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Red-Throated Diver Energetics Project
2019 Field Season Report

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EQA:

This report is compliant with the JNCC Evidence Quality Assurance Policy http://jncc.Defra.gov.uk/default.aspx?page=6675.

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Summary

Offshore wind deployment around the UK is due to increase from the current 8GW to 30GW in the next ten years along with ambitious plans for offshore wind development elsewhere in Europe. Development in the marine environment may affect marine bird populations. Red-throated divers are known to be displaced, causing effective habitat loss, by construction and operation of offshore wind farms, with this effect primarily seen during the non-breeding season when divers use areas of offshore wind development. However, the energetic, physiological and demographic consequences of displacement are currently unknown. If divers are already energetically constrained in the non-breeding season, they may struggle to meet the additional energetic demands following displacement. The aim of the Red-throated Diver Energetics Project (https://jncc.gov.uk/our-work/rtde-project/) is to collect and compare novel data on foraging and movement behaviour of red-throated divers in the breeding and non-breeding season.

In 2018, the Red-throated Diver Energetics Project tagged 74 divers breeding in Iceland, Orkney, Shetland and Finland with archival time depth recorder (TDR) and geolocator (GLS) tags. In 2019, tagged divers were found, caught and tags removed to obtain data on their approximate location and their dive behaviour in the 2018/19 non-breeding season. Analyses of these data are presented in a separate report (JNCC Report No. 638). The present report describes the 2019 breeding season, tag retrieval/redeployment and tag/trapping effects on red-throated divers.

Recapturing tagged divers was challenging. Locating tagged birds was difficult and catching them took much longer than during tag deployment in 2018. A total of 27 tagged divers were caught and tags removed. Of these, 18 were fitted with new TDR and GLS tags to obtain information on inter-annual variation in foraging behaviour for the same individuals. A further 15 sets of tags were deployed on divers that had not been tagged previously. In 2020, attempts will be made to recapture divers carrying these newly deployed tags plus divers carrying the 2018 deployment that were missed in 2019.

Three methods were used to look for any tag and trapping effects: resighting rates of tagged divers, changes in body mass of tagged divers between 2018 and 2019 and breeding success at nest sites where trapping was attempted compared with control sites. Additionally, mortality of three tagged divers was considered in the context of bycatch rates of ringed divers.

Across all sites (countries) combined, the resighting rate of tagged divers was reported to be 69% (n=50 tagged divers seen) although this varied from 53% to 92% depending on site. For a long-lived species, a resighting rate of 80-90% would be expected. However, finding tagged divers was challenging and it is possible that tagged birds did return but were not seen. Alternatively, divers may not breed every year, irrespective of whether they are tagged. Without a marked control group of untagged divers, e.g. by using colour rings on untagged divers, it is not possible to make a quantitative evaluation of this resighting rate.

Body mass of tagged divers retrapped in 2019 was not significantly different to their body mass in 2018. This suggests that carrying tags does not reduce body condition in individuals that returned to breed. However, it was not possible to look at body mass of tagged birds that were not recaptured so our sample could have been biased.

Breeding success was found to be significantly lower at nest sites where trapping was attempted, compared with control nest sites (breeding success = 38% at trapped nests, 58% at control nests for Scotland and Finland, combined), although evidence for this effect in Finland was weak. This suggests that disturbance from attempting to catch divers to deploy

or retrieve tags can increase the likelihood of a breeding attempt failing, but that this effect was seen more strongly in some trapping locations than others.

Mortality of three Finnish tagged divers was reported during August 2018-June 2019, with two due to drowning in freshwater nets and a third of unknown causes. Bycatch is known to be a problem for adult red-throated divers, e.g. 75% and 60% of ring recoveries of Finnish- and British-ringed divers, respectively, were due to being caught in a net, where cause of death was known. However, drowning in a net set in freshwater is much more common in Finland compared with Britain (60% and 8%, respectively, of mortalities of known cause for ringed divers). Therefore, these mortalities of tagged divers could have happened irrespective of them carrying tags.

Despite breeding success potentially being decreased by attempts to trap divers, and no discernible tag effects (i.e. no decrease in body mass of tagged divers detected) we still recommend trying to recapture and remove as many tags as possible from red-throated divers. It is still possible that ongoing undetected tag effects exist and, given the red-throated diver life history strategy of high adult survival and low productivity, the population will better withstand short-term reductions in productivity from trapping over any small decrease in adult survival due to carrying tags for many years.

Contents

1 Introduction

Globally, offshore wind deployment is expected to undergo a massive increase to assist with mitigating climate change. By 2030, the UK could see an increase in installed capacity from the current 8GW up to 30GW of offshore wind, under the Offshore Wind Sector Deal[1]. Whilst the UK is currently the world leader in offshore wind deployment, Europe has also seen substantial offshore wind development, with growth in the offshore wind sector forecast to continue.

Whilst offshore wind development clearly helps mitigate climate change, the impact on the environment is less well understood. There is some evidence of marine birds colliding with turbines, being displaced and wind farms acting as barriers to flight paths (Dierschke *et al*. 2016; Drewitt & Langston 2006). Red-throated divers (*Gavia stellata*) are known to be displaced by offshore wind farms (Dierschke *et al*. 2016; Furness *et al.* 2013; Halley & Hopshaug 2007; Mendel *et al*. 2019; Percival 2014; Petersen *et al*. 2006, 2014; Webb *et al*. 2016; Welcker & Nehls 2016). However, the behavioural, physiological and demographic consequences of displacement for red-throated divers are currently unknown.

The Red-throated Diver Energetics Project (https://jncc.gov.uk/our-work/rtde-project/) aims to obtain the first empirical data on red-throated diver foraging behaviour during the non-breeding season. Using biologging techniques; information on dive depth, foraging bout duration, time spent foraging each day and diurnal patterns in foraging behaviour have been obtained. Understanding red-throated diver foraging behaviour and activity budgets throughout the year will allow inference on the potential ability of divers to accommodate the additional energetic costs of displacement. These preliminary results are presented in Duckworth *et al.* (2020) and Duckworth *et al.* (*in press*).

When attaching biologging devices to wild animals it is important to quantify any detrimental effects on the individuals carrying devices. Since TDR devices had never been deployed on red-throated divers for the non-breeding season and since the effects of attachment of GLS tags, nor any other leg-mounted devices, to divers have never been quantified, we attempted to measure the effects of carrying tags (tag effects). Additionally, since red-throated divers are known to be highly sensitive to disturbance (although there is individual variation in the extent to which they appear to respond to disturbance at the nest site), we investigated whether a trapping and handling effect was evident (trapping effect).

This report describes tag retrieval and the 2019 breeding season in detail and makes an assessment of (a) red-throated diver breeding success in 2019; (b) resighting rates of tagged divers; (c) changes in body mass of tagged divers; (d) evidence of elevated probability of bycatch of tagged divers, and (e) changes in breeding success at nests where trapping occurred. Information on tag deployment and the 2018 breeding season are presented in O'Brien *et al.* (2018).

2 Methods

2.1 Breeding success

Breeding success was monitored at nest sites in Finland, Orkney, Shetland and Iceland, including sites where trapping was attempted and control nest sites. Surveys in May and early June 2019 identified sites where red-throated divers were nesting, including sites where divers were tagged in 2018, and nest status was recorded. Where possible, multiple visits were made throughout the breeding season (April-August) to monitor nest fate and

[1] https://www.gov.uk/government/publications/offshore-wind-sector-deal

record any second breeding attempts (a ‘relay’). A nest was deemed occupied by breeding birds if clear evidence of nesting activity was observed at a pond or lake, using at least one or more of the following criteria: clear scrape (a shallow depression created by a nesting diver in which eggs are laid), incubating adult present, egg(s) or chick(s) present. A nesting attempt was deemed successful if at least one ¾ grown chick (i.e. approximately three weeks old) was seen at that site. Red-throated diver chicks passing the three-week old threshold are more likely to fledge successfully (*pers obs.*, D. Okill & J. Williams). The metric of a three-week old chick as a measure of breeding success has been used for many years in Orkney and Shetland, enabling comparisons of breeding success across years.

2.2 Tag deployment and retrieval

2.2.1 Tag deployment in 2018

During the 2018 breeding season, 74 breeding red-throated divers were fitted with leg-mounted time depth recorder (TDR) tags (Cefas G5 Standard Time Depth Recorder) and global location sensor (GLS) tags (Biotrack/Lotek MK4083 Geolocator). Divers breeding in Iceland (n=12), Shetland (n=14), Orkney (n=17) and Finland (n=31) were tagged. See O’Brien *et al*. (2018) for information on choice of study area and details of deployment methods.

2.2.2 Tag retrieval and further deployment in 2019

During the 2019 breeding season, fieldworkers focussed on re-trapping birds tagged in 2018, to retrieve tags. As described above, at the start of the breeding season, lakes and ponds where birds were tagged in 2018 were revisited to search for tagged birds. Although generally divers have high inter-annual site fidelity (Okill 1992), where tagged birds were not seen, fieldworkers also visited nearby lakes and ponds in case divers had moved nest site. These searches revealed that divers can change nest sites but generally remain close to their previous nest site.

Once a tagged bird was seen, attempts were made to catch that diver using the same methods as in 2018. Methods included use of traps at the nest (spring traps, walk-in traps) as well as wader nets and nets in the water, with divers sometimes lured to nets using decoy birds and by playing territorial calls (see O’Brien *et al.* 2018). Most trapping was done during incubation when nest trap methods could be used. Incubation stage was established by floating eggs in water (see O’Brien *et al.* 2018; Paassen *et al.* 1984); trapping was not attempted during the first 7-10 days of incubation as birds are more likely to abandon their nests when disturbed at this stage. Trapping duration was taken to be the total time spent at a nest site before catching a tagged bird, which included multiple visits to that nest site in some cases. Trapping duration in 2019 was compared with 2018 for each recaptured tagged bird to investigate whether trapping duration was longer in 2019. Longer trapping duration could increase the likelihood of a trapping effect.

Once caught, tags were quickly removed and morphometrics taken. New tags were then fitted to the diver if all the criteria below were met:

- the diver’s legs showed no signs of abrasion from rings or tags;
- the diver otherwise appeared fit and healthy;
- body mass was not <150g lighter than in 2018.

The 150g threshold for change in mass was based on previous work on Hoy, Orkney. Between 1987 to 2001, 21 adult red-throated divers were caught on more than one occasion and body mass was recorded. This small dataset (n=41 repeated body mass measurements) gives some information on measurement error and natural variation in red-throated diver body mass. Diver body mass was measured on one to five occasions after initial measurement, usually in subsequent years. The residual in measured body mass on each subsequent occasion after recording initial body mass was found and the mean residual for each individual calculated. Across the 21 individuals mean residual measured body mass was -29.8g (SD = 123.1g, range = -255g to + 300g), suggesting no change in subsequent measurements of body mass given the substantial variation in measured body mass. Whilst these data are from a single site with only two ringers recording body mass, they provide some information on plausible ranges of changes in body mass between 2018 and 2019, that might be due to natural variation and measurement error, rather than tag effects. Thus, a threshold of 150g was set as approximately one standard deviation of the change in mass recorded previously.

Tags deployed in 2019 were exactly the same as in 2018, i.e. CTL G5 TDR tags and Lotek MK4083 GLS tags, mounted on red darvic rings, and were programmed with the same sampling schedule as in 2018.

2.2.3 Feather sampling

All birds caught in 2019 had feathers sampled for stable isotope analysis and genetic analysis. Feathers were clipped from a secondary feather for insight into post-breeding moult location. The corresponding secondary covert was also sampled as it is expected these feathers are grown at the same time as the secondary flight feathers. If analysis shows this to be the case, in future only coverts will need to be sampled and not flight feathers. Additionally, a sample of a red breeding plumage neck feather was taken to identify pre-breeding moult location. Finally, a single flank feather was plucked for genetic analysis.

At this stage no stable isotope analysis or genetic analysis has been undertaken so results are not reported here.

2.3 Tag effects

2.3.1 Resighting rates

Resighting rate is the number of tagged divers seen in 2019 as a proportion of divers tagged in 2018 (n=74). If numbers of divers seen in 2019 are much lower than would be expected, allowing for natural mortality, it might suggest that tagged divers are either suffering mortality or are failing to get into breeding condition due to carrying tags. As well as tag effects, trapping effects could cause divers to move nest sites, resulting in them less likely to be seen in subsequent years, or cause them to fail to breed in subsequent years. However, for long-lived marine birds, it is not unusual to miss a breeding season (Giudici *et al.* 2010), so divers may fail to return to breed irrespective of carrying tags. Unfortunately, we did not have a marked untagged population of divers in our study sites against which to make a detailed quantitative assessment of resighting rates of tagged divers. Whilst some colour-ringing of divers has been undertaken in the past in Orkney, no systematic searching for colour-ringed birds was undertaken to quantify return rates.

2.3.2 Tag effects on body mass

If tags are having a detrimental impact on divers, e.g. through making foraging more difficult due to attaching devices to their legs when they are foot-propelled foragers, we might expect divers to be in poorer body condition after carrying tags for a year (e.g. Elliott *et al.* 2012). Body condition can be measured by body mass when taking repeated measures on the same individuals.

Body mass in 2018 was compared with body mass in 2019 for tagged birds recaptured in 2019. A linear mixed effect model was used with a response variable, Body Mass, and Bird ID as a random variable to account for repeated measures on the same individuals. Year of body mass measurement and Location (country in which birds were tagged) were included as categorical variables in the model. The response variable Body Mass was log-transformed to improve model fit. Model selection was informed by AIC values.

Changes in body mass of red-throated divers through the breeding season were investigated to test whether stage of breeding needed to be included as a covariate when looking for changes in body mass in tagged birds. Body mass is known to decline in some marine birds as the breeding season progresses (Golet & Irons 1999; Harris *et al.* 2000; Harris & Wanless 1988). This was investigated for red-throated divers using body mass recorded for the 74 divers tagged in 2018. A simple linear regression was performed on body mass of divers against day of sampling after 21 May 2018 to see if body mass decreased with day of measuring body mass. Additionally, residual body mass measured in 2019 compared with 2018 for 27 retrapped individuals was plotted against residual date of recaptured in 2019, compared with first capture in 2018. A linear regression was used to test for any relationship between change in body mass with change in capture date between 2018 and 2019. Body mass data were also available from a dataset of repeated measures of 21 individuals on Hoy. However, no statistical analyses were carried out on this dataset as sample sizes were too small to account for variation in day, year and individual.

2.3.3 Bycatch of divers

Three tagged divers from Finland are known to have died during the period August 2018 to June 2019, two of which were caught in freshwater nets and a third that was found washed up on a beach in Denmark with no tags, suggesting it may have been caught in a fishing net at sea. To investigate whether carrying tags increased likelihood of bycatch for red-throated divers, a review of information including ringing data was used to assess baseline bycatch rates for untagged but ringed red-throated divers. Ringing and recovery data were requested from the Finnish Ringing Scheme (https://www.luomus.fi/en/bird-ringing) and from the British Trust for Ornithology Bird Ringing Scheme, to compare mortality rates due to bycatch in Finnish and British recoveries.

2.4 Trapping effects

2.4.1 Trapping effects on breeding success

To investigate whether breeding success was reduced by attempts to catch red-throated divers (“trapping”) a comparison was made of breeding success at nest sites where trapping was attempted and at control nest sites where no trapping took place. Trapping was undertaken in 2018 to deploy tags on divers and then in 2019 to retrieve tags from birds, i.e. in 2019 ringers deliberately attempted to trap at nest sites where trapping had taken place in 2018. Nest sites where trapping was attempted in 2019 therefore included sites where trapping occurred in 2018 as well as new sites where no previous trapping had taken place. Data from Orkney, Shetland and Finland were used in the analysis as there were no control data available from Iceland at the time of analysis.

In order to investigate whether trapping had a detrimental effect on the fate of red-throated divers’ breeding attempts, first a Generalised Mixed Effect Models (GLMM) was run on a dataset combining nest fates from both years of trapping (2018 and 2019). An additional 22 nests of unknown fate were discarded (final sample size for analysis = 381 data points). GLMMs were fitted with a binomial distribution of the response variable “Breeding Success” (nest was successful vs. nest failed) and a logit link function. Nest sites at which trapping had occurred in 2018 could be more likely to fail in 2019 due to elevated susceptibility to disturbance, than previously untrapped nests. Nest Site ID (n = 291 individual nests) was included as a random variable in the models to account for non-independency between nest fates in 2018 and 2019 (i.e. most nests trapped in 2018 were also trapped in 2019).

Three categorical explanatory variables were included in Model 1:

A. “Trapping Attempt”: trapping attempted vs trapping not attempted at that nest site;
B. “Location”: where nest site was, i.e. Orkney, Shetland or Finland;
C. “Year”: year in which trapping took place, i.e. 2018 or 2019.

We did not include the interaction term “Trapping attempt” * ”Location” to investigate whether breeding success was affected more strongly by trapping efforts in some countries than others due to low sample size (<10) in some variable levels. However, sufficient data were available for Finland, so the analysis was repeated using data from only this site. Estimated laying date was not included in Model 1 due to lack of information in 62% of nest sites (n = 250 nest sites, including 231 control sites) but was included in Model 2 below that analysed a subset of data. Results presented include β, the parameter estimate of the model output indicating the strength and direction of the effect.

To investigate whether the effect of trapping on breeding success occurred in both 2018 and 2019, an interaction term, "Trapping attempt" * "Year" was added but, based on AIC values, did not improve model performance so was not included in the final model (Model 1).

We then further explored variables that could be influencing whether breeding success was reduced by trapping efforts. Firstly, we examined trapping duration to assess whether it differed from 2018 and to test the hypothesis that longer trapping durations increased the likelihood of breeding failure. Secondly, we investigated the effect of different trapping methods, testing the hypothesis that trapping away from the nest was less likely to reduce breeding success. Thirdly, we looked at laying date, testing the hypothesis that trapping at nests late in the season increased the likelihood of breeding failure compared with early in the season.

A second model (Model 2) was run on a subset of the overall dataset to explore these three variables for nest sites where trapping had occurred, and nest fate was known (n = 104 across years and locations; an additional seven nests of unknown fate were discarded). We constructed a GLMM with a binomial distribution of the response variable “Breeding success” and a logit link function. Nest Site ID was included as a random variable. Model 2 included the three following explanatory variables:

A. “Trapping Duration”: cumulative number of minutes across all trapping attempts at a nest site, from when a trapping attempt was first started to when a bird was released;
B. “Nest Trapping”: whether an attempt was made to catch the diver on the nest, as opposed to away from the nest elsewhere on their breeding lake;
C. “Laying Date”: recorded as Julian date.

For birds that had a second nesting attempt (relay) after breeding failure, the laying date of the last, and not first, breeding attempt was taken (when known; n = 8). Continuous variables were centred by subtracting their respective means to aid model convergence.

3 Results

3.1 Breeding success

Breeding success varied across the study sites. Across Orkney, Shetland, Finland and Iceland, a total of 304 occupied red-throated diver nest sites were monitored during 2019 (Table 1). At all of these nest sites a breeding attempt was recorded, i.e. at least a nest scrape was noted even if no eggs or chicks were seen.

Approximately half of nests at which breeding success was measured produced at least one chick that was at least ¾ grown (Table 1). Breeding success was similar across all sites, ranging from 48%-57%, except for Iceland which had higher breeding success (73%).

Table 1. Breeding success (number of nests producing at least one ¾ grown chick of all nests of known fate) in Scotland, Iceland and Finland in 2019 (includes nest sites at which trapping was attempted and control nests).

Sites	No. of nests monitored	No. of failed nests	No. of successful nests	No. nests of unknown fate	Breeding success (%)
Orkney	63	32	30	1	48%
Shetland	38	18	20	0	53%
Finland	109	43	58	8	57%
Iceland	95	19	52	24	73%

3.2 Tag effects

3.2.1 Resighting rates

The primary aim of the 2019 field season was to recapture red-throated divers tagged in 2018 and to remove tags. Unsurprisingly, this proved challenging. During 2019, a total of 50 tagged divers were seen, of which 27 were recaptured (ten birds were from Finland, eight from Iceland, five from Orkney and four from Shetland). Average resighting rate was 68% for the original 74 divers tagged in 2018. However, resighting rate varied markedly among sites, from 53% in Orkney to 92% in Iceland (Table 2). Two of the remaining 23 tagged divers that were not seen in 2019 were known to have died in August 2018 and January 2019. The fate of the other 21 tagged birds is currently unknown. Recapture of resighted birds varied across sites, from 44% in Shetland to 73% in Iceland (Table 2. No substantial difference in sex ratio of birds caught was observed.

Table 2. Resighting rates in 2019 of divers tagged in 2018, recapture rates (proportion (%) of tagged divers that were seen in 2019) and proportion (%) of birds caught that were female in 2018 and 2019.

Site	No. tagged in 2018	% female	No. tagged birds seen in 2019	Resighting rate (%)	No. tagged birds trapped in 2019	% female	Recapture rate (%)
Finland	31	48%	21	68%	10	40%	48%
Orkney	17	53%	9	53%	5	40%	56%
Shetland	14	64%	9	64%	4	50%	44%
Iceland	12	50%	11	92%	8	63%	73%
Total	74	53%	50	68%	27	48%	54%

Resighting rates do not necessarily represent a survival rate for tagged birds. There are many reasons why tagged birds were not seen and so not recorded as a returning bird. Firstly, finding tagged divers proved difficult. Whilst tags were mounted on red darvic rings, the position of the tag on the ring masked much of the red ring and it was difficult to spot rings at a distance unless divers brought their legs above the water surface. Divers are asynchronous breeders with some arriving back on breeding lakes and ponds in April and others not arriving until well into the breeding season. Consequently, searching for tagged birds was undertaken throughout the breeding season to attempt to find all tagged birds, including those attempting to breed late in the season. Occasionally, divers were found to move breeding lake/pond. Two tagged birds in Finland, three in Scotland and two in Iceland were found to have moved from their 2018 nest site to a nearby lake in 2019. This increased search time for tagged birds as fieldworkers had to check both divers in a pair on a lake/pond at all waterbodies close to where a bird was tagged in 2018. This required waiting until both individuals in a pair were on the water and their legs had been checked, which was very time consuming. It was not feasible to repeatedly check all lakes throughout the breeding season and it is very likely some tagged birds were present but not seen. The exception to this is Iceland, where the topography and vegetation of the study area made monitoring all potential nesting lakes feasible. In Iceland, only a single tagged bird was not seen in 2019. This individual was presumed dead as its partner had a new mate and the tagged bird was not seen on any neighbouring lakes.

3.2.2 Tag effects on body mass

Body mass of divers did not appear to decrease as the breeding season progressed. Body mass of 74 divers tagged in 2018 did not show any significant change with day when divers were measured (*body mass* = -2.11**day* + 1856, R^2 = 0.008, p = 0.449, n = 74) (Figure 1a). Similarly, inspection of a plot of repeated measures of body mass of 21 divers in Hoy over many years also showed no change in body mass with day (Figure 1b) although no statistical analyses of these data was undertaken due to small sample sizes. Note the substantial variation in body mass among divers sampled, due in part to sexual dimorphism.

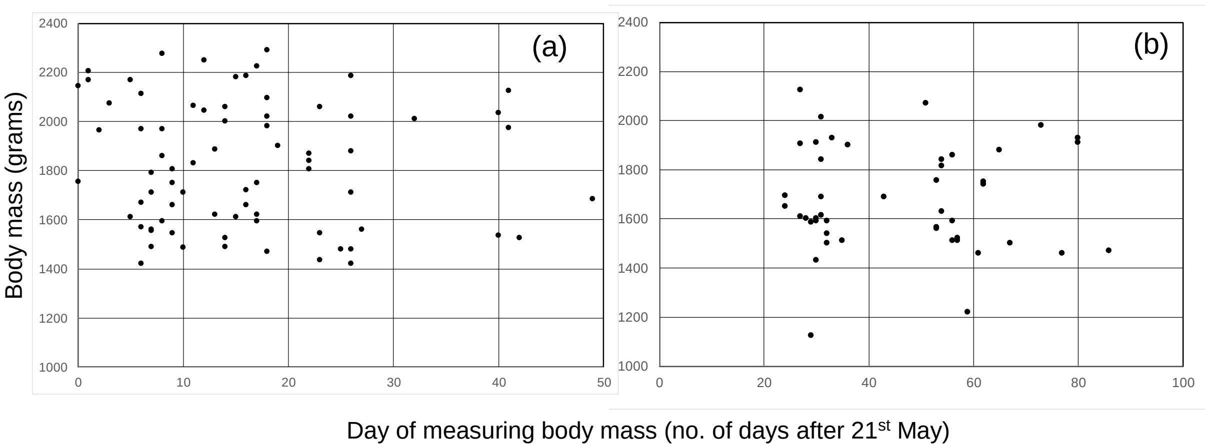

Figure 1. Body mass of red-throated divers against day when sampled, for (a) 74 tagged divers in Finland, Scotland and Iceland in 2018, and (b) repeated measures across many years on the same 21 individuals breeding on Hoy (Orkney).

Tagged divers were not significantly lighter in 2019, compared with 2018 (Figure 2). If tag effects were causing divers to lose condition, we would expect the frequency histogram to have a peak to the left of zero. Conversely, if mortality was higher on lighter birds, we would expect a skew to the right with only heavier birds returning in 2019. Since the peak is at zero, it suggests divers in 2019 are no lighter nor heavier on average than in 2018.

0

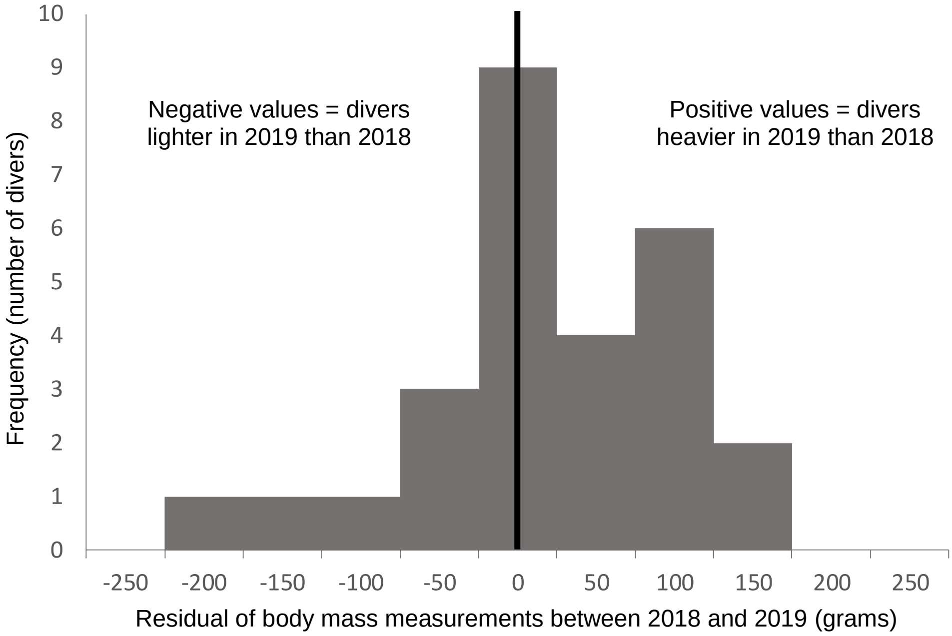

Figure 2. Frequency histogram showing residual of body mass of tagged divers in 2019 compared with 2018.

This is supported by a statistical analysis. The LMM performed well (residuals were normally distributed, variances were homogeneous). No significant change in body mass of tagged adults was found over the 2018-2019 period (β = -0.01, SE = 0.01, p = 0.56, average annual body mass change per individual = -7.4g, SD = 86.8g, 95%CI = [-13.7; -1.1]; n = 54).

Finally, although no evidence was found of a decline in body mass as the breeding season progressed (Figure 1), we investigated whether birds caught later in 2019 than in 2018, tended to be lighter. Body mass change (residual of body mass in 2019 compared with 2018) for the divers tagged in 2018 and recaptured in 2019, was compared with residual of date of capture in 2019, compared with 2018 (Figure 3).

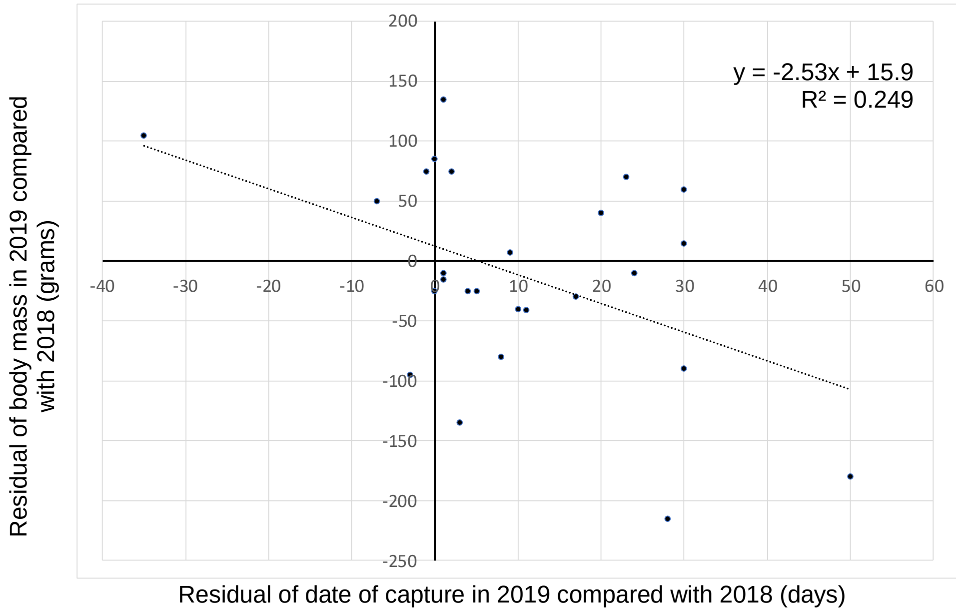

Figure 3. Residual of body mass against residual of date of capture for birds caught in 2018 and recaptured in 2019.

Tagged birds tended to be recaptured later in 2019 than in 2018 (more points to the right of the plot). There was some evidence of divers that were caught later in 2019, compared with 2018, being lighter than they had been in 2018 (linear regression: *body mass residual* = -2.53**date residual* + 15.9, R^2 = 0.249, p = 0.007, n = 27). This result would imply that any decrease in body mass in divers recaptured in 2019 could be attributed to them being caught later in the breeding season than when caught in 2018, rather than due to a tag effect. However, body mass was not found to differ significantly in 2019, compared with 2018 (Figure 2). The reduction in body mass for birds caught later in 2019 is in contrast to the lack of evidence for a decline in body mass as the breeding season progressed among the 74 divers caught in 2018 (Figure 1). Small sample sizes and the wide range of body masses recorded across all divers measured (1400 - 2300g) preclude concluding decisively on whether body mass of divers declines as the breeding season progresses.

Whilst there was no evidence of tag effects on body mass of recaptured tagged divers, a small number of darvic rings, on which tags were mounted, had caused abrasions on the divers' legs. Individuals with leg abrasions were not retagged in 2019.

3.2.3 Bycatch of divers

Three red-throated divers tagged in Finland were found dead. One was found on 29 January 2019, washed up on a beach in north-west Denmark. The cause of death was unknown, but the tags were missing (as was one darvic ring; the other darvic ring and metal ID ring remained) suggesting this individual may have been caught in a fishing net at sea during which tags were removed either accidentally or deliberately. A further two Finnish-tagged divers were found drowned in fishing nets in freshwater lakes in Finland, one in August 2018 and one in June 2019. Tags were recovered from both these birds, the former producing data which have been published (Duckworth *et al. in press*), the latter yielding no data due to very little time between deployment and recovery of tags. To investigate whether these causes and rates of mortality were higher than expected, i.e. whether tagging divers increases the risk of mortality, particularly from being bycaught in fishing nets, we compared rates and causes of mortality for ringed red-throated divers with tagged divers.

A total of 1993 red-throated divers were ringed in Finland during 1962 to 2019, mostly as dependent young (93% of red-throated divers ringed). Of these, 99 (5%) have been recovered dead, excluding the three ringed birds which were also tagged. Tagged birds appeared to be more likely recovered dead than ringed birds, with 10%[2] of Finnish-tagged birds being recovered dead, compared with 5% of Finnish-ringed birds.

Two of the three tagged birds that died, drowned in fishing nets, in freshwater lakes. The cause of death for the third tagged diver was unknown. Similarly, three-quarters of mortalities of ringed divers of known cause of death, were attributed to being caught in a net (Table 3).

[2] Proportion of tagged birds reported dead was calculated as 1/31+1/30+1/29 since the number of individuals believed to still be alive and remaining in the population was reduced by one, with each reported mortality.

Table 3. Reported cause of death (number and percentage) for the 99 dead recoveries of red-throated divers ringed in Finland (1962-2019) and percentage of birds dying from various causes after removing records where cause of death was unknown or not reported is also given. Tagged birds have been removed from these figures. Data reproduced from the Finnish Bird Ringing and Recovery Database.

Reported cause of death	No. reported	% of all dead recoveries	% known cause
Unknown/not reported	32	32%	
Other (injury, starvation, predated)	3	3%	5%
Shot	3	3%	5%
Oiled	11	11%	16%
Net (caught in a trap for other animals, e.g. fish net in use or fish-hook)	50	51%	75%

Of the 50 recoveries where death was reported to be due to a net, 10 were on the coast around Europe and the remaining 40 were inland in Finland. Figure 4 shows a diver ringed in Finland is more likely to be caught in a fishing net on the coast or at sea during winter months and inland during summer months, which is as expected due to the different habitats used by Finnish divers during the breeding and non-breeding seasons. However, Figure 4 also illustrates the increased number of reported bycatch mortalities in inland freshwater lakes compared with marine bycatch. This may reflect reporting rates rather than freshwater nets necessarily posing a greater mortality risk to ringed divers than marine nets.

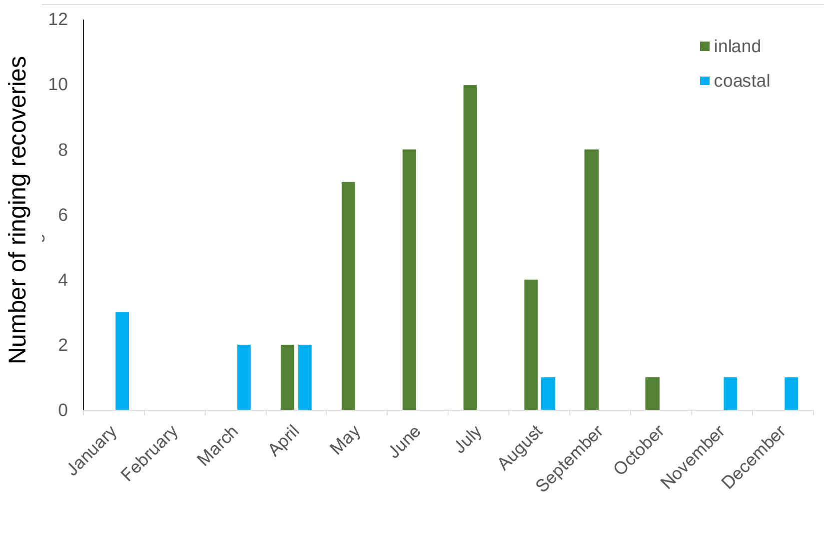

Figure 4. Number of Finnish ringed red-throated diver mortalities due to being caught in a net in different months. Divers recovered on the coast or at sea are shown in blue and divers recovered inland, e.g. on a freshwater lake, are shown in green.

The prevalence of tagged diver deaths, with two found in freshwater nets in August 2018 and June 2019, concur with timing and frequency of deaths in freshwater nets for ringed divers.

Red-throated divers ringed in Britain also suffer bycatch. Of the 283 British-ringed red-throated divers found dead, 62 died of known cause. Of these, 37 were in a fishing net, i.e. 60% of British ringed divers that died of known causes died in fishing nets. This is lower than the 75% reported for Finnish birds (Table 3). Only 8% of bycatch mortalities for British-ringed birds were on freshwater/inland bodies of water, compared with 60% for Finnish ringed birds, as a percentage of birds dying from known causes of mortality. However, small sample sizes and biases in reporting mean these results should be treated with caution.

3.3 Trapping effects

3.3.1 Trapping effects on breeding success

Breeding success at nest sites at which trapping was attempted was compared with breeding success at control nest sites on Orkney, Shetland and Finland in 2018 and 2019 (Table 4). Note that control sites were also visited during the breeding season to assess nest status but that no trapping was attempted, i.e. control nest sites still had a low level of disturbance but much less than nest sites at which trapping was attempted. Trapping was attempted at some nest sites in both 2018 and 2019 whilst at other nest sites, trapping was only attempted in 2019 (Table 4).

Table 4. Sample sizes (number of nests) in dataset used to assess trapping effects on breeding success (nests with unknown fates were not included).

Site	Total no. monitored for breeding success	No. where trapping was attempted	No. with trapping in 2018 and 2019
Finland (2018)	96	31	
Finland (2019)	101	14	15
Orkney (2018)	46	20	
Orkney (2019)	60	11	9
Shetland (2018)	40	16	
Shetland (2019)	38	12	11

* Note not all birds caught were tagged in either 2018 or 2019 – some were untagged individuals, usually the mate of a tagged individual.

Trapping was attempted multiple times at most nest sites in 2019 (Table 5), i.e. a successful catch might have been preceded by multiple failed attempts. Total trapping duration was much higher in 2019 (Figure 5) due to tagged divers being much harder to recapture than when first deploying tags on them. Trapping duration was much longer in Finland than in Scotland (Table 5).

Table 5. Number of trapping attempts at nest sites in 2019 and trapping duration in 2018 and 2019.

Site	Mean no. trapping attempts in 2018	Mean no. trapping attempts in 2019	Mean trapping duration (mins) in 2018	Mean trapping duration (mins) in 2019
Finland	1.11 (SD=0.32)	1.31 (SD=0.48)	89 (SD=43)	701 (SD=374)
Orkney	1.12 (SD=0.33)	2.17 (SD=1.11)	78 (SD=57)	214 (SD=247)
Shetland	1.18 (SD=0.39)	1.75 (SD=0.62)	82 (SD=58)	138 (SD=101)

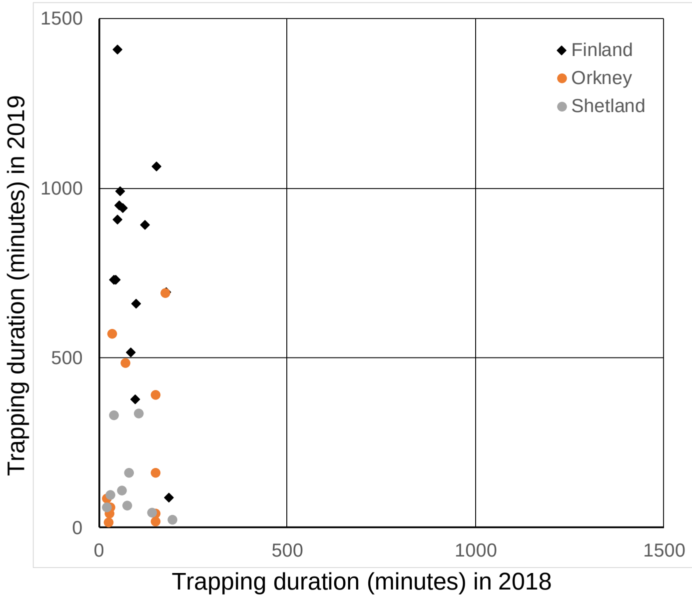

Figure 5. Total trapping duration across all attempts at a nest site in 2019 compared with 2018, with points clustered to the left of the plot rather than evenly across the plot due to trapping duration being much longer in 2019.

The outputs of Model 1, which included data from both trapped and control nest sites, indicated that overall, across study sites and years, the probability of a nest being successful was significantly lower when trapping was attempted than when trapping was not attempted (β = -0.80, SE = 0.27, p = 0.01) (Figure 6a). While 38% of the nest sites where trapping was attempted at least once in 2018 and/or 2019 successfully reared chicks, 58% of the nest sites at which no trapping occurred were successful. Overall, the probability of a nest being successful, regardless of whether or not trapping was attempted, was also lower on Orkney compared to Finland (β = -0.67, SE = 0.27, p = 0.01) (Figure 6b). However, there was no significant difference in breeding success probability between Shetland and Finland (β = -0.29, SE = 0.29, p = 0.32) (Figure 6b), nor between years (β = -0.03, SE = 0.22, p = 0.91) (Figure 6c).

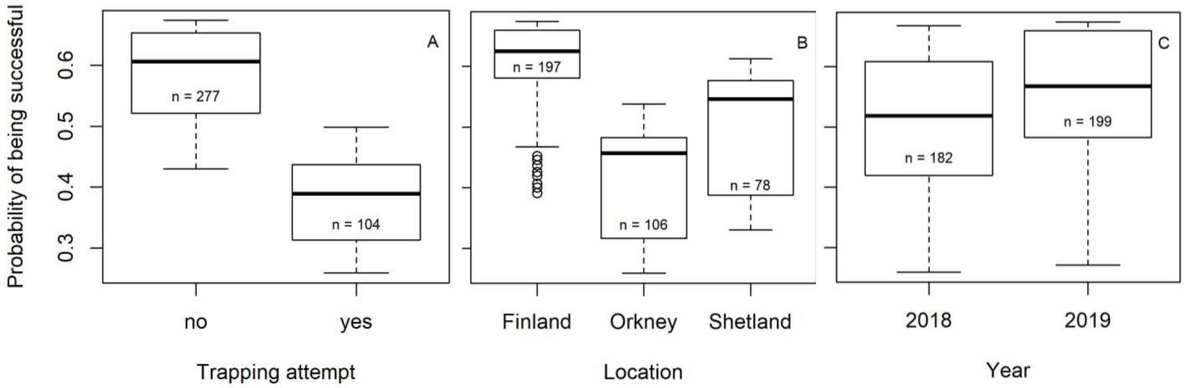

Figure 6. Boxplots presenting variation in breeding success probability in relation to the three explanatory variables explored in Model 1: (a) whether trapping was attempted at that nest site; (b) location of nest site; and (c) year of trapping. Plots show median observations across variable levels, as well as lower (Q1) and upper (Q3) quartiles. Data falling outside the Q1–Q3 range are plotted as outliers. Sample sizes for each variable level are indicated.

This analysis combined data from Orkney, Shetland and Finland but, due to small sample sizes, it was not possible to use an interaction term of Trapping Effect * Location to see if the extent to which trapping reduced breeding success varied among sites. However, when considering data from only Finland, no strong effect of trapping was found (β = -0.725, SD = 0.432, p = 0.09) nor year (β = -0.335, SD = 0.349, p = 0.34).

Model 2, which only used data from nest sites where trapping occurred and not any control nests, indicated that the probability of a nest site being successful did not significantly vary with trapping duration (β = -0.40, SE = 0.56, p = 0.48) nor with whether trapping took place at the nest itself or elsewhere on the nest lake/pond (β = 0.27, SE = 0.67, p = 0.69). However, breeding success probability significantly decreased as the season progressed (β = -1.49, SE = 0.72, p = 0.04) (Figure 7).

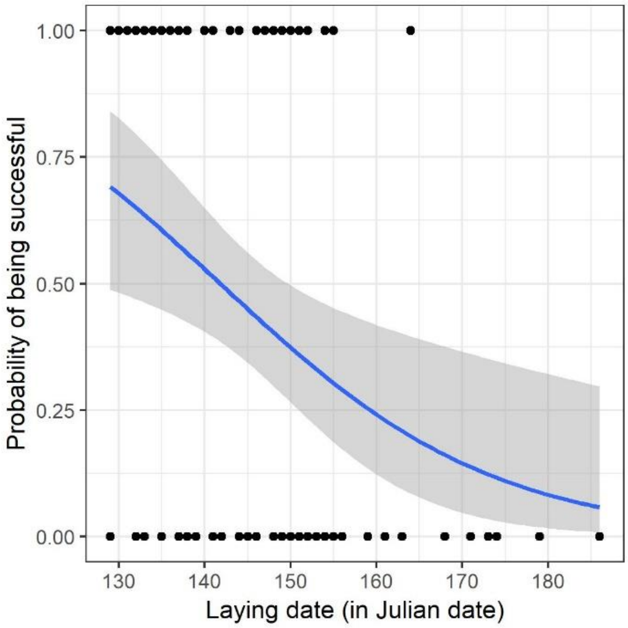

Figure 7. Predicted decline in breeding success probability (blue line) with associated 95% confidence interval (grey area) as breeding season progressed. Black dots represent data points (0 = failure; 1 = success). Confirmed relays with known laying date (n = 8) are included.

In Iceland, breeding success at trapped and control nest sites was also monitored but data were not available to include in this statistical analysis. However, productivity, i.e. numbers of young fledged per nest was lower (mean = 0.3, n = 10) at nests where trapping was attempted compared with productivity across all nests of known fate (mean = 1.11, n = 71). (Note, productivity across all nest sites includes both nest sites where trapping was attempted and control nest sites.)

3.4 Deployment of new tags in 2019

During 2019, a total of 33 divers were tagged with new TDR and GLS tags, 18 of them were divers that had carried tags during the 2018/19 winter and 15 were birds that were previously untagged. The intention was to tag the same individuals for a second winter to look at inter-annual variation in wintering location and diving behaviour but difficulty with re-trapping tagged individuals meant some tags were deployed on previously untagged birds. On Hoy, no further deployment of tags in 2019 was undertaken, due to concerns that the red-throated diver population, an interest feature of the Hoy SPA, is declining and disturbance levels caused by tagging might accelerate this decline. Therefore, only one set of tags was deployed in Orkney in 2019 (on mainland Orkney outside of an SPA). In Shetland, ten divers were tagged, four of which were also tagged in 2018. In Iceland, 12 divers were tagged, five of which had been tagged previously. Ten divers were tagged in Finland, only one of which was not tagged in 2018.

4 Discussion

4.1 Breeding success

Breeding success in 2019, compared with 2018, was better in Orkney and Iceland, was worse in Finland and was similar to 2018 in Shetland. Breeding success in Orkney was better in 2019, compared with the previous three years (*pers. obs*., J. Williams). Breeding success on Hoy in 2018 was only 31% compared with 50% in 2019 (48% if the two failed nests on mainland Orkney are included in breeding success estimates). During 2016-2018, mean number of nests on Hoy was only 51 nests, compared with the five year mean from 2011-2015 of 62.8 nests (*pers. obs*., J. Williams). With 61 nests in 2019, the number of active nests returned to similar levels to 2011-15. In Iceland too, breeding success was better in 2019, compared with 2018, (73% and 50%, respectively). On Shetland, breeding success in 2019 was similar to 2018, at 53% and 47% respectively. By contrast, there was a poor breeding season in Finland with divers producing more second clutches after first nests failed (*pers. obs*., P. Lehikoinen), although breeding success was not greatly different between 2018 and 2019 (62% and 57%, respectively).

4.2 Tag effects

Tag effects were evaluated by (a) investigating resighting rates of tagged birds in 2019, (b) comparing body mass of tagged birds in 2019 with body mass in 2018 and (c) by comparing bycatch rates of tagged divers with bycatch of ringed divers.

4.2.1 Resighting rates

Resighting rates were lower than expected, at 68%, compared with a published adult annual survival rate of 84% (Hemmingson & Eriksson 2002; Schmutz *et al*. 2014). (Note, this survival rate seems low for such a long-lived species and a survival rate of >90% would seem more likely.) This suggests either that tagged birds were less likely to return or tagged divers were present but were not seen. Resighting rate was highly variable among sites, varying from 53% (Orkney) to 92% (Iceland). To some extent this is likely to be caused by topography, vegetation and spacing of nest sites making detection of tagged divers more challenging at some sites, with Icelandic breeding lakes and ponds being relatively accessible compared to those on Orkney, Shetland or Finland. The high resighting rate in Iceland suggests that tag effects were not influencing return rate and instead, at other sites, detection rate was <100% and/or divers were not returning to breed for reasons other than carrying tags. Consequently, due to potentially incomplete detection of returned tagged birds, resighting rate of marked birds alone does not provide a quantitative measure of tag effects for red-throated divers. Ideally, an untagged but marked population would have provided a control group to assess return rate of untagged divers but this is not possible without causing substantial and unacceptably high amounts of disturbance.

4.2.2 Body mass comparison

An alternative metric for assessing tag effects is to investigate whether body mass of tagged divers was lower in 2019, compared with 2018, testing the hypothesis that carrying tags makes foraging more difficult for divers, seen as a reduction in body condition. No significant change was found in mean body mass of tagged divers in 2019, compared with 2018, suggesting no marked effect from carrying tags on body condition. However, this sample includes only tagged individuals that returned to breed and were captured; body mass of others that were missed on the breeding grounds or failed to return / died were not assessed and could have been lower. Additionally, there was no evidence of a substantial change in sex ratio of birds recaptured, compared with those initially tagged, implying no sex- or size-based differential mortality from carrying tags.

We also investigated whether divers' body mass decreased during the breeding season, as found for other marine birds (Golet & Irons 1999; Harris *et al.* 2000; Harris & Wanless 1998). Analysis of the small sample (n = 27) of divers for which measures of body mass were taken in 2018 and 2019 on the same individuals found divers that were recaptured later in 2019, compared to 2018, tended to be lighter. However, no evidence for a decline in body mass as the breeding season progressed was found when looking across 74 divers measured throughout the 2018 breeding season. This may be due to the lack of repeated measures on the same individuals during 2018 and to the wide variation in body mass among red-throated divers, which show sexual size dimorphism (Okill 1989).

At present, we do not have sufficient evidence to conclude on whether body mass decreases as the breeding season progresses. Obtaining repeated measures of body mass on a species such as red-throated divers which are particularly difficult to catch, will always be challenging.

4.2.3 Bycatch

Tag effects could also occur through tags increasing risk of entanglement in fishing nets. When catching divers to remove tags, divers have been observed becoming entangled in nets by their tags (*pers. comm*., J. Green, J. Duckworth and A. Petersen). Two tagged divers were found dead, entangled in freshwater nets and a third died of unknown causes. Bycatch in fishing nets is a common cause of mortality for red-throated divers (Dagys & Zydelis 2002; Warden 2010; Zydelis *et al* 2009). There is no published information on bycatch of divers in Finland in freshwater lakes. Whilst it is known to occur, e.g. recoveries of ringed birds in nets, it appears to be currently unquantified for the wider population. In Sweden, 69% of ringed red-throated diver mortalities of known cause were due to birds being caught in fishing gear, both in freshwater lakes and at sea (Hemminsson & Eriksson 2002). Bycatch of divers in Scotland inland is a rare event associated with fish farming. Practices have changed with use of different netting resulting in diver bycatch no longer happening (*pers. obs.,* D. Okill). There is evidence of bycatch for red-throated divers in Iceland, all from the marine environment. For example, of 283 red-throated divers ringed, 2.4% were recovered as caught in fishing gear during the period 1932-1994 and were the second most-frequently recovered species as a proportion of the ringed population, after black guillemot (*Cepphus grylle*) (Petersen 2002). These results are biased by uneven ringing effort, but red-throated divers are thought to be most frequently bycaught compared to population size (*pers. obs*. A. Petersen). By contrast, a recent study did not record any bycatch of red-throated divers across Canada, Norway, Iceland and Denmark (Christensen-Dalsgaard *et al.* 2019).

Examination of ringing data from Finland and Britain revealed that bycatch is the most common cause of mortality where cause was reported but that entanglement in freshwater nets was more frequent in Finland whereas marine nets were a more common cause of mortality for British-ringed divers. Making a quantitative comparison of mortality rates between tagged and ringed birds is likely to be biased due to the potential for tagged dead birds to be reported more frequently than ringed dead birds. The tags, mounted on red darvic rings, are more obvious than a metal ring and the tags might warrant more interest than a metal ring. Given rates of bycatch of ringed divers, it would be expected for a small number of tagged red-throated divers in Finland to be entangled in nets set in freshwater lakes and we cannot be sure that tagging elevated risk of entanglement.

Geen *et al*. (2019) found that device mass is particularly important for seabirds when deployment duration is relatively long (>3 months). Whilst deployment period was longer in our study, of at least 12 months, device mass relative to body mass was low for red-throated divers, with combined tag mass (excluding darvic and metal rings) = 0.3% of the body mass of the lightest diver trapped in 2018 (body mass = 1420g, GLS tag = 1.8g, TDR tag = 2.7g). For a foot-propelled diving bird, drag on the birds' legs when moving through water is more likely to cause a tag effect than tag mass. Very few studies have investigated the effects of attaching tags to foot-propelled diving birds but one study on great cormorants (*Phalacrocorax carbo carbo*) found no discernible effect of attaching GLS tags to birds' legs over a short study period (Ropert-Coudert *et al.* 2009). Generally, leg-mounted devices tended to have lower reported tag effects than more invasive methods (Geen *et al.* 2019). Tag effects have been reported for implanted devices on red-throated divers (Schmutz *et al.* 2014) and great northern divers (*Gavia immer,* Kenow *et al*. 2003) but no published evidence for effects from leg-mounted devices on divers exists. Tag effects from leg-mounted devices have been reported for other marine diving birds, e.g. Atlantic puffins (*Fratercula arctica,* Harris *et al.* 2013) and common guillemots (*Uria aalge*) such as a reduction in body mass and raised corticosterone (Elliot *et al.* 2012) although other studies on these two species found no effects from leg mounted devices (Geen *et al.* 2019). Similarly, studies of European shags reported no effects, nor in great cormorants or black guillemots from leg-mounted devices (see review by Geen *et al*. 2019). Given the low mass of our tags and the fact that they are leg-mounted rather than implanted in the body cavity, we anticipate small or negligible tag effects. However, without an effective control group and being able to examine body mass in all tagged individuals rather than only those that returned to breed and were recaptured, it is not possible to demonstrate this.

4.3 Trapping effects

Divers are known to be highly sensitive to disturbance during breeding and trapping effects have been reported for other diver species (Uher-Koch *et al.* 2015). We investigated whether disturbance caused by trapping red-throated divers to deploy and remove tags affected divers by comparing breeding success at nest sites where trapping occurred with control sites.

Analysis of breeding success from Scotland and Finland combined, from both 2018 and 2019 showed that nest sites where trapping was attempted had lower breeding success, i.e. were less likely to produce a well grown chick, than nest sites where no trapping took place, although evidence for this effect was weak in Finland. This is in contrast to results from a similar analysis undertaken on breeding success data from only 2018 (O'Brien *et al.* 2018) which did not report any effect of trapping on breeding success. Whilst the trapping effect may be stronger in 2019 (i.e. greater levels of disturbance in 2019 compared with 2018), no effect of year was found in the statistical model. This therefore suggests that a trapping effect may have also occurred in 2018 but that sample sizes were too small to detect it. Data on breeding success in Iceland were not included in the statistical analysis but breeding success appeared to be lower at nest sites where trapping was undertaken. These results emphasise the importance of continuing to monitor breeding success at both control and trapped nest sites throughout the duration of this study.

A more detailed analysis of the mechanism by which trapping reduces breeding success found no effect of trap duration nor trap method on breeding success. This is surprising as it might be expected that spending longer at a nest and/or trapping directly at the nest rather than away from the nest itself might influence the levels of disturbance perceived by breeding divers. In Finland, fieldworkers spent extended periods at nests, waiting for tagged birds to leave before deploying a nest trap and then waiting for the tagged bird to return, rather than flushing the bird. Consequently, trapping duration was long and trap method was focussed around the nest itself, rather than being away from the nest site. However, disturbance to tagged birds was low using this approach and breeding success was not markedly reduced at nest sites where trapping occurred, compared with control sites in Finland.

Trapping effects on breeding success in 2019 included any tag effects, since divers breeding at most nest sites where trapping was taking place will have been carrying tags for the last 12 months. Separating these two effects was not feasible due to small sample sizes and confounding effects of trapping an untagged individual at a nest site with a tagged bird present. Whilst the observed reduction in breeding success at nest sites where trapping occurred could be caused by both trapping and tag effects, the body mass analysis suggests that tags were not having an obvious effect on body condition in these individuals. Additionally, no interaction effect of year * trapping attempt was found on breeding success, implying that carrying tags for a year did not reduce breeding success for tagged birds between 2018 and 2019. Therefore, the reduced breeding success at nest sites where trapping took place is probably predominantly caused by a disturbance effect at the nest site rather than from carrying tags. The apparently low resighting rate could also be caused by trapping effect with birds more likely to move to a new nest site in subsequent years after failing to breed due to disturbance caused by trapping and therefore be less likely to be resighted.

5 Conclusions and Recommendations

Attaching small leg-mounted devices to red-throated divers appears, after one year, to have no effect on body mass of individuals that return to breed. However, resighting rate was lower than expected, suggesting either tagged birds were less likely to return to breed or they were difficult to find in subsequent years. Trapping divers to deploy and retrieve tags appears to reduce breeding success and may also contribute to reduced resighting rate, by causing birds to move to different nest sites in subsequent years. Additionally, carrying tags may increase the risk of entanglement in fishing nets for divers although bycatch mortality rates appeared to be similar to those for ringed divers.

Consequently, we recommend avoiding deploying tags on red-throated divers in areas where freshwater fishing nets are used extensively. We also recommend minimising disturbance at nest sites and not repeatedly tagging individuals at the same nest site over multiple years. Despite evidence for trapping effects and no evidence for tag effects, we recommend trying to recapture tagged birds and remove tags from as many divers as possible. Red-throated diver life history strategy relies on high adult survival and deferred breeding success to maintain high survival. Consequently, the population is likely to be able to better withstand short-term reduced productivity caused by capture and removing tags than any possible increase to adult mortality caused by carrying tags for many years. It is important to also consider the high value of data obtained by this study in informing management decisions for the conservation of the wider red-throated diver population, particularly with respect to offshore wind development and other marine industry activities in areas used by non-breeding individuals.

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