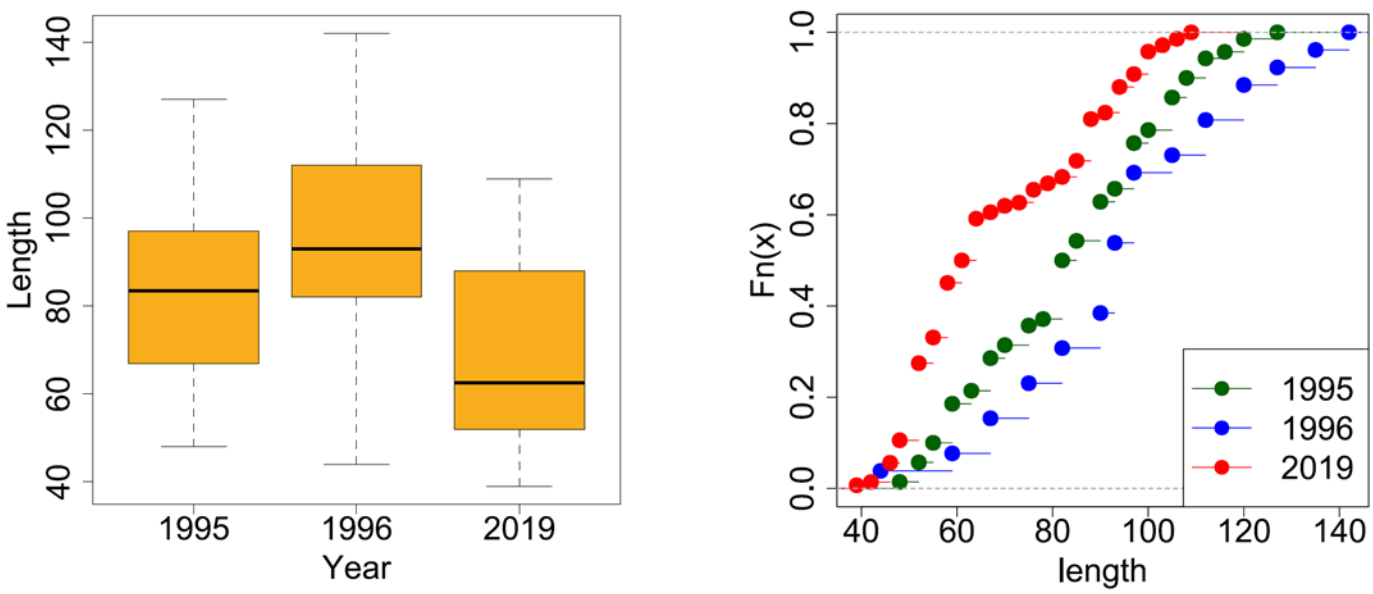


Figure 24. Boxplots for the estimated Salmon lengths from the stomach contents of R. Dee Goosander smolt run sample period 2019 and two other broadly comparable samples (a, left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (b, right). Further sample details in Figure 23, note on boxplot presentation in Methods.

5a.2 River Nith Goosanders

Salmon from the 2019 R. Nith Goosander sample were not significantly different in length to those recorded from the Mar-Apr 1995 sample (K-S test, D = 0.17, P = 0.21).

The frequency distributions of the estimated Salmon lengths for these two Nith Goosander samples are shown in Figure 25, boxplots for them in Figure 26a, and ecdf plots in Figure 26b. As can be seen in the boxplots, Salmon in the stomachs of Nith Goosanders in 2019 had a median length of 70mm, the median length of the Mar-April 1995 sample was 0.5cm longer at 75mm.

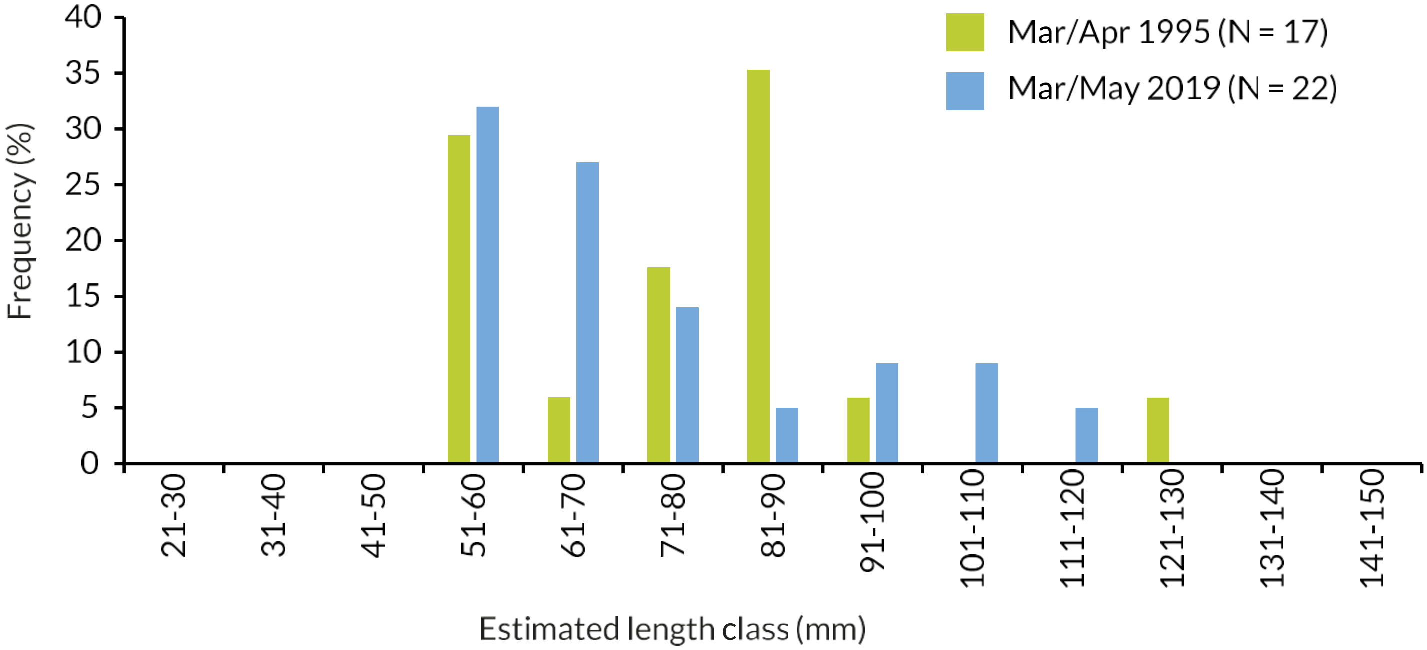


Figure 25. Estimated Salmon length frequency distribution from the stomach contents of R. Nith Goosanders: smolt run sample period 2019 and another broadly comparable sample (legend indicates date of sampling and number of Salmon for each sample).

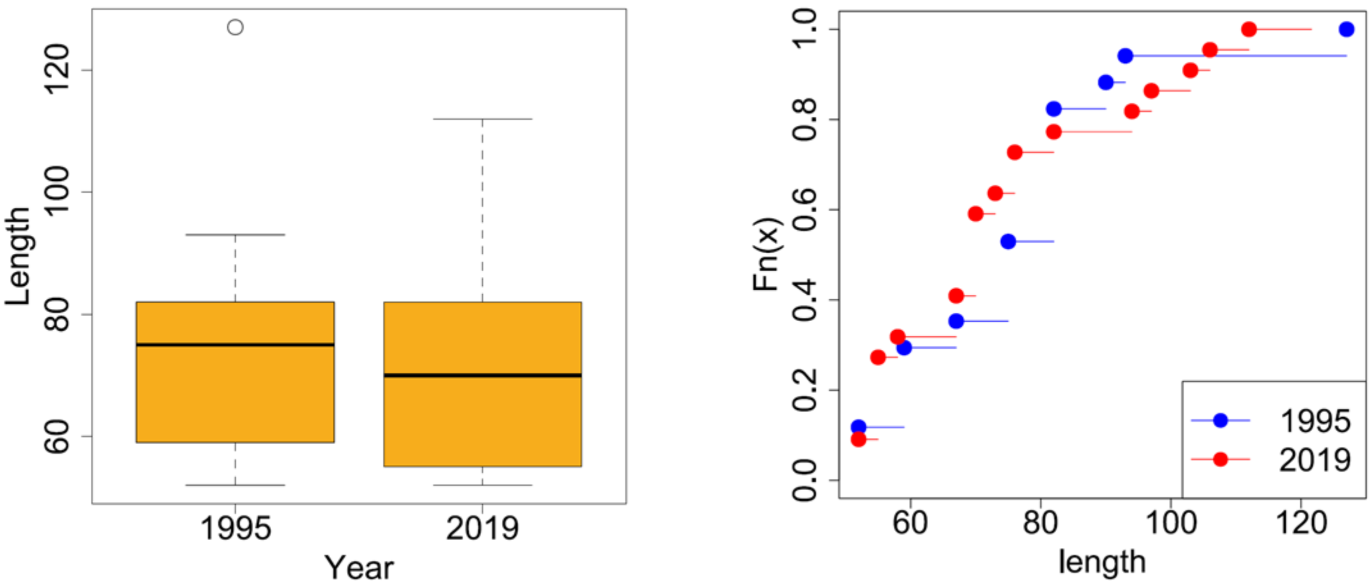


Figure 26. Boxplots for the estimated Salmon lengths from the stomach contents of R. Nith Goosander smolt run sample period 2019 and another broadly comparable sample (left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (right). Further sample details in Figure 25, note on boxplot presentation in Methods.

5a.3 River Tweed Goosanders

Salmon from the 2019 R. Tweed Goosander sample were not significantly different in length than those recorded from the April 1995 sample (K-S test, D = 0.20, P = 0.20). These Salmon from the 2019 R. Dee Goosander sample were however significantly smaller than those recorded from the April 1991 sample K-S test, D = 0.48, P = 6.96e-06).

The frequency distributions of the estimated Salmon lengths for these three Tweed Goosander samples are shown in Figure 27, boxplots for them in Figure 28a, and ecdf plots in Figure 28b. As can be seen in the boxplots, Salmon in the stomachs of Tweed Goosanders in 2019 had a median length of 79mm, the median length of the April 1995 sample was 3mm longer at 82mm, and that for the April 1991 sample was 2.5cm longer at 104mm.

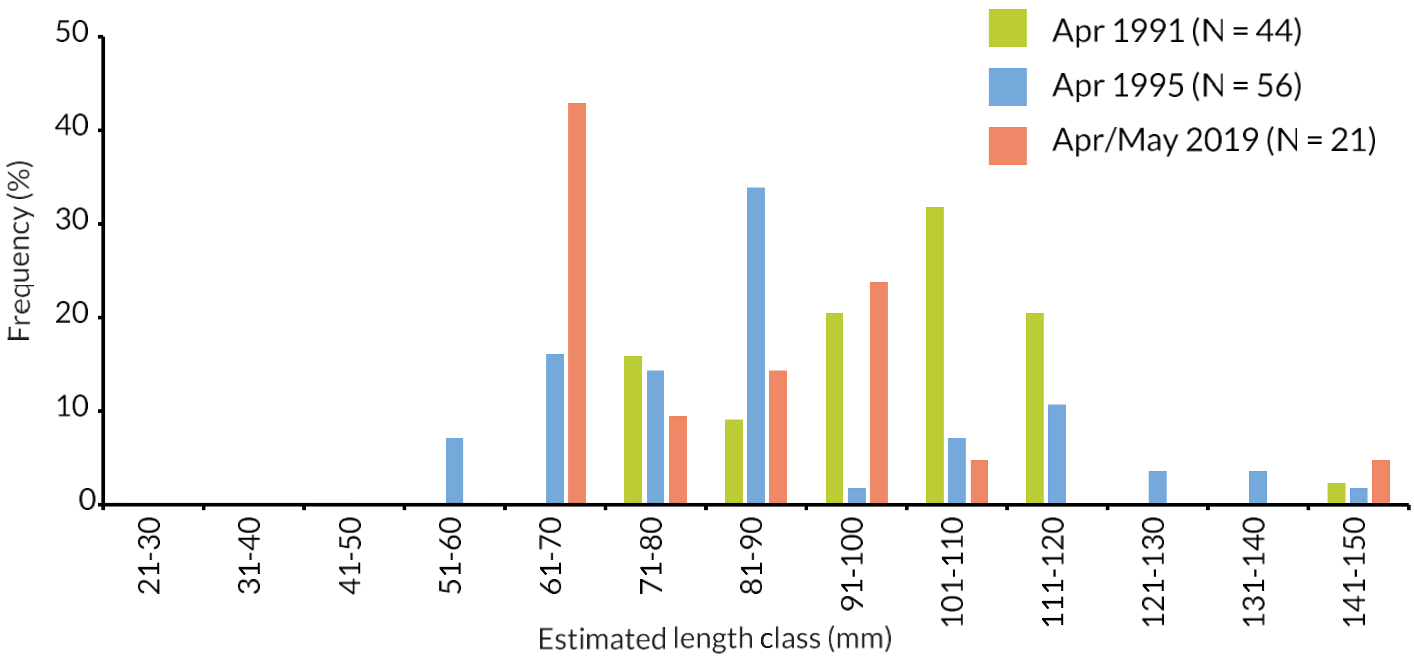


Figure 27. Estimated Salmon length frequency distribution from the stomach contents of R. Tweed Goosanders: smolt run sample period 2019 and another broadly comparable sample (legend indicates date of sampling and number of Salmon for each sample).

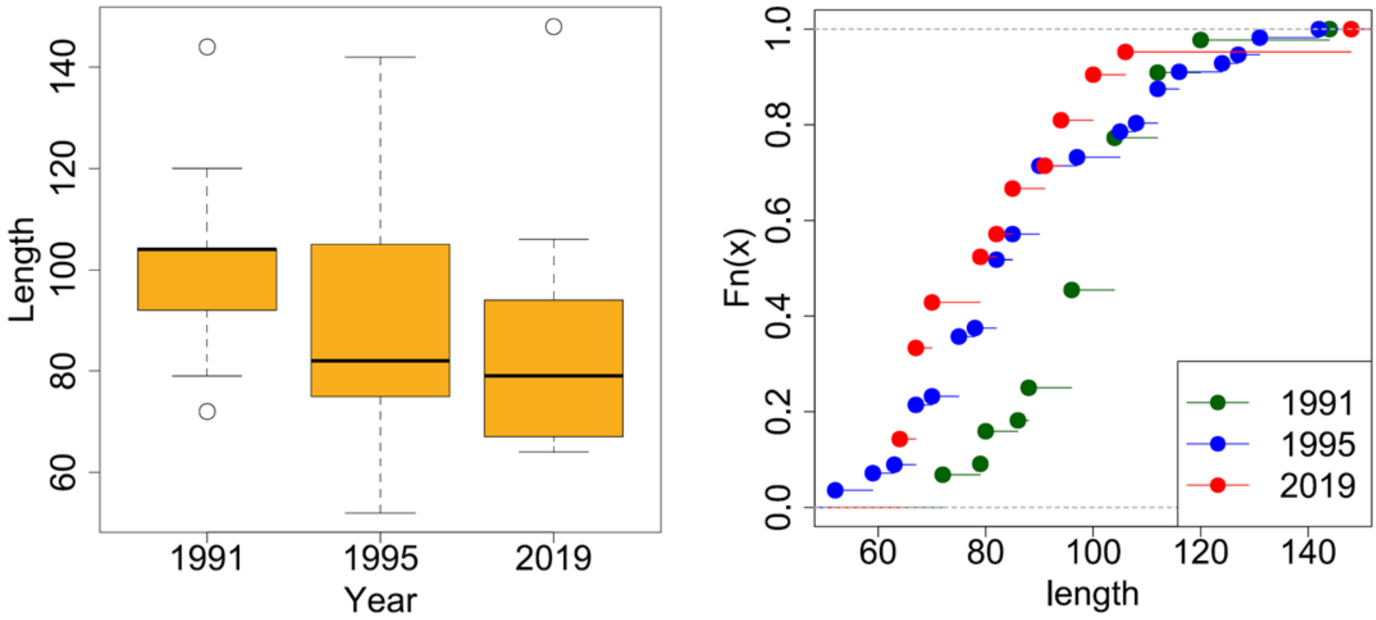


Figure 28. Boxplots for the estimated Salmon lengths from the stomach contents of R. Tweed Goosander smolt run sample period 2019 and two other broadly comparable samples (a, left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (b, right). Further sample details in Figure 27, note on boxplot presentation in Methods.

5a.4 River Spey Goosanders

Salmon from the 2019 R. Spey Goosander sample were significantly smaller than those recorded from the April 1996 sample (K-S test, D = 0.29, P = 2.274e-3).

The frequency distributions of the estimated Salmon lengths for these two Spey Goosander samples are shown in Figure 29, boxplots for them in Figure 30a, and ecdf plots in Figure 30b. As can be seen in the boxplots, Salmon in the stomachs of Spey Goosanders in 2019 had a median length of 79mm, the median length of the April 1996 sample was 1.1cm longer at 90mm.

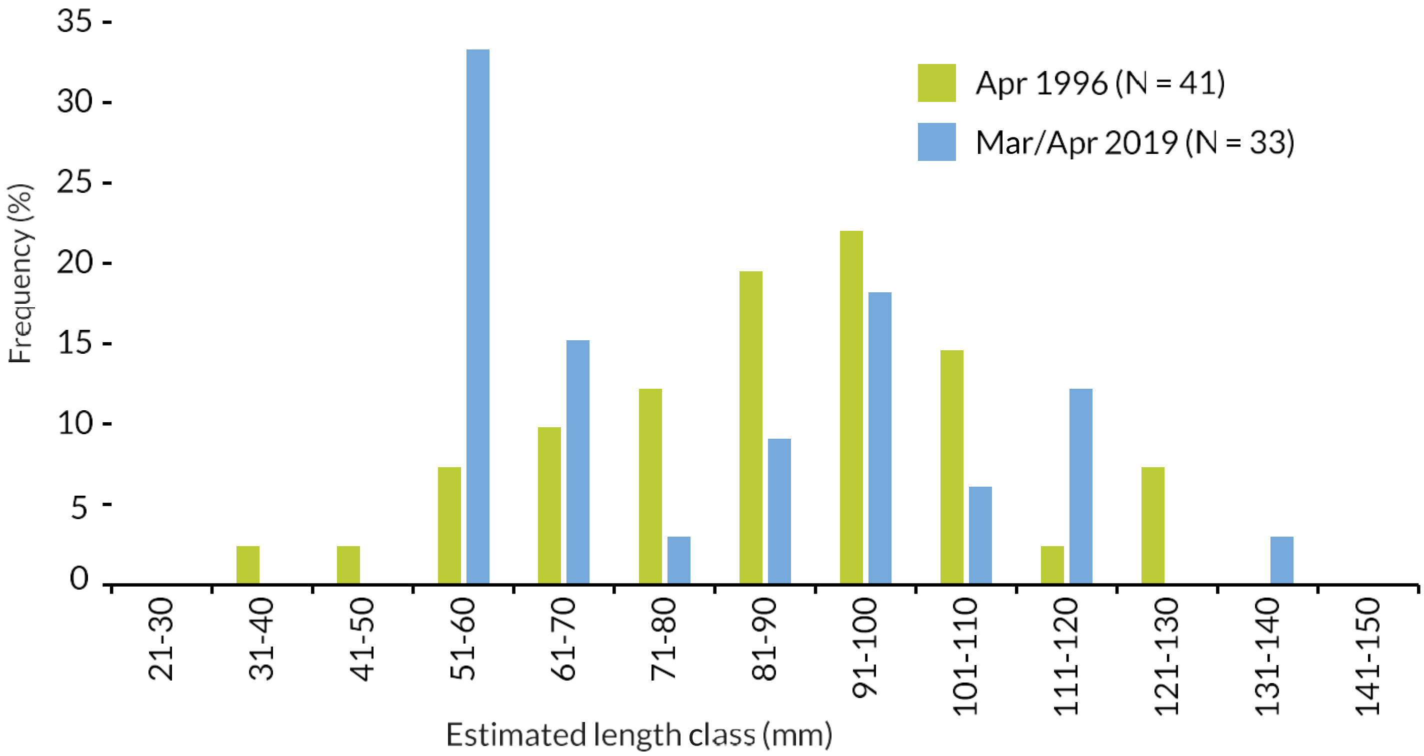


Figure 29. Estimated Salmon length frequency distribution from the stomach contents of R. Spey Goosanders: smolt run sample period 2019 and another broadly comparable sample (legend indicates date of sampling and number of Salmon for each sample).

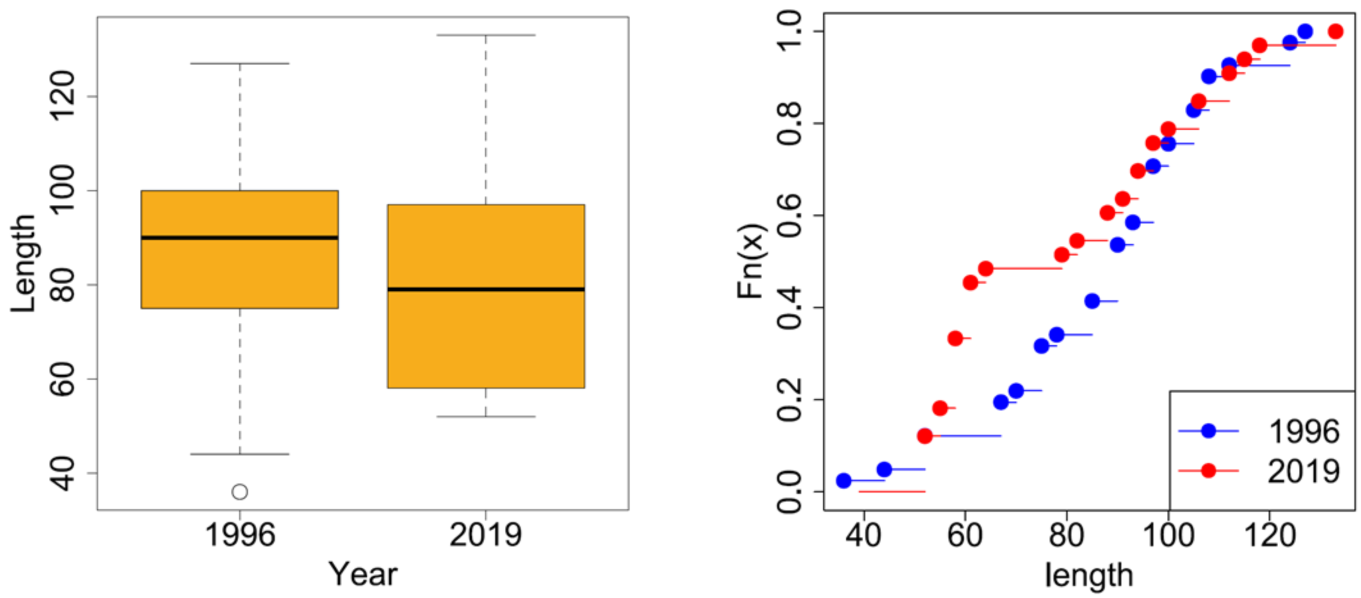


Figure 30. Boxplots for the estimated Salmon lengths from the stomach contents of R. Spey Goosander smolt run sample period 2019 and another broadly comparable sample (left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (right). Further sample details in Figure 29, note on boxplot presentation in Methods.

5a.5 River Dee Cormorants

No birds were sampled during the smolt run period. No Salmon length frequency analysis was therefore possible.

5a.6 River Nith Cormorants

Only three birds were sampled during the smolt run period. No Salmon length frequency analysis was therefore possible.

5a.7 River Tweed Cormorants

Salmon from this R. Tweed Cormorant sample were significantly smaller than those recorded from the Mar-Apr 1995 sample (K-S test, D = 0.53, P = 3.03e-11).

The frequency distributions of the estimated Salmon lengths for these two Tweed Cormorant samples are shown in Figure 31, boxplots for them in Figure 32a, and ecdf plots in Figure 32b. As can be seen in the boxplots, Salmon in the stomachs of Tweed Cormorants in 2019 had a median length of 88mm, the median length of the Mar-April 1995 sample was 2.4cm longer at 112mm.

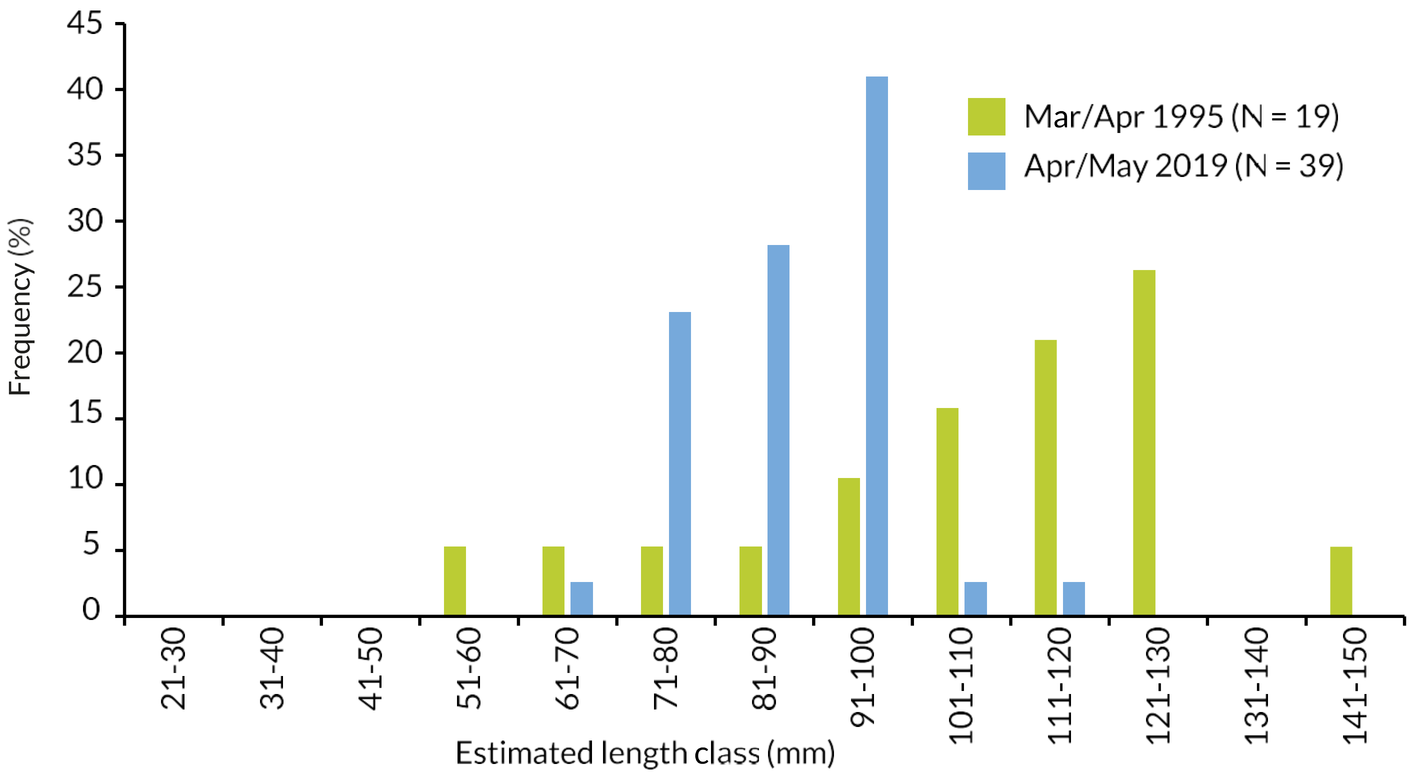


Figure 31. Estimated Salmon length frequency distribution from the stomach contents of R. Tweed Cormorants: smolt run sample period 2019 and another broadly comparable sample (legend indicates date of sampling and number of Salmon for each sample). Note: the 2019 sample comes from a small number of Cormorant stomachs (N = 5) and so may not be representative.

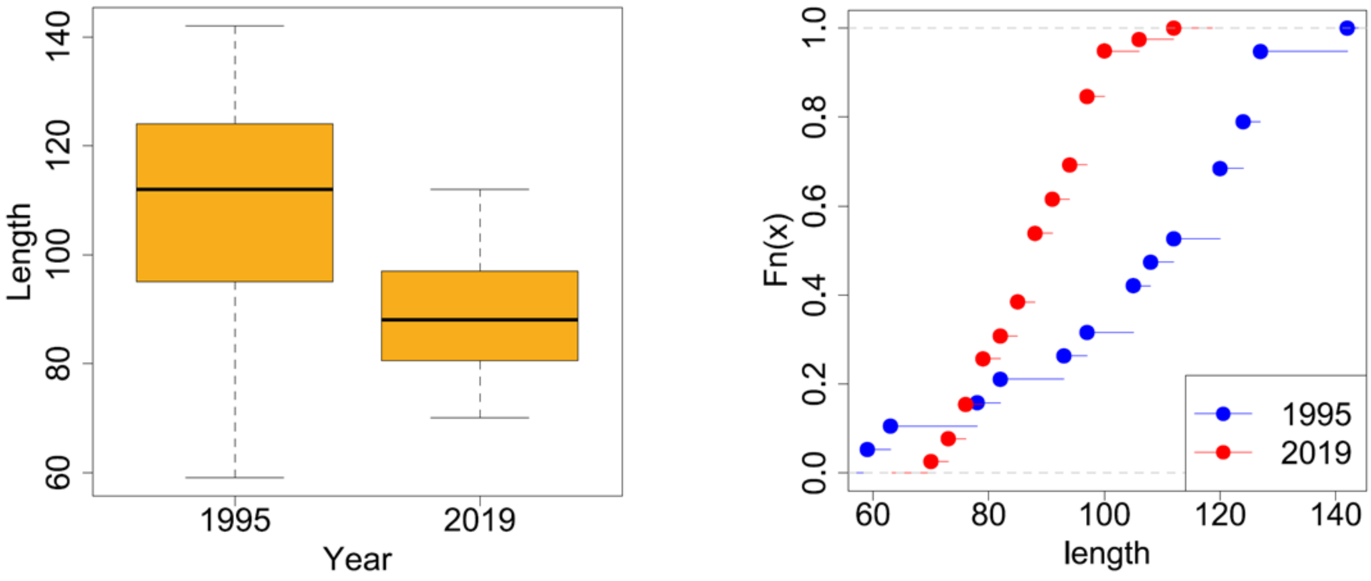


Figure 32. Boxplots for the estimated Salmon lengths from the stomach contents of R. Tweed Cormorant smolt run sample period 2019 and another broadly comparable sample (left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (right). Further sample details in Figure 31, note on boxplot presentation in Methods.

5a.8 River Spey Cormorants

Only a single bird was sampled during the smolt run period. No Salmon length frequency analysis was therefore possible.

(b) Autumn-winter period

The lengths of Salmon from the current autumn-winter 2019/20 samples are given in Table 15).

River	Bird species	Sample date	No. Salmon	Fish Length
Dee	Goosander	Nov 2019	33	52 - 124
Nith	Goosander	Oct 19-Feb 20	11	67 – 130
Tweed	Goosander	Sep-Nov 2019	36	64 – 127
Spey	Goosander	Sep-Dec 2019	57	48 – 124
Nith	Cormorant	Nov 19-Feb 20	8	94 - 127
Tweed	Cormorant	Sep-Nov 2019	26	73 – 157

Table 15. Descriptive statistics for Salmon recovered from fish-eating birds in relation to sample river, bird species, and sampling date. For each sample, values are given for the numbers of Salmon recorded and the range of estimated fork lengths (mm).

Only two possible comparisons could be made between the current autumn-winter 2019/20 samples and those from a similar period in earlier years (i.e. Tweed Goosanders, Tables 22[k] and 22[v] of Appendix 5.1 in Marquiss *et al*. 1998, see also Figure 14 for general diet comparison). This was because either no samples were available at all in most cases, or sample sizes were very small (i.e. three samples each with only 3-4 stomachs containing food). Unfortunately, Salmon fork length data were not available for either of these relevant earlier material and so no comparisons could be made with previous historic samples.

Given this, the only possible comparisons that could be made in the current study are between these autumn-winter Salmon length frequencies and those from the preceding smolt run period in the spring of 2019. However, in relation to Salmon lengths from both sampling periods, it is important to note that samples may be compromised by small numbers of stomachs containing Salmon or small numbers of Salmon, or a combination of both. The precise influence of both sample size (i.e. number of stomachs containing Salmon) or the location of sampling on our confidence in the wider applicability of the resulting Salmon length frequencies is currently unknown (see Discussion).

In order to start a preliminary exploration of the data, an arbitrary decision was made to restrict comparisons to those samples where 12 or more stomachs contained Salmon and/or where 20 or more Salmon had been recorded. This number of stomachs corresponds to the minimum needed to estimate of the diet of Goosanders and Cormorants from Scottish salmon rivers (Marquiss & Carss 1997). However, it should be noted that whilst this sample size is adequate for determining the fish species composition of birds' diet, it is not known whether it is appropriate for determining the complete length frequency distributions of any of those fish species that are eaten (see Discussion). The choice to include samples with 20 or more Salmon was more arbitrary and was primarily determined by the desire to exclude those samples containing very few (in this case 11 or fewer) Salmon.

For six samples (38%), neither selection criteria (number of stomachs or of Salmon) was satisfied and these (and their associated pairing) were excluded from further analysis. Furthermore, for no pairing of smolt run period vs autumn-winter samples were selection criteria met in every instance. Consequently, samples where at least one criteria was met in each of the seasonal pairings were considered. Thus, with the caveat that one element of each seasonal pairing was unlikely to provide information on Salmon lengths to a high degree of confidence, comparisons are made for three Goosander samples (Dee, Tweed, Spey) and for Tweed Cormorants (see Table 16)

River and bird species		Smolt run period 2019		Autumn-winter 2019/2020	
		No. stomachs	No. Salmon	No. stomachs	No. Salmon
(i)	Dee Goosander	18	142	2	33
(ii)	Nith Goosander	11	22	8	11
(iii)	Tweed Goosander	7	21	14	36
(iv)	Spey Goosander	12	33	6	57
(v)	Dee Cormorant	0	0	3	0
(vi)	Nith Cormorant	3	22	6	8
(vii)	Tweed Cormorant	5	39	11	26
(viii)	Spey Cormorant	1	0	1	1

Table 16. Stomach content samples in relation to Salmon length frequencies.

Samples with 12 or more stomachs containing Salmon or of 20 or more Salmon

Samples without 12 or more stomachs containing Salmon or of 20 or more Salmon

Paired samples excluded from analysis because no samples met selection criteria

5b.1 River Dee Goosanders

Thirty-three Salmon from only 2 stomachs were available from the Nov 2019 R. Dee Goosander sample. These were significantly larger than those recorded from the smolt run period in Mar- May 2019 (K-S test, D = 0.38, P = 9.63e-14).

The frequency distributions of the estimated Salmon lengths for these two Dee Goosander samples are shown in Figure 33, boxplots for them in Figure 34a, and ecdf plots in Figure 34b. As can be seen in the boxplots, Salmon in the stomachs of Dee Goosanders in Mar-May 2019 had a median length of 62mm, the median length of the Nov 2019 sample was 0.5cm longer at 67mm.

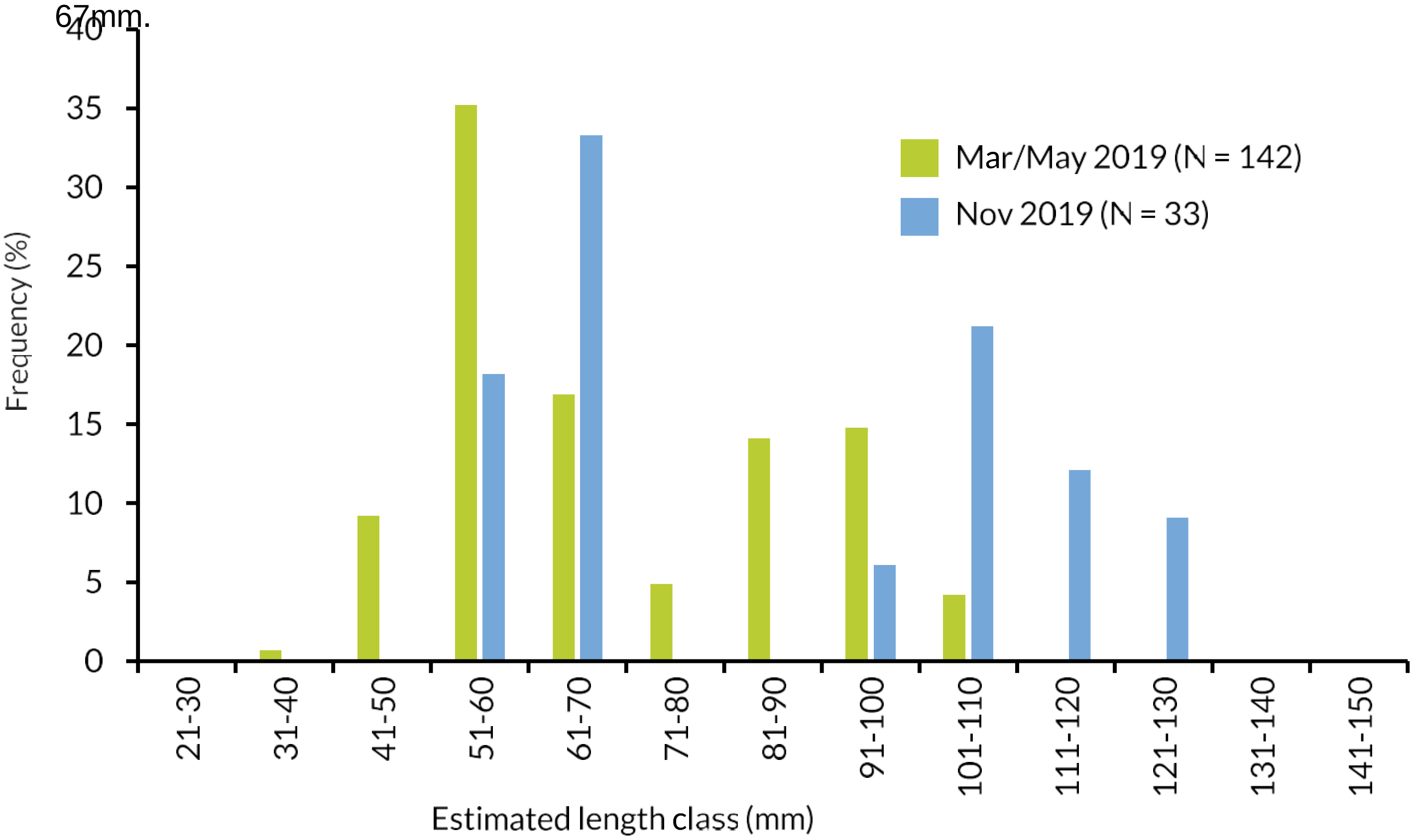


Figure 33. Estimated Salmon length frequency distribution from the stomach contents of R. Dee Goosanders: smolt run sample period 2019 and the autumn (November 2019) sample (legend indicates date of sampling and number of Salmon for each sample).

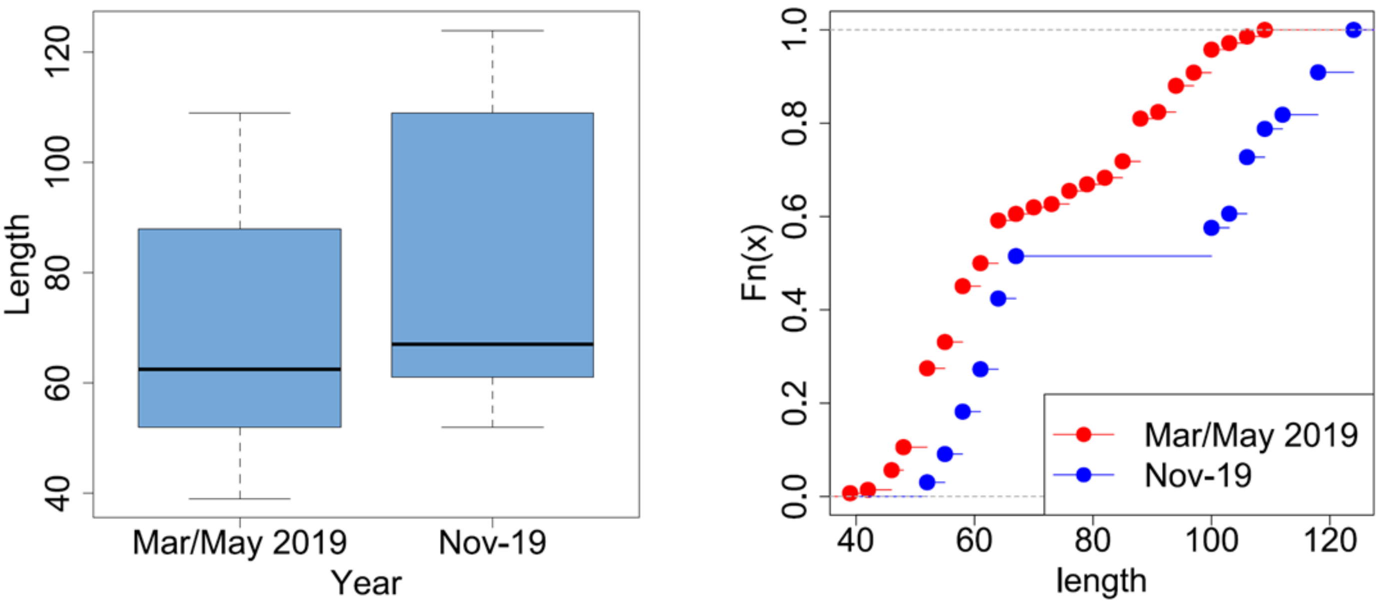


Figure 34. Boxplots for the estimated Salmon lengths from the stomach contents of R. Dee Goosander samples from Mar-May and Nov 2019 (left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (right). Further sample details in Figure 33, note on boxplot presentation in Methods.

5b.2 R. Nith goosanders

Only 11 Salmon from 8 stomachs were available from the Oct 2019-Feb 2020 R. Nith goosander sample. These fish had a median length of 85mm (range: 67-130mm).

5b.3 River Tweed Goosanders

Twenty-one Salmon from only 7 stomachs were available from the Apr-May 2019 R. Tweed Goosander sample. These were not significantly different in length to those recorded from the Sep-Nov 2019 sample (K-S test, D = 0.21, P = 0.16).

The frequency distributions of the estimated Salmon lengths for these two Tweed Goosander samples are shown in Figure 35, boxplots for them in Figure 36a, and ecdf plots in Figure 36b. As can be seen in the boxplots, Salmon in the stomachs of Tweed Goosanders in Apr-May 2019 had a median length of 79mm, the median length of the Sep-Nov 2019 sample was 0.53cm longer at 82mm.

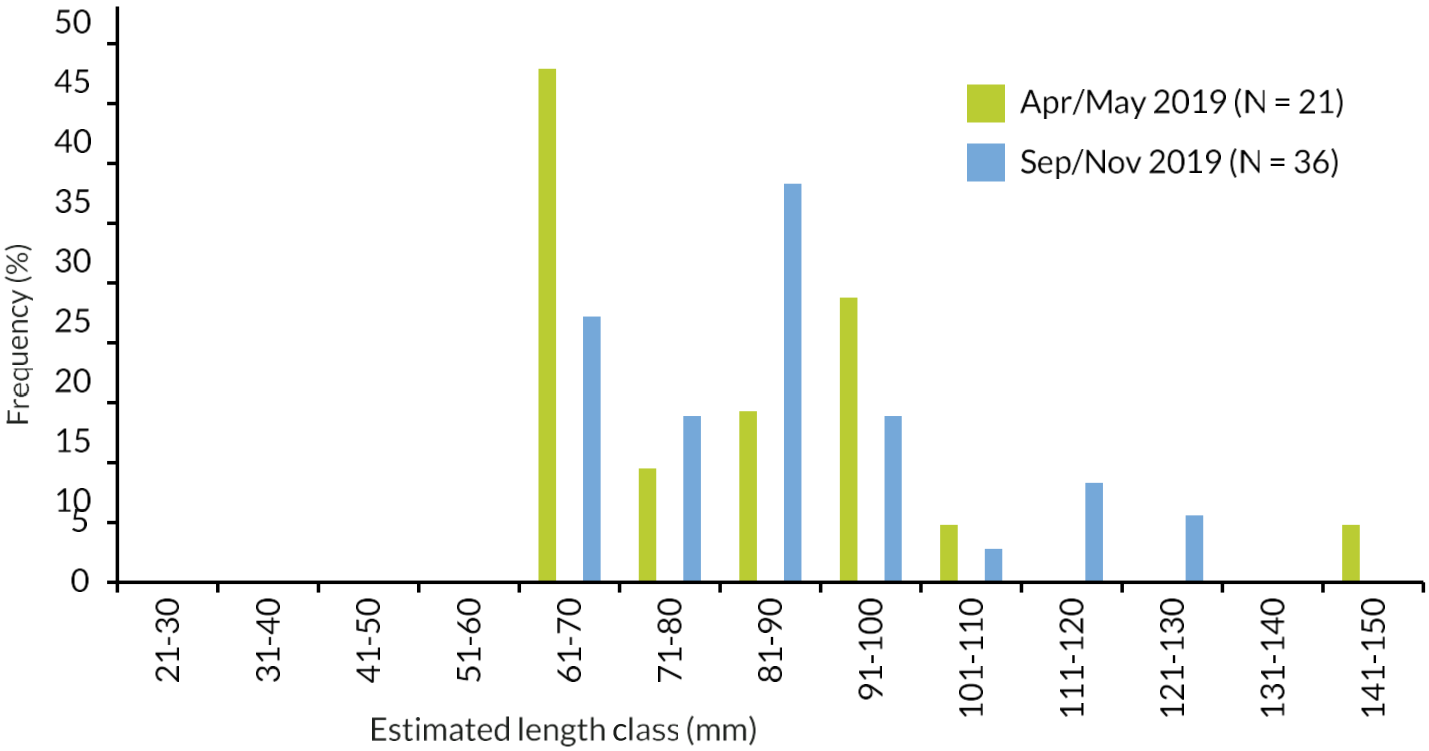


Figure 35. Estimated Salmon length frequency distribution from the stomach contents of R. Tweed Goosanders: smolt run sample period 2019 and the autumn (Sep-Nov 2019) sample (legend indicates date of sampling and number of Salmon for each sample).

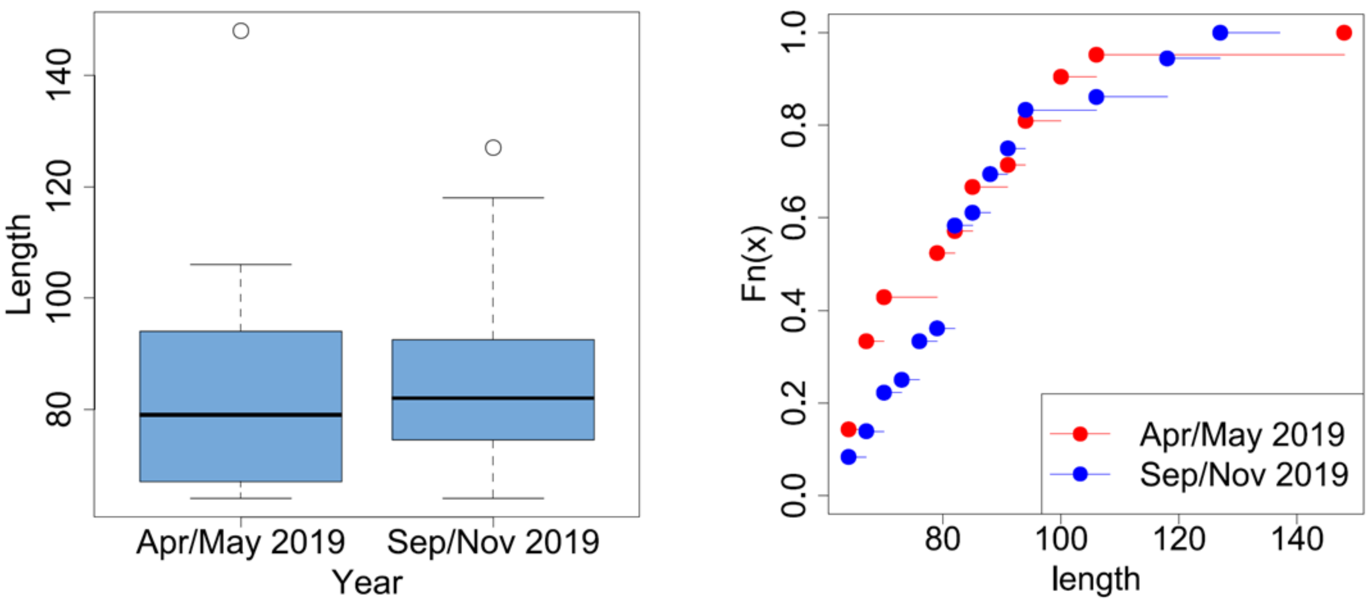


Figure 36. Boxplots for the estimated Salmon lengths from the stomach contents of R. Tweed Goosander samples from Apr-May and Sep-Nov 2019 (left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (right). Further sample details in Figure 35, note on boxplot presentation in Methods.

The autumn R. Tweed Goosander sample could be split into ‘early’ (Sep-Oct 2019) and ‘late’ (Nov 2019) periods based on the 36 Salmon from 14 stomachs that were available. Care must be taken as the number of stomachs containing Salmon in each sample are small (also, no account is taken of possible differences in sampling locations between the two periods), but comparisons between early and late autumn samples are clearly of interest.

Salmon from the early autumn R. Tweed Goosander sample were not significantly different in length to those recorded from the late autumn sample (K-S test, D = 0.23, P = 0.23).

Five birds contained 15 Salmon in the early autumn sample and nine stomachs contained 21 Salmon in the late autumn one. The frequency distributions of the estimated Salmon lengths for these two Tweed Goosander samples are shown in Figure 37, boxplots for them in Figure 38a, and ecdf plots in Figure 38b. As can be seen in the boxplots, Salmon in the stomachs of Tweed Goosanders in early autumn had a median length of 82mm, as did those from the late autumn sample.

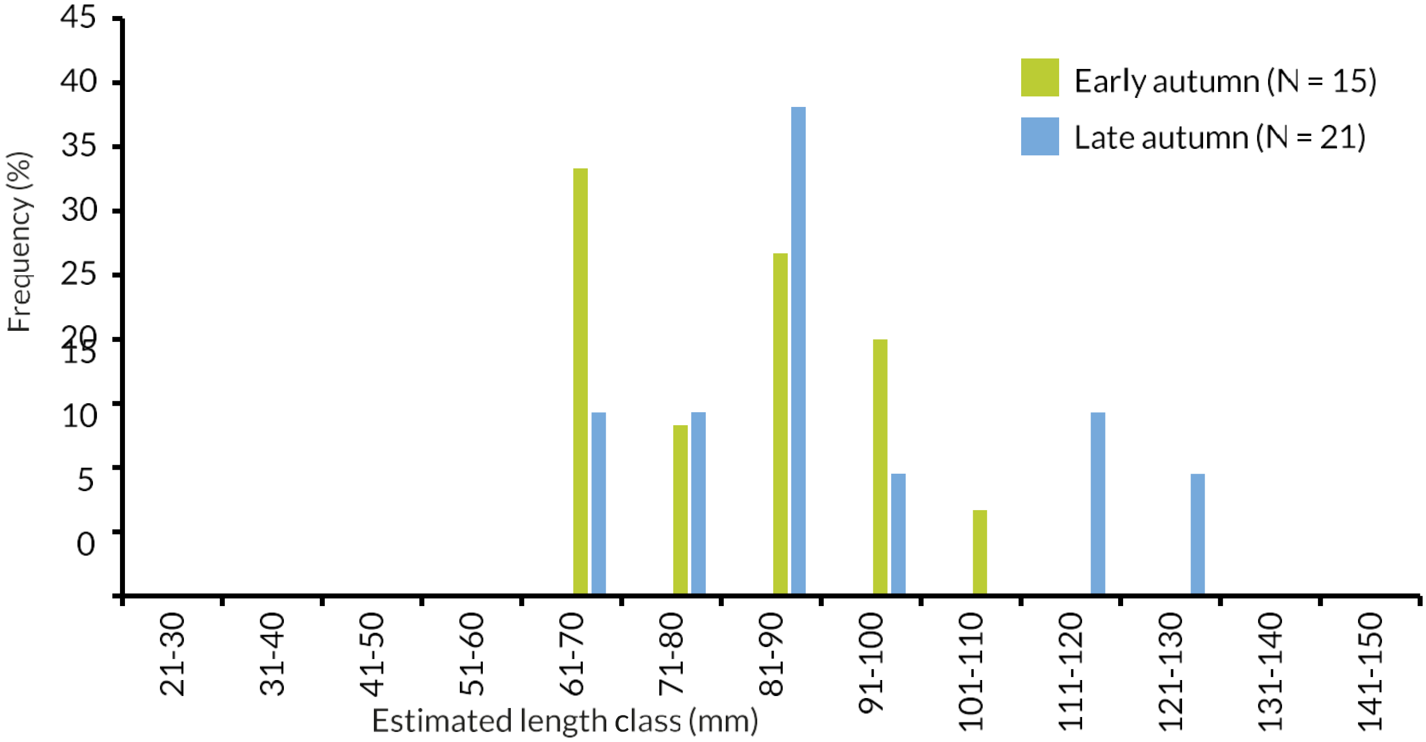


Figure 37. Estimated Salmon length frequency distribution from the stomach contents of R. Tweed Goosanders: early autumn (Sep-Oct 2019) sample and late autumn (Nov 2019) sample (legend indicates date of sampling and number of Salmon for each sample).

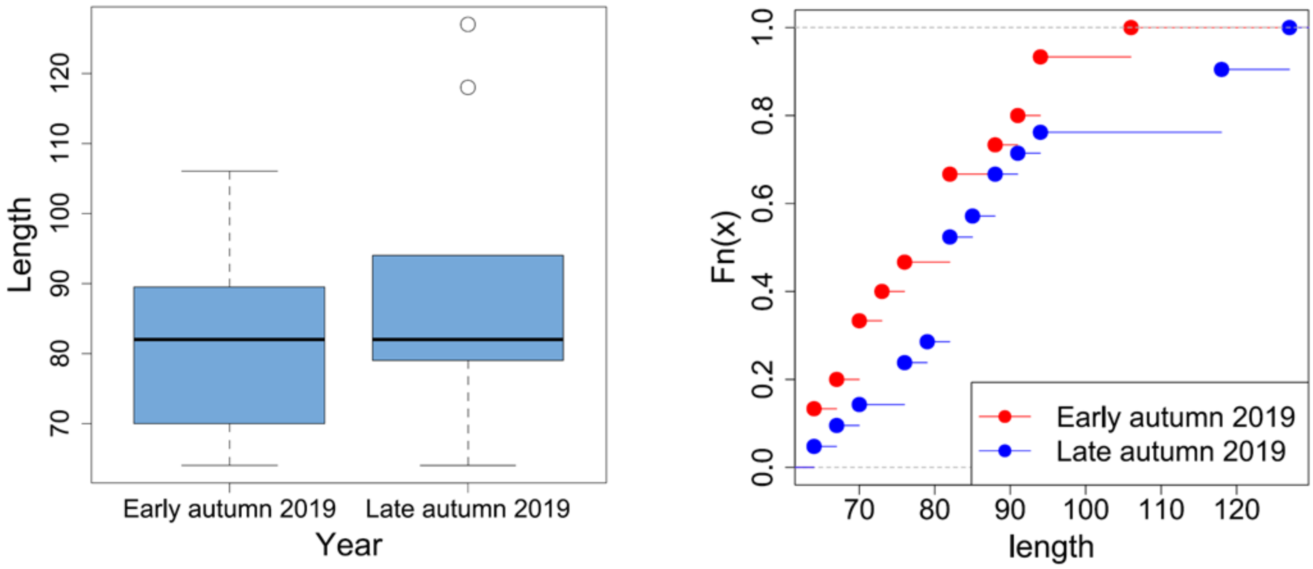


Figure 38. Boxplots for the estimated Salmon lengths from the stomach contents of R. Tweed Goosander samples in early and late autumn (left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (right). Further sample details in Figure 37, note on boxplot presentation in Methods.

5b.4 River Spey Goosanders

Fifty-seven Salmon from only 7 stomachs were available from the Sep-Dec 2019 R. Spey Goosander sample. These were significantly larger than those recorded from the smolt run period in Mar-Apr 2019 (K-S test, D = 0.23, P = 0.03).

The frequency distributions of the estimated Salmon lengths for these two Spey Goosander samples are shown in Figure 39, boxplots for them in Figure 40a, and ecdf plots in Figure 40b. As can be seen in the boxplots, Salmon in the stomachs of Spey Goosanders in Mar-Apr 2019 had a median length of 79mm, the median length of the Sep-Dec 2019 sample was 2.1cm longer at 100mm.

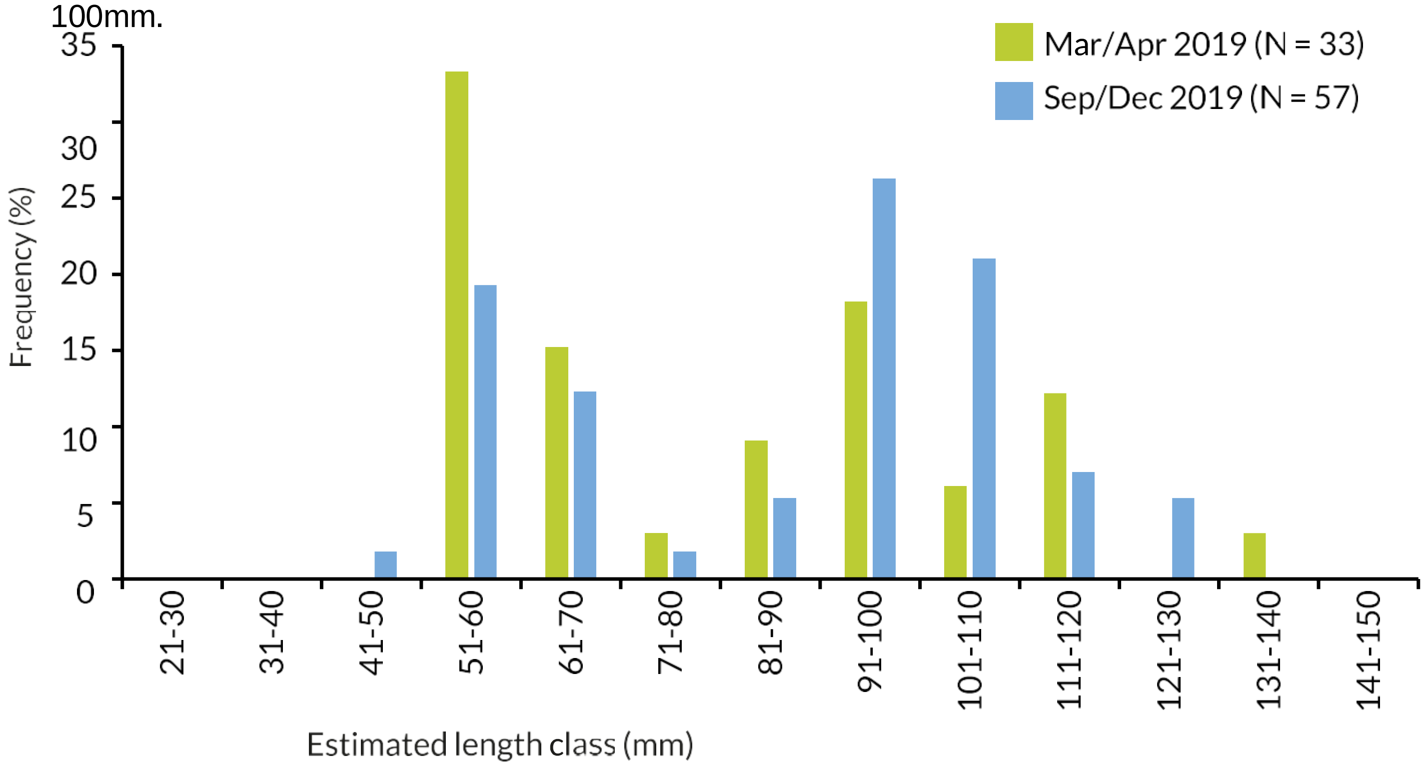


Figure 39. Estimated Salmon length frequency distribution from the stomach contents of R. Spey Goosanders: smolt run sample period 2019 and the autumn (Sep-Dec 2019) sample (legend indicates date of sampling and number of Salmon for each sample).

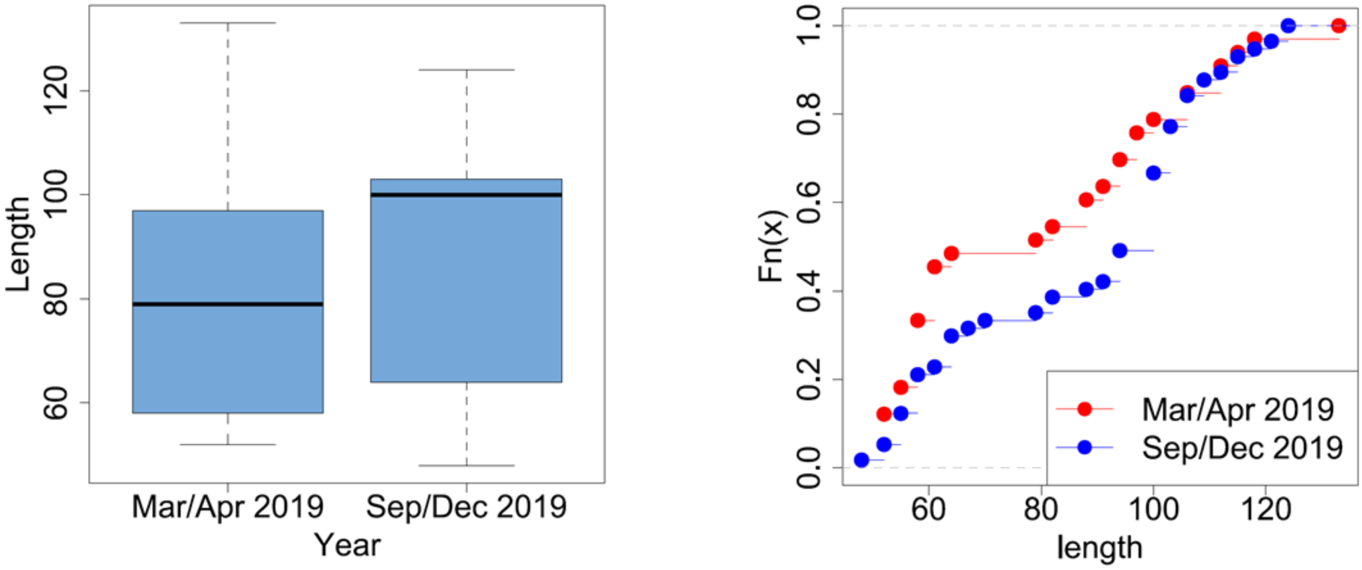


Figure 40. Boxplots for the estimated Salmon lengths from the stomach contents of R. Spey Goosander samples in March-Apr and Sep-Dec 2019 (left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (right). Further sample details in Figure 39, note on boxplot presentation in Methods.

5b.5 River Dee Cormorants

No Salmon were recorded in any of the three Cormorant stomachs with food from the Dee in the winter sample (Dec 2019-Jan 2020).

5b.6 River Nith Cormorants

Only 8 Salmon from 8 stomachs were available from the Nov 2019-Feb 2020 R. Nith Cormorant sample. These fish had a median length of 112mm (range: 94 - 127mm).

5b.7 River Tweed Cormorants

Twenty-six Salmon from only 11 stomachs were available from the autumn (Sep-Nov 2019) R. Tweed Cormorant sample. These were significantly larger than those recorded from the previous Apr-May 2019 sample (K-S test, D = 0.50, P = 6.41e-10).

The frequency distributions of the estimated Salmon lengths for these two Tweed Cormorant samples are shown in Figure 41, boxplots for them in Figure 42a, and ecdf plots in Figure 42b. As can be seen in the boxplots, Salmon in the stomachs of Tweed Cormorants in Apr-May 2019 had a median length of 88mm, the median length of the Sep-Nov 2019 sample was 3.0cm longer at 118mm.

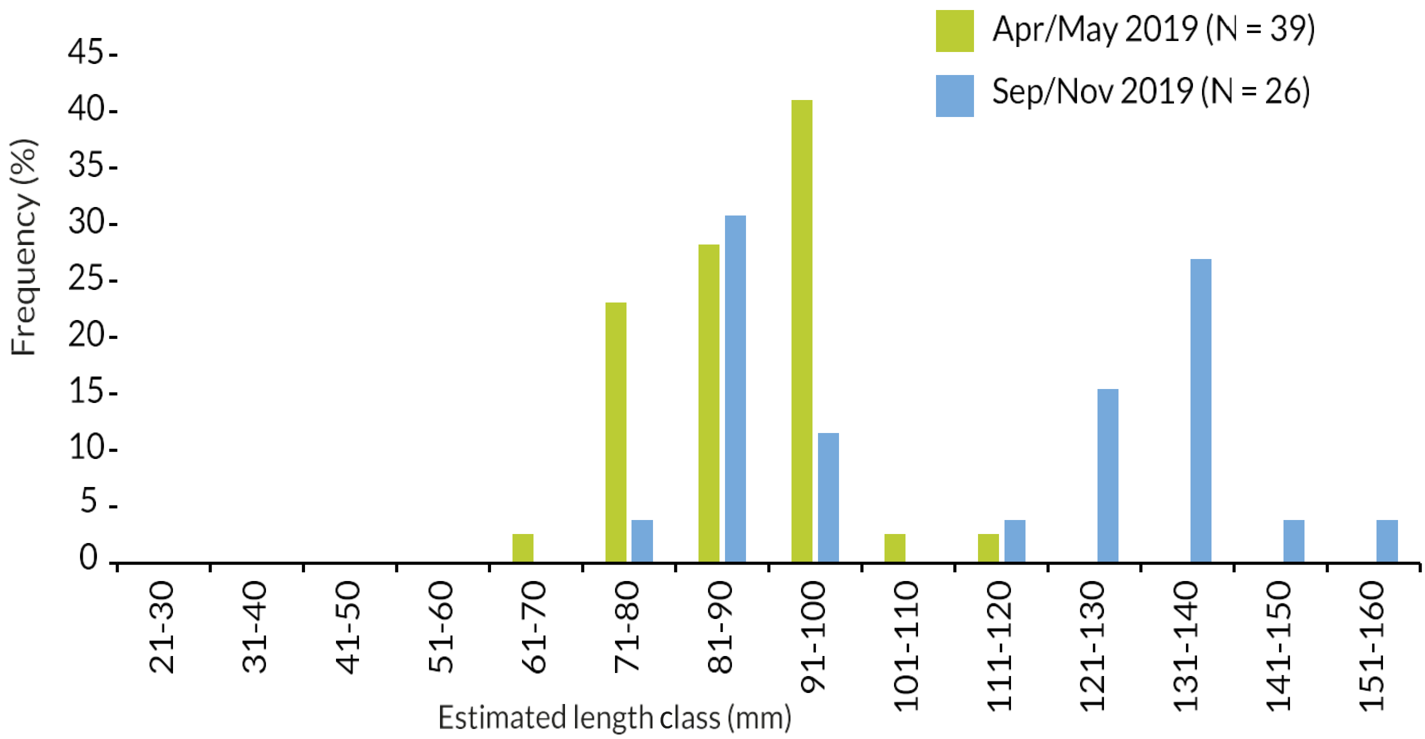


Figure 41. Estimated Salmon length frequency distribution from the stomach contents of R. Tweed Cormorant smolt run sample period 2019 and the autumn (Sep-Dec 2019) sample (legend indicates date of sampling and number of Salmon for each sample).

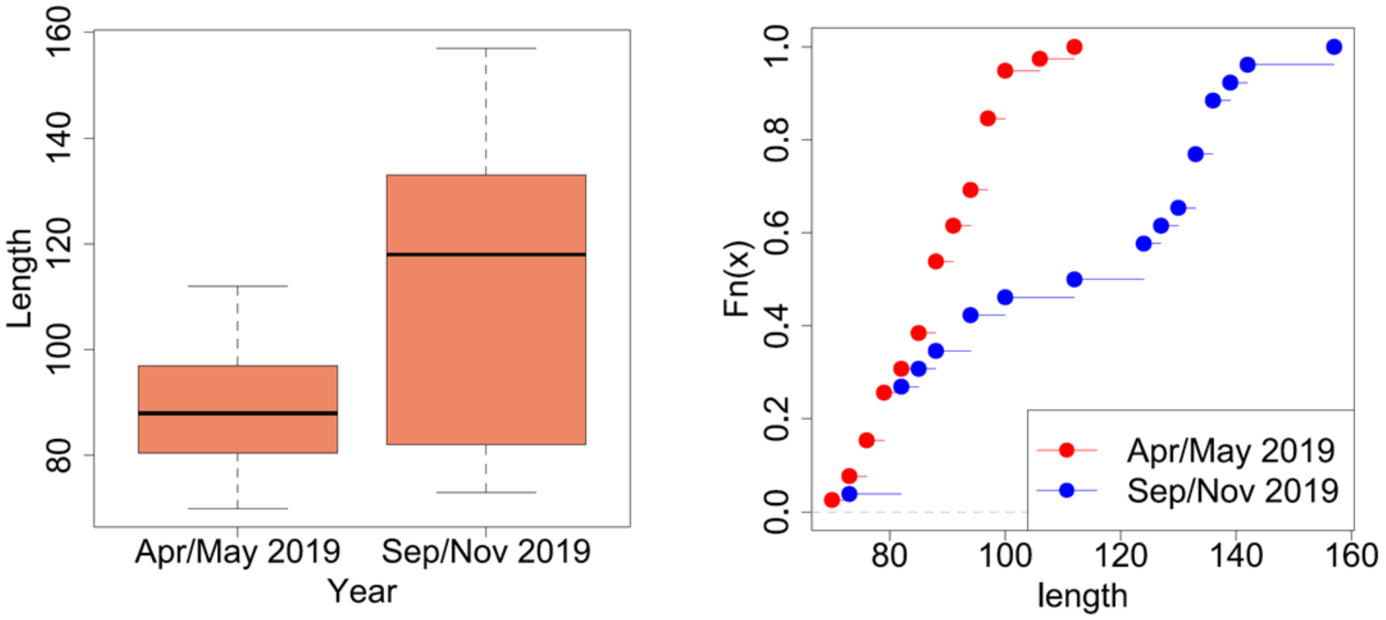


Figure 42. Boxplots for the estimated Salmon lengths from the stomach contents of R. Tweed Cormorant samples from Apr-May and Sep-Nov 2019 (left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (right). Further sample details in Figure 41, note on boxplot presentation in Methods.

The autumn R. Tweed Cormorant sample could be split into 'early' (Sep-Oct 2019) and 'late' (Nov 2019) periods based on the 26 Salmon from 11 stomachs that were available. Care must be taken as the number of stomachs containing Salmon in each sample are small (also, no account is taken of possible differences in sampling locations between the two periods), but comparisons between early and late autumn samples are clearly of interest.

Salmon from the early autumn R. Tweed Cormorant sample were significantly smaller than those recorded from the late autumn sample (K-S test, D = 0.48, P = 2.13e-04).

Six birds contained 15 Salmon in the early autumn sample and five stomachs contained 11 Salmon in the late autumn one. The frequency distributions of the estimated Salmon lengths for these two Tweed Goosander samples are shown in Figure 43, boxplots for them in Figure 44a, and ecdf plots in Figure 44b. As can be seen in the boxplots, Salmon in the stomachs of Tweed Goosanders in early autumn had a median length of 88mm, the median length of the late autumn sample was 4.5cm longer at 133mm.

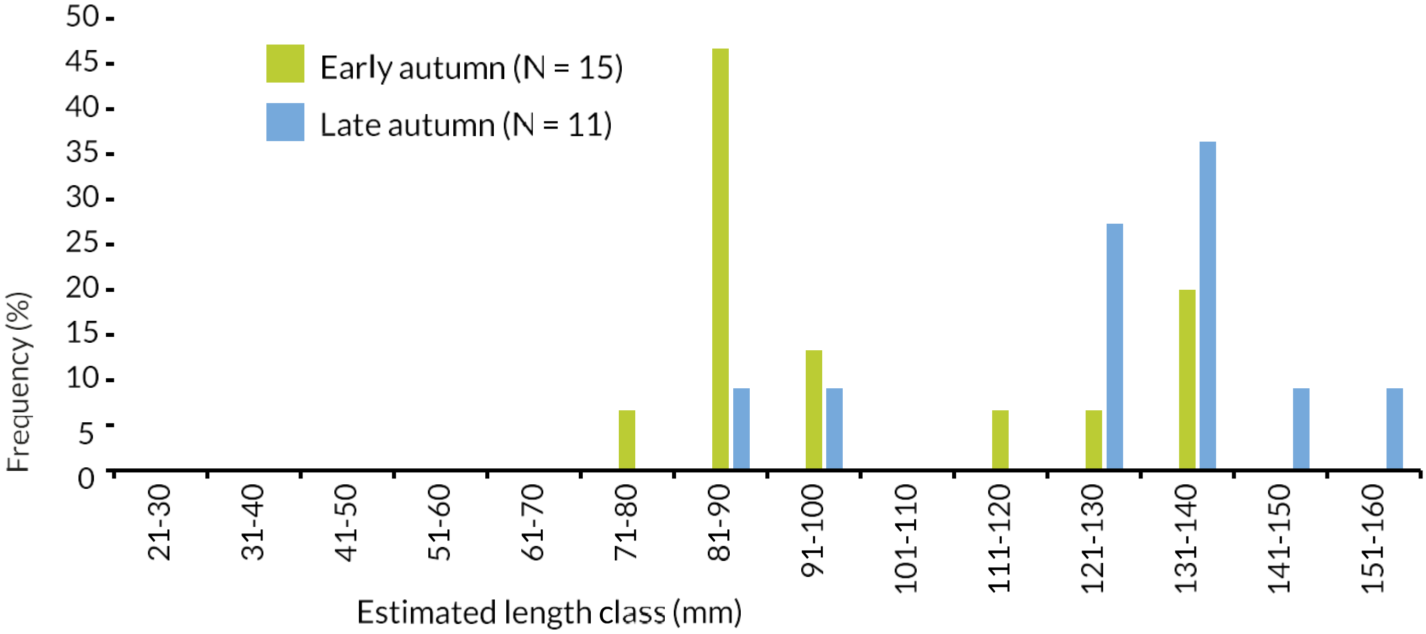
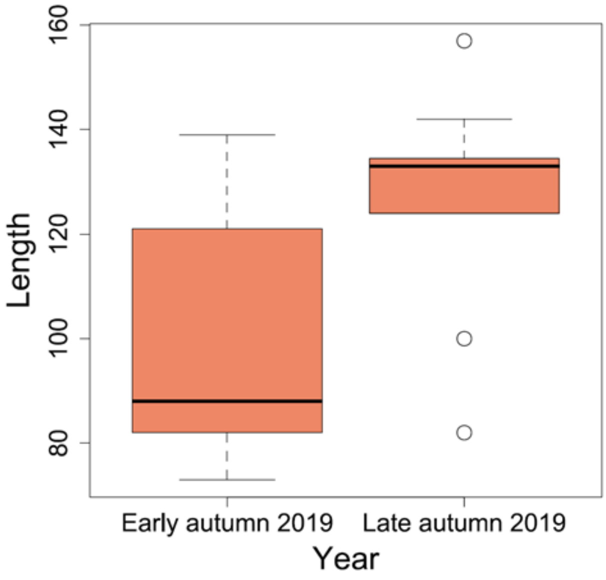


Figure 43. Estimated Salmon length frequency distribution from the stomach contents of R. Tweed Cormorant early autumn (Sep-Oct 2019) sample and late autumn (Nov 2019) sample (legend indicates date of sampling and number of Salmon for each sample).



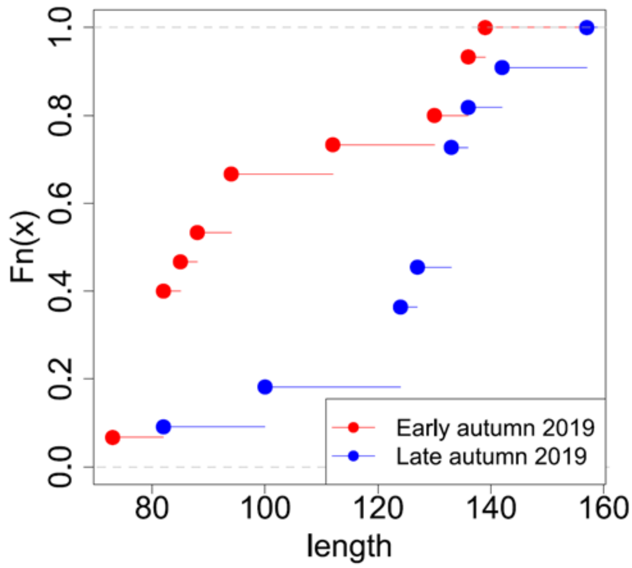


Figure 44. Boxplots for the estimated Salmon lengths from the stomach contents of R. Tweed Cormorant samples in early and late autumn (left), and plots of empirical Cumulative Distribution Functions (ecdf) for the same data (right). Further sample details in Figure 43, note on boxplot presentation in Methods.

5b.8 River Spey Cormorants

Only one Salmon (estimated FL = 91mm) from one stomach was available from the winter (Dec-Feb 2020) R. Spey Cormorant sample.

6. Discussion

Samples available

Care must be taken when interpreting the findings of the present study because of the relatively small sample sizes of both birds and study rivers. Indeed, in several instances, samples of fewer than 12 stomachs with food were available and these were likely to be too small to ensure that they were representative of general diet. Only samples of Goosanders from all four rivers during the smolt run period, for Tweed Goosanders and for Tweed and Nith Cormorants during the following autumn-winter had 12 or more stomachs that contained food.

There was a general paucity of Cormorants on rivers during the smolt run sample period and of Goosanders during the autumn-winter period, at least as indicated by the consistently small samples sizes of birds provided. The reasons for this are unclear but are likely to have been related to the numbers of birds on particular rivers at particular times of year. For instance, it is thought (DSFB pers. comm.) that relatively few Cormorants are present on the Spey (and the Dee) throughout most of the year, few are on the Tweed in spring, and few on the Dee during the smolt run. There may also have been fewer Cormorants than ‘normal’ on the Nith and Dee during the 2019 smolt sampling period (possibly related to local river conditions). Similarly, Goosanders may have been relatively scarce in the autumn on some rivers, and there will be always be practical difficulties in obtaining samples depending on local conditions and the availability of resources.

Whilst current information on the dietary composition of, and the length frequencies of Salmon consumed by, these birds is undoubtedly informative and the first of its kind for over 20 years, it is nevertheless limited. Future research involving larger samples of Goosanders and Cormorants at other times of year and from a larger number of rivers is required to improve levels of confidence in the evidence for predation by these species in relation to the protection of Salmon stocks in Scottish rivers.

General diet

(a) Smolt run period

During the 2019 smolt run sample period (March/May), the proportion of Salmon (50% by mass) in the diet of Goosanders on the R. Dee was higher than that for any other species in the diet and was also similar to comparable historic samples from the 1990s (Marquiss et al. 1998). The proportion of Trout (26% by mass, the second highest dietary proportion in spring 2019) was lower, and the proportion of Minnow (15% by mass) considerably higher, than these previous samples.

Goosander diet on the R. Nith during the 2019 smolt run sample period (April/May) comprised Trout (31% by mass) and Stone Loach (26% by mass) and proportions of both species were higher than recorded previously. The proportion of Salmon (16% by mass) was higher than previously recorded but only slightly. Conversely, proportions of Eel (5% by mass) and 3-Spined Stickleback (1% by mass) in 2019 were considerably lower than in previous samples.

On the R. Tweed during the smolt run sample period (Apr/May), the proportion of Salmon (15% by mass) in the diet of Goosanders was similar to historical samples (although considerably lower than estimated in April 1991). The proportion of Trout (20% by mass) was strikingly lower in 2019 than in three of the four historical samples, whereas that of Minnow (38% by mass) was some 4-13 times greater than recorded historically. Indeed, Minnow was by far the largest dietary component by mass in the 2019 Goosander smolt run sample period.

On the R. Spey, Trout (40% by mass) was the largest component in the diet of Goosanders during the smolt run sample period (March/April), very closely followed by Salmon (36% by mass) and these proportions were within historical levels. Proportions of Minnow (4% by mass) and 3-Spined Stickleback (6% by mass) were low in spring 2019 but still higher than historically recorded, whilst the proportion of Eel (14% by mass) was similar to the previous 1994 level.

The numbers of Cormorants available (and/or containing food) from the smolt run sampling period were very low (or zero) from the rivers Dee, Nith, and Spey in 2019 and so little could be determined about their diet and comparisons with earlier samples were not possible. The numbers of Cormorants sampled on the R. Tweed during the 2019 smolt run sample period were also likely to be too small to be representative of general diet (N = 6 with food). Nevertheless, Trout (45% by mass) and Salmon (40% by mass) were the largest components of the diet of Cormorants in this sample, and these were generally higher than the proportions recorded previously. The relatively low proportion of Minnow (10% by mass) recorded in 2019 was higher than that previously recorded. Conversely, the proportion of Grayling (6% by mass) was considerable lower than recorded previously, when proportions were around 40% by mass.

Overall, for Goosanders, the proportions of Salmon recorded in the diet during the 2019 smolt run sample period were broadly similar to historical levels for the rivers Dee and Tweed, and possibly lower for the R. Spey and slightly higher for the R. Nith than previous samples. Few Cormorants were sampled during the 2019 smolt run period and historical comparisons were only possible for the R. Tweed, albeit limited by small sample size in 2019. Nevertheless, comparisons do suggest a reduction in the proportion of Grayling recorded in the diet, and a coincidental increase in the proportions of Salmon, Trout, and Minnow.

Statistical comparisons of general diet assessments could only be made for a restricted number of samples, namely those of Goosanders from the Tweed (see Section 4). Data on the mass of each prey species in each bird stomach was only available for these samples. Statistical comparisons were further confounded by limitations caused by the absence of particular fish species in some samples and by the need to establish a threshold for the number of values (mass of fish/stomach, including zero values). The latter was necessary in order to reduce the 'uncertainty' of diet estimates for samples where a particular fish species is only recorded in a small number of stomachs and to increase confidence in the interpretation of the statistical test. Whilst, there is a future research requirement for simulation studies to understand what sample size, and what number of positive values within a sample, might be most appropriate for statistical comparisons, the restricted statistical tests possible here confirmed the broader observations of variation in general diet assessments described in Section 4.

Sampling and the timing of the smolt run

There are a number of sampling issues that should be remembered when considering how best to interpret the findings produced from the stomach contents analysis used in the present study, where the sampling unit is an individual stomach and not the number of fish recorded it contains. At its simplest, a relatively small sample of stomachs is examined, the findings from any sample of stomachs (realistically, this is necessarily always going to be a relatively small number) should not be considered 'representative' subsequently nor applied to a wide area such as a river catchment, or to a different year or time of year.

Marquiss & Carss (1997) showed that the prevalence of smaller fish species is underestimated, and the average size of juvenile Salmon eaten overestimated by about 20% by considering only the intact fish in stomachs (as smaller individuals could be too digested to be recognisable), and concluded that measurements of uneroded bony material in stomachs (which would also include that from smaller fish) gave more accurate diet estimates in terms of the numbers and sizes of fishes consumed. These authors also explored the effect of sample size on general assessments of Goosander and Cormorant diet in terms of the fish community represented in stomachs (see Methods re. 'adequate' estimates of diet from samples of 12-15 stomachs containing food).

There are also potential temporal issues with sampling, and the issue of the level of synchrony between bird sampling and the smolt run period is discussed below. A broader issue, concerns the 'patchiness' of sampling and its potential influence on the degree of confidence in, and wider applicability of, the findings of stomach contents analysis. Here, such interpretation could be compromised by the fact that birds are often aggregated within samples, generally coming from particular locations and particular days (or times of day). Furthermore, birds might only be collected from locations where, and when, it is possible to get close to birds and so sampling opportunities are most appropriate and favourable.

The timing of the sampling of birds in relation to the timing of the smolt run is an important issue to consider in the present study because the synchrony of these two events is not clear. This means that sampling (and hence diet assessments) might not be 'representative' of the peak of the smolt run, and that comparisons with previous samples may be difficult because they rarely included birds from May for instance. Nevertheless, the smolt run period birds included in the present study (and those spring birds in Marquiss *et al.* 1998) were sampled at times and places when predation on smolts was thought to be an important issue.

Factors such as increasing day length and water temperature, and varying flow rates are likely to influence biological events like smolt migration, although the details have only recently begun to be quantified through smolt catching and tagging research. **Appendix 5** thus provides a preliminary exploration of the sampling dates for Goosanders and Cormorants on the river Tweed in relation to information on the timing of the smolt run there in spring 2019. This Appendix does not explore issues of spatial abundance (of birds or fishes) which might also be important in understanding and interpreting dietary findings - as birds were sampled from a limited number of locations in the absence of information on the distribution of smolts within any of the study river systems.

Consideration of the possibility of 'mismatch' between the timing of bird sampling and the timing of the smolt run raises similar issues over the comparability of samples in relation to the timing of their collection. For instance, the majority of historical smolt run samples were collected in March and April whilst those in the present study also covered these months but were also extended into May. Theoretically, there could thus be up to a 13 week difference in timing between birds sampled in the first week of March and those from the last week of May. The implications of such a temporal mismatch in sampling dates are currently poorly understood, as are the likely levels of inter-annual variation in diet assessments from samples from the same location taken in different years.

Knowledge of the temporal and spatial dynamics of the smolt run is advancing, and so exploring the implications for sampling regimes, and the timing thereof, to assess fish-eating bird diet requires further investigation. Future research requirements will also include fine-scale analysis of temporal dietary composition (e.g. to better understand over what time-periods dietary estimates are representative), examination of the influence of sampling location on diet assessments and of both sample location and sample size on subsequent length frequency estimation for prey fishes, particularly Salmon. As birds can be highly mobile, it is also vital to know where birds are actually foraging rather than where they were sampled and so further research (including tagging and tracking) is needed to better understand the spatial and temporal distribution of birds within river systems, their movements and behaviour, and levels of fidelity to different locations (e.g. foraging sites, roosts) at different times of year.

(b) Autumn-winter period

During the autumn-winter 2019/20 period (November), only two Goosanders were sampled on the R. Dee. Both contained Salmon and Trout, and one contained Minnow. Due to the constraints of small samples (current and historical), no comparison was possible with previous data, including that from the 2019 smolt run period.

The sample of R. Nith Goosanders from the autumn-winter (Oct 2019-Feb2020) period was too small (10 birds, all with food) to be confident it was representative of general diet. Nevertheless, by far the highest dietary proportions in this sample comprised Trout (41% by mass) and Grayling (34%). The proportion of Trout had increased since the smolt run period whilst Grayling was not recorded at all earlier in the year. The proportion of Salmon (7% by mass) in the autumn-winter was low and much lower than reported in the preceding smolt run period (16%). The same trend of lower proportions in the autumn-winter was also apparent for Stone Loach and Minnow.

On the R. Tweed during the autumn 2019 period (Sep/Nov), the proportion of Salmon (13% by mass) in the diet of Goosanders was roughly similar to that in November 1992 but considerably smaller than was estimated in November 1991. The proportion of Trout (40% by mass) in autumn 2019 was higher than any other species in this sample and also the two historical samples. About a third of the autumn 2019 diet was Grayling (34% by mass), considerably higher than most other species but a little lower than recorded in the November 1993 sample. The proportions of Minnow, 3-Spined Stickleback, and Stone Loach were relatively small in autumn 2019 but tended to be higher that levels recorded historically. Proportions of Salmon recorded in the autumn samples were similar to those earlier in the year during the smolt run period, although they were lower than for many other prey fish in both samples. Comparing the 2019/20 sampling periods, there was a striking increase in the proportions of Trout and Grayling in the autumn sample, the latter species being absent in the spring. The proportion of Minnow declined dramatically later in the year in comparison to the level in the smolt run period. This pattern was also seen within the autumn sample itself, with increased Trout and Grayling proportions later in the autumn, and lower proportions of Minnow, 3-spined Stickleback and Stone Loach later in the season.

The sample of R. Spey Goosanders from the autumn-winter 2019/20 period was too small (8 birds, 7 with food) to be confident it was representative of general diet. Nevertheless, the diet of this sample was dominated by Salmon (64% by biomass), followed by Trout (34%) and Minnow (2%). Due to the constraints of small samples (current and historical), no comparison was possible with previous data. Comparisons with findings from the 2019 smolt run period may be compromised by small sample size, but it is interesting to note that the proportion of Salmon increased later in the year compared to the smolt run sample period (from 36% to 64% by mass). At the same time, the dietary proportion of Trout decreased somewhat (from 40% by mass to 34%).

The numbers of Cormorants available (and/or containing food) from the autumn-winter 2019/20 sampling period were higher than those sampled in the spring, but were sometimes still small. For instance, only three of the four autumn-winter Cormorants from the R. Dee contained food. One contained a large adult Salmon and the other two each contained a single Pike. Due to the constraints of small samples (current and historical), no comparison was possible with previous data, including that from the 2019 smolt run period when no Cormorants were available.

The small number of Cormorants from the R.Nith during the smolt run period meant that comparisons were not possible with the autumn-winter sample of 12 stomachs with food where the diet was dominated by adult Salmon (37% by mass), Grayling (34%), and Trout (16%). The proportion of Salmon in the autumn-winter diet was low (2% by mass), as it was for several other species that were recorded in small (sometimes single) numbers. Due to a lack of historical samples, comparisons were not possible with historical data.

Good samples of Cormorants were collected during autumn 2019 on the R. Tweed (24 stomachs with food) and the highest proportion of the diet comprised Trout (26% by mass). This was considerably lower than the proportion recorded during the smolt run period, although the sample of Cormorants in the spring was very small. The same trend was apparent for Salmon with the proportion by mass falling between the smolt run and autumn periods from 40% to 8%. Apart from Trout, much of the autumn diet (44%) comprised single large (adult) Salmonids in each of three stomachs. Several Grayling were taken in the autumn (11% by mass), higher than the level recorded in spring (6%). Within the autumn period itself, dietary proportions of Trout and Salmon increased a little, whilst the proportion of Grayling increased considerably. More large Salmonids (presumably breeding fish) might have been taken later in the autumn (one fish early vs two late) but the sample is not large enough to certain of this.

With only a single Cormorant available from the R. Spey during the smolt run period, no comparison was possible with the autumn-winter where samples were also small (only 8 stomachs with food). Later in the year, the diet was dominated by large (presumably breeding) fish: seven large Trout, two adult Salmon and an unidentified Salmonid. The dietary proportions of Salmon and Minnow were exceptionally low in the autumn-winter sample – with only one individual of each species being found in those stomachs with food. Due to a lack of historical samples, no other comparisons were possible with previous data.

Overall, for both Goosander and Cormorant diet in the autumn-winter 2019/20, there were very few available historical comparisons. The exception was for Tweed Goosanders where, broadly similar to both historical samples, diet was dominated by Trout and Grayling, proportions of Salmon were lower, and those of other fish species were lower still. However, as noted above for the smolt run period, care has to be taken with such comparisons because of the possible temporal mismatch between sampling dates.

Samples from both the smolt run and autumn-winter periods in 2019/20 were, again, generally too small to compare - either in autumn-winter (Dee and Nith Goosanders and Cormorants) or in both periods (Spey Cormorants). For the three paired samples where dietary comparisons were possible, there appeared to be broad patterns. For Nith Goosanders and Tweed Goosanders and Cormorants, the proportions of Salmon in the diet (by mass) were lower in the autumn-winter period than in the smolt run samples. Proportions of Minnow were also higher in the diet of Goosanders earlier in the year on both rivers, whilst the proportions of Trout, and particularly Grayling, were higher in the autumn-winter. A similar but more modest increase in the proportion of Grayling in the diet of Tweed Cormorants was also recorded later in the year.

These birds contained considerably lower proportions of Salmon and Trout in the autumn than during the spring, as well as many large (adult) Salmonids, presumably reflecting the abundance and activity of adult spawners later in the year. Comparing Goosander and Cormorant diets in early and late autumn for the Tweed showed a general pattern of similar proportions of Salmon but higher proportions of Trout and Grayling later in the autumn for both bird species. There was also a suggestion that Cormorants might consume more adult Salmonids as the autumn progressed but further samples would be needed to confirm this, both on the Tweed and other rivers.

There is thus a clear future research requirement for further dietary data for Goosanders and Cormorants from times of year outside the smolt run period in the spring. For both bird species, this would improve our understanding seasonal variations in the relative proportions (and sizes, see below) of juvenile Salmon throughout the year as well as putting predation during the spring into broader context and improving our understanding of fine-scale temporal variation in diet and any implications this has for the degree of mismatch between comparative samples (see above).

Proportions of Salmon in the diet: broad summary

Where samples were adequate (12 or more stomachs with food), the proportions of Salmon (by mass) in Goosander stomach contents varied between each of the four rivers sampled. For the smolt run period samples, these were 50% (Dee), 36% (Spey), 16% (Nith), and 15% (Tweed). The only adequate sample in the autumn-winter was from the Tweed where the dietary proportion of Salmon was 13%. The broad pattern from the present study was thus that Salmon comprised higher proportions of the diet in northern rivers than in southern ones, a finding consistent with earlier work (Marquiss *et al.* 1998) that showed a similar latitudinal trend. Salmon comprised the highest dietary proportion only for the Dee Goosander sample in spring. For the remaining samples, 1-3 other fish species were consumed in larger proportions by mass, invariably Trout and/or Minnow and up to one other species. Again, this is consistent with Marquiss *et al.* (1998, and references therein) that Goosanders and Cormorants are generalist predators.

For Cormorants sampled in the smolt run period and for all other autumn-winter samples, similar dietary trends were apparent, despite the small sample sizes involved (10 or fewer stomachs with food).

Estimated Salmon length frequencies

Salmon length frequencies were generally bimodal, sometimes multimodal, and occasionally unimodal distributions and were often skewed to some degree. The differences in Salmon length frequencies between samples were compared using a statistical test applicable to data with such distributions. Furthermore, the test had no restrictions on sample size and so small sample sizes were acceptable.

Nevertheless, as before, care had to be taken when interpreting these findings and making comparisons between samples, primarily because of the incidence of small samples (fewer than 12 stomachs with food) which might not be representative of general diet (and similarly particular prey species within it). However, because even a sample of more than 12 birds is still relatively small, there may also be an - untested - influence of sampling location and/or of restricted sampling period on dietary assessments. For example, samples may come from a relatively small number of beats and/or from a short, restricted sampling period (e.g. a high proportion of birds sampled in particular weeks during the season) - see Section 2 and Appendix 3 for details. Further research is thus required to explore the scale of any potential influence of sampling location and sampling period on the results of stomach contents analysis, including Salmon length frequencies. Similarly, any individual bird may select smaller (or larger) than average fish when foraging (or, alternatively, be feeding in a location where such fish occur). As such, the fish recorded in the stomach contents are not an independent sample. Larger datasets than were available in the present study should thus be used to explore whether statistical analyses need to take account of the stomach as a 'sampling unit' (see similar approach for general diet assessment in Methods), perhaps comparing the 'average' size of fish per stomach.

(a) smolt run period

Estimated Salmon length frequencies for Dee Goosanders in spring 2019 were significantly smaller than those recorded from birds sampled in Mar-Apr 1995 and spring 1996. Length frequency distributions suggested fewer large individuals over 100mm and more smaller ones, especially in the 41-70mm length range. Salmon from R. Tweed Goosanders in 2019 were significantly shorter than those recorded in Apr 1991 and in April 1995. Length frequency distributions suggested fewer large fish over 100mm and more smaller ones, especially in the 61- 70mm length category.

Salmon length frequencies estimated from Tweed Cormorants in 2019 were also significantly shorter than those recorded in the Mar-Apr 1995 sample. The length frequency distribution suggested that numbers increased with size between 61-100mm length range and that almost no fish over 100mm were recorded.

Length frequency distributions of Salmon taken by Goosanders in 2019 were not significantly different to that recorded in the 1990s for the Nith (Mar-Apr 1995) or the Spey (April 1996), and all other samples were too small for any comparisons to be made.

Whilst the proportions of Salmon (by mass) in the diet of birds appeared to be fairly similar to those recorded previously (see Section 4), their size was often significantly smaller in most 2019 smolt run period samples than was recorded historically. This was the case in five of the seven possible comparisons where median Salmon lengths in these 2019 smolt run period samples were 62mm (Dee Goosanders), 70mm (Nith Goosanders), 79mm (Tweed and Spey Goosanders), and 88mm (Tweed Cormorants).

Smoltification is a growth- and size-related developmental event in the life-history of juvenile Salmon with photoperiod as the major cue determining development, modulated by both water temperature and water flow. These are likely to vary in importance (and stimulate migration differently), probably reflecting adaptations to ensure optimal timing of migration in relation to subsequent survival and growth at sea (Todd *et al*. 2011). Although the major movement of juvenile Salmon is generally considered to be the spring smolt run, juveniles can also make major downstream movements in autumn prior to their outmigration as smolts in the following spring (McCormick *et al*. 1998). Such autumn movements are discussed further below.

For many fish species, the length frequency distribution of individuals of each given year-class (i.e. all approximately the same age) typically approximates to a Normal distribution about some mean length, often with an appreciable standard deviation (Gulland & Rosenberg 1992). These length-at-age distributions are a striking feature of juvenile Atlantic Salmon growth variation and there is a strong size and growth bimodality between early and late smolts (Thorpe *et al*. 1982). This size (i.e. length) bimodality can be established as early as age 0+ (young-of-the-year) for Salmon in rivers with relatively fast growth (Letcher & Gries 2003). As a consequence, fish smolting in a particular spring are considerably larger than those that delay smolting for one or more years.

Across its natural range in the temperate and subarctic regions of the North Atlantic Ocean, the average total body length of wild Atlantic Salmon smolts is usually 10-20 cm, with minimum-maximum values from about 7cm to 30 cm (Thorstad *et al*. 2011), although these values are for Total Length (TL) and so likely to be a few millimetres longer than the Fork Lengths (FL) reported here.

As yet there is no way that Salmon smolts can be differentiated from parr in the partially digested remains of most fish in stomach contents of birds. Marquiss *et al.* (1998) considered that "larger" Salmon greater than 89mm in length were "of most interest to fisheries managers". Although not explicitly categorising individuals as either smolts or parr, it was presumably considered that individuals over 89mm were more likely to be either smolts or parr prior to smoltification.

Identifying the precise nature of Salmon length frequency distributions in the 2019 smolt run period samples was not straightforward. Nevertheless, those from each sample of Goosanders seemed to show (at least) a bimodal size distribution of Salmon less than 80mm long and of larger individuals (Dee, Tweed, Spey), and of less or more than 90mm long (Nith). However, in the absence of assessments of the length frequency distribution of smolts in each of the four study rivers, and given that those determined from samples in the present study were found to be smaller (median length 63-88mm) than those reported from historical samples, it is worth noting that these fish are smaller than those categorised as "larger salmon" by Marquiss *et al*. (1998).

Consistent findings in the present study of relatively small Salmon in the diet of Goosanders and Cormorants does not necessarily mean that at least some of the individuals consumed were not smolts. Indeed there is evidence of a steady, long-term (1963-2003) reduction in mean river age (i.e. the period spent in freshwater), and hence size, for juvenile Salmon in the North Esk, Scotland (data presented by Todd *et al*. 2011). This reduction may be the response of juveniles to recent milder winters in freshwater or to seasonal changes of return migration timing of returning (1SW) adults of contrasting river age, although clear interpretation was hampered by the possible influence of a legal netting season. Nevertheless, this reduction in mean river age for juveniles is not the result of an increase in their smolting at only one year of age, but of a clear shift from three- to two-year old smolts (Todd *et al*. 2011), presumably with a concomitant reduction in smolt size.

It is currently not possible to determine how much of the Goosander (or Cormorant) diet in the 2019 spring samples comprised (smaller) resident parr compared to larger (migrating) smolts. A future research requirement is thus to improve our understanding of the relationship between the length-at-age distributions of juvenile Salmon in river systems and the length frequency distributions of those individuals consumed by Goosanders and Cormorants. Inevitably, this will be linked to improved understanding of the both the timing and length of the smolt run period and to the temporal dynamics and spatial distribution of juvenile Salmon in the mainstem and tributaries over this period, but also at other times of year, particularly the period of downstream movements in autumn.

(b)autumn-winter period

Autumn-winter 2019/20 samples could not be compared with any historical ones, but only with those from the preceding smolt run period. However, these comparisons should be treated with caution because of the sample size issues described above for both the number of stomachs containing Salmon and the numbers of Salmon recorded therein (see Section 5b and Table 16). Nevertheless, in three of the four pairs of samples that could be tested statistically, the sizes of Salmon recorded in autumn-winter 2019/20 were larger than those recorded in the previous smolt run period.

Estimated Salmon length frequencies from Dee Goosanders in November 2019 were significantly larger than those recorded the previous Mar-May, with more larger individuals over 100mm and fewer smaller fish 60mm or less. Similarly, Salmon from Spey Goosanders in autumn-winter 2019/20 were significantly larger than those recorded in the previous Apr-May with more larger fish over 90mm and fewer smaller than this. For Tweed Cormorants, Salmon recorded in autumn 2019 were again significantly larger than those recorded in the preceding Apr-May, with no fish over 120mm being recorded in the spring. No significant difference was found between the lengths of Salmon taken by Tweed Goosanders in the autumn and smolt run period samples in 2019.

Relatively large numbers of birds were available from the R. Tweed, and, whilst acknowledging that the numbers of stomachs containing Salmon were small (N = 5-9), it was possible to compare Salmon lengths in 'early' and 'late' autumn 2019. Salmon taken by Tweed Cormorants later in the autumn (November) were significantly larger than those taken by birds earlier that season (Sep- Oct). The same pattern was found for Tweed Goosanders too, although the differences were not significant.

For the autumn-winter samples, Salmon from Dee Goosanders fell into two groups: those less than 70mm and those over 91mm. Corresponding groups for Spey Goosanders, were less than 70mm or over 80mm, and for Tweed Cormorants were less than 100mm or over 111mm. In these samples, Salmon consumed in the autumn-winter were larger than those consumed in the previous spring. Similarly, on a finer temporal scale, Tweed Cormorants appeared to take larger Salmon as autumn advanced, with the median length of 133mm in November of 133mm (cf. Sep- Oct = 88mm) being the largest recorded in the present study. There was thus a clear bimodality in Salmon length frequencies in the autumn-winter samples (as described above for the smolt run period) and evidence that both Goosanders and Cormorants later in the year were taking larger Salmon than they were recorded consuming in the spring.

It is possible that at least some of the predation of Salmon in autumn could be related to the downstream movement of juveniles at that time of year, prior to their outmigration as smolts the following spring (see McCormick *et al*. 1998). An important future research requirement is thus to collect more information on the dietary proportions of likely smaller ('resident') and larger ('mobile') parr at times of year outside the smolt run period, particularly during the downstream movement phase of larger pre-smolt fish in the autumn. As with the smolt run period itself, this will inevitably be linked to improved understanding of both the timing and length of autumn parr movements and to the temporal dynamics and spatial distribution of juvenile Salmon in the mainstem and tributaries over this period.

7. Future research requirements

1. Current information on the dietary composition and sizes of Salmon taken by Goosanders and Cormorants is limited by the small sample sizes of birds and rivers. Research involving larger samples of birds at various times of year, and from a larger number of rivers, is required to quantify (temporal and spatial) dietary variation and to improve levels of confidence in the evidence for the possible effects of predation by fish-eating birds in relation to the protection of Salmon stocks in Scottish rivers.
2. The possibility of 'mismatch' between the timing of bird sampling and the timing of biological events, such as the smolt run, raises issues over the comparability of samples in relation to the timing of their collection. This is currently poorly understood and so the implications of such temporal mismatches in sampling dates require investigation. So too do the likely levels of inter-annual variation in diet assessments from bird samples from the same location taken in different years.
3. The implications of bird sampling regimes (including their timing) to assess fish-eating bird diet requires further investigation. This should include fine-scale analysis of temporal assessments of dietary composition to better understand over what time-periods dietary assessments are representative, to examine the influence of sampling location on these assessments, and the likely levels of inter-annual variation in diet assessments from bird samples collected from the same location in different years. Such information could then be used, for instance, to plan a more intensive sampling programme for evidence gathering of bird diet in relation to the smolt run on Scottish rivers (including new information provided from fish trapping and tagging studies).
4. Assessments of general diet from samples of bird stomach contents are currently hard to compare statistically. For each sample, such assessments are the sum of the mass of each fish species recorded, which will either be zero or a positive value. As zero values contribute to the total sample size for statistical tests, simulation studies are needed to understand what sample size, and what number of positive values within a sample, might be most appropriate for robust statistical comparisons.
5. Fine-scale data analysis is required to better understand the influence of both sample location and sample size of birds on subsequent length frequency distributions for prey fishes, particularly Salmon, recorded in stomachs.
6. Any individual bird may opportunistically capture smaller (or larger) than average fish when foraging or, alternatively, be feeding in a location where such fish occur. Fish recorded in stomach contents are therefore not necessarily independent samples. Larger datasets could be used to explore whether statistical analyses should take account of the stomach as a 'sampling unit' – for both assessments of general diet and for estimates of length frequency distributions for particular prey species.
7. It is vital to know where birds are actually foraging, rather than where they are sampled for subsequent diet assessment. Further research (including the tagging and tracking of birds) is thus needed to better understand the spatial and temporal distribution of fish-eating birds within river systems, their (seasonal) movements and behaviour, and levels of fidelity to different locations (e.g. foraging sites, roosts) at different times of year.

8. An analysis of all available data on Goosander and Cormorant numbers and distribution on Scottish Salmon rivers, coupled with a programme of more standardised counts, would help determine the spatial and temporal distribution of birds in relation to both sampling regimes to assess bird diet and future management actions to protect fisheries.
9. Further dietary data are needed for Goosanders and Cormorants from times of year outside the spring smolt run period. For both bird species, an improved understanding is needed of seasonal variations in the relative proportions (and sizes) of juvenile Salmon consumed throughout the year. This would help to put predation during the spring into broader context and improve our understanding of fine-scale temporal variation in diet and any implications this has for the degree of mismatch between comparative samples (see 2).
10. An improved understanding is needed of the relationship between the length-at-age distributions of juvenile Salmon (e.g. ‘resident’ parr, ‘mobile’ pre-smolt parr, smolts) in river systems (mainstem and tributaries) and the length frequency distributions of those individuals consumed by Goosanders and Cormorants. Inevitably, this is linked to improved understanding of both the timing and length of the smolt run period, the efficiency and wider representativeness of smolt trap data, and to the temporal dynamics and spatial distribution of juvenile Salmon in the mainstem and tributaries over this period. This understanding should also be improved for other times of year, for instance the period when larger parr move downstream in autumn. Overall, further information on fish abundance, behaviour, and vulnerability to predation (mainstem and tributaries) is needed, along with year-round population modelling at the catchment scale to determine whether (and to what degree) bird predation is a contributory factor to the demographic rates of fish.

Acknowledgements

Many thanks to Simon Dryden for initial discussions about this work. Samples were collected and delivered by staff from the River Dee Trust, Nith District Salmon Fishery Board, the Nith Catchment Fishery Trust, The Tweed Foundation, and the Spey Fishery Board. Jamie Urquhart, Jim Henderson, Debbie Parke, James Hunt, Roger Knight, Brian Shaw, and Jason Hysert provided local background information throughout this work. Rob Brooker, Duncan White, and Lucinda Robinson helped with temporary lab access at The James Hutton Institute to enable the timely processing of some of the samples. The four river catchment maps (Figures 3-7) were kindly produced by James Hunt. James also provided information (and interpretation) from the Gala Water smolt trap in the Tweed catchment. Dina Sadykova, environmental statistician at UKCEH, helped with data analysis, provided statistical advice and computation, and produced the boxplots and ecdf plots presented in this report. Kate Randall, graphic designer at UKCEH, reformatted the full content of this report to ensure it complied with the Scottish Government's accessibility standards for publishing. Earlier drafts of this report benefitted from comments from Marine Scotland and Francis Daunt and Richard Pywell at UKCEH. Heartfelt thanks to all.

8. References

Arnold, T.B., & Emerson, J.W. (2011). Nonparametric goodness-of-fit tests for discrete null distributions. The R Journal 3/2, 34-39.

Britton, J.R. & Shepherd, J.S. (2005) Biometric data to facilitate the diet reconstruction of piscivorous fauna. Folia Zool. 54(1–2): 193–200.

Carss, D.N. (in press) There must be some kind of way out of here: towards “reframing” European Cormorant-fisheries conflicts. Ardea 109(3) doi:10.5253/arde.v109i2.a31

Carss, D.N. (ed.) (2003) Reducing the conflict between Cormorants and fisheries on a pan-European scale REDCAFE: Pan European Overview. Final Report to European Commission, (August 2003), pp169. Also available at: http://www.intercafeproject.net

Carss, D. N., Bevan, R. M., Bonetti, A., Cherubini, G., Davies, J., Doherty, D., EL Hili, A., Feltham, M. J., Grade, N., Granadeiro, J. P., Grémillet, D., Gromadska, J., Harari, Y. N. R. A., Holden, T., Keller, T., Lariccia, G., Mantovani, R., McCarthy, T. K., Mellin, M., Menke, T., Mirowska-Ibron, I., Müller, W., Musil, P., Nazirides, T., Suter, W., Trauttmansdorff, J., Volponi, S., & Wilson, B. (1997) Techniques for assessing Cormorant diet and food intake: towards a consensus view. Suppl. Ric. Biol. Selvaggina 26: 197-230.

Carss, D.N. & Brockie, K. (1994) Prey remains at osprey nests in Tayside and Grampian, 1987- 1993. Scott. Birds 17: 132-145.

Carss, D.N. & Ekins, G.R. (2002) Further European integration: mixed sub-species colonies of great Cormorants *Phalacrocorax carbo* in Britain – colony establishment, diet, and implications for fisheries management. Ardea 90(1): 23-41.

Carss, D.N., Kruuk, H. & Conroy, J.W.H. (1990) Predation on adult Atlantic Salmon, *Salmo salar* L., by otters, *Lutra lutra* (L.), within the River Dee system, Aberdeenshire, Scotland. J. Fish Biol. 37: 935-944.

Carss, D.N., van Eerden, M., Enstipp, M., Govedic, M., Gwiazda, R. & Trauttmansdorff, J. (2012)
Cormorant diet, food and energy intake. In: Carss, D.N., Parz-Gollner, R. & Trauttmansdorff, J. (2012) The INTERCAFE Field Manual: research methods for Cormorants, fishes, and the interactions between them. pp37-46.

Carss, D.N., Parz-Gollner, R. & Trauttmansdorff, J. (2012) The INTERCAFE Field Manual: research methods for Cormorants, fishes, and the interactions between them. INTERCAFE COST Action 635 Final Report II. NERC/Centre for Ecology & Hydrology on behalf of COST, pp142.

Correia, M.J., Costa, J.L., Antunes, C., De Leo, G. & Domingos, I. (2018) The decline in recruitment of the European Eel: new insights from a 40-year-long time-series in the Minho estuary (Portugal). ICES Journal of Marine Science (2018), 75(6), 1975–1983. doi:10.1093/icesjms/ fsy073

Cramp, S. & Simmons, K.E.L. (1977) Handbook of the Birds of Europe the Middle East and North Africa. The Birds of the Western Palearctic. Volume I Ostrich to Ducks. Oxford University Press, Oxford.

Dimitrova, D.S., Kaishev, V.K. and Tan, S. (2020). Computing the Kolmogorov-Smirnov distribution when the underlying CDF is purely discrete, mixed, or continuous. Journal of Statistical Software. 95/10, 1–42.

Feltham, M.J. (1990) The diet of red-breasted mergansers (*Mergus serrator*) during the smolt run in N.E. Scotland: the importance of Salmon (*Salmo salar*) smolts and parr. J. Zool., Lond. 222 285- 292.

Gulland, J.A. & Rosenberg, A.A. (1992) A review of length-based approaches to assessing fish stocks. FAO Fisheries Technical Paper. No. 323. Rome, FAO. 1992. 100p.

Hájková, P., Roche, K. & Kocain, U. (2003) On the use of diagnostic bones of brown Trout, Salmo trutta m. fario, Grayling, *Thymallus thymallus* and Carpathian sculpin, *Cottus poecilopus* in Eurasian otter, *Lutra lutra* diet analysis. Folia Zool. 52(4): 389–398.

Hindar, K, Hutchings, J.A., Diserud, O. & Fiske, P. (2011) Stock, Recruitment and Exploitation. In: Aas, O, Einum, S., Klenentsen, A., and Skurdal, J. (eds) Atlantic Salmon Ecology, pp299-331, Blackwell Publishing.

Letcher, B.H. & Gries, G. (2003) Effects of life-history variation on size and growth in stream-dwelling Atlantic salmon. Journal of Fish Biology 62: 97-114.

Marquiss M. & Carss, D.N. (1997) Methods of estimating the diet of sawbill ducks *Mergus* spp. and Cormorants *Phalacrocorax carbo*. Supplemento Ricerche di Biologia della Selvaggina 26: 247-258.

Marquiss, M. & Carss, D.N. (1994) Avian piscivores: basis for policy. National Rivers Authority, Bristol, pp106.

Marquiss, M., Carss, D.N., Armstrong, J.D., & Gardiner, R. (1998) Fish-eating birds and Salmonids in Scotland. Report on fish-eating birds research (1990-97) to the Scottish Office Agriculture, Environment and Fisheries Department, 156pp. Stationary Office, Edinburgh. Also available at: https://www.researchgate.net/publication/338037364_Fish_Eating_Birds_and_Salmonids_in_Scotland

McCormick, S.D., Hansen, L.P., Quinn, T.P. & Saunders, R.L. (1998) Movement, migration, and smolting of Atlantic salmon (*Salmo salar)*. Canadian Journal of Fisheries & Aquatic Sciences 55: 77-92.

Morgan, R.I.G., Greenstreet, S.P.R. & Thorpe, J.E. (1986) First observations on distribution, food and fish predators of postsmolt Atlantic salmon, *Salmo salar*, in the outer Firth of Clyde. ICES CM 1986/M: 27, 8pp.

Russell, I.C., Dare, P.J., Eaton, D.R. & Armstrong, J.D. (1996) Assessment of the problem of fish-eating birds in inland fisheries in England and Wales. Lowestoft: Directorate of Fisheries Research.

SalmonBusiness 2018 https://Salmonbusiness.com/scottish-wild-Salmon-count-investigation-into-decline-begin/

Siegel, S. & Castellan, N.J. (1988) Nonparametric Statistics for the Behavioural Sciences. 2nd Edition, McGraw-Hill, New York.

Spencer, R. (1983) The Ringers' Manual. Third Edition, British Trust for Ornithology, Tring, Herts.

Thorpe, J.E., Talbot, C. & Villarreal, C. (1982) Bimodality of growth and smolting in Atlantic salmon, Salmo salar L. Aquaculture 28: 123-132.

Thorstad, E.B., Whoriskey, F., Rikardsen, A. & Aarestrup, K. (2011) Aquatic nomads: the life and migrations of the Atlantic Salmon. In: Aas, O, Einum, S., Klenentsen, A., and Skurdal, J. (eds) Atlantic Salmon Ecology, pp1-32, Blackwell Publishing.

Todd, C.D., Friedland, K.D., MacLean, J.C. Hazon, N. & Jensen, A.J. (2011) Getting into hot water? Atlantic Salmon responses to climate change in freshwater and marine environments. In: Aas, O, Einum, S., Klenentsen, A., and Skurdal, J. (eds) Atlantic Salmon Ecology, pp409-443, Blackwell Publishing.

van Eerden, M.R., van Rijn, S., Volponi, S., Paquet, J-Y. & Carss, D.N. (2012) Cormorants and the
European environment: exploring Cormorant status and distribution on a continental scale. INTERCAFE COST Action 635 Final Report I. NERC/Centre for Ecology & Hydrology on behalf of COST, pp126.

Ward, D.M. & Hvidsten, N.A. (2011) Predation: compensation and context dependence. In: Aas, O, Einum, S., Klenentsen, A., and Skurdal, J. (eds) Atlantic Salmon Ecology, pp199-220, Blackwell Publishing.

Wires, L.R., Carss, D.N., Cuthbert, F.J. & Hatch, J.J. (2003) Transcontinental connections in relation to Cormorant-fisheries conflicts: perceptions and realities of a “bête noire” (black beast) on both sides of the Atlantic. Vogelwelt 124, Suppl.: 389-400.

Appendix 1: Stomach contents analysis and diet assessment methodology

Processing of bird carcasses and wet prey remains

Bird carcasses

1.1 Fit each carcass with a permanent label affixed to the leg to guarantee individual identity throughout processing.

1.2 Where necessary, thaw bird carcasses at room temperature for 24-48 hrs.

1.3 Identify birds to species and sex (and age where possible based on plumage characteristics).

1.4 Take beak measurements from Cormorants (to investigate possible racial differences).

1.5 Weigh birds (nearest 10g) and measure wing (nearest 1 mm).

1.6 Dissect birds from the beak to the vent to record all material in the digestive tract.

Prey remains: wet

1.7 Remove any whole ('freshly eaten') fish carefully, for identification and measurement.

1.8 Flush out all remaining partially-digested material and collect in individually labelled sample jars.

1.9 Digest these remains (4-6 days in oven at ca. 37˚C) in a saturated solution of biological washing powder to remove all flesh.

1.10 Rinse the digested samples thoroughly with cold water through 1.0mm and 0.5mm sieves until completely clean.

1.11 Transfer thoroughly-rinsed bones to filter paper and air dry (1-3 days).

1.12 Transfer dried material to individually labelled paper envelopes for dry analysis and/or storage.

Identification, counting and measuring of dry prey remains

Prey remains: dry

2.1 Transfer dried material to Petri dish for examination under low powered binocular microscope.

2.2 Ignore obvious highly-eroded (well digested) hard parts from previous meals.

2.3 Identify key bones to fish species and extract/store them (as described in literature and with extensive UK CEH reference collection).

2.4 Measure specific key bones (e.g. Salmonid atlas vertebrae, cyprinid pharyngeal teeth) to estimate original fish length.

2.5 Identify any other remains (e.g. some specific species/bones) and estimate fish lengths from comparison with curated UK CEH reference material.

Calculating proportions (mass, number) of each species in the diet

Subsequent calculations

3.1 Determine the numbers of individuals recorded for each fish species.

3.2 For each individual fish, convert each length estimate (or measurement in the case of ‘fresh fish) into an estimate of body mass from a series of length:mass equations (from the published literature and some based on previous UK CEH work e.g. Appendix in Carss & Ekins 2002).

3.3 For each fish species, combine numbers and estimated individual mass to estimate the total (mass) contribution.

3.4 Combine the mass of each fish species to determine the overall mass of whole sample.

3.5 Derive the proportion (by mass and by number) of each fish species in the diet, collated in a form directly comparable (and equivalent) “*as contained in appendix 5.1 and 5.3, for Goosanders and Cormorants respectively, of the ‘Fish-eating Birds and Salmonids in Scotland’ report published in November 1998 (ISBN 0 7480 7232 2)*” (7.1 of contract requirements).

Appendix 2: Biometric measurements of Goosanders and Cormorants received

Biometric details of Goosanders and cormorants received in the present study. Sex determined as male (M) or female (F), age as adult (Ad) or Juvenile (Juv) based on plumage (Cramp & Simmons 1977). Body mass to the nearest 5g. Wing length is maximum flattened chord length to nearest mm (Spencer 1983).

Code	Species	River	Date of collection	Sex	Age class	Body mass (kg)	Standard wing length (mm)
DeeG1	Goos	Dee	25/04/2019	M	Ad	1.60	285
DeeG2	Goos	Dee	01/05/2019	M	Ad	1.65	296
DeeG3	Goos	Dee	26/03/2019	M	Ad	1.60	287
DeeG4	Goos	Dee	17/04/2019	F	N/d	1.25	269
DeeG5	Goos	Dee	06/04/2019	M	Juv	1.35	285
DeeG6	Goos	Dee	17/04/2019	F	Ad	1.25	263
DeeG7	Goos	Dee	02/05/2019	M	Ad	1.65	285
DeeG8	Goos	Dee	22/03/2019	M	Juv	1.45	287
DeeG9	Goos	Dee	02/04/2019	M	Ad	1.50	287
DeeG10	Goos	Dee	29/03/2019	F	Ad	1.50	271
DeeG11	Goos	Dee	09/04/2019	M	Ad	1.45	289
DeeG12	Goos	Dee	25/04/2019	F	Juv	1.20	261
DeeG13	Goos	Dee	02/04/2019	F	Ad	1.15	265
DeeG14	Goos	Dee	23/04/2019	F	Ad	1.35	263
DeeG15	Goos	Dee	18/04/2019	F	Ad	1.50	268
DeeG16	Goos	Dee	01/05/2019	M	Ad	1.65	302
DeeG17	Goos	Dee	29/04/2019	F	Ad	1.40	263
DeeG18	Goos	Dee	06/03/2019	F	Juv	1.25	266
DeeG19	Goos	Dee	02/04/2019	F	Ad	1.45	261
DeeG20	Goos	Dee	10/04/2019	M	Ad	1.65	294
NithG1	Goos	Nith	18/04/2019	M	Ad	1.60	296
NithG2	Goos	Nith	18/04/2019	M	Juv	1.80	280
NithG3	Goos	Nith	24/04/2019	M	Ad	1.70	279
NithG4	Goos	Nith	24/04/2019	M	Ad	1.60	292

NithG5	Goos	Nith	24/04/2019	M	Ad	1.65	290
NithG6	Goos	Nith	24/04/2019	F	Ad	1.35	265
NithG7	Goos	Nith	08/05/2019	M	Ad	1.55	282
NithG8	Goos	Nith	08/05/2019	M	Ad	1.50	291
NithG9	Goos	Nith	08/05/2019	M	Ad	1.60	294
NithG10	Goos	Nith	22/05/2019	M	Ad	1.40	284
NithG11	Goos	Nith	26/04/2019	M	Juv	1.70	275
NithG12	Goos	Nith	30/04/2019	M	Juv	1.90	290
NithG13	Goos	Nith	05/04/2019	M	Juv	1.50	281
NithG14	Goos	Nith	16/04/2019	M	Juv	1.50	271
NithG15	Goos	Nith	16/04/2019	M	Ad	N/d	285
TwG23	Goos	Tweed	01/05/2019	M	Ad	1.55	296
TwG24	Goos	Tweed	16/04/2019	F	N/d	1.20	261
TwG25	Goos	Tweed	15/04/2019	M	Ad	1.75	291
TwG26	Goos	Tweed	12/04/2019	M	Ad	1.55	286
TwG27	Goos	Tweed	03/05/2019	M	Ad	1.45	291
TwG28	Goos	Tweed	29/05/2019	M	Ad	1.55	291
TwG29	Goos	Tweed	25/05/2019	M	Ad	1.40	N/d
TwG30	Goos	Tweed	30/04/2019	F	N/d	1.15	276
TwG31	Goos	Tweed	15/04/2019	M	Ad	1.30	299
TwG32	Goos	Tweed	24/05/2019	M	Ad	1.70	294
TwG33	Goos	Tweed	30/04/2019	M	Ad	1.70	293
TwG34	Goos	Tweed	31/05/2019	M	Ad	1.85	287
TwG36	Goos	Tweed	03/04/2019	F	N/d	1.35	251
TwG53	Goos	Tweed	04/04/2019	F	Ad	1.35	263
SpeyG1	Goos	Spey	13/04/2019	M	Ad	1.60	293
SpeyG2	Goos	Spey	01/04/2019	F	Juv	1.00	261
SpeyG3	Goos	Spey	09/04/2019	F	Ad	1.35	271
SpeyG4	Goos	Spey	29/04/2019	M	Ad	1.50	293
SpeyG5	Goos	Spey	24/04/2019	M	Ad	1.65	302
SpeyG6	Goos	Spey	11/04/2019	F	Ad	1.45	266
SpeyG7	Goos	Spey	25/04/2019	M	Ad	1.70	295
SpeyG8	Goos	Spey	25/04/2019	M	Ad	1.80	294
SpeyG9	Goos	Spey	26/03/2019	M	Ad	1.55	297

SpeyG10	Goos	Spey	18/03/2019	M	Ad	1.45	286
SpeyG11	Goos	Spey	15/04/2019	M	Ad	1.60	288
SpeyG12	Goos	Spey	01/04/2019	M	Ad	1.50	282
SpeyG13	Goos	Spey	11/04/2019	M	Ad	1.50	295
SpeyG14	Goos	Spey	03/04/2019	M	Ad	N/d	291
SpeyG15	Goos	Spey	11/04/2019	F	Ad	1.35	273
Nith Corm1	Corm	Nith	04/04/2019	N/d	Juv	2.70	357
NithCorm2	Corm	Nith	05/04/2019	N/d	Ad	2.05	330
NithCorm3	Corm	Nith	26/04/2019	N/d	Juv	2.50	357
NithCorm4	Corm	Nith	20/03/2019	N/d	Juv	2.50	339
NithCorm5	Corm	Nith	20/03/2019	N/d	Juv	2.40	332
NithCorm6	Corm	Nith	11/04/2019	N/d	Juv	3.00	360
TweedCorm4	Corm	Tweed	11/04/2019	N/d	Juv	2.90	360
TweedCorm5	Corm	Tweed	23/05/2019	N/d	Juv	2.85	345
TweedCorm6	Corm	Tweed	02/04/2019	N/d	Juv	2.40	355
TweedCorm7	Corm	Tweed	23/05/2019	N/d	Juv	3.05	364
TweedCorm8	Corm	Tweed	24/05/2019	N/d	Juv	1.85	340
TweedCorm9	Corm	Tweed	24/05/2019	N/d	Juv	2.15	357
TweedCorm10	Corm	Tweed	24/05/2019	N/d	Juv	3.05	361
TweedCorm11	Corm	Tweed	28/05/2019	N/d	Juv	2.00	353
TweedCorm12	Corm	Tweed	24/05/2019	N/d	Juv	2.40	350
SpeyCorm1	Corm	Spey	02/04/2019	N/d	Juv	3.65	364
DeeG21	Goos	Dee	22/11/2019	F	N/d	1.35	253
DeeG22	Goos	Dee	25/11/2019	M	Juv	1.85	286
NithG16	Goos	Nith	13/10/2019	F	N/d	1.45	271
NithG17	Goos	Nith	15/11/2019	F	N/d	1.45	263
NithG18	Goos	Nith	08/11/2019	F	N/d	1.40	259
NithG19	Goos	Nith	08/11/2019	M	N/d	1.65	272
NithG20	Goos	Nith	20/11/2019	F	N/d	1.35	252
NithG21	Goos	Nith	20/11/2019	M	N/d	1.45	278
NithG22	Goos	Nith	28/01/2020	M	Juv	1.65	285
NithG23	Goos	Nith	22/01/2020	M	Ad	1.60	302
NithG24	Goos	Nith	04/02/2020	F	N/d	1.45	260
NithG25	Goos	Nith	03/02/2020	M	Ad	1.65	282

TweedGoos61	Goos	Tweed	09/09/2019	F	N/d	1.20	255
TweedGoos62	Goos	Tweed	25/10/2019	M	Juv	1.60	286
TweedGoos63	Goos	Tweed	05/11/2019	M	Juv	1.55	292
TweedGoos64	Goos	Tweed	20/11/2019	F	N/d	1.10	264
TweedGoos65	Goos	Tweed	09/09/2019	F	N/d	1.20	230
TweedGoos66	Goos	Tweed	14/10/2019	M	Juv	1.45	281
TweedGoos67	Goos	Tweed	20/09/2019	F	N/d	1.35	251
TweedGoos68	Goos	Tweed	23/09/2019	M	Juv	1.80	286
TweedGoos69	Goos	Tweed	23/09/2019	M	Juv	1.55	276
TweedGoos70	Goos	Tweed	03/10/2019	M	Juv	1.40	285
TweedGoos71	Goos	Tweed	04/10/2019	M	Ad	1.60	274
TweedGoos72	Goos	Tweed	14/10/2019	F	N/d	1.25	255
TweedGoos73	Goos	Tweed	17/10/2019	M	Ad	1.60	286
TweedGoos74	Goos	Tweed	22/10/2019	M	Juv	1.70	283
TweedGoos75	Goos	Tweed	24/10/2019	M	Juv	1.30	275
TweedGoos76	Goos	Tweed	06/11/2019	M	Ad	1.55	284
TweedGoos77	Goos	Tweed	08/11/2020	F	N/d	1.45	258
TweedGoos78	Goos	Tweed	09/11/2020	F	N/d	1.30	252
TweedGoos79	Goos	Tweed	10/11/2019	F	N/d	1.40	268
TweedGoos80	Goos	Tweed	10/11/2020	F	N/d	1.25	258
TweedGoos81	Goos	Tweed	11/11/2020	M	Juv	1.70	280
TweedGoos82	Goos	Tweed	19/11/2020	M	Ad	1.50	273
TweedGoos83	Goos	Tweed	20/11/2020	M	Ad	1.85	286
TweedGoos84	Goos	Tweed	28/11/2020	F	N/d	1.30	268
SpeyG16	Goos	Spey	11/09/2019	M	Ad	1.40	286
SpeyG17	Goos	Spey	03/10/2019	F	N/d	1.15	266
SpeyG18	Goos	Spey	03/10/2019	F	N/d	1.30	265
SpeyG19	Goos	Spey	14/10/2019	F	N/d	1.05	262
SpeyG20	Goos	Spey	29/11/2019	M	Juv	1.50	271
SpeyG21	Goos	Spey	04/12/2019	F	N/d	1.50	260
SpeyG22	Goos	Spey	18/12/2019	M	Ad	1.60	297
SpeyG23	Goos	Spey	19/12/2019	F	N/d	0.90	218
DeeCorm1	Corm	Dee	02/12/2019	N/d	Juv	3.70	375
DeeCorm2	Corm	Dee	05/12/2019	N/d	Juv	3.15	366

DeeCorm3	Corm	Dee	20/01/2020	N/d	Juv	3.30	366
DeeCorm4	Corm	Dee	03/12/2019	N/d	Juv	2.45	358
NithCorm7	Corm	Nith	08/11/2019	N/d	Juv	2.75	333
Nith Corm8	Corm	Nith	12/11/2019	N/d	Juv	2.85	356
NithCorm9	Corm	Nith	12/11/2019	N/d	Juv	2.25	353
NithCorm10	Corm	Nith	15/11/2019	N/d	Juv	2.75	353
NithCorm11	Corm	Nith	20/11/2019	N/d	Juv	2.20	340
NithCorm12	Corm	Nith	21/11/2019	N/d	Juv	2.85	337
NithCorm13	Corm	Nith	03/12/2019	N/d	Juv	3.65	373
NithCorm14	Corm	Nith	23/01/2020	N/d	Juv	3.40	366
NithCorm15	Corm	Nith	19/01/2020	N/d	Juv	2.70	353
NithCorm16	Corm	Nith	28/01/2020	N/d	Juv	3.10	380
NithCorm17	Corm	Nith	13/02/2020	N/d	Ad	2.90	354
NithCorm18	Corm	Nith	19/01/2020	N/d	Juv	1.65	308
TweedCorm24	Corm	Tweed	25/09/2019	N/d	Ad	2.90	361
TweedCorm25	Corm	Tweed	25/09/2019	N/d	Juv	2.90	348
TweedCorm26	Corm	Tweed	23/09/2019	N/d	Juv	2.15	340
TweedCorm27	Corm	Tweed	20/09/2019	N/d	Juv	2.10	353
TweedCorm28	Corm	Tweed	22/10/2019	N/d	Juv	2.80	365
TweedCorm29	Corm	Tweed	20/10/2019	N/d	Juv	2.65	358
TweedCorm30	Corm	Tweed	31/10/2019	N/d	Juv	2.40	353
TweedCorm31	Corm	Tweed	23/10/2019	N/d	Juv	2.70	354
TweedCorm32	Corm	Tweed	23/10/2019	N/d	Juv	2.75	352
TweedCorm33	Corm	Tweed	23/10/2019	N/d	ad	2.30	347
TweedCorm34	Corm	Tweed	02/10/2019	N/d	Juv	2.80	353
TweedCorm35	Corm	Tweed	05/10/2019	N/d	Juv	3.20	374
TweedCorm36	Corm	Tweed	24/10/2019	N/d	Juv	3.45	370
TweedCorm37	Corm	Tweed	15/10/2019	N/d	Ad	2.60	357
TweedCorm38	Corm	Tweed	23/10/2019	N/d	Juv	2.10	331
TweedCorm39	Corm	Tweed	22/10/2019	N/d	Juv	2.25	335
TweedCorm40	Corm	Tweed	22/10/2019	N/d	Juv	3.05	357
TweedCorm41	Corm	Tweed	06/11/2019	N/d	Juv	2.95	363
TweedCorm42	Corm	Tweed	19/11/2019	N/d	Juv	2.80	350
TweedCorm43	Corm	Tweed	01/11/2019	N/d	Juv	2.60	370

TweedCorm44	Corm	Tweed	19/11/2019	N/d	Juv	3.55	364
TweedCorm45	Corm	Tweed	10/09/2019	N/d	Juv	2.05	351
TweedCorm46	Corm	Tweed	21/09/2019	N/d	Juv	2.50	342
TweedCorm47	Corm	Tweed	15/10/2019	N/d	Juv	3.30	370
TweedCorm48	Corm	Tweed	24/10/2019	N/d	Juv	2.85	363
TweedCorm49	Corm	Tweed	25/10/2019	N/d	Juv	2.15	355
TweedCorm50	Corm	Tweed	19/11/2019	N/d	Ad	3.75	366
SpeyCorm2	Corm	Spey	04/12/2019	N/d	Juv	N/d	373
SpeyCorm3	Corm	Spey	04/12/2019	N/d	Juv	3.45	360
SpeyCorm4	Corm	Spey	05/12/2019	N/d	Juv	4.15	374
SpeyCorm5	Corm	Spey	19/12/2019	N/d	Juv	3.95	372
SpeyCorm6	Corm	Spey	06/01/2020	N/d	Juv	3.45	373
SpeyCorm7	Corm	Spey	07/01/2020	N/d	Juv	3.45	357
SpeyCorm8	Corm	Spey	14/01/2020	N/d	Juv	2.90	366
SpeyCorm9	Corm	Spey	04/02/2020	N/d	Juv	3.60	375
SpeyCorm10	Corm	Spey	04/02/2020	N/d	Juv	3.85	366
SpeyCorm11	Corm	Spey	07/02/2020	N/d	Juv	1.95	344
SpeyCorm12	Corm	Spey	13/02/2020	N/d	Juv	4.30	381
SpeyCorm13	Corm	Spey	13/02/2020	N/d	Juv	1.75	330

Appendix 3: Chronology and locations of samples received

In the present study, the collection period of the birds was different among rivers. It is useful to have full information on exactly when the birds were sampled. For example although samples taken in "March-May" could cover 31st March and 1st May or 1st March to 31st May – an important temporal difference. Although potential analysis is limited, such information could be important when making comparisons between rivers and when trying to put findings in the context of the smolt run for instance. Similarly, location information is important, and so it is useful to have information on exactly where in the different catchments the birds were sampled.

Date and location details (beats are named in bold and locations within them, if given, are in parenthesis) of all birds examined are provided in this Appendix, which covers:

(a) The smolt run period - effectively "spring 2019", which ran from 1st March 2019 to 31 May 2019, and

(b) Other times of year – effectively the following "autumn-winter 2019/20", which ran from 1st September 2019 to 29 February 2020.

Throughout, "empty" birds with no food in their stomachs are indicated by *.

(a) Samples from the smolt run period, 2019

During spring 2019, Goosanders from the R. Dee were collected from **Lower Crathes, Woodend, Commonty** (Cattie Burn), **Sluie, Borrowston** (Sands Pool), **Dess**, and **Crathie** (Polmonier). Goosanders from the R. Nith came from **Cowhill, Blackwood** (including Auld girth), **Barjarg** (including Cleughfoot), **Buccleuch**, and **Upper Nithsdale** (Dalpeddar). Goosanders from the R. Tweed were sampled from the **Lees, Lower Floors, Markestoun, Rutherford,** and **Bemersyde**. Those from the R. Spey were sampled at **Easter Echlies** (including Orn's Beat and Inverfiddich), **Pitchroy, Ballindalloch Tulchan** (B and D), and **Castle Grant**.

No Cormorants were sampled on the R. Dee in spring 2019. Birds from the R. Nith were taken from **Cowhill, Boatford** (Newhole), **Buccleuch** (**Lower**) (Doctor's Pool), and **Buccleuch** (**Mid**) (Whitehill). Cormorants from the R. Tweed came from the **Lees, Rutherford**, and **Bemersyde**, and the single Cormorant available from the Spey came from **Kinchurdy**.

(1a) R. Dee Goosanders (N = 20)

06 March	Lower Crathes
22 March	Lower Crathes
26 March	Lower Crathes
29 March	Lower Woodend
02 April	Lower Crathes*
02 April	Lower Crathes
02 April	Polmonier, Crathie
06 April	Sluie
09 April	Sluie
10 April	Dess, Rossachs Pool
17 April	Woodend
17 April	Sluie
18 April	Borrowston, Sands
23 April	Cattie Burn/Commonty
25 April	Woodend
25 April	Sluie
29 April	Lower Crathes
01 May	Lower Crathes
01 May	Lower Crathes
02 May	Dess

The R. Dee 2019 ‘smolt run’ Goosanders were sampled during a 7-week period from the third week of March to the last week of April/first few days of May, except for a single bird from the first week of March (see Figure AP3.1).

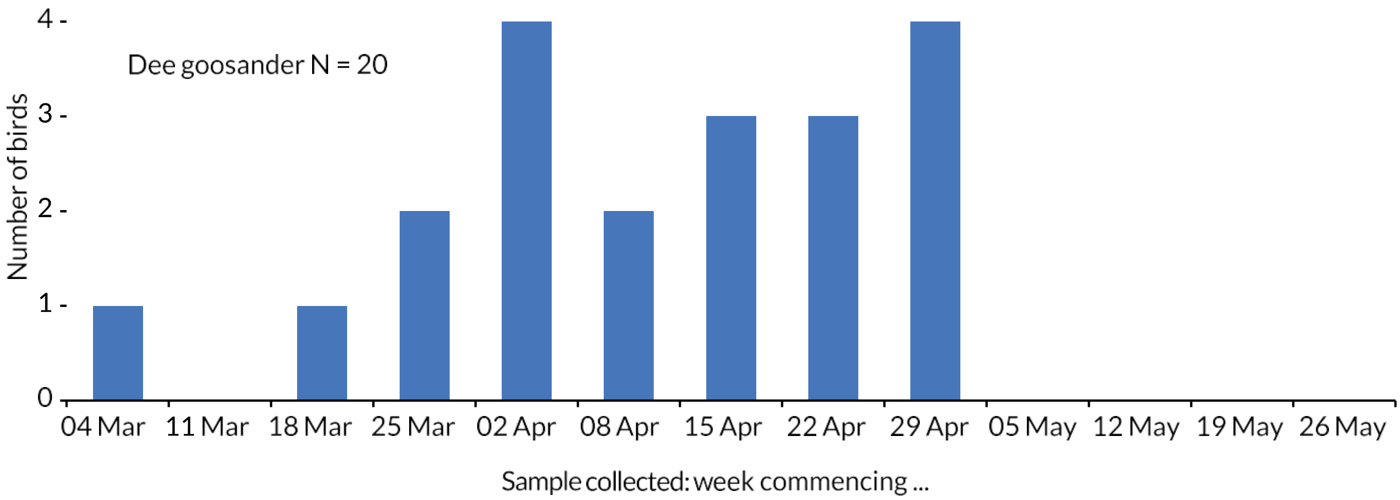


Figure AP3.1 The number of R. Dee Goosanders collected each week during the 2019 smolt run period.

The R. Dee 2019 smolt run period Goosanders were sampled from seven beats, most birds (15/20 = 75%) coming from just three of these: Lower Crathes, Sluie, and Woodend. Apart from the Polmonier bird, all Goosanders were sampled on the stretch between Banchory and Aboyne (Table AP3.1).

Beat	**Goosanders sampled**	
	No.	**(%)**
Lower Crathes	8	40
Woodend	3	15
Cattie Burn/Commonty	1	5
Borrowston/Sands Pool	1	5
Sluie	4	20
Dess	2	10
Polmonier, Crathie	1	5
Total	**20**	-

Table AP3.1 The numbers (%) of Goosanders sampled on various beats on the R. Dee, in the 2019 smolt run period.

(2a) R. Nith Goosanders (N = 15)

05 April	Buccleuch	24 April	Cleughfoot, Barjarg
16 April	Cowhill	26 April	Blackwood
16 April	Cleughfoot, Barjarg	30 April	Blackwood
18 April	Dalpeddar	08 May	Buccleuch*
18 April	Cowhill	08 May	Buccleuch
24 April	Dalpeddar	08 May	Blackwood
24 April	Dalpeddar	22 May	Cleughfoot, Barjarg*
24 April	Auldgirth		

Most R. Nith 2019 'smolt run' Goosanders were sampled during a 4-week period from mid-April to the first week of May, except for single birds from the first week of April and from the third week of May (see Figure AP3.2).

The R. Nith 2019 'smolt run' Goosanders were sampled from six beats, 4 of these produced 3 (20%) birds each, a fifth produced two birds (13%), and the sixth a single bird (7%, Table AP3.2).

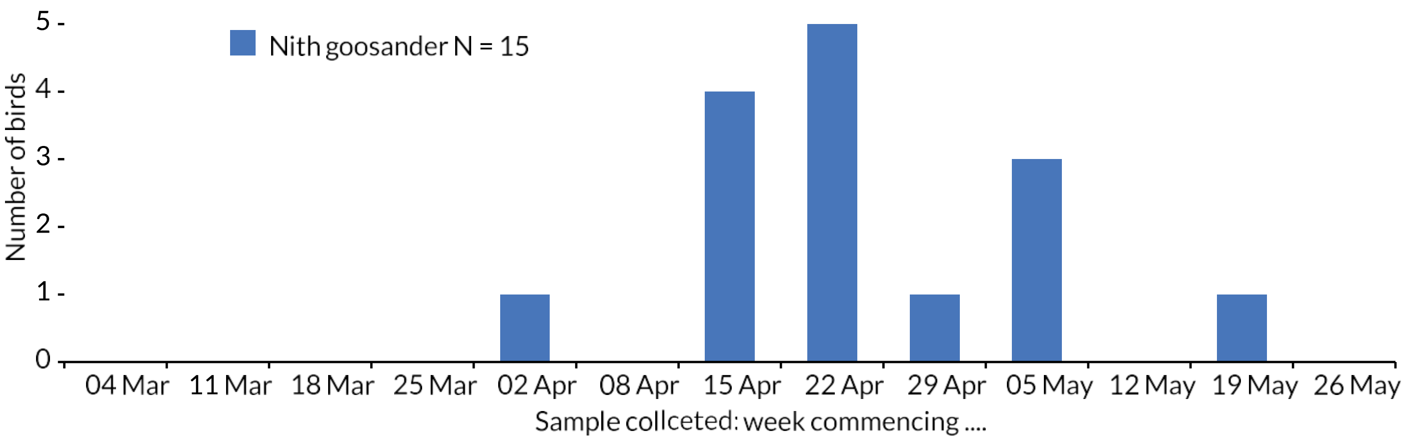


Figure AP3.2 The number of R. Nith Goosanders collected each week during the 2019 smolt run period.

Beat	Goosanders sampled	
	No.	(%)
Buccleuch	3	20
Cowhill	2	13
Cleughfoot/Barjarg	3	20
Dalpeddar	3	20
Auldgirth	1	7
Blackwood	3	20
Total	**15**	-

Table AP3.2 The numbers (%) of Goosanders sampled on various beats on the R. Nith, in the 2019 smolt run period.

(3a) R. Tweed Goosanders (N = 14)

03 April	Lower Floors	30 April	The Lees
04 April	Lower Floors	01 May	Lower Floors
12 April	Rutherford*	03 May	Bemersyde
15 April	Lower Floors	24 May	Lower Floors
15 April	Markestoun	25 May	Lower Floors*
16 April	Lower Floors	29 May	Lower Floors
30 April	Lower Floors	31 May	Lower Floors

The R. Tweed 2019 smolt run period, Goosanders were sampled in four periods: the first few days of April, the third week of April, the last week of April/first few days of May, and over the last two weeks of May (see Figure AP3.3).

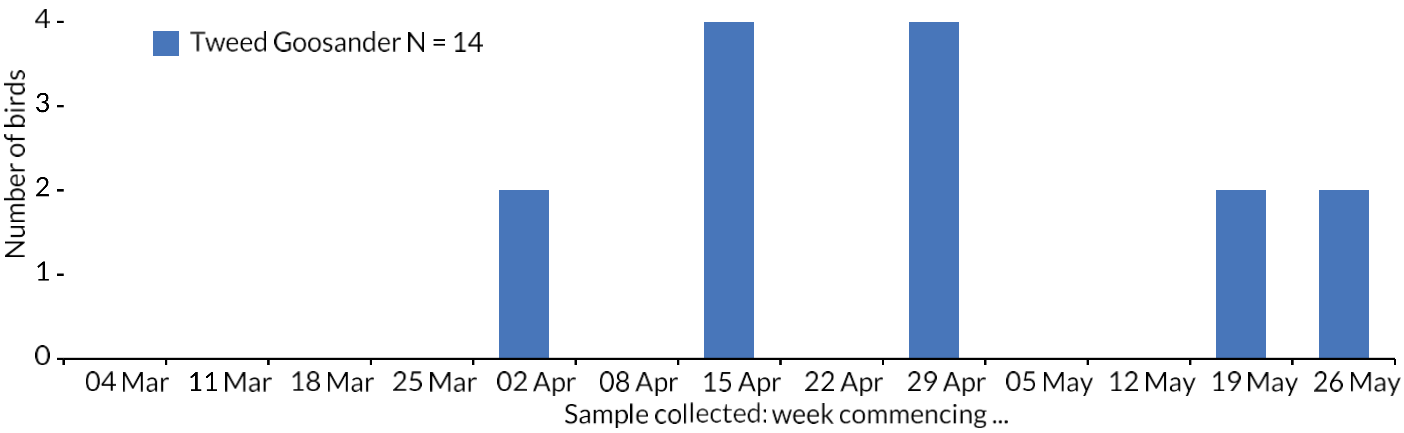


Figure AP3.3 The number of R. Tweed Goosanders collected each week during the 2019 smolt run period.

The R. Tweed 2019 smolt run period Goosanders were sampled from five beats, most birds (10/14 = 71%) coming from just one of these (Lower Floors), and single birds coming from each of four others (Table AP3.3).

Beat	Goosanders sampled	
	No.	(%)
The Lees	1	7
Lower Floors	10	71
Rutherford	1	7
Markerstoun	1	7
Bemersyde	1	7
Total	**14**	**-**

Table AP3.3 The numbers (%) of Goosanders sampled on various beats on the R. Tweed, in the 2019 smolt run period.

(4a) R. Spey Goosanders (N = 15), 2019

08 March	Easter Echlies
26 March	Orn's Beat
01 April	Ballindalloch*
01 April	Ballindalloch
03 April	Tulchan D*
09 April	Ballindalloch
11 April	Tulchan B
11 April	Lower Pitchroy
11 April	Inverfiddich
13 April	Tulchan B
15 April	Lower Pitchroy
24 April	Ballindalloch
25 April	Castle Grant
25 April	Castle Grant
29 April	Castle Grant

The R. Spey 2019 smolt run period Goosanders were sampled during a 6-week period from the last week of March to the last week of April/first few days of May, except for a single bird from the first week of March (see Figure AP3.4).

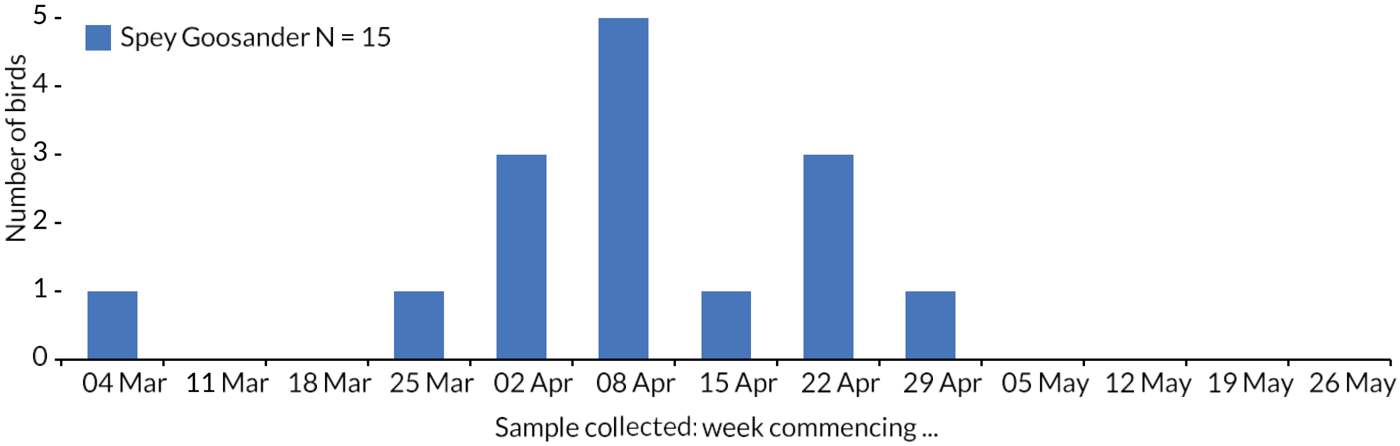


Figure AP3.4 The number of R. Spey Goosanders collected each week during the 2019 smolt run period.

The R. Spey 2019 smolt run period Goosanders were sampled from seven beats, most birds (10/15 = 67%) coming from three of these, and 1-2 birds coming from each of four others (Table AP3.4).

Beat	Goosanders sampled	
	No.	(%)
Easter Echlies	1	7
Orn's Beat	1	7
Balindalloch	4	27
Tulchan	3	20
Lower Pitchroy	2	13
Inverfiddich	1	7
Castle Grant	3	20
Total	**15**	-

Table AP3.4 The numbers (%) of Goosanders sampled on various beats on the R. Spey, in the 2019 smolt run period.

(5a) R. Dee Cormorants (None)

No Cormorants sampled from the R. Dee during the 2019 smolt run period.

(6a) R. Nith Cormorants (N= 6)

20 March Cowhill*
20 March Cowhill* … … likely
regurgitated 04 April Newhole,
Buccleuch
05 April Doctor's Pool,
Buccleuch 11 April Cowhill*
26 April White Hill, Buccleuch

The R. Nith smolt run period Cormorants were sampled during the third week of March (2 birds), the first and second weeks of April (2 birds and a single, respectively), and another single bird during the penultimate week of April. These Cormorants were sampled from four beats, three birds from Cowhill and three each from a different stretches of Buccleuch water.

(7a) R. Tweed Cormorants (N = 9)

02 April	The Lees
11 April	Bemersyde
23 May	Rutherford*
23 May	Rutherford
24 May	Rutherford*
24 May	Rutherford
24 May	Rutherford
24 May	Rutherford
28 May	Rutherford*

Most (7/9 = 78%) of the R. Tweed smolt run period Cormorants were sampled during the last two weeks of May, with single birds collected five weeks earlier - in each of the first two weeks of April. These Cormorants were sampled from three beats, most birds (7/9 = 78%) coming from a single beat, with single birds collected in each of the two other beats.

(8a) R. Spey Cormorants (N = 1)

The single Cormorant sampled from the R. Spey during the smolt run period came from Kinchurdy during the first week of April.

In summary for the smolt run period 2019, Goosanders were sampled on the Dee over quite a protracted period of over seven weeks with 75% of birds coming from three beats (Lower Crathes, Sluie, Woodend). Those from the Nith were sampled mainly in a 4-week period, spread mostly across four beats (Blackwood, Buccleuch, Dalpeddar, Cleughfoot/Barjarg). Goosanders on the Tweed were sampled on separate weeks in April and the last fortnight in May, 71% of them from a single beat (Lower Floors). On the Spey, Goosanders were sampled over quite a protracted period of over six weeks from March - but concentrated in April - with 67% of birds coming from three beats (Balindalloch, Tulchan, Castle Grant). Nith Cormorants showed quite disparate sampling, from two beats/estates (Cowhill, Buccleuch) and most Cormorants from the Tweed were sampled on 3 days in May, 78% came from a single beat (Rutherford).

Overall, samples from the smolt run period appeared to either be spread over the season (Dee, Spey) or concentrated in a few weeks (Nith, Tweed). Very often, a large proportion of birds came from a relatively small number of beats. In general, samples during the smolt run period were dominated by Goosanders (full samples collected on all four rivers), with few Cormorants being collected (predominantly from the Tweed and Nith, although full samples were not collected on any of the rivers).

(b) Samples from the autumn-winter period, 2019/20

During the autumn winter 2019/20, Goosanders from the R. Dee were collected from **Lower Crathes** (including Greenbanks). Goosanders from the R. Nith came from **Dalswinton, Blackwood, Boatford** (including Kirkbog), **Buccleuch**, and **Buccleuch** (**Mid**) (including Whitehill). Goosanders from the R. Tweed were sampled from the **Lees, Hendersyde, Lower Floors, Markestoun** (**Upper and Lower**), **Middle Mertoun**, and **Bemersyde**. Those from the R. Spey were sampled at **Low Water** (**Groynes**), **Arndilly, Easter Elchies, Pitchroy**, and a single bird had no location provided.

Cormorants from the R. Dee were collected from only Lower Crathes. Cormorants from the R. Nith came from **Cowhill, Blackwood, Boatford** (Kirkbog), and **Buccleuch** (**Mid**) (Whitehill). Cormorants from the R. Tweed were sampled from **Ladykirk**, the **Lees, Hendersyde, Lower Floors, Rutherford, Middle Mertoun**, and **Bemersyde**. Those from the R. Spey were sampled at **Brae Water** (including Intake, Beat 5, Flats Pool), **Delfur, Arndilly, Easter Elchies** (including Inverfiddich), **Knockando Tulchan** (D), and **Kinchurdy**.

(1b) R. Dee Goosanders (N = 2)

22 Nov Crathes,
Greenbanks 25 Nov Lower
Crathes

On the R. Dee, only two Goosanders were sampled during the autumn-winter. These birds were collected over a 4-day period in late November and both came from the Crathes beat on the lower river.

(2b) R. Nith Goosanders (N = 10)

13 Oct	Blackwood
08 Nov	Whitehill, Buccleuch
08 Nov	Whitehill, Buccleuch
15 Nov	Dalswinton
20 Nov	Kirkbog
20 Nov	Boatford
22 Jan	Blackwood
28 Jan	Dalswinton
3 Feb	Blackwood
4 Feb	Buccleuch

On the R. Nith, only ten Goosanders were sampled during the autumn-winter in two main periods. The first was a 3-week period throughout November 2019, the second a 3-week period covering the last two weeks of January and the first week of February 2020. In addition, a single Goosander was sampled in the first half of October 2019 (Figure AP3.5).

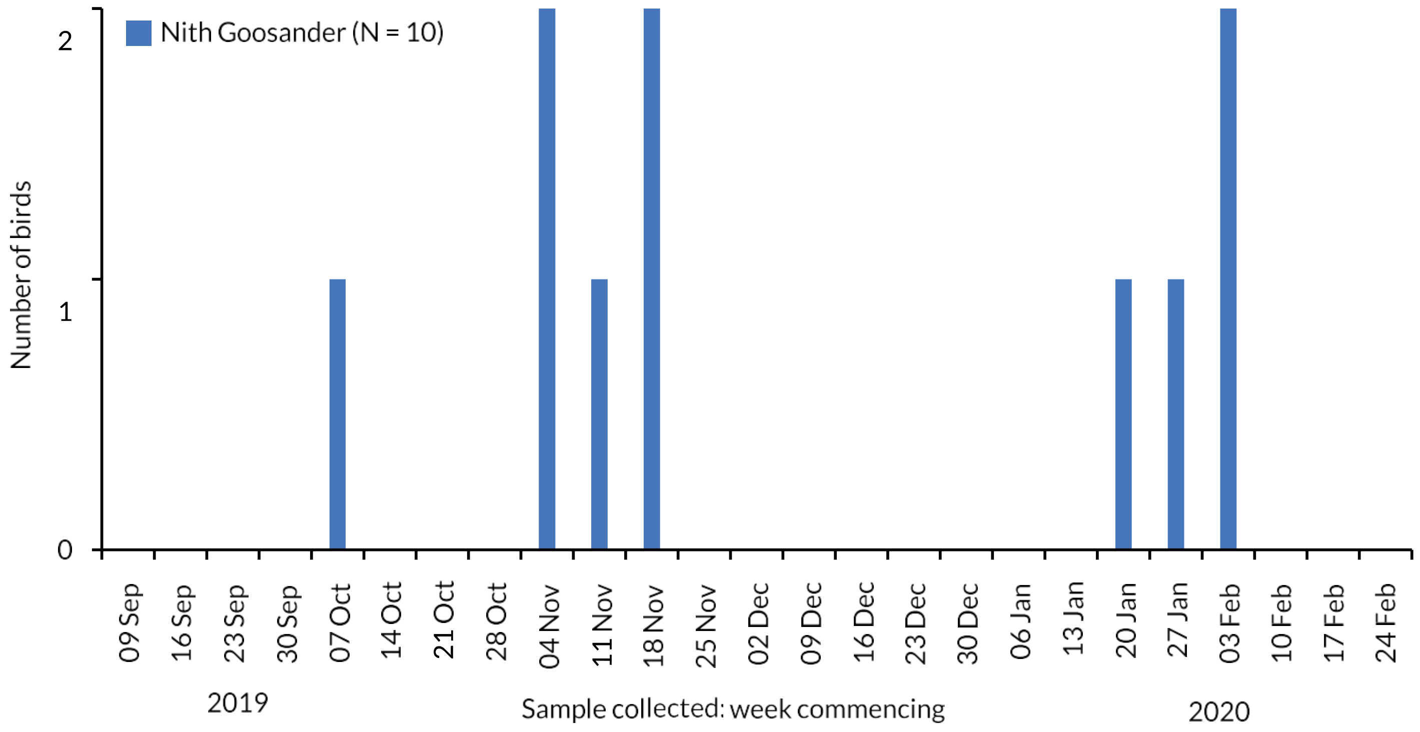


Figure AP3.5 The number of R. Nith Goosanders collected each week during the autumn-winter period 2019/20.

Goosanders from the R. Nith in autumn-winter were sampled from six beats, one of these produced three (30%) birds, two others produced two birds (20%) each, and the remaining three beats a single bird (10% each (Table AP3.5).

Beat	**Goosanders sampled**	
	No.	**(%)**
Blackwood	3	30
Whitehill, Buccleuch	2	20
Dalswinton	2	20
Kirkbog	1	10
Boatford	1	10
Buccleuch	1	10
Total	**10**	**-**

Table AP3.5 The numbers (%) of Goosanders sampled on various beats on the R. Nith, in the autumn-winter period 2019/20.

(3b) R. Tweed Goosanders (N = 24)

09 Sep	M. Mertoun	25 Oct	L. Floors
09 Sep	M. Mertoun	05 Nov	L. Floors
20 Sep	U. Markestoun	06 Nov	Hendersyde
23 Sep	M. Mertoun	08 Nov	Hendersyde
23 Sep	M. Mertoun	09 Nov	L. Markestoun
03 Oct	Hendersyde	10 Nov	Bemersyde
04 Oct	Bemersyde	10 Nov	Bemersyde
14 Oct	U. Markestoun	11 Nov	Bemersyde
14 Oct	The Lees	19 Nov	Bemersyde
17 Oct	U. Markestoun	20 Nov	Bemersyde
22 Oct	L. Floors	20 Nov	Bemersyde
24 Oct	L. Markestoun	28 Nov	L. Floors

On the R. Tweed, some 24 Goosanders were sampled in three periods during autumn 2019. Samples were taken throughout September and the first few days of October (29%), during the middle two weeks of October (25%), and throughout November (46%, Figure AP3.6).

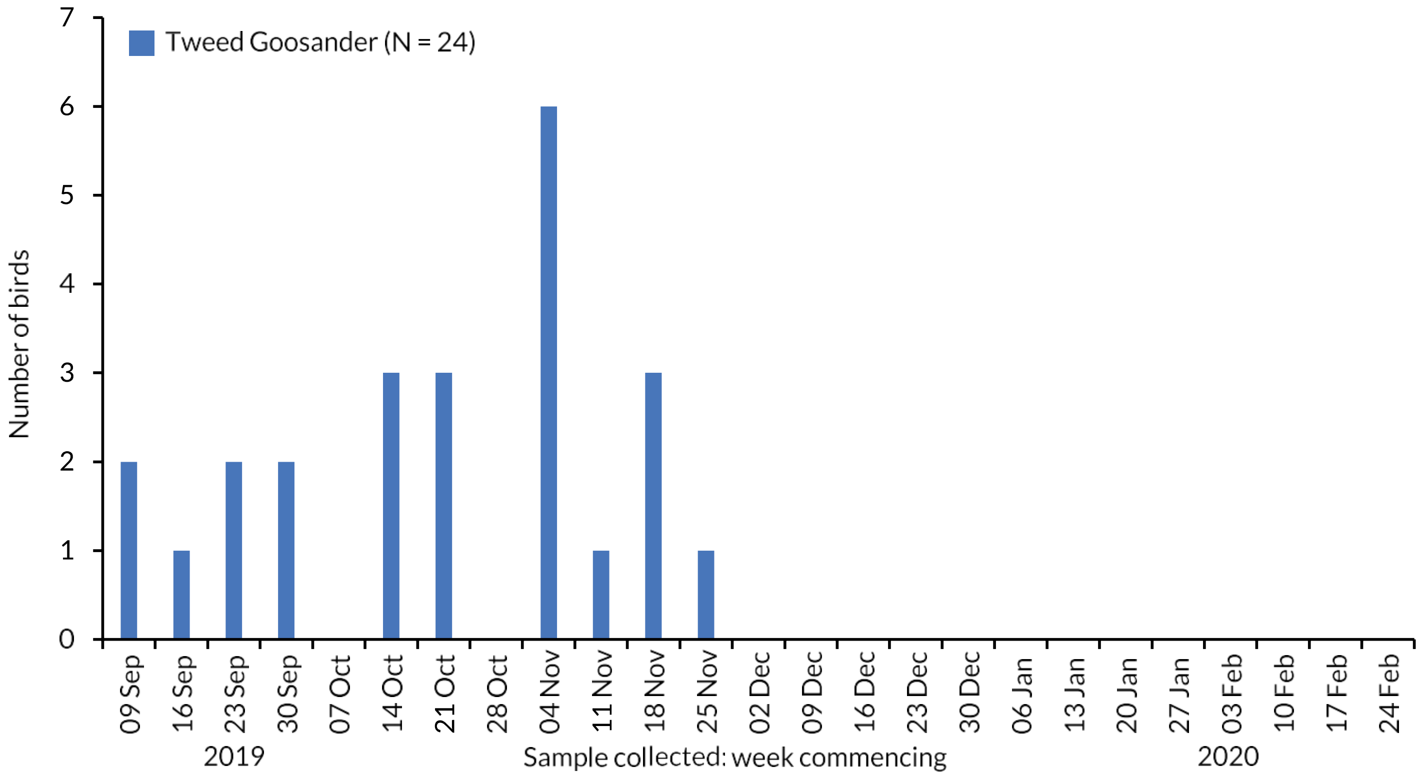


Figure AP3.6 The number of R. Tweed Goosanders collected each week during the autumn-winter period 2019/20.

Goosanders from the R. Tweed in the autumn were sampled from seven beats. About a third of birds (29%) came from Bemersyde, and a fifth of them (20%) from Markestoun, and slightly fewer (17% each) from M. Mertoun and L. Floors. Three Goosanders came from Hendersyde, and a single one from Lees (Table AP3.6).

Beat	**Goosanders sampled**	
	No.	**(%)**
M. Mertoun	4	17
U. Markestoun	3	12
Hendersyde	3	12
Bemersyde	7	29
The Lees	1	4
L. Floors	4	17
L. Markestoun	2	8
Total	**24**	-

Table AP3.6 The numbers (%) of Goosanders sampled on various beats on the R. Tweed, in the autumn-winter period 2019/20.

(4b) R. Spey Goosanders (N = 8)

11 Sep	Pitchroy
03 Oct	Arndilly
03 Oct	Arndilly
14 Oct	L. Pitchroy*
29 Nov	Arndilly
04 Dec	No location
18 Dec	East Elchies
19 Dec	Groynes

On the R. Spey, only eight Goosanders were sampled during the autumn-winter period. Birds came from the first half of September (single bird), the first half of October (three birds), the end of November and beginning of December (two birds), and the week before Christmas (two birds, Figure AP3.7).

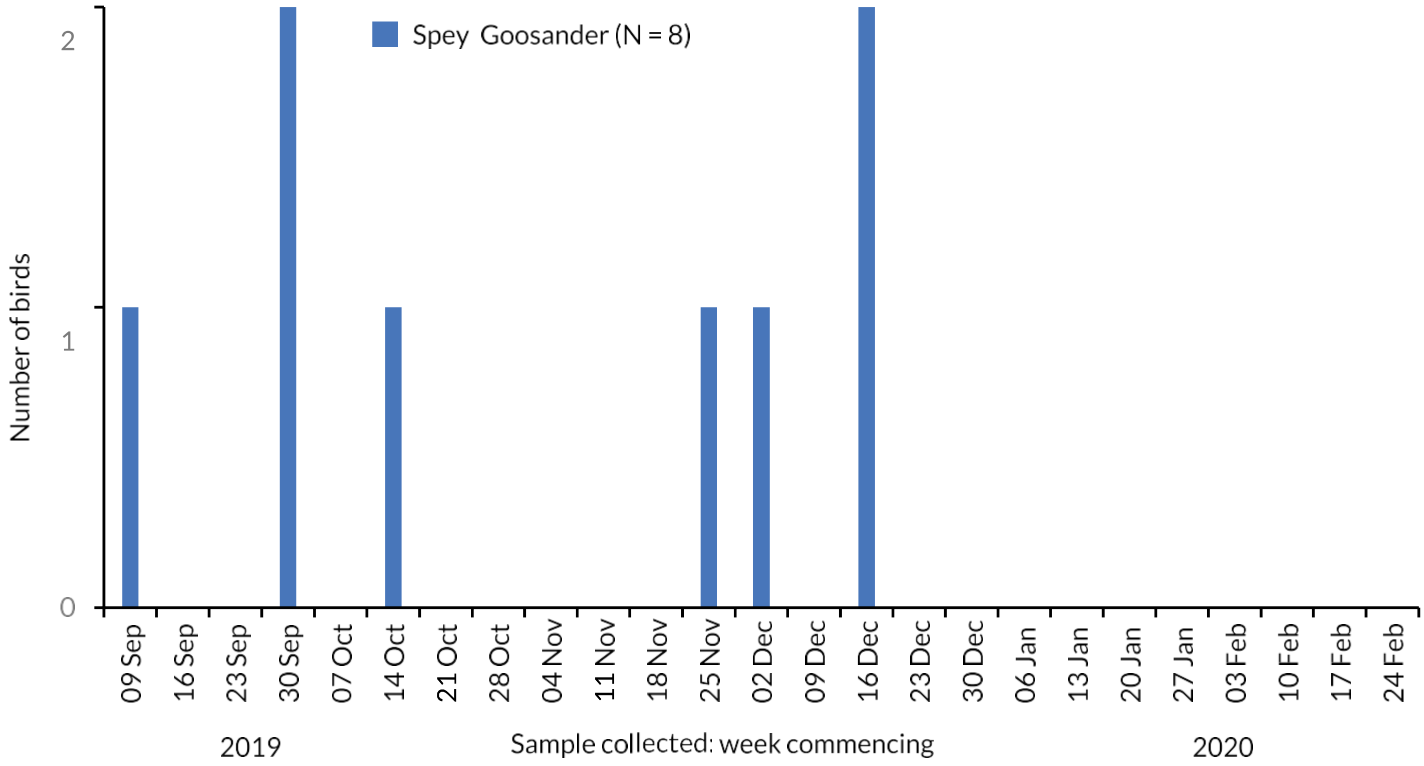


Figure AP3.7 The number of R. Spey Goosanders collected each week during the autumn-winter period 2019/20.

Goosanders from the R. Spey in autumn-winter were sampled from at least four beats (the location of one bird was not given). About a third of birds (38%) came from Arndilly, a quarter of them (20%) from Pitchroy, and single birds came from each of the remaining beats (Table AP3.7).

Beat	**Goosanders sampled**	
	No.	**(%)**
Pitchroy	2	25
Arndilly	3	38
Easter Elchies	1	12
Groynes	1	12
No location given	1	12
Total	**8**	-

Table AP3.7 The numbers (%) of Goosanders sampled on various beats on the R. Tweed, in the autumn-winter period 2019/20.

(5b) R. Dee Cormorants (N = 4)

2 Dec	L. Crathes
3 Dec	L. Crathes*
05 Dec	L. Crathes
20 Jan	L. Crathes

Small numbers of R. Dee Cormorants were sampled in autumn-winter, most (three birds, 75%) in the first week of December 2019, and a fourth bird (25%) in the second half of January 2020. All birds came from the Crathes beat on the lower river.

(6b) R. Nith Cormorants (N = 12)

08 Nov	Kirkbog
12 Nov	Kirkbog
12 Nov	Kirkbog
15 Nov	Whitehill, Buccleuch
20 Nov	Boatford
21 Nov	Kirkbog
03 Dec	Kirkbog
19 Jan	Cowhill
19 Jan	Cowhill
23 Jan	Blackwood
28 Jan	Cowhill
13 Feb	Cowhill

On the R. Nith, 12 Cormorants were sampled during the autumn-winter, in two main periods. The first covered the first three weeks of November (6 birds, 50%) plus a single bird (8%) from the first week of December 2019, the second covered the last three weeks of January 2020 (4 birds, 33%) plus a single bird (8%) around mid-February 2020 (Figure AP3.8).

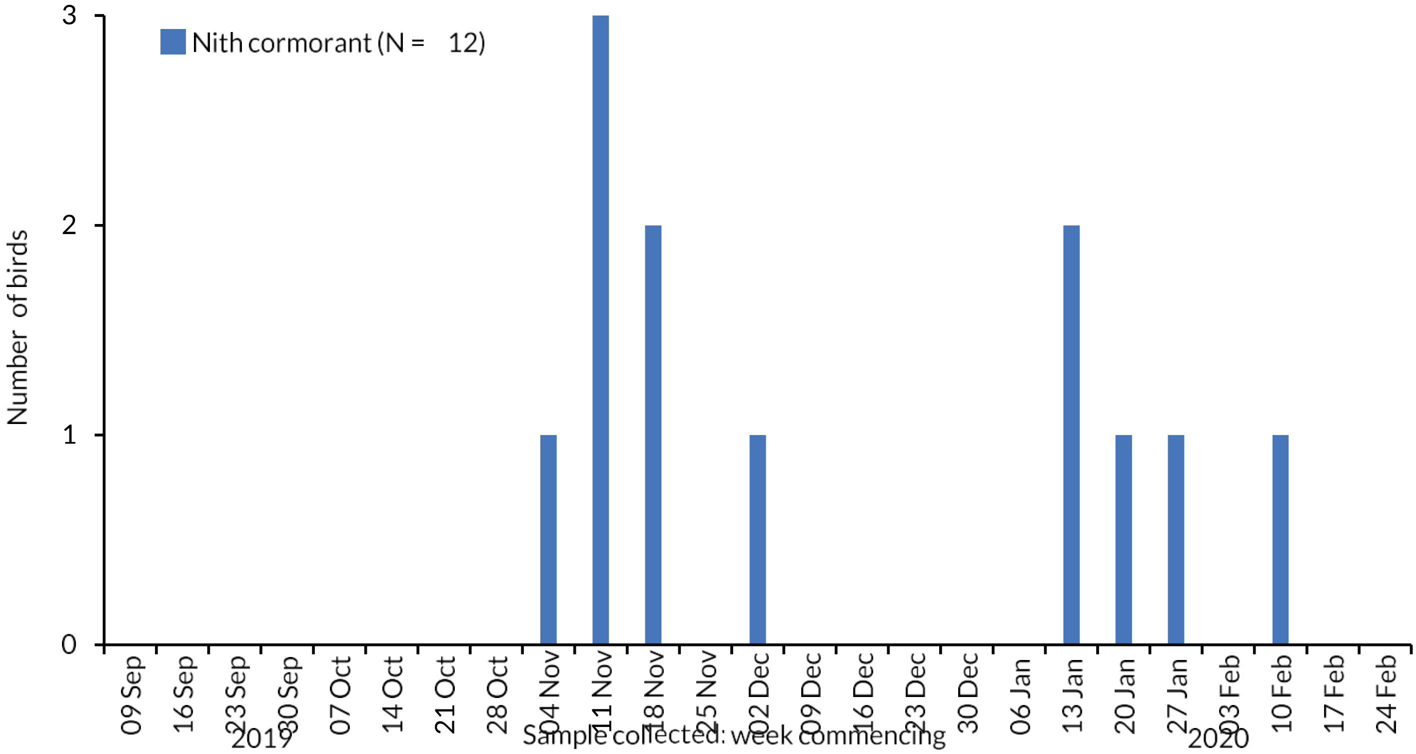


Figure AP3.8 The number of R. Nith Cormorants collected each week during the autumn-winter period 2019/20.

Cormorants from the R. Nith in autumn-winter were sampled from at least four beats. Just under half of birds (42%) came from Kirkbog, a third of them (33%) from Cowhill, two birds (16%) from Buccleuch, and a single one from Blackwood (Table AP3.8).

Beat	Goosanders sampled	
	No.	**(%)**
Kirkbog	5	42
Whitehill, Buccleuch	1	8
Boatford	1	8
Cowhill	4	33
Blackwood	1	8
Total	**12**	-

Table AP3.8 The numbers (%) of Cormorants sampled on various beats on the R. Nith, in the autumn-winter period (2019-20).

(7b) R. Tweed Cormorants (N = 27)

10 Sep	L. Floors
20 Sep	L. Floors
21 Sep	The Lees
23 Sep	Hendersyde
25 Sep	L. Foors
25 Sep	Rutherford
02 Oct	Lady Kirk
05 Oct	L. Floors
15 Oct	L. Floors*
15 Oct	M. Mertoun
20 Oct	Hendersyde
22 Oct	M. Mertoun
22 Oct	M. Mertoun
22 Oct	Rutherford
23 Oct	L. Floors
23 Oct	L. Floors
23 Oct	L. Floors
23 Oct	L. Floors*
24 Oct	L. Floors
24 Oct	L. Floors
25 Oct	L. Floors
31 Oct	The Lees
01 Nov	Rutherford
06 Nov	Bemersyde
19 Nov	Rutherford
19 Nov	Rutherford
19 Nov	Rutherford

On the R. Tweed, 27 Cormorants were sampled throughout autumn 2019. Most of these birds (16 birds, 59%) were sampled throughout October, and the remaining six birds (22%) in September (mostly toward the end of the month). A further five birds (19%) came from the first three weeks of November 2019 (Figure AP3.9).

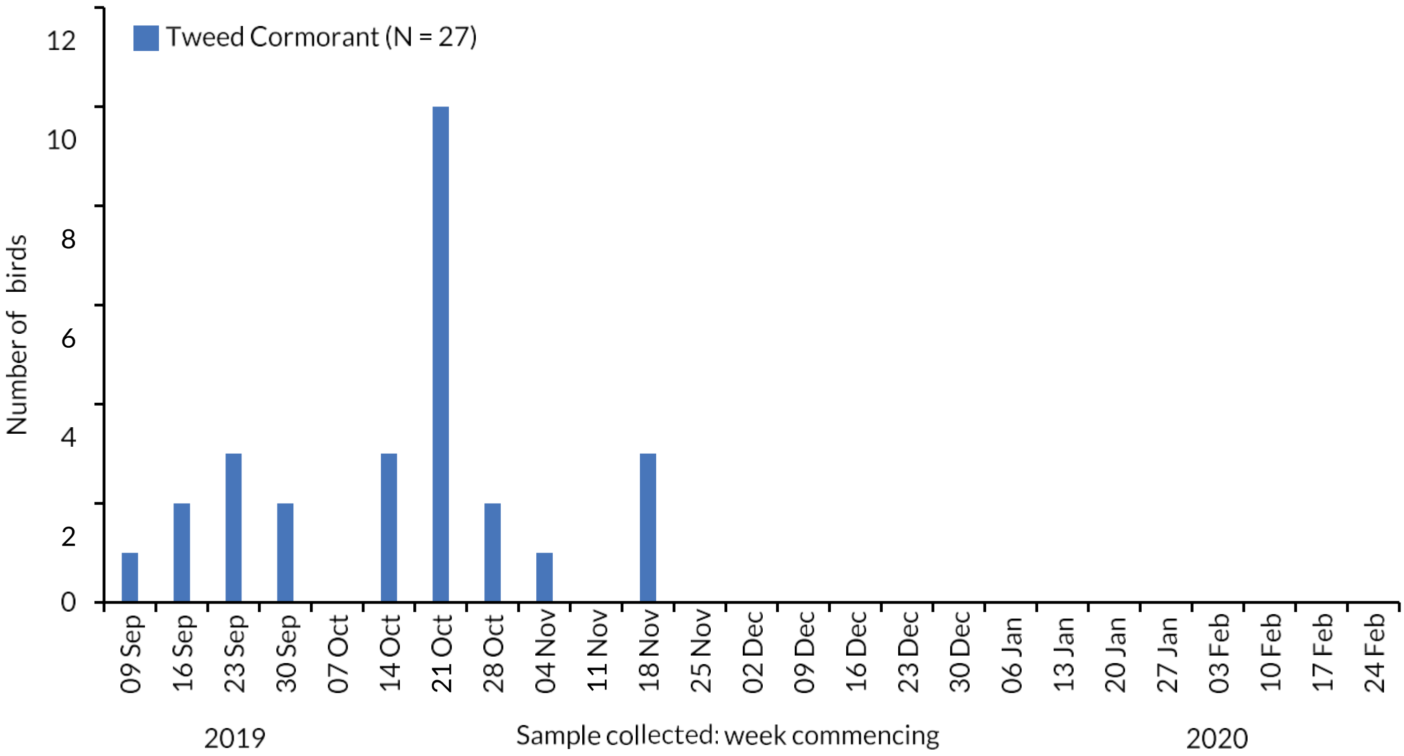


Figure AP3.9 The number of R. Tweed Cormorants collected each week during the autumn-winter period 2019/20.

Cormorants from the R. Tweed in the autumn were sampled from seven beats. Just under half of the 27 birds (44%) came from L. Floors, and just under a quarter of them (22%) from Rutherford, three birds (11%) from M. Mertoun, two (7%) each from Lees and Hendersyde, and a single bird (4%) from Bemersyde (Table AP3.9).

Beat	Goosanders sampled	
	No.	(%)
L. Floors	12	44
Lees	2	7
Hendersyde	2	7
Rutherford	6	22
Lady Kirk	1	4
M. Mertoun	3	11
Bemersyde	1	4
Total	**27**	-

Table AP3.9 The numbers (%) of Cormorants sampled on various beats on the R. Tweed, in the autumn-winter period 2019/20.

(8b) R. Spey Cormorants (N = 13)

04 Dec	Knockano*	04 Feb	Tulchan D
04 Dec	Arndilly	04 Feb	Tulchan D
05 Dec	Delfur	07 Feb	Beat 5*
19 Dec	Intake	13 Feb	Kinchurdy
06 Jan	Arndilly*	13 Feb	Easter
07 Jan	Arndilly	24 Feb	Flats Pool
14 Jan	Inverfiddich*		

On the R. Spey, Cormorants were sampled throughout the winter. Four birds (31%) were taken in the first three weeks of December 2019, three birds (23%) in the first half of January 2020, with most (6 birds, 46%) being sampled throughout February 2020 (Figure AP3.10).

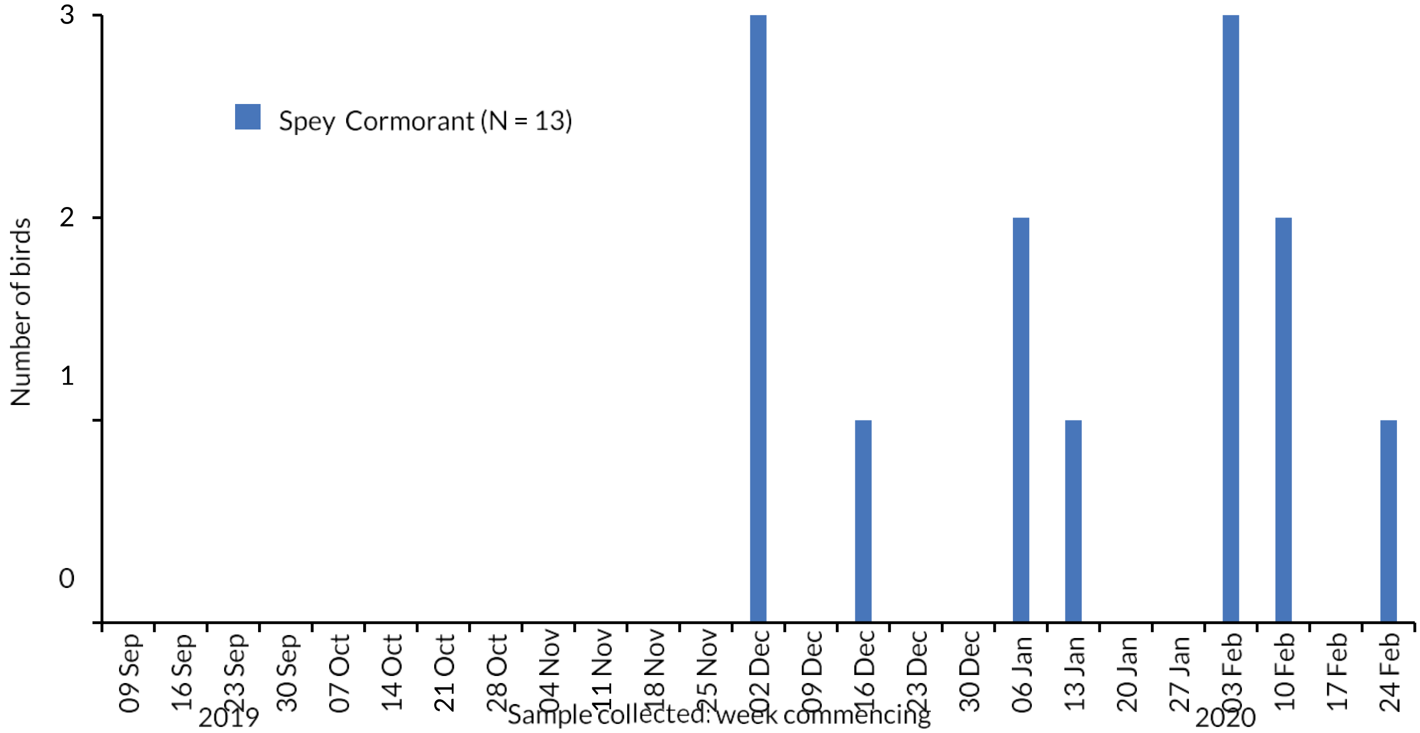


Figure AP3.10 The number of R. Spey Cormorants collected each week during the autumn-winter period 2019/20.

Cormorants from the R. Spey in the winter were sampled from ten beats. Three birds (23%) came from Delfur and two (15%) from Tulchan D. The remaining eight beats each provided a single bird (Table AP3.10).

Beat	**Goosanders sampled**	
	No.	**(%)**
Knockando	1	8
Arndilly	3	23
Delfur	1	8
Intake	1	8
Inverfiddich	1	8
Tulchan D	2	15
Beat 5	1	8
Kinchurdy	1	8
Easter Elchies	1	8
Flats Pool	1	8
Total	**13**	-

Table AP3.10 The numbers (%) of Cormorants sampled on various beats on the R. Spey, in the autumn-winter period 2019/20.

In summary for the autumn-winter 2019/20 period, only two Goosanders were sampled on the Dee, both in the autumn in last ten days of November on the lower river (Greenbanks and Lower Crathes). Those from the Nith were also a small sample (10 birds) sampled in two three-week periods throughout the autumn-winter: the first in November and the second between the end of January and first week in February. Samples were collected from up to six beats, but mostly from Blackwood, Whitehill Buccleuch, and Dalswinton). A full sample of Goosanders (n = 24) from the Tweed were sampled in three periods during the autumn: throughout September and the first few days of October, during the middle two weeks of October, and throughout November. Samples came from seven beats, but most came from Bemersyde, Lower Floors, and M Mertoun). On the Spey, only a small number of Goosanders (n = 8) were sampled over quite a protracted period during the autumn-winter: 1-2 birds being shot a week during six weeks between September and December. Birds came from at least four beats, with most (N = 5) from Arndilly and Pitchroy.

Small numbers of Cormorants (N = 4) were sampled on the Dee in the winter, three in the first week of December and the fourth in late January. All birds came from a single beat (Lower Crathes) in the lower river. A full sample of Nith Cormorants (N = 12) was collected in two main periods throughout the autumn-winter: seven birds from Kirkbog and Buccleuch throughout November and the first few days of December, and five birds from Cowhill and Blackwood from mid-January to mid-February. There was a large sample of Cormorants (N = 27) from the Tweed, all sampled in the autumn. Several birds were sampled throughout September and the first three weeks of November, but the majority were collected throughout October. Cormorants were sampled on seven Tweed beats but over three-quarters of the Cormorants came from Lower Floors, Rutherford, and M. Mertoun. A full sample of Cormorants (N = 13) was collected on the Spey in the winter with several birds in December, a few in January, and the largest number in February. Sampling appeared to be relatively widespread compared to the other rivers, with small numbers of birds (no more than three) coming from ten Nith beats.

Overall, samples from the autumn-winter period appeared to either be spread over the sampling period (Nith, Spey) or sampled in the autumn (Tweed). Very often, a large proportion of birds came from a relatively small number of beats. In general, the autumn-winter samples of Goosanders were small on all rivers except the Tweed, and considerably more Cormorants were sampled in the autumn-winter period than were in the preceding smolt run period. Full samples of Cormorants were collected on all rivers except the Dee, although those on the Spey were compromised by a high proportion (42%) of empty stomachs without food.

Appendix 4: Scientific names of prey species mentioned in the text

Lampreys	**Family Petromyzonidae**
Brook Lamprey	*Lampetra planeri*
River Lamprey	*L. fluviatilis*
Eels	**Family Anguillidae**
European Eel	*Anguilla anguilla*
Salmons	**Family Salmonidae**
Atlantic Salmon	*Salmo salar*
Brown/sea Trout	*S. trutta*
Rainbow Trout	*Onchorynchus mykiss*
Grayling	*Thymallus thymallus*
Pikes	**Family Esociade**
Pike	*Esox lucius*
Carps	**Family Cyprinidae**
Gudgeon	*Gobio gobio*
Minnow	*Phoxinus phoxinus*
Loaches	**Family Cobitidae**
Stone Loach	*Barbatula barbatula*
Sticklebacks	**Family Gasterosteidae**
3-Spined Stickleback	*Gasterosteus aculeatus*
Perches	**Family Percidae**
Perch	*Perca fluviatilis*
Grey Mullets	**Family Mugilidae**
Flatfishes	**Family Pleuronectidae**
Class Amphibia	**Family Ranidae**
Common Frog	*Rana temporaria*

Appendix 5: The timing of bird sampling and the smolt run

Given the ‘patchy’ nature of the material available in the present study, this Appendix provides a preliminary exploration of the sampling dates for Goosanders and Cormorants on the river Tweed in relation to information on the timing of the smolt run there in spring 2019. It does not explore issues of spatial abundance which might also be important in understanding dietary findings - as birds were sampled from a limited number of locations, in the absence of information on the distribution of smolts within any of the study river systems.

Collecting bird samples is obviously constrained by many issues, and so it is not surprising that they were often aggregated – generally coming from particular locations and particular times during the season (for full details see Appendix 3). Sampling thus occurs at times and places when predation on smolts is thought to be at its maximum and/or when collection opportunities are most appropriate/favourable. This patchiness – and the confidence associated with interpreting the present findings - was further compromised by the necessarily small samples available. Here, samples of each species were limited to 12 bird stomachs with food, and so in practice the number of birds available from each river during the smolt run was only 12-14 birds.

There is thus an important issue in relation to matching when the majority of the bird samples were taken and the timing of the smolt run. The Tweed Foundation were able to provide some information on the timing of the smolt run which could help investigate this point.

To provide an indication of smolt movements, James Hunt (JH) of The Tweed Foundation kindly provided some raw data from the Gala Water smolt trap, a tributary of the Tweed located 70 km upstream of the estuary. In 2018, when the trap was first installed, the main run started on the 6th May with almost no smolts counted until then, presumably as a consequence of an exceptionally cold spell of weather affecting water temperature. In 2019, the main run on the Gala Water started earlier on the 22nd April, although the first smolts were trapped on 30th March and the last on the 7th June that year. The main 2019 smolt run started on the 3rd May, again after a cold spring.

The raw daily catch data from 2018-2019 (number of smolts/day) were amalgamated to show the relative proportion of the catch on a weekly basis throughout the season. This temporal smolt run pattern is shown alongside the numbers of birds sampled on the Tweed, for each calendar week (Figure AP5.1).

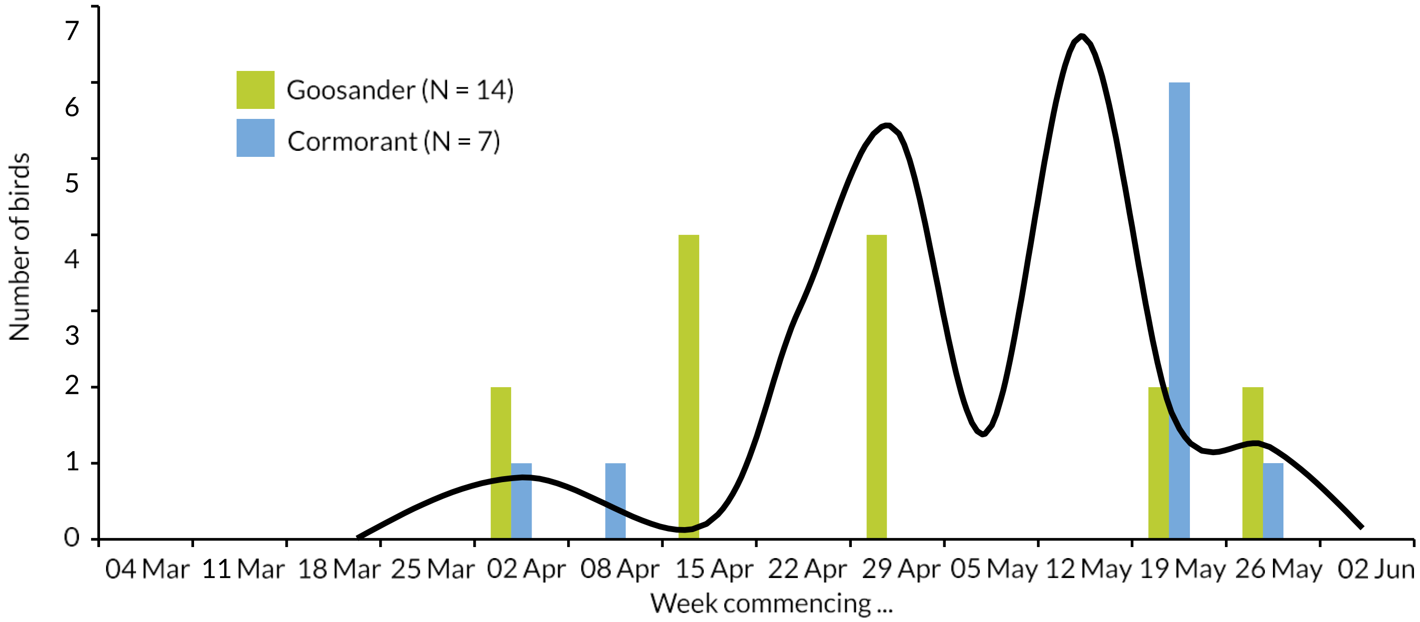


Figure AP5.1 The number of Goosanders and Cormorants sampled each week on the R. Tweed during the 'smolt run period' of the present study. The curve indicates the general temporal pattern of the smolt run, based on catches from the Gala Water smolt trap.

Gala Water trap data show that smolts were caught during April but suggest the main run started on the 22nd April in 2019. Taking the graphical interpretation of the smolt run data at face value for now (see trap efficiency/river flow comment below), data suggest that the birds sampled in the first half of April might have been before the main smolt run whilst those at the end of May might have been towards the end/after the main run (Figure AP5.1).

Some words of caution are needed here though. As well as the actual 'magnitude/scale' of the run, the amount of smolts caught in the trap is also affected by water flow. The smolt trap gives only a partial count because when the river is high, trap efficiency will be lower. Indeed James' interpretation of the "*relatively small*" peak on the 5th/6th April (i.e. in week commencing 02 Apr in Figure AP5.1) is that the river was high on these days, so trap efficiency would be lower. Thus, although Figure AP5.1 shows the temporal distribution of smolts trapped, it has not been 'corrected' for river flow/trap efficiency, which could change the picture. JH's "*suspicion is there is a smaller annual run of smolts in early April, but the main run is late April*."

Such speculation highlights the imprecision with which such comparisons can currently being made, and also highlights that further bird samples are needed to better understand the dynamics of their diet in relation to the timing and magnitude of the smolt run and evidence of the scale of smolt consumption. The increasing availability of smolt run data from traps does suggest the possibility of better understanding bird diet in relation to the timing of the run in specific years, and might be an aid to refining the timing of samples. Smolt trap data are probably available from at least the rivers Tweed, Dee, and Spey.

A further caveat is that the relationship between the timing of smolt catches in the Gala Water trap and the actual pattern of the smolt run in locations on the main stem of the Tweed where birds were sampled is currently not clear. Further investigation may illuminate this. To paraphrase JH, smolts migrated out of the Gala Water relatively early in 2019, either as a consequence of the tagging process or because they were early-running smolts. Also, 2019 was a dry year and so there was no rise in water level and flow that would help fish out to sea. The 2020 smolt tagging study on the Tweed provided further insights and showed that smolts were typically in the main river until mid- to late-May that year. However, it is not clear how this fits with the curve sketched in Figure AP5.1 and the interpretation offered above.

It is interesting to note that if Gala Water data truly reflects the smolt run on the entire Tweed catchment (although this is not clear), then around half of the Goosanders were sampled before the main runs commenced. Nevertheless, given the smolt run itself lasts for several weeks and aggregations of fish are presumably moving down the system throughout this period, there should be some broad accordance between bird diet and the 'availability' of smolts during the run. It seems that stomach samples are thus unlikely to be completely unrepresentative of the prey consumed at this time of year. However, further research is required into the possible mismatch of bird samples and the timing of biological events such as the smolt run, as well as the efficiency – and wider representativeness – of smolt trap data.

Data from smolt trapping on the Tweed suggest the main smolt run is in May (at least in the last couple of years for which data are available). Many bird stomach samples from the 1990's were from March-April, and although considered by all at the time to be essentially representing the smolt run, it would be interesting to understand how representative of the main smolt run they might be considered now. Of course, such retrospective exploration might not be possible and/or the timing of the smolt run in the 1990s might have been earlier than it is now, but it is not clear whether any data might be available to help explore this issue. Again, this lack of clear evidence suggests that more intensive bird diet sampling is required to explore dietary changes alongside concurrent smolt run timing data.

Given that there is some finer resolution location and date information available for the R. Tweed bird samples from the 1990s, it might be possible to explore this alongside the samples in the present study to (i) undertake a fine-scale analysis of temporal dietary composition throughout the sampling periods available to us so far, and to (ii) perform some form of power analysis to examine issues of sample size (i.e. numbers of stomachs with food) in relation to the resulting length frequency estimates of fish therein, particularly Salmon. This could also be linked to an exploration of the potential influence of sampling location (i.e. beat/stretch) and used to plan a more intensive sampling programme for evidence gathering of bird diet in relation to the smolt run on Scottish rivers. This, in turn, should be linked to further studies of smolt movements and distribution within study rivers. It is also vital to know where birds are actually foraging rather than the locations where they were sampled.

UK Centre for Ecology & Hydrology

BANGOR

UK Centre for Ecology & Hydrology
Environment Centre Wales
Deiniol Road
Bangor
Gwynedd
LL57 2UW
United Kingdom
T: +44 (0)1248 374500

LANCASTER

UK Centre for Ecology & Hydrology
Lancaster Environment Centre
Library Avenue
Bailrigg
Lancaster
LA1 4AP
United Kingdom
T: +44 (0)1524 595800

EDINBURGH

UK Centre for Ecology & Hydrology
Bush Estate
Penicuik
Midlothian
EH26 0QB
United Kingdom
T: +44 (0)131 4454343

WALLINGFORD

UK Centre for Ecology & Hydrology
Maclean Building
Benson Lane
Crowmarsh Gifford
Wallingford
Oxfordshire
OX10 8BB
United Kingdom
T: +44 (0)1491 838800

enquiries@ceh.ac.uk
www.ceh.ac.uk
@UK_CEH

Scottish Government
Riaghaltas na h-Alba

This publication is available at **www.gov.scot**

Any enquiries regarding this publication should be sent to us at

The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

ISBN: 978-1-80435-833-7 (web only)

Published by The Scottish Government, October 2022

Produced for The Scottish Government by APS Group Scotland, 21 Tennant Street, Edinburgh EH6 5NA
PPDAS1141622 (10/22)