Cyfoeth Naturiol Cymru
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Spring 2021 survey of Cormorant and Goosander on the River Usk

Report No: 593

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Crynodeb Gweithredol

Mae ysglyfaethu gan adar pysgysol yn un o'r achosion sylweddol posibl o farwolaeth eogiaid, a hynny yn ystod rhan olaf cam cylchred bywyd dŵr croyw (rhedfa leisiaid y gwanwyn) eogiaid yr Iwerydd *Salmo salar*. Mae CNC yn ceisio tystiolaeth wyddonol i benderfynu a oes amrywiadau tymhorol yn nosbarthiad cydgasgliadau gofodol ac amserol y fulfran, *Phalacrocorax carbo* ('y fulfran''), a'r hwyaden ddanheddog, *Mergus merganser,* ar hyd afon Wysg yn yr achos hwn, ac, os felly, a yw'r amrywiadau hyn yn gysylltiedig â chydgasgliadau o leisiaid.

Gwnaeth arolygwyr Ymddiriedolaeth Adareg Prydain arolygu prif sianel afon Wysg yn ystod gwanwyn 2021, gan gwblhau dau arolwg llawn yn ystod y rhedfa leisiaid ac ar ei ôl (y cyfathrebodd CNC yn ei chylch drwy raglen gydamserol o ddal gleisiaid ar gyfer rhaglen delemetreg ar hyd yr afon). Ar yr un pryd, ac yn unol chynllun arolwg CNC ac Ymddiriedolaeth Adareg Prydain ar y cyd, arolygodd gwirfoddolwyr o Sefydliad Gwy ac Wysg bwyntiau cydgasglu gleisiaid hysbys a thybiedig a safleoedd rheolaeth ar gyfer adar pysgysol. Cofnododd pob un o'r arolygwyr nifer, rhywedd ac oedran yr adar (lle roedd hynny'n bosibl) a chategorïau o weithgareddau, gan gynnwys adegau o bysgota gweithredol.

Cafodd cyfanswm o 24 o rannau afonydd eu harolygu (12 yn ystod pob ymweliad arolwg), a chofnodwyd 121 o arsylwadau ar 213 o adar unigol (25 o fulfrain a 188 o hwyaid danheddog). Roedd llawer llai o fulfrain ac roeddent yn llai helaeth nag yn y gaeaf, gydag amcangyfrifiad o ~13 (5-22) yn yr arolwg hwn (amcangyfrifiad y gaeaf ~65, 45-86) gyda thueddiad gofodol yn bellach i lawr yr afon, tuag at yr aber. Roedd nifer yr hwyaid danheddog yn debyg yn y gwanwyn (amcangyfrifiad ~73, 53-94) a'r gaeaf (amcangyfrifiad ~72, 52-95). Roedd dosbarthiadau gofodol cymharol yn yr afon hefyd yn debyg yn y gaeaf a'r gwanwyn. Gwnaeth cyfansoddiad y poblogaethau o hwyaid danheddog newid yn sylweddol rhwng y ddau ymweliad arolwg a wnaed yn ystod y gwanwyn, gyda gwrywod yn absennol a saith cofnod o ieir hwyaid danheddog benywaidd â nytheidiau o gywion yn ystod yr ail ymweliad. Amcangyfrifwyd bod poblogaeth yr adar benywaidd aeddfed yn cynnwys 32-65 o unigolion, gan awgrymu naill ai bod yr arolwg wedi cael ei amseru'n wael o ran canfod nytheidiau, neu fod y cynhyrchiad bridio yn wael.

Gwnaed cyfanswm o 28 o ymweliadau arolwg, sef 14 o ymweliadau pâr, â chydgasgliadau gleisiaid hysbys. Arolygwyd yr holl barau o leiaf unwaith yn ystod y rhedfa leisiaid ac arolygwyd pedwar pâr ar ôl i'r rhedfa ddod i ben hefyd. Yn gyffredinol, gwnaed 151 o arsylwadau ar adar, gyda gwerthoedd y cyfrif brig o rhwng 0 ac 11, a gwerthoedd pwysau pysgota o rhwng 0 a 70 munud aderyn.

Ymgasglodd hwyaid danheddog mewn mannau cyfyng ni waeth ble roedd y rhedfa leisiaid, ac roedd pwysau pysgota gan hwyaid danheddog yn sylweddol uwch yn ystod y rhedfa leisiaid. Ychydig o gofnodion neu ddim cofnodion o gwbl a wnaed o'r crëyr glas, *Ardea cinerea*, y crëyr bach copog, *Egretta garzetta* neu'r hwyaden frongoch, *Mergus serrator*. Ni chafwyd unrhyw dystiolaeth ystadegol i brofi bod mulfrain yn targedu cydgasgliadau o leisiaid fel adnodd pysgota yn ystod y rhedfa leisiaid. Er bod y llif afon yn ystod rhedfa leisiaid 2021 yn anarferol o uchel o gymharu â blynyddoedd blaenorol, nid yw'n bosibl priodoli'r canlyniad ar gyfer mulfrain ag amodau'r afon yn absenoldeb data y gellir ei gymharu ar gyfer blwyddyn fwy arferol.

Executive summary

One potentially significant source of salmon mortality is predation by fish-eating birds during the final stage of the freshwater life cycle phase (the spring smolt run) of the Atlantic salmon *Salmo salar*. NRW is seeking scientific evidence to determine whether there are seasonal variations in the spatial and temporal distribution of great cormorant *Phalacrocorax carbo* and goosander *Mergus merganser* aggregations, in this case on the River Usk, and if so whether these variations are associated with aggregations of smolts.

BTO surveyors surveyed the main channel of the River Usk in spring 2021, completing two full-coverage surveys during and after the smolt run (as communicated by NRW through a concurrent programme of smolt trapping for a telemetry programme on the river). At the same time, and to a joint NRW and BTO survey design, volunteers from the Wye and Usk Foundation surveyed known and suspected smolt-aggregation points and control sites for fish-eating birds. All surveyors recorded bird numbers, sex and age (where possible) and activity categories including active fishing.

In total, 24 river sections (12 in each survey visit) were surveyed, and 121 observations recorded 213 individual birds (25 cormorants and 188 goosander). Cormorants were substantially and significantly less abundant than in winter, with an estimate of ~13 (5-22) in this survey (winter estimate ~65, 45-86) with a spatial bias lower in the river, towards the estuary. Goosander numbers were similar in spring (estimate ~73, 53-94) and winter (estimate ~72, 52-95). Relative spatial distributions in the river were also similar in winter and spring. Goosander population composition changed markedly between the two spring survey visits, with males absent and seven records of female goosander with broods of young in the second visit. The population of adult females was estimated to be 32-65, indicating either poor survey timing to detect broods, or poor breeding productivity.

A total of 28 survey visits, representing 14 paired visits, were made at known smolt aggregations. All pairs were surveyed at least once during the smolt run and four also surveyed after the run had ended. Overall, 151 bird observations were made, with peak counts from 0-11 and fishing pressure values between 0-70 bird-minutes.

Goosander gathered at pinch-points irrespective of the smolt run, and fishing pressure from goosander was significantly higher during the smolt run. There were no or few records of grey heron *Ardea cinerea*, little egret *Egretta garzetta* or red-breasted merganser *Mergus serrator*. There was no statistical support for cormorant targeting smolt aggregations as a fishing resource during the smolt run. Although river flow during the 2021 smolt run was atypically high compared to previous years, it is not possible to ascribe the cormorant result to river conditions in the absence of comparable data from a more typical year.

1. Introduction

Atlantic salmon *Salmo salar* and many sea trout *Salmo trutta* populations have been in decline for many years and both are now considered to be endangered fish species of conservation concern. Both species are fully protected by law and salmon are Annex II species under the EU Habitats Directive, supporting the classification of six rivers in Wales as Special Areas of Conservation (SAC). Atlantic salmon ('salmon') and sea trout numbers have declined significantly in 23 principal salmon and 33 main sea trout rivers across Wales over the last three decades and most stocks are now classified as at "At risk" or "Probably at Risk" of failing to achieve their respective management targets. Such chronic declines, coupled with a Ministerial request, led NRW to develop a Plan of Action for Salmon and Sea Trout in Wales (NRW 2020). This plan, launched in April 2020, outlines ongoing and new actions for the remediation of adverse pressures on salmon and sea trout in Wales.

The potential impacts of goosander *Mergus merganser* and great cormorant *Phalacrocorax carbo* ('cormorant') on wild and stocked fisheries have been the focus of a number of scientific studies in the UK and elsewhere within Europe. These studies suggest that, at a site level, both can take large numbers of fish from natural and stocked fisheries. In Wales, the highest levels of concern have been raised for cormorant and goosander in catchments where salmon parr and smolts are liable to be taken, and at stocked and natural stillwater fisheries.

The impacts of fish-eating birds on salmonid populations and game fisheries in the UK has been considered as part of extensive reviews in Scotland (Harris *et al.,* 2008 and Humphreys *et al.,* 2016) and England (Defra, 2013). In Scotland, the review presented evidence for population-level and economic impacts on Scottish salmon fisheries by fish-eating birds. Defra reviewed the existing fish-eating bird's policy in England whilst in Wales, in the absence of a fish-eating bird's policy, an NRW-led advocacy paper recommended an expert group be established to develop such a policy.

All wild birds in Wales have legal protection. Natural Resources Wales (NRW) has a number of powers under which we can authorise others to kill or take particular species of wild birds, eggs and nests for certain purposes, for example in order to prevent serious damage to crops, livestock or fisheries, to protect public health or safety or to conserve other species of wildlife. NRW is responsible for assessing and issuing licences to authorise lethal control of fish-eating birds (cormorant and goosander) over the winter and early spring period for the purpose of preventing serious damage to fisheries and for the conservation of flora and fauna, in this case principally salmon and sea trout. In balancing these responsibilities, NRW seek to work towards the restoration and protection of a healthy and balanced biodiversity in Welsh aquatic ecosystems, extending to populations of both fish and birds. NRW have also recognised the need to protect populations of fish species other than migratory salmonids, including non-migratory brown trout in rivers and lakes, and other fish species in stillwaters.

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

In 2020, NRW commissioned BTO to undertake winter (2020/21) cormorant and goosander surveys across ten principal migratory salmon rivers in Wales (Wye, Usk, Tywi, Cleddaus, Teifi, Dyfi, Mawddach, Conwy, Clwyd and Dee) and selected tributaries within each river catchment. This included four rivers (Wye, Usk, Teifi, and the Dee with Llyn Tegid (Bala Lake)) designated as Special Areas of Conservation (SAC) with Atlantic salmon among the primary reasons for site selection. Fish stocks in each of these rivers have declined significantly and are below safe biological limits and potentially at risk from predation by fish-eating birds as a factor further limiting populations or suppressing stock recovery.

For each of these ten important ‘salmonid’ catchments, a robust population estimate for non-breeding (wintering) cormorant and goosander has been developed (Taylor *et al.* 2022). These estimates will be used to develop catchment-specific cormorant and goosander population models to assess the consequences of different levels of licensed control on wintering populations as an aid to salmonid conservation action and to prevent serious damage to still-water fisheries in Wales.

One potentially significant source of salmon mortality is predation by fish-eating birds during the final stage of the freshwater phase of the salmon and sea trout life cycles (the largely synchronous smolt runs in spring). NRW recognised the need to understand any seasonal differences in the spatial and temporal distribution of fish-eating birds (FEBs) in Welsh salmonid rivers. In 2018, 2019 and 2020, organised counts of fish-eating birds between February – June were undertaken on the River Usk by the Wye and Usk Foundation. These surveys determined numbers and locations of breeding goosander in proximity to known salmon smolt aggregations (The Wye and Usk Foundation, 2020; 2021). NRW are now seeking scientific evidence to determine whether there are seasonal variations in fish-eating bird distribution and aggregations, in this case on the River Usk, and if so whether these variations are associated with aggregations of smolts.

There have been large increases in breeding populations of cormorant across Europe over the past 40-50 years, which have been mirrored in the UK (Chamberlain *et al*., 2013), with birds also making increased use of inland fishery sites at which to feed and breed. Goosander have also increased in numbers across the UK in recent decades and spread to many new parts of the country. Both species are widely distributed in Wales and, as elsewhere in the UK, this has resulted in widespread conflicts with fishery interests. Principal concerns in Wales have centred on the potential impact of these FEBs on river catchments supporting populations of salmonid species, mainly salmon and sea trout. However, concerns have also been raised about the potential impact of the birds on other riverine fish stocks and on stillwater fisheries, both stocked and ‘natural’, that all support important fisheries.

This work, reflecting previous findings of a 2017 survey on the River Dee (Taylor and Noble, 2017), highlighted substantial spatial variations in wintering bird distributions, both among different aquatic habitats and within river channels. For Cormorant, estuarine birds (i.e. those monitored by the Wetland Bird Survey (WeBS)) represented 52% of the wintering population in Wales, while a further 42% were found in the rivers above the upper limit of WeBS counts, and only 6% of the total estimate added by surveying stillwaters. For Goosander the proportions were very different, with the majority (68%) of birds found on rivers and a further 28% added from the stillwaters survey. Estuarine

(WeBS counted) birds represented less than 4% of the winter population estimate. Within river channels, the majority of records were within 50km of the estuary spatial reference.

One potentially significant source of salmon and sea trout mortality is predation by fish-eating birds during the later stages of the freshwater phase of a salmon's life cycle; i.e. the smolt run in spring, which roughly coincides with the breeding seasons of both cormorant and goosander. Distributions of both species could differ substantially between winter and spring, partly due to the winter influx of continental migrants, which contribute an unknown proportion of overwintering Welsh populations. Seasonal distributional change is especially pertinent for goosander, which tend to breed high in river catchments but were largely observed in the lower reaches of rivers and on stillwaters during winter surveys (Taylor *et al*., 2022). There is a recognised need to determine whether there are seasonal differences in spatial distribution between wintering and breeding birds across salmonid rivers in Wales.

In particular, it has been reported that piscivorous birds (especially breeding goosander) may gather in proximity to river features where salmon smolts aggregate (The Wye and Usk Foundation 2020, 2021). Salmon smolts migrate downstream at night, and during daylight may gather at high densities at these "pinch points" in the river channel (e.g. bridges, weirs). The smolt run represents a density-independent phase of the salmon life cycle, so increased predation risk here may have amplified impacts on return rates and hence the adult breeding population. It is considered particularly important to improve understanding of bird foraging behaviour at such vulnerable locations in the river system.

This study aims to provide, scientific evidence to determine whether there are seasonal variations in fish-eating bird numbers, distribution and aggregations, in this case on the River Usk, and if so whether these variations are associated with smolt aggregations.

2. Methods

2.1 Approach set out by BTO

Cormorant and goosander distributions are expected to change, quite likely very significantly, between the non-breeding and breeding seasons, and the two species will also differ from each other. Reconciling these differences under a single survey methodology is challenging and carries considerable interpretation risk.

In May, the overall populations (of both species) in Wales will most likely be smaller, as the majority (adult) birds from continental populations have returned to their breeding countries. Actively breeding cormorants, as colonial breeders, will be spatially associated with the locations of their colonies through April to late June; and spatial data on inland colony locations in Wales is lacking. goosander are solitary breeders using cavities in woodland, and with a complex moult-migration strategy. They would be expected to be much more thinly distributed, more strongly associated with the upper catchments, and males and failed-breeders may be completely absent (depending on survey timing).

Survey in late May therefore provides an estimate of the number of successfully-breeding females (and broods) in a given year that use the areas surveyed during daylight, and if repeated periodically a limited index (relative breeding density in the main channel); in the absence of true demographic rates (breeding attempt status, age at first breeding, spring sex ratio) it is unlikely to be a true population estimate.

A second significant concern is the use of a single-visit survey for highly mobile species subject to human disturbance (scaring, shooting) and therefore known to be reactive to the presence of observers. Although goosander females with broods are likely to be moulting and temporarily flightless, cormorant can and do respond to the presence of observers by flushing, often at and to considerable distances. Repeat surveys in the winter survey were designed to compensate for this behaviour. A single visit main-channel survey would only provide a number and density estimate for birds using the main Usk channel, and it was considered not possible to assume this estimate would be representative of either species' breeding population at river or catchment scale.

A single survey would permit basic spatial distribution comparisons between survey data collected under this contract and that provided by the Wye and Usk Foundation, and also with known salmonid risk sites. To improve understanding of breeding-season population, distribution and density requires greater survey effort including repeat survey and ideally, additional information such as sample-based coverage of tributary rivers, mapping of cormorant colony sites, controlling for riparian and other woodland habitat, and an understanding of the timing of smolt movements as well as an extended survey period.

2.2 Survey design

As for the winter survey (Taylor *et al*., 2022), the survey method followed the approach of Taylor and Noble (2017) to survey river survey units (single 10km stretches of waterway) by one surveyor in a day from one bank, walking upstream and mapping all encounters of the target species including recording sex (goosander) and standardised behaviour categories (both species). This survey unit and field method was the same as used to generate winter population estimates (Taylor *et al*., 2022). A total of 12 sections of the

River Usk, as far upstream as the Usk Reservoir, were surveyed, but a 13th section above the reservoir, surveyed in winter, was omitted from this survey round.

Full details of the statistical analysis are presented in Taylor *et al*. (2022). The final recommended survey design for the main river channel was a complete survey and resurvey (both 100% coverage) in April-May 2021, approximately coinciding with commencement and conclusion of the smolt run. 100% resurvey significantly improves confidence in the population estimates (Taylor *et al.,* 2022).

Smolt aggregation surveys

Additional to the main river channel surveys framed by NRW, targeted surveys were carried out at key locations on the river channel where smolt aggregations were considered to occur (Wye & Usk Foundation, *pers. comm*.). Six such “pinch points” along the main channel of the River Usk were identified for survey (Table 1). Each pinch point was chosen as a location where migrating smolts are believed to gather and therefore may be more vulnerable to predation. In total, three weirs, two bridges and one naturally shallow rapids-like river section were selected. For each pinch point, a nearby control site was identified, which was a section of river channel with no discernible features expected to elevate smolt density.

Recorders worked in pairs, such that sites within pairs could be surveyed simultaneously. During each survey, each site was observed for at least one hour, starting at or soon after 06:00, since dawn was considered to be a key time for fishing among the bird species of interest. At five-minute intervals throughout the survey period, the number of individuals present was noted for each of five piscivorous, riverine bird species: cormorant, goosander, little egret *Egretta garzetta*, grey heron *Ardea cinera* and red-breasted merganser *Mergus serrator*. The behaviour of each individual was also noted, with particular respect to whether it was actively engaged in fishing.

Population estimates for birds using the main channel in May will be calculated using a modelling approach based on the winter population estimates and compared with results from the winter 2020/21 cormorant and goosander population estimates (Taylor *et al.,* 2022) and with the 2018, 2019 and 2020 data collected by The Wye and Usk Foundation (The Wye and Usk Foundation 2020, 2021).

2.3 Analytical approach

River Population modelling

Statistical modelling methods follow those applied to winter survey data (Taylor *et al*., 2022). Predictive count models for both Cormorant and Goosander use Generalised Linear Models (GLM) with a Bayesian framework, fitted to the field survey data using the R package ‘brms’. Models were fitted with a Poisson error distribution, with a log link function; and were validated by inspection of residuals and posterior predictive checks (comparing the empirical distribution of observed data to predicted data from the model posteriors). Each model was fitted with four Markov Chain Monte Carlo (MCMC)[1] chains, each of which had 2,000 iterations (i.e. 1,000 post-warmup samples). The model fixed effects were river segment position (a multiple of 10km distance from the geo-referenced

[1] A method for progressively refining the fit of a model.

near-estuary start point of the main river channel) and log-transformed segment length as an offset term:

count ~ segment position + offset(log segment length)

For each river segment, as many population estimates were made from the model as post-warmup MCMC samples had been taken, yielding a posterior distribution of ≥ 4,000 estimates. Posterior distributions at river-scale were generated by summing estimates at segment-scale. The population estimates given at both segment- and river-scale were calculated from these posterior distributions, as the mean and 95% confidence intervals of each distribution.

Analysis of temporal variation

Further models were fitted to the data to assess whether the abundance of Cormorants and Goosanders, and their relative distribution within the channel, varied over time, both between winter (Taylor *et al*., 2022) and spring surveys, and between survey rounds in spring, which roughly correspond to during and after the salmon smolt run.

First, models were fitted to compare between winter and spring surveys. Data from surveys of the River Usk main channel undertaken in winter by Taylor *et al.* (2022) were modelled using the same model structure as above, to allow direct comparison between abundance in winter and spring. Population estimates for winter were made, as above, both from these models and the original national-scale model of Taylor *et al*. (2022). Models were also fitted to the combined data from both surveys. Generalised Linear Mixed-effects Models (GLMMs) with Bayesian framework were used to allow fitting of an observation-level random effect, intended to reduce the potential influence of overdispersion in the count data. Fixed effects were river segment position, survey (winter vs spring), the interaction between the two, and (as above) log-transformed segment length as an offset term:

count ~ (1|observation) + segment position * survey + offset (log segment length)

A significant interaction between segment position and survey (i.e. if the 95% confidence intervals of the effect size did not overlap 1, the value of no effect) was considered to be evidence that the distribution of birds throughout the main river channel differed between winter and spring.

Second, models were refitted to the data from spring only, using the same approach but with spring survey round (initial survey vs resurvey) in place of survey (winter vs spring) as an interacting fixed effect. In this case, significance of the interaction term was used to determine whether the distribution of birds throughout the main river channel differed between initial surveys and resurveys.

Analysis of sex-specific patterns in goosander

For goosander, initial models were fitted to counts of adult birds only (with broods of chicks excluded) for comparability to winter surveys, during which no chicks were present. To assess the possible influence of moult-migration (of males) away from Wales and the arrival of broods of chicks onto the river - both of which were expected to occur at approximately the same time as the salmon smolt run - spring models were subsequently refitted (and population estimates remade) using counts of (i) adult female birds only (i.e. modelling the population size of all birds that are probably on the river for the entire duration of the smolt run), and (ii) all birds including chicks (i.e. modelling the population size of all birds that may be on the river for at least a part of the smolt run). This effectively yields lower and upper bounds for the number of birds that may be actively feeding on the river (and therefore potentially fishing for smolts) during the smolt run.

Smolt aggregation surveys

Two metrics were generated at survey level (n = 28 surveys) from the five-minute observations. First, the peak count of birds was recorded, which was the maximum number of individuals of each species recorded in a single five-minute interval during the survey. Second, a metric of fishing pressure was calculated, which approximates the total number of bird-minutes actively fishing per species across the entire survey. Specifically, the number of individuals recorded as fishing in each five-minute interval was summed to give a total for the survey. This metric took into account both whether birds were actively fishing (since birds that were present at pinch points but not actively fishing could potentially be responding to factors other than elevated smolt density, such as the presence of conspecifics or availability of river furniture for perching), and also the duration of fishing activity (i.e. one bird fishing continuously across four intervals, for 20 minutes, might exert equivalent fishing pressure to four birds fishing simultaneously for only one five-minute interval).

Generalised Linear Mixed-effects Models with Bayesian frameworks were fitted (as above) to test whether abundance of, and fishing pressure from, the four bird species varied between pinch points and control sites, and between surveys conducted during the smolt run and those conducted after its completion. Site type (pinch point vs control site) and survey timing (during vs after smolt run) were fitted as additive fixed effects, with site pair as a random effect. Models were fitted with a Poisson error distribution, which is the most theoretically-appropriate distribution for count data of this nature and validated by posterior predictive checks.

Species were modelled separately at all times. An overall pan-species fishing pressure metric was considered, but as preliminary inspection of the survey data suggested that the overwhelming majority of fishing pressure came from one species (goosander, see below), it was determined that a pan-species metric would not produce meaningfully different results from models of data for goosander only. Little egret was observed only once throughout the study and red-breasted merganser was never observed, so no models were fitted for these species and the latter is not discussed further. Cormorant was observed fishing once only, so models were only fitted for peak count for this species, not for fishing pressure.

Smolt aggregation surveys and the subsequent data analyses were designed specifically to test the hypotheses that piscivorous birds gather at, and exert increased fishing pressure at, pinch points during the smolt run. Although small (*N* = 28 surveys), power analyses suggest the dataset was broadly sufficient to detect a significant doubling in each metric of interest between categories, if present.

3. Results

3.1 Survey delivery

River channel surveys

In total, 24 surveys were carried out across the 12 segments of the River Usk main channel. The first survey round took place between 23/04/2021 to 03/05/2021 and was targeted to the early stages of the smolt run, expected to be prior to goosander incubation and male moult-migration, such that both male and female goosanders were expected to be recorded. The second survey round took place between 15/05/2021 and 31/05/2021, initiated after NRW reported that smolt migration appeared to be reaching its conclusion. It was expected that male goosander would be absent from this survey round but some females accompanying broods of chicks may be present.

Smolt aggregation surveys

In total, 28 surveys (in 14 pairs) were carried out across the six pairs of sites. Each pair of sites was surveyed between 1-3 times from 27/04/2021 to 26/05/2021. All pairs were surveyed on 1-2 occasions during the active smolt run (approximately 20/04-20/05), when smolts could be expected to be present at pinch points. In addition, four pairs were resurveyed one additional time after the smolt run had ended, when smolts were expected to be absent (or at low density) throughout the river channel, including at pinch points.

3.2 Raw observation data

River channel surveys

Across all surveys, 121 observations were made of cormorant or goosander, with 213 individuals of the two species recorded (Figure 1). In total, only 25 cormorants were recorded, with 0-11 (median 0) per survey; this was far fewer compared to surveys of the Usk conducted during the winter survey (Taylor *et al*., 2022), when 101 cormorants were observed, with 0-21 (median 4) per survey. However, numbers of goosander observed were very similar between spring and winter surveys, with 145 adults (0-25, median 4, per survey) observed in spring compared to 113 adults (0-16, median 4, per survey) in winter. In addition, seven broods of goosander chicks were recorded on the river, totalling 43 chicks (2-9 chicks per brood). Birds were largely distributed lower in the Usk catchment, with the peak count of goosander occurring in segment 3 (i.e. 20-30km upstream from the estuary spatial reference point), and cormorant never observed above segment 9 (i.e. no further than 90km upstream).

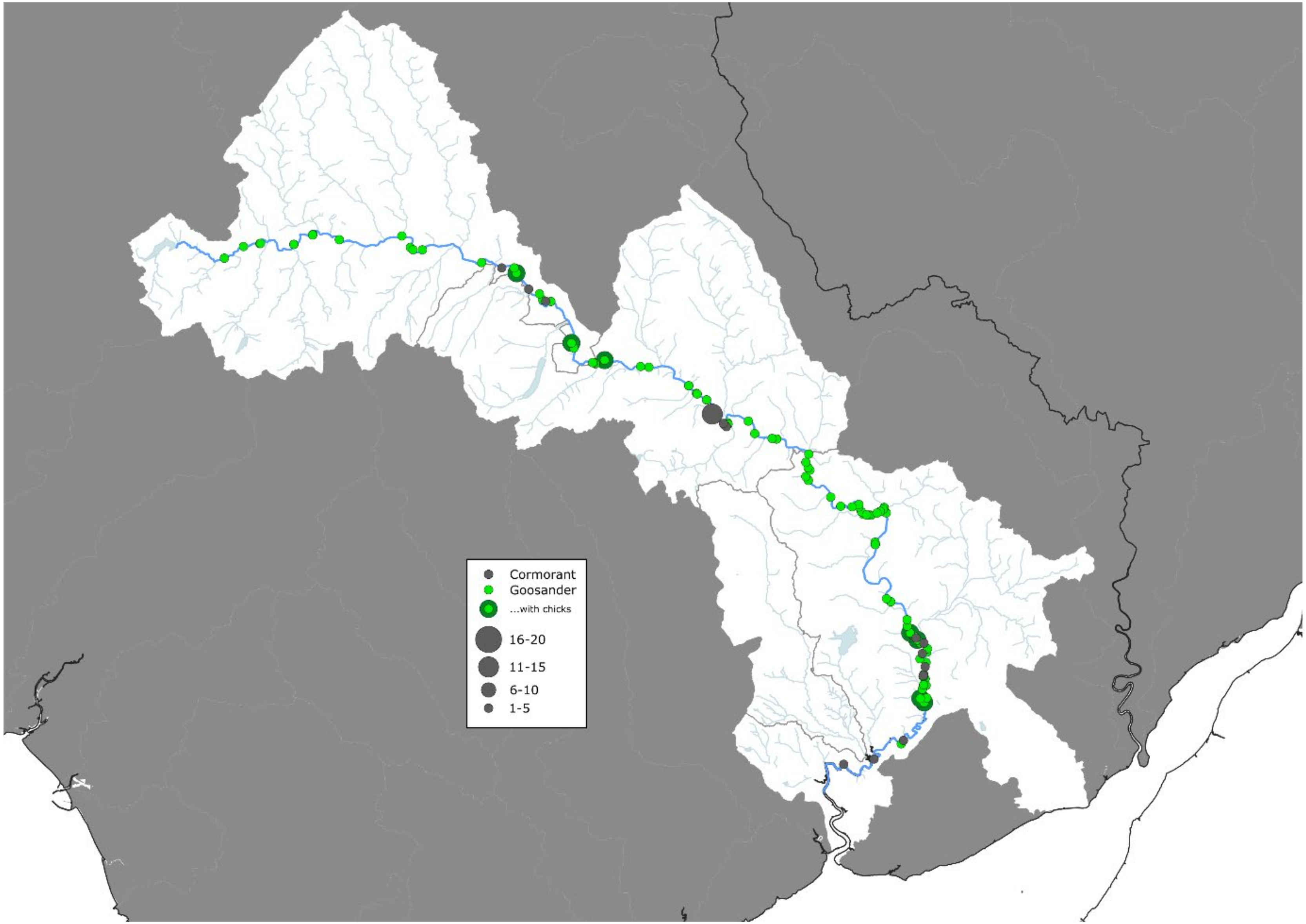

Figure 1. Map of survey coverage (river segments in blue) with unsurveyed tributaries and major stillwaters within the Usk operational catchment (white area) shown in grey. All survey records of cormorant (grey) and goosander (green) are overlaid. See Appendix 1 for larger maps.

Smolt aggregation surveys

A summary of the sites surveyed is presented in Table 1. In total, 391 observations were made, of which 151 were non-zero (i.e. at least one bird of one of the five target species was present). Within single surveys, peak count ranged from 0-11 and fishing pressure ranged from 0-14 (i.e. 70 bird-minutes; Table 2). One of the five species of interest, red-breasted merganser, was not observed at any point during the surveys and therefore is not discussed further in relation to smolt aggregation surveys.

Table 1. Site pairs surveyed during the smolt aggregation surveys

Pair number	Pair name	Pinch grid reference	Control grid reference	No. surveys per site
1	Usk town	SO 37410 00740	ST 38920 98920	3
2	Trostrey Weir	SO 35770 04170	SO 34620 05580	2
3	Crickhowell Bridge	SO 21440 18190	SO 22330 17540	3
4	Hornet's Oak	SO 18730 19760	SO 20180 19300	3
5	Brecon Weir	SO 03810 28920	SO 02190 28860	2
6	Trostre Weir	SO 35730 07530	SO 35880 08280	1

Table 2. Summarised records of piscivorous birds at smolt aggregation survey sites. Note that records are summarized across multiple surveys for the majority of sites; therefore "peak count" here represents the maximum value of peak count across surveys, and "total fishing pressure" here represents the sum of fishing pressure across surveys.

Pair number	Pair name	Site type	Species	Peak count	Total fishing pressure
1	Usk town	Pinch	Cormorant	1	0
			Goosander	11	21
			Little egret	1	4
			Grey heron	1	0
		Control	Cormorant	1	0
			Goosander	1	0
			Little egret	0	-
			Grey heron	1	0
2	Trostre Weir	Pinch	Cormorant	0	-
			Goosander	2	10
			Little egret	0	-
			Grey heron	1	1
		Control	Cormorant	0	-
			Goosander	2	1
			Little egret	0	-
			Grey heron	0	-
3	Crickhowell Bridge	Pinch	Cormorant	3	2
			Goosander	3	14

Pair number	Pair name	Site type	Species	Peak count	Total fishing pressure
			Little egret	0	-
			Grey heron	1	1
		Control	Cormorant	3	0
			Goosander	5	11
			Little egret	0	-
			Grey heron	1	1
4	Hornet's Oak	Pinch	Cormorant	1	0
			Goosander	3	2
			Little egret	0	-
			Grey heron	1	0
		Control	Cormorant	1	0
			Goosander	1	1
			Little egret	0	-
			Grey heron	1	0
5	Brecon Weir	Pinch	Cormorant	0	-
			Goosander	4	0
			Little egret	0	-
			Grey heron	0	-
		Control	Cormorant	0	-
			Goosander	4	0
			Little egret	0	-
			Grey heron	0	-
6	Trostre Weir	Pinch	Cormorant	0	-
			Goosander	4	5
			Little egret	0	-
			Grey heron	1	1
		Control	Cormorant	0	-
			Goosander	1	0
			Little egret	0	-
			Grey heron	0	-

3.3 Statistical modelling

3.3.1 River channel surveys

Modelled population estimates for the River Usk are presented in Table 3 with comparison to models fitted to data from the winter survey both (a) for all ten principal salmonid rivers (i.e. the model used for national population estimates in winter) and (b) for the River Usk only.

Table 3. Modelled population estimates for the River Usk. Winter population estimates are presented both for the national-scale model from Taylor *et al*. (2022), and for a model fitted to winter survey data from the Usk main channel only, because the potential effect of modelling data from other catchments and their tributaries on estimates for the Usk main channel is uncertain.

Species	Survey	Model fitting scale	Estimate	Lower CI	Upper CI
Cormorant	Spring	River Usk only	12.54	5	22
	Winter	River Usk only	64.65	45	86
		National	68.33	51	87
Goosander	Spring	River Usk only	72.65	53	94
		River Usk only, chicks included	94.11	72	118
		River Usk only, females only	47.70	32	65
	Winter	River Usk only	72.35	52	95
		National	57.76	42	74

Cormorant

Cormorant population estimates on the River Usk in spring were substantially and significantly lower than in winter (Table 3, Figure 2), with an estimated fivefold reduction from ~65 (95% confidence interval: 45-86) based on winter survey data to only ~13 (95% CI: 5-22) in the spring survey. However, the effect of the interaction between segment position and survey was non-significant (Table 4). Therefore, there was no evidence that the relative distribution of cormorants throughout the river channel changed between seasons (Figure 2). In both winter and spring, cormorants were less abundant further upriver (Table 5). Similarly, within the spring survey, there was no significant change in the distribution of cormorants throughout the river channel between the initial surveys and resurveys (i.e. during and after the smolt run, respectively); nor was there significant evidence that the abundance of cormorants in the river channel changed between spring survey rounds (Figure 3, Table 6).

Goosander

Goosander population estimates did not differ significantly between spring (~73, 95% CI: 53-94) and winter (~72, 95% CI: 52-95) surveys (Table 3); nor did their relative distribution within the channel change significantly (Table 3), with lower abundance further upriver in both winter and spring (Figure 2 and Table 5). Similarly, there was no evidence that the spring distribution of goosander throughout the river changed between initial surveys and resurveys (Figure 3, Table 6).

However, the composition of the goosander population did change substantially between initial surveys and resurveys (fewer males, more chicks). Sex ratio among adults changed significantly (Chi-squared test, X = 14.84, d.f. = 1, $P = 0.0001$), with almost no male birds being recorded during resurveys, suggesting that males depart on moult-migration during the smolt run (Table 7). By contrast, all but one brood of chicks were recorded during resurveys (suggesting that at least some broods of chicks leave the nest during the smolt run), such that the total number of individual birds recorded in each survey round was similar. To account for this, the data were remodelled twice with, respectively, (i) only data on adult female birds, and (ii) data on all birds including chicks. The population of adult females (c.f. the lower bound of birds fishing during the smolt run) was estimated to be 32-65 birds, roughly half to two-thirds of the total estimated population of adults in spring; whilst the population of all birds including chicks (c.f. the upper bound) was estimated to be approximately double this, at 72-118 birds (Table 3). Regardless of whether males and chicks were included or excluded, all models agreed that the abundance of goosanders and their relative distribution throughout the river channel was unchanged between initial surveys and resurveys (i.e. during and after the smolt run).

Table 4. Modelled effects of segment position (1–12, ascending upstream), survey (winter or spring) and their interaction on population estimates for cormorant and goosander in the River Usk main channel. Models were fitted with spring as the baseline, so the spring population estimate multiplied by the effect size yields the winter population estimate. Segment position was fitted as a numerical variable, so the population estimate for segment n multiplied by the effect size yields the population estimate for segment n+1. In winter, the baseline estimates should also be multiplied by the effect size of the interaction term. For all effect sizes, if the 95% confidence intervals of the estimate contain 1 (the value of no effect), the effect is considered to be non-significant.

Species	Variable	Effect size – estimate	(- CI)	(+ CI)
Cormorant	Segment position	0.86	0.67	1.09
	Survey	5.13	0.72	43.04
	Segment position: survey interaction	1.10	0.81	1.49
Goosander	Segment position	0.95	0.83	1.08
	Survey	0.95	0.25	3.92
	Segment position: survey interaction	1.03	0.85	1.24

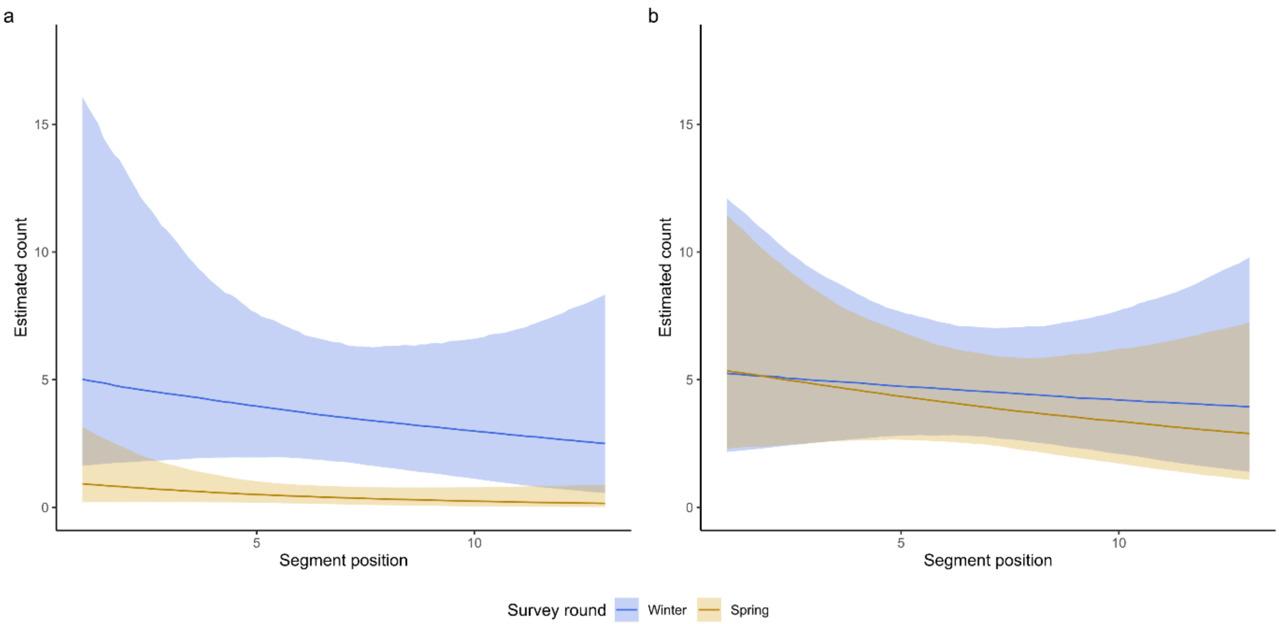

Figure 2. Model-estimated counts of (a) cormorant and (b) goosander throughout the River Usk main channel, as fitted to data from winter (blue) and spring (gold) surveys. Ribbons depict 95% Confidence Intervals.

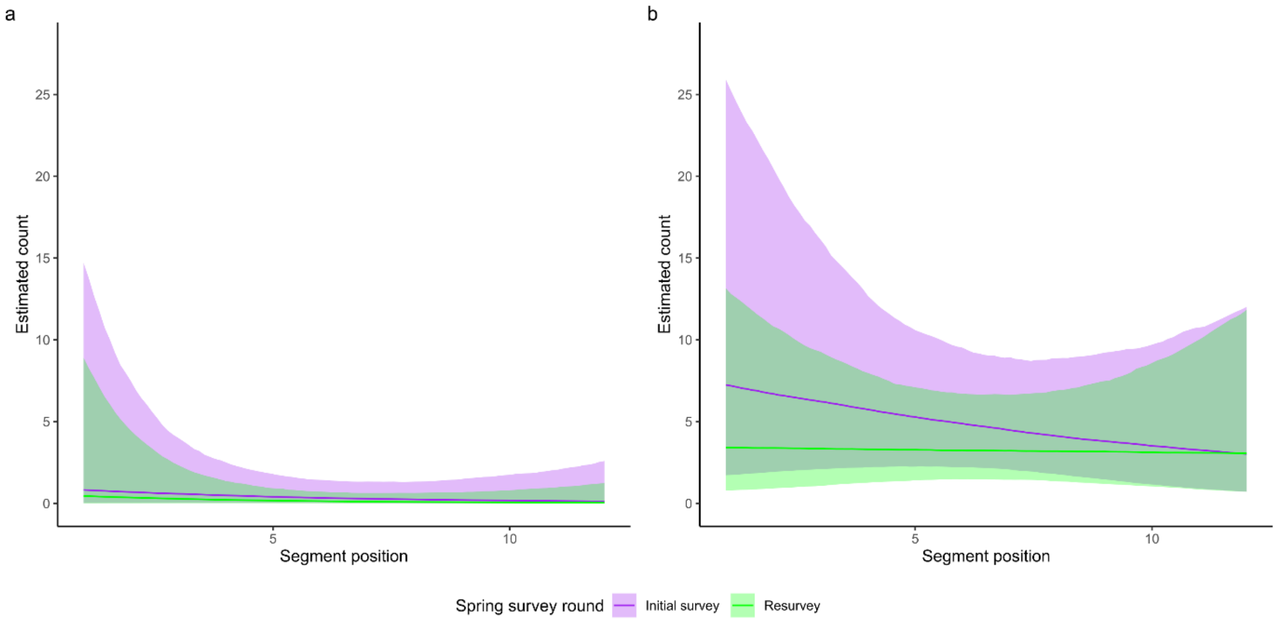

Figure 3. Model-estimated counts of (a) cormorant and (b) goosander throughout the River Usk main channel, as fitted to data from spring initial surveys (purple) and resurveys (green). Ribbons depict 95% Confidence Intervals

Table 5. Estimated no. individual birds of cormorant and goosander in the River Usk main channel during spring. Winter estimates modelled from the data of Taylor *et al*. (2022) are presented for comparison.

Species	Survey	Model fitting scale	Section 1	Section 2	Section 3	Section 4	Section 5	Section 6	Section 7	Section 8	Section 9	Section 10	Section 11	Section 12
Cormorant	Spring	River Usk only	1.5 (0–5)	1.5 (0–4)	1.3 (0–4)	1.2 (0–4)	1.1 (0–4)	1.0 (0–3)	1.0 (0–3)	0.9 (0–3)	0.9 (0–3)	0.8 (0–3)	0.8 (0–3)	0.5 (0–2)
	Winter	River Usk only	6.0 (1–12)	5.9 (2–12)	5.8 (1–11)	5.7 (2–11)	5.6 (1–11)	5.5 (1–11)	5.4 (1–11)	5.3 (1–10)	5.3 (1–10)	5.2 (1–10)	5.2 (1–10)	3.7 (0–8)
		National	6.6 (2–12)	6.4 (2–12)	6.3 (2–12)	6.1 (2–12)	6.0 (2–11)	5.8 (2–11)	5.7 (2–11)	5.6 (1–11)	5.4 (1–10)	5.4 (1–11)	5.2 (1–10)	3.7 (0–8)
Goosander	Spring	River Usk only	8.9 (3–16)	8.3 (3–15)	7.7 (3–14)	7.2 (2–13)	6.7 (2–12)	6.2 (2–12)	5.7 (1–11)	5.3 (1–11)	5.0 (1–10)	4.6 (1–9)	4.3 (1–9)	2.9 (0–7)
		River Usk only, chicks included	11.9 (5–20)	11.0 (5–18)	10.1 (4–17)	9.3 (4–16)	8.7 (3–15)	8.0 (3–14)	7.3 (2–13)	6.8 (2–13)	6.3 (2–12)	5.8 (2–11)	5.4 (1–11)	3.6 (0–8)
		River Usk only, females only	5.7 (1–11)	5.3 (1–11)	5.0 (1–10)	4.6 (1–9)	4.4 (1–9)	4.0 (1–9)	3.7 (1–8)	3.6 (0–8)	3.3 (0–7)	3.1 (0–7)	2.9 (0–7)	2.0 (0–5)
Goosander	Winter	River Usk only	6.4 (2–12)	6.4 (2–12)	6.3 (2–12)	6.3 (2–12)	6.2 (2–12)	6.2 (2–12)	6.1 (2–12)	6.1 (2–12)	6.0 (2–11)	6.0 (2–12)	6.1 (2–12)	4.3 (1–9)
		National	5.6 (1–11)	5.4 (1–10)	5.2 (1–10)	5.2 (1–10)	5.0 (1–10)	4.9 (1–9)	4.8 (1–10)	4.7 (1–9)	4.7 (1–9)	4.5 (1–9)	4.4 (1–9)	3.1 (0–7)

Table 6. Modelled effects of segment position (1–12, ascending upstream), spring survey round (initial or resurvey) and their interaction on population estimates for cormorant and goosander in the River Usk main channel. Models were fitted with initial surveys as the baseline, so the population estimate multiplied by the effect size yields the resurvey population estimate. Initial surveys took place during the smolt run and resurveys shortly after its conclusion. Segment position was fitted as a numerical variable, so the population estimate for segment n multiplied by the effect size yields the population estimate for segment n+1. For resurveys, the baseline estimates should also be multiplied by the effect size of the interaction term. For all effect sizes, if the 95% confidence intervals of the estimate contain 1 (the value of no effect), the effect is considered to be non-significant.

Species	Variable	Effect size – estimate	(- CI)	(+ CI)
Cormorant	Segment position	0.83	0.46	1.37
	Spring survey round	0.55	0.00	103.57
	Segment position: spring survey round interaction	0.96	0.43	2.17
Goosander	Segment position	0.92	0.75	1.14
	Survey round	0.44	0.05	3.60
	Segment position: spring survey round interaction	1.07	0.80	1.47

Table 7. Numbers of goosanders identified as males, females, chicks, or with sex not recorded across initial surveys and resurveys.

	No. individuals recored Initial surveys	No. individuals recored Resurveys
Males	31	2
Females	52	43
Sex not recorded	9	8
Chicks	9	34

3.3.2 Smolt aggregation surveys

Cormorant

Cormorants were observed at 6/14 sites in total, including three pinch points. There was no statistical support for an increase in cormorant peak count either at pinch points compared to control sites, or during the smolt run compared to after its completion (Table 8). However, all counts of > 1 individual took place during the smolt run (Figure 4). Cormorants were only recorded actively fishing on one occasion throughout the surveys; therefore, no analysis of the fishing pressure metric was conducted for this species. These results suggest that cormorant do not make use of elevated smolt density at pinch points.

Goosander

Goosander were observed at all 14 sites in the survey. Peak count of goosander was 1.06-2.96 times higher at pinch points than at control sites but did not differ between surveys during and after the smolt run (Table 8). In other words, goosanders were observed to gather at pinch points regardless of whether smolts were present. However, fishing pressure exerted by goosander was significantly higher both at pinch points than controls (at least 2.3 times higher), and during the smolt run (at least 16.4 times higher): indeed, goosander were never observed to be fishing during the post-smolt run surveys (Figure 4). These results suggest that goosander do fish preferentially at pinch points when smolts are liable to be present.

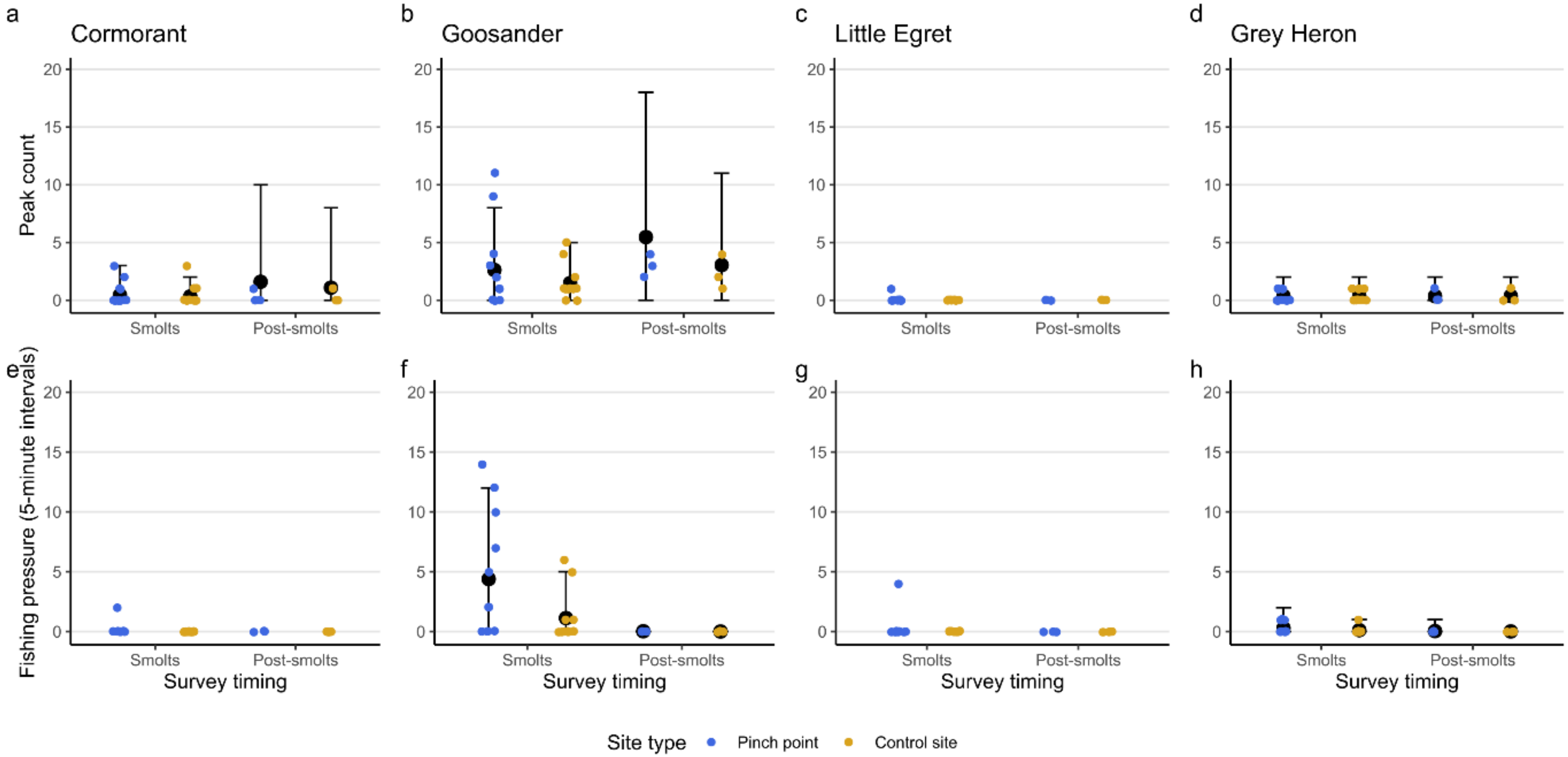

Figure 4. Peak count of (a–d), and fishing pressure exerted by (e–h), four piscivorous riverine bird species at pinch points (blue) and control sites (orange) on the River Usk, Wales, both during and after the Atlantic salmon smolt run. Points show observations from single surveys and are 'jittered' for clarity. Black dots and error bars show the mean and 95% Confidence Interval of the modelled posterior distributions.

Table 8. Summary of statistical models tested in the study. Models were fitted with Poisson error distributions (log link function); therefore, effect sizes are multiplicative, such that pinch point metric = control site metric x effect size and smolt run metric = post-smolt run metric x effect size. Models were fitted within a Bayesian framework, so *P*-values are not provided; however, cases where the 95% confidence interval of the effect size does not contain 1 (indicated in bold font) is considered to have statistical significance. Little egret was observed once throughout the study, so no models were fitted for this species. Cormorant was observed fishing once, so models were only fitted for peak count for this species, not for fishing pressure. For grey heron fishing pressure, the effect of each test variable was tested in a separate model.

Metric	Species	Test variable	Effect size – estimate (95% Confidence Interval)
Peak count	Cormorant	Pinch point	1.37 (0.46 – 4.17)
		Smolt run	0.53 (0.05 – 6.44)
	Goosander	Pinch point	**1.77 (1.06 – 2.96)**
		Smolt run	0.51 (0.22 – 1.11)
	Grey heron	Pinch point	1.01 (0.27 – 3.89)
		Smolt run	1.32 (0.26 – 9.28)
Fishing pressure	Goosander	Pinch point	**4.17 (2.28 – 8.02)**
		Smolt run	**2.20×10^4 (16.39 – 2.25×10^9)** †
	Grey heron	Pinch point	3.80 (0.39 – 72.06)
		Smolt run	525.53 (0.62 – 5.52×10^7) †

† For both goosander and grey heron, fishing was never recorded outside of the smolt run, so the respective effect sizes are relative to an effective baseline of 0. Therefore, theoretically, the effect is infinite, and the estimate (and upper confidence interval) derived from the posterior distribution is accordingly very large. However, this does not necessarily translate to a very high level of fishing pressure once multiplied by an intercept value of ~ 0 (Figure 1).

Little egret

Only one little egret was observed throughout the surveys (actively fishing at a pinch point, during the smolt run). Therefore, no statistical testing was conducted for either peak count or fishing pressure for this species. There is little support in these data for little egret to be considered a major predator of smolts in the River Usk, due to their low density.

Grey heron

Grey herons were observed at 7/14 sites in total, including five pinch points, but there was no statistical support for an increase in grey heron peak count at pinch points, or during the smolt run (Table 8). Fishing pressure exerted by grey heron was substantially but non-significantly higher at pinch points (estimated to be 3.8 times that at control sites, but with a lower confidence interval (LCI) of 0.4; less than 1, the value of no difference), and similarly during the smolt run (estimated to be 525.5 times higher, but with an LCI of 0.6). This suggests inconclusively that grey heron may fish preferentially for smolts at pinch points. However, it is noteworthy that grey herons were only recorded fishing on four occasions in the surveys, in each case for one five-minute interval only. Therefore, although this species may make use of pinch points, it is unlikely to act as a major predator of smolts.

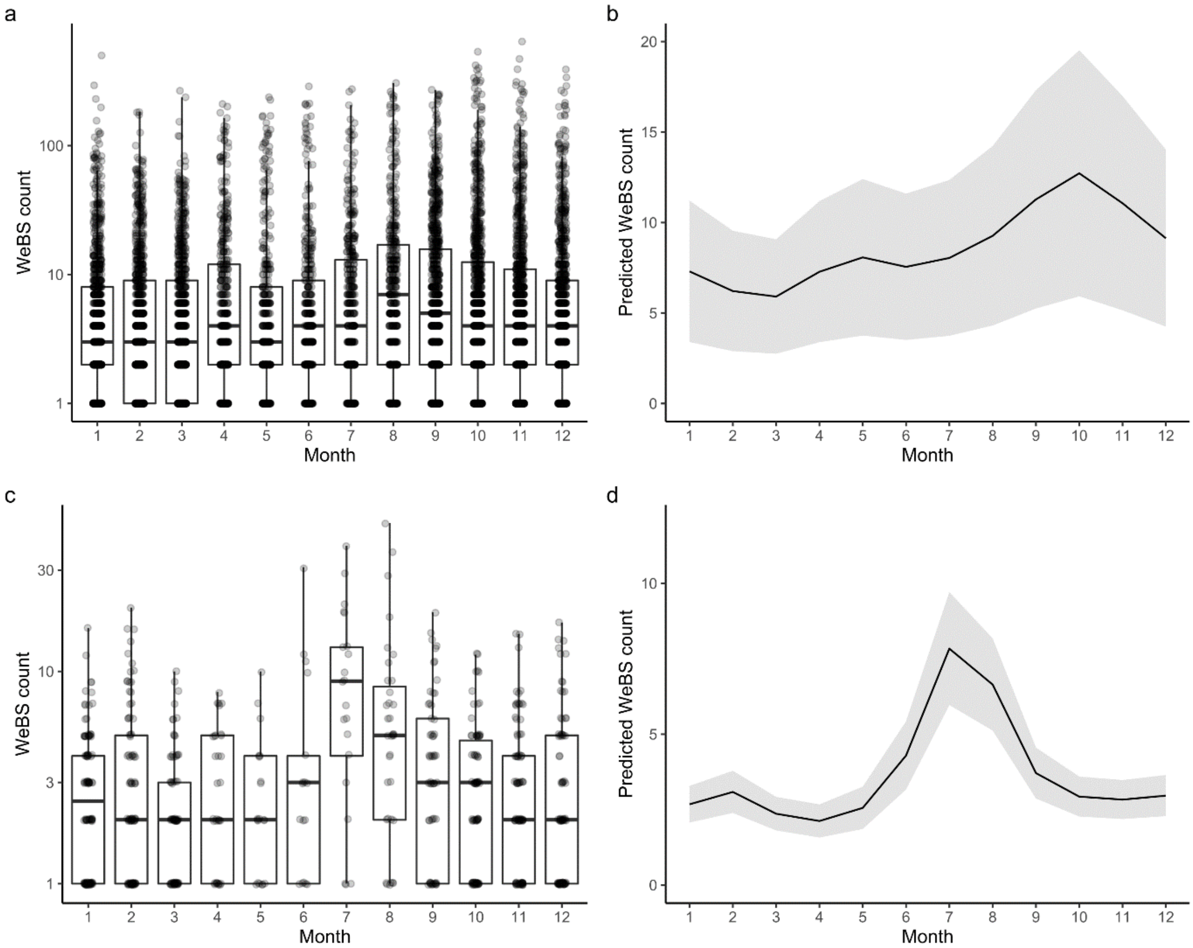

Figure 5. Counts of cormorant (**a**, **b**) and goosander (**c**, **d**) derived from Wetland Bird Survey (WeBS) counts undertaken at estuarine sites associated with the ten principal salmonid rivers in Wales. Variation over the course of the year is shown in raw counts (**a**, **c**; plotted on a logarithmic *y*-axis scale) and modelled using a Generalized Additive Model (**b**, **d**; plotted on a linear *y*-axis scale), with 95% Confidence Intervals plotted in grey.

4. Discussion

Spring population estimates, and comparison with winter population

Abundance of cormorants on the River Usk during the spring survey was approximately 5 times lower than the corresponding winter survey (Taylor *et al.,* 2022). This suggests that the majority of birds recorded on the Usk in winter may be overwintering continental birds, since virtually all known Welsh breeding colonies are coastal (Pritchard *et al*., 2021). This appears to represent a different pattern to that recorded through the Wetland Bird Survey (WeBS) on estuarine sites across the ten principal salmonid rivers in Wales, where cormorant numbers reach their lowest ebb in March, but are at similar levels in April-May as in December-January (see Figure 5). The present surveys are not sufficient to establish whether riverine cormorant abundance would have been even lower had additional surveys taken place during March. Nevertheless, these results suggest that using established monitoring of WeBS sites to extrapolate population change in riverine cormorants would be an unreliable approach.

Despite their substantially reduced abundance in spring, the relative distribution of cormorants within the main channel of the River Usk was the same as in winter, with the majority of observations made in segments closer to the estuarine survey limit. This reflects the findings of previous surveys (Taylor and Noble, 2017; Taylor *et al*., 2022) and is in agreement with the known ecology of this species. As has previously been suggested, this offers opportunities for reduced-effort surveying of this species in future; by focussing on the lower reaches of river channels (Taylor *et al*., 2022).

Abundance of goosanders on the River Usk during the spring survey was not significantly different to that estimated from the winter survey data. Indeed, when the same model structure was applied to both datasets, population estimates and their confidence intervals were virtually identical between winter and spring (Table 2; and see "Further analysis/future recommendations", below). This result suggests that, unlike cormorant, immigration from the continent may represent only a small proportion of the winter goosander population in Wales.

Within the river channel, models fitted linearly and suggested a shallow (non-significant) decline in goosander abundance as distance from the estuary increased. This result was somewhat unexpected, given that goosanders are reported to breed higher up in river catchments (Taylor *et al.,* 2022). However, raw count data revealed very few records of goosander from segments 1 & 2 (i.e. up to 20km from the estuary survey limit), with abundance peaking in segments 3 & 4. This suggests a more complex non-linear relationship between goosander abundance and distance upriver, but trials fitting models with a quadratic (non-linear) relationship found they fitted the data substantially less well than the simpler linear relationship.

Many of the recorded individuals may have been non-breeding (many more females were recorded than broods of chicks, even in the later part of the survey); but on the other hand, broods were recorded across segments 2, 3, 8 and 9, which does not lend support to the notion of goosander breeding primarily high up in the catchment, at least for the River Usk.

Survey timing in relation to the 2021 smolt run

The salmon smolt run was reported by NRW to have taken place approximately between 20th April and 20th May 2021. This means that initial surveys took place entirely within the period of the smolt run, and resurveys primarily at or after its end. Therefore, any differences between populations during the two survey rounds could conceivably be related to differences in availability of the food resource of salmon smolts. Nonetheless, neither species showed any significant evidence for changes in abundance or distribution within the river between the two survey rounds. Certainly, for cormorant, there was no suggestion in the current survey that this species attends the River Usk during spring in any substantial numbers when the smolts are running. This is likely because cormorant breeding sites are almost entirely coastal, so travelling upriver to fish may not be an efficient foraging strategy. However, a different story might emerge in estuarine locations, given that cormorant abundance in Welsh WeBS sites appears to increase between March and April/May. The degree to which smolts are a prey item for estuarine-fishing cormorants may be an important area for future research. Additionally, flow conditions during the survey period were atypical (with unusually high river levels; see Figure 6); a further survey in a year with closer-to-average flow conditions would be necessary to ascertain whether this had any impact on use of the river by cormorants.

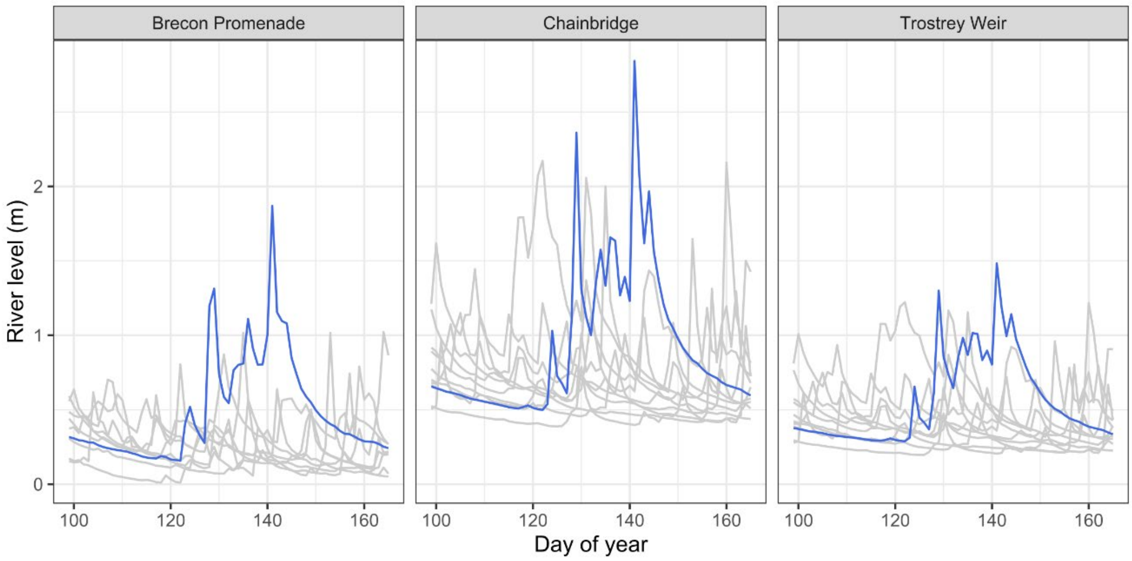

Figure 6. River flow was above average during the survey period. Daily river levels are shown at three monitoring stations on the main channel of the River Usk during the weeks surrounding the survey period. Data are plotted for Julian days 99–165 (9th April to 14th June in a non-leap year), for years 2011–2021 (except for Brecon Promenade, which is plotted for 2013–2021). Data from the survey year, 2021, is plotted in blue, with all other years in grey.

Although total abundance of goosander was similarly stable between the first and second surveys, it is important to note that there was a substantial change in population composition for this species between the survey visits. During the first visit, the observed sex-ratio of this species was approximately 40:60 in favour of females, but by the time resurveys were undertaken, almost all males had departed on moult-migration, with an observed sex-ratio of 5:95 in favour of females. This indicates that males depart on moult-migration during the smolt run, rather than remaining on the river until its conclusion to capitalise on a resource.

In terms of raw numbers of birds, males were largely replaced by chicks by the time of the resurvey, with all but one brood of chicks being observed only in the second survey visit. Chicks at this stage of development are unlikely to be large enough to catch and swallow running smolts. In total, six goosander broods were recorded during resurveys (in addition to one brood recorded during an initial survey of segment 9 on 3rd May 2021, the final day of initial surveys, which may potentially have been the same brood as one of two recorded during the resurvey of segment 8). 6-7 broods across 120km of main channel is substantially lower than the 13 breeding pairs reported from the River Usk in 2014 (Tyler, *pers comm*), and also is at lower density than the one brood per 6km reported from the River Wye between 1990-2000 by Mitchell *et al*. (2004). This suggests that some broods may not yet have moved from nest to river at the time of our surveys. Either way, few of the females recorded during resurveys actually had broods of chicks on the river (6 broods to 43 adult females; 14%). This could either indicate that most broods leave the nest too late to be feeding on smolts, or (if broods leave the nest in time to be feeding on smolts) that a very low proportion of the River Usk population of goosanders is currently breeding successfully.

Smolt aggregations

BTO surveyors conducting main river channel surveys were asked to record pinch points that they thought might harbour smolt aggregations (including natural river features, such as braided river sections, and artificial features such as weirs). In total, 18 such potential smolt aggregation points were recorded by river channel surveyors, of which three were identified and surveyed by The Wye and Usk Foundation (WUF) during the smolt aggregation surveys. Three smolt aggregation points surveyed by WUF were not recorded by the BTO surveyors, indicating that other potential smolt aggregation points may also have gone unrecorded, and the total number along the full length of the River Usk main channel is likely to be higher than 21.

BTO surveyors recorded goosanders in proximity to 8/18 potential smolt aggregation points, and these birds were actively fishing at half of those: one cormorant was recorded fishing at one potential smolt aggregation point. Compared to the smolt aggregation surveys, which recorded cormorants at 3/6 smolt aggregation points and goosander at 6/6, these relatively low rates of detection could indicate that the smolt aggregation points selected for targeted survey were more attractive to piscivores than average, which should be borne in mind when interpreting the results from those surveys. It is also possible that the WUF smolt surveys were performed at the most important time of day for active fishing (just after dawn) whilst the river surveyors recorded potential aggregation points as they were encountered throughout the survey day.

Many of the findings of the river channel survey complemented those of the targeted surveys of smolt aggregations. Cormorants (and indeed other piscivorous species) were generally recorded at low abundance at smolt aggregations, and exerted little apparent fishing pressure, suggesting that this species does not exploit the food resource of smolts to any great degree. Goosander were only observed fishing during the smolt run, both at and away from smolt aggregations, but there was no significant difference in their abundance between survey times. Goosander were also observed to exert greater fishing pressure at smolt aggregations than at control sites. Further investigation of goosander behaviour at such aggregation points (including their response to control measures, such as scaring, targeted at these key locations) may be beneficial.

It is important to recognise that the dataset used in this analysis is relatively limited. Models generated from these analyses are therefore not suitable for the estimation of bird abundance or extrapolation to levels of fishing pressure more broadly, either within the Usk catchment or across other river catchments. The method may be suitable for future data collection across other catchments and in other years, as it does produce analysable data relevant to building a better understanding of smolt vulnerability in aggregation points during the smolt-run.

Recommendations for further analysis or research

How representative is the Usk in spring 2021?

The population estimate for goosander on the River Usk was noticeably different (albeit not significantly) when predictions were made from a model fitted specifically to data from the Usk surveys, than when made from the national-scale model of Taylor *et al.* (2022). This suggests that patterns of goosander distribution within the Usk may not be perfectly representative of patterns in other rivers, since the national-scale model effectively offers a smoothed mean distribution across all 10 of the principal salmonid rivers in Wales.

Further surveys along other river channels in springtime will be necessary to confirm whether the findings of this study are more widely representative. Similarly, WeBS data shows that within-year patterns of abundance for both species (but especially cormorant) on estuarine sites are highly complex, and WeBS data were not available for the winter of 2020-21 owing to pandemic restrictions on volunteer survey activity. The present study suggests that such patterns may be different on riverine sites, but to establish this for certain would require further survey effort through other times of year.

Flow conditions on the Usk in 2021 were not typical of recent years (Figure 6). Unusually high river flow may have influenced survey results and bird distributions through a number of mechanisms, including by potentially affecting bird behaviour and causing smolt migratory delay. Further surveys in years with more typical conditions would establish when the abundance and distribution of cormorants and goosander within the river channel was influenced by flow conditions. An NRW-led smolt telemetry programme was conducted simultaneously to this survey; review of the two surveys alongside each other might also facilitate understanding of the impacts of flow conditions on fish-eating birds. It should also be noted that flow conditions currently considered to be atypical (such as those in 2021) may become more frequent under future climate change.

How significant are smolts as a food resource for piscivorous birds?

The results of this survey imply that cormorants do not make targeted use of smolts as a food resource within the riverine section of the Usk. Patterns of cormorant abundance in estuarine sites raise the question of whether smolt predation may take place further downstream, but it is unknown whether smolts are significantly predated upon (by any species) once they cross into the estuary, where fishing conditions and other prey availability may be very different.

Goosander, on the other hand, do appear to exploit smolt aggregations during the run. Nevertheless, in this survey male goosanders departed on moult-migration while the smolt run was still active, and therefore may not be particularly dependent on this resource. Chicks fledge onto the river during the active smolt run (though it is unclear what proportion of broods within the Usk catchment had done so by the conclusion of our surveys), but whether smolts form any part of chick diet at this early life stage is also not apparent. Small chicks are thought to feed on much smaller fish (species or life-stages) and invertebrates. Only adult females are present on the river for the entirety of the smolt run and are definitely able to feed on smolts; population estimates for these alone were substantially lower than those for the population of goosander as a whole (see Table 3).

Can measures to reduce smolt predation be effectively applied at smolt aggregations?

Given that fishing pressure on smolts appears to be particularly focussed on a few key locations along the river channel, the possibility is raised that targeted measures to reduce fishing activity at these locations at key times during the smolt run (e.g. fish refugia or bird-scaring early in the morning) could result in a substantial reduction in predation of smolts. To better understand this, trials of such interventions might be beneficial, especially if combined with behavioural/satellite telemetry studies of how individual birds (especially goosander) respond to such interventions.

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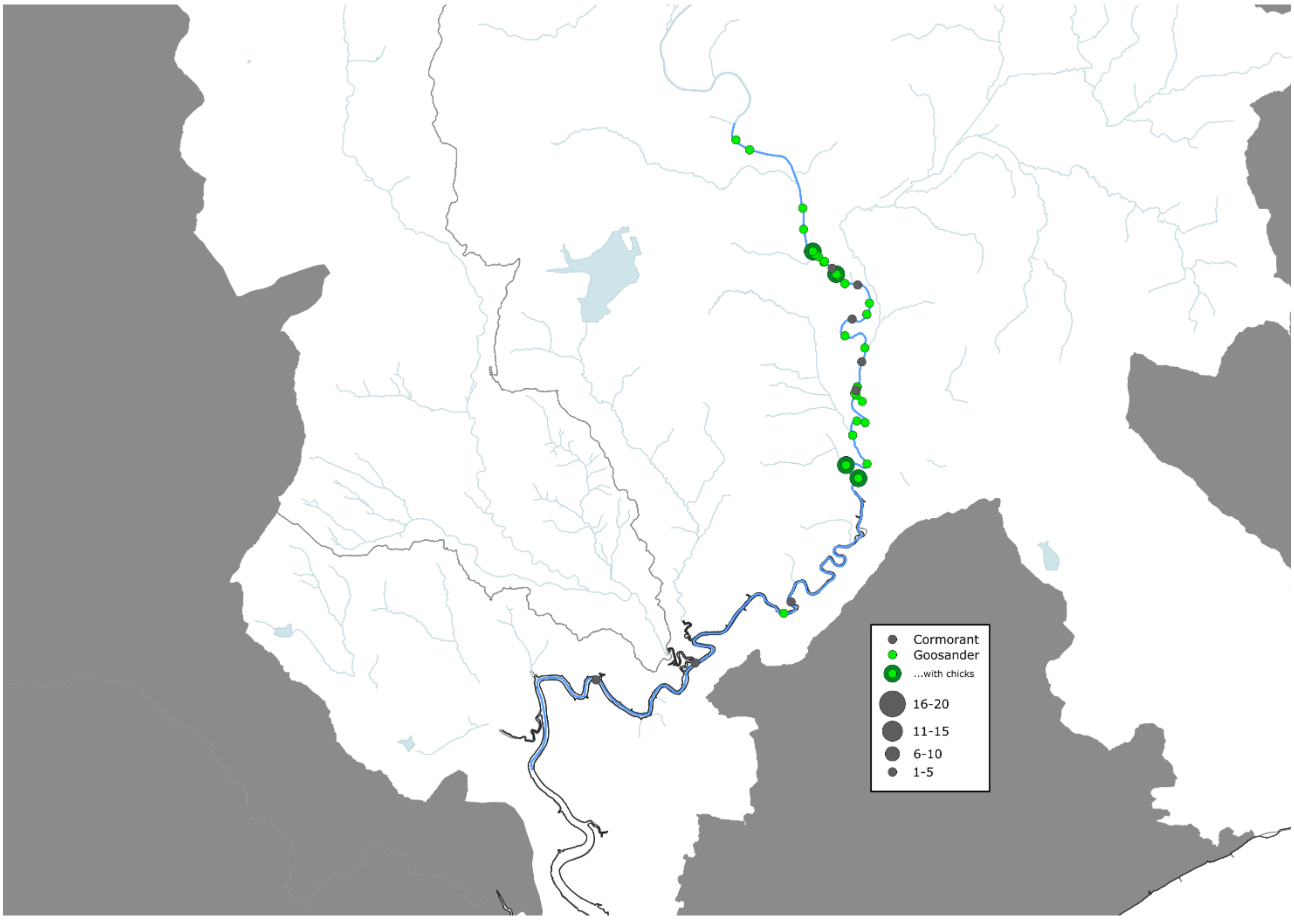
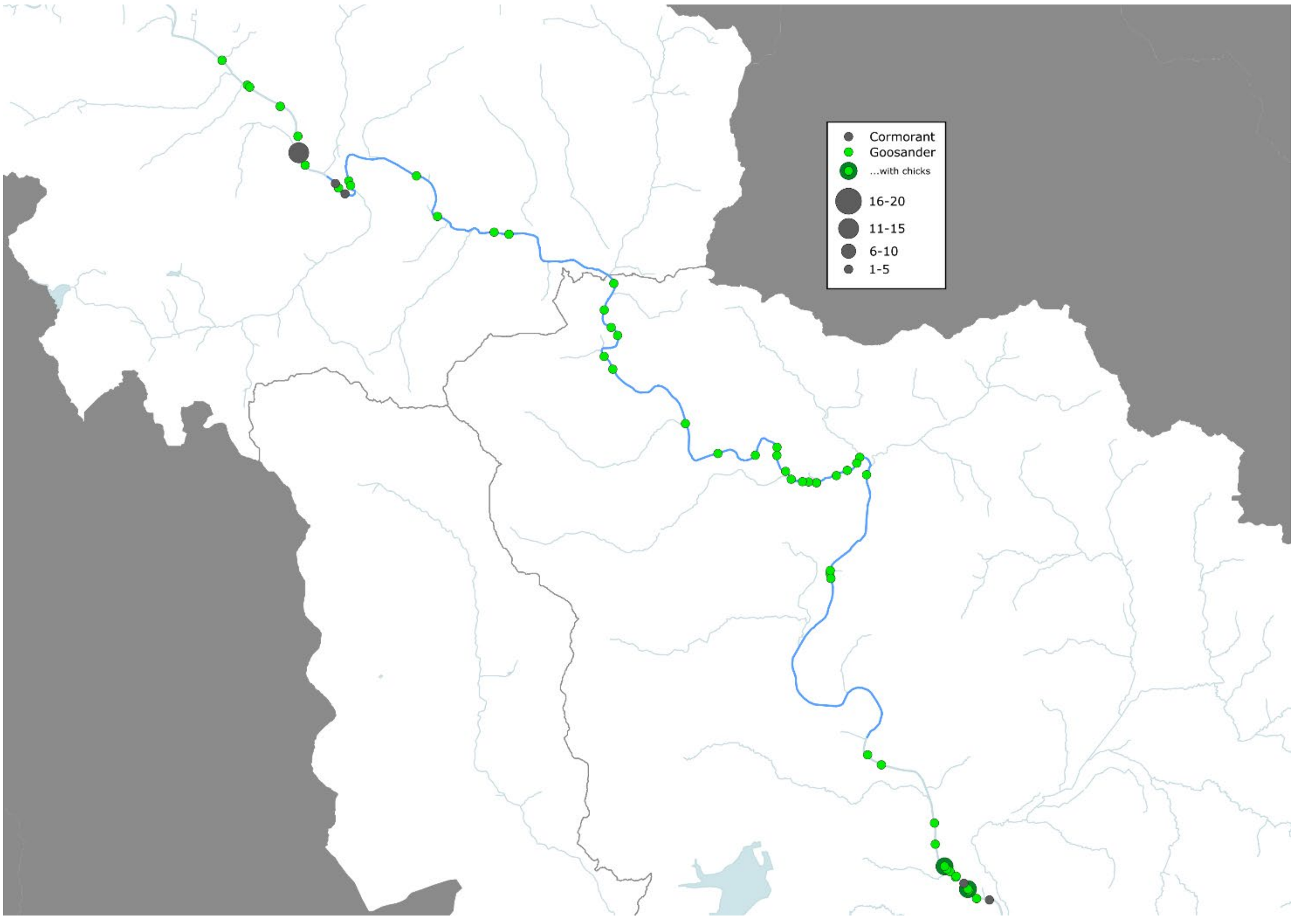
Appendix 1: Maps showing survey coverage

Maps of survey coverage with focus on three 10 km sections per map. The focal river segments are depicted in blue with other river segments, unsurveyed tributaries and major stillwaters within the Usk operational catchment (white area) shown in grey. All survey records of cormorant (grey) and goosander (green) are overlaid.

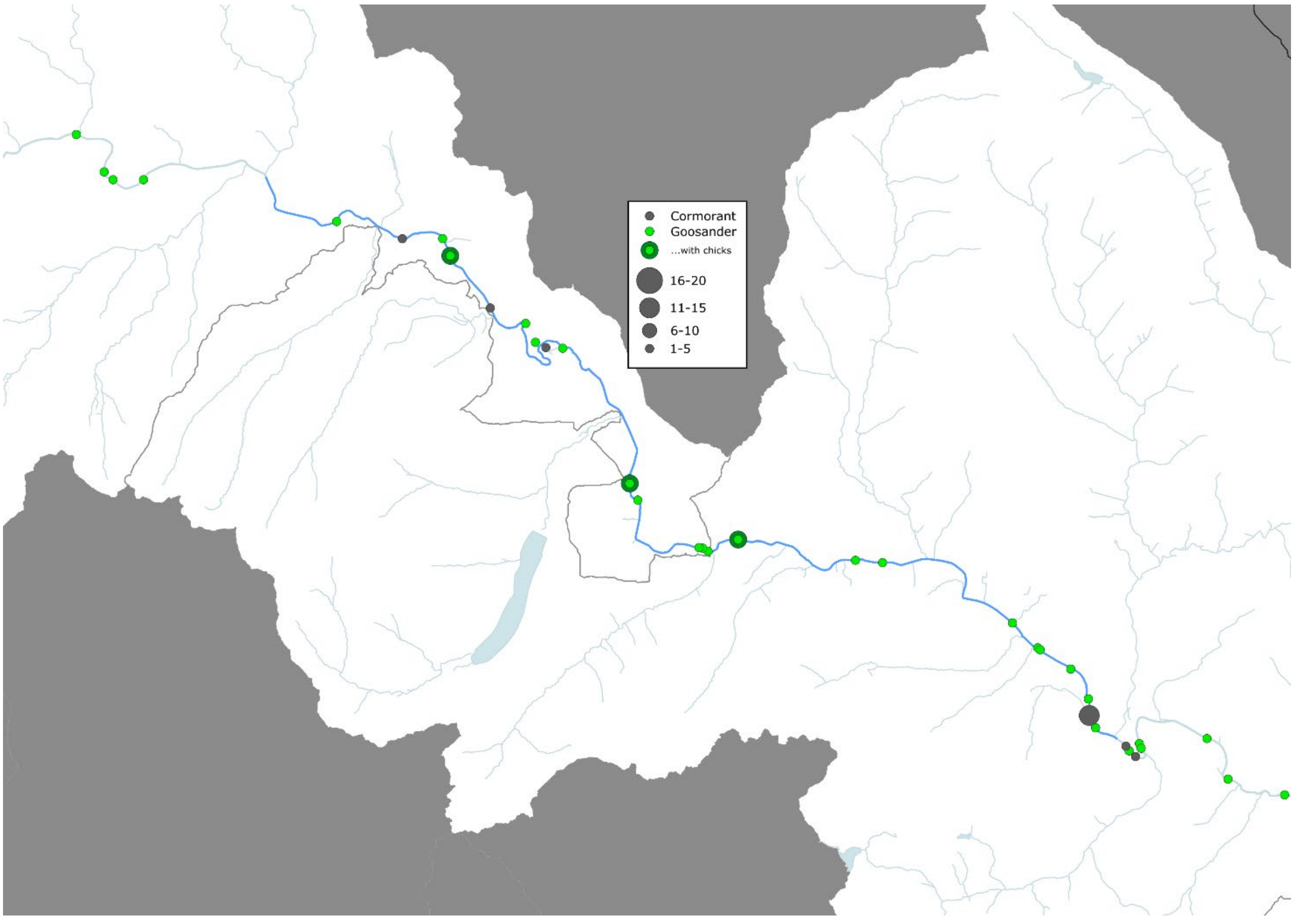
Appendix 1.1: Map of survey coverage for river sections 1-3.



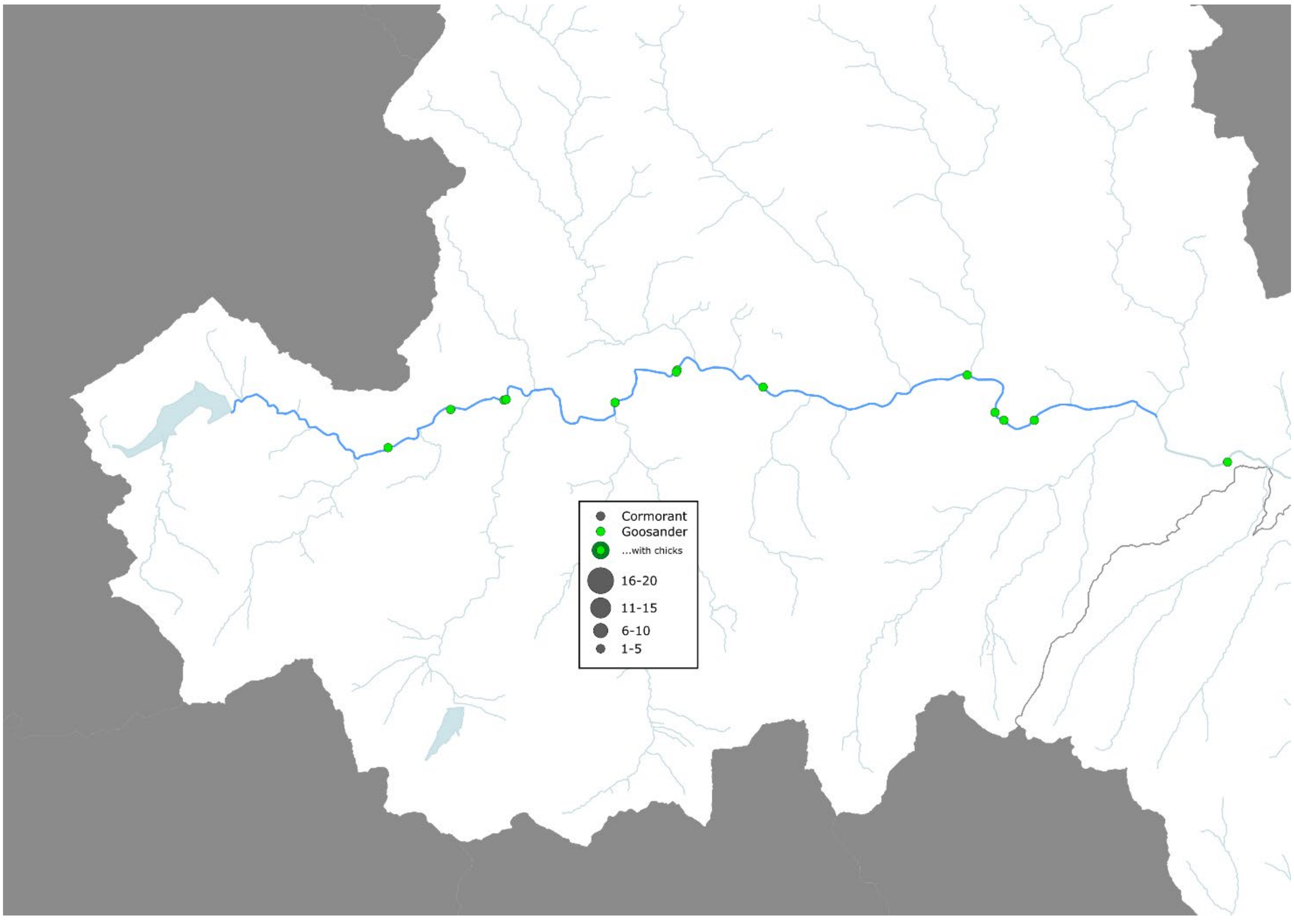
Appendix 1.2: Map of survey coverage for river sections 4-6.



Appendix 1.3: Map of survey coverage for river sections 7-9.



Appendix 1.4: Map of survey coverage for river sections 10-12.



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