JNCC Report
No: 627

Red-Throated Diver Energetics Project
2018 Field Season Report

O'Brien, S., Ruffino, L., Lehikoinen, P., Johnson, L., Lewis, M., Petersen, A., Petersen, I.K., Okill, D., Väisänen, R., Williams, J. & Williams, S.

November 2018
(Revised December 2018)

© JNCC, Peterborough 2018

ISSN 0963-8091

For further information please contact:

Joint Nature Conservation Committee
Monkstone House
City Road
Peterborough PE1 1JY
www.jncc.defra.gov.uk

This report should be cited as:

O'Brien, S., Ruffino, L., Lehikoinen, P., Johnson, L., Lewis, M., Petersen, A., Petersen, I.K., Okill, D., Väisänen, R., Williams, J. & Williams, S. (2018) Red-Throated Diver Energetics Project - 2018 Field Season Report. *JNCC Report No. 627*. JNCC, Peterborough, ISSN 0963-8091.

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

Peer-review of the analysis of tagging effects was undertaken by Dr Jon Green. All authors and Red-throated Diver Energetics Project partners were invited to comment on and correct this report, prior to publication.

A tagged red-throated diver, foot-waving as it relaxes on its breeding loch. Photograph by Julia Gregory at Mossy Hill, Shetland.

Summary

Around Europe, large-scale deployment of offshore wind is already well underway and is forecast to continue until at least 2020. However, uncertainties around the impacts of offshore wind on the environment, particularly marine birds, increase consent risk for future developments. Offshore wind farms are known to cause displacement of wintering red-throated divers (*Gavia stellata*), resulting in increased consent risk for projects planned for areas of high diver density. However, the consequences of this displacement at the individual and population level are unknown. Displacement is likely to increase energetic costs for divers but their ability to cope with these additional costs will depend on how energetically constrained they are. For the first time, energetics of red-throated divers is being investigated by the Red-throated Diver Energetics Project. Using time depth recorders and geolocators attached to red-throated divers on their breeding grounds, novel information on foraging behaviour of divers will be obtained.

Divers are sensitive to disturbance and are a difficult species to work with, but the experience and expertise of ringers ensured all tags were successfully deployed. During the summer of 2018, a total of 74 red-throated divers were tagged. Breeding birds were caught either using a nest trap or a wader net. All birds were fitted with two tags, a time depth recorder and a geolocator tag, as well as a metal ring with a unique number. Altogether, 31 red-throated divers were tagged in southern Finland, 31 in Scotland and 12 in Iceland. In Iceland and Finland, approximately equal numbers of males and females were tagged, whereas there was a slight bias towards tagging females in Scotland. Sex was assigned according to biometrics.

Red-throated divers had a poor breeding season in the Northern Isles, Scotland, with an average of 38% of nesting attempts producing a well grown chick, close to fledging. By contrast, 62% of nests in Finland fledged at least one chick. Given the sensitivity of divers to disturbance and the poor breeding season in Scotland, it was important to check that trapping divers did not affect their breeding success. Reassuringly, a comparison of breeding success for red-throated diver nests at which trapping of divers occurred and control nests with no trapping, showed no discernible effect of trapping on breeding success, in both Scotland and Finland.

Tagged divers will be recaptured in 2019, tags removed and data downloaded and analysed. Additionally, breeding success and other data will be collected at nests where trapping occurs and at control sites, to investigate any effects on divers from carrying tags for a year and/or a second season of trapping. Analyses of data retrieved from the tags will reveal dive frequency, depth and duration for red-throated divers, enabling assessment of the proportion of time divers spend foraging throughout the year. Periods when divers spend longest foraging will indicate when they are most energetically challenged. This information will provide key evidence to understand the time of year when divers are least able to cope with additional energetic costs, which will provide insight into the potential consequences of displacing wintering red-throated divers.

Contents

1 Introduction

1.1 Offshore wind development in Europe

To significantly reduce the risks and impacts of climate change, the Paris Agreement[1], aims to hold future global average temperature increases to well below 2°C above pre-industrial levels. To meet this target, the European Commission initiated policies under a European Climate Change Programme[2], including promoting production of electricity from renewable energy, such as offshore wind. In response to this, deployment of offshore has undergone an exponential increase with a total of 92 wind offshore wind farms installed in European waters at the end of 2017, providing a total capacity of 16GW across 11 European countries (Figure 1, WindEurope 2018).

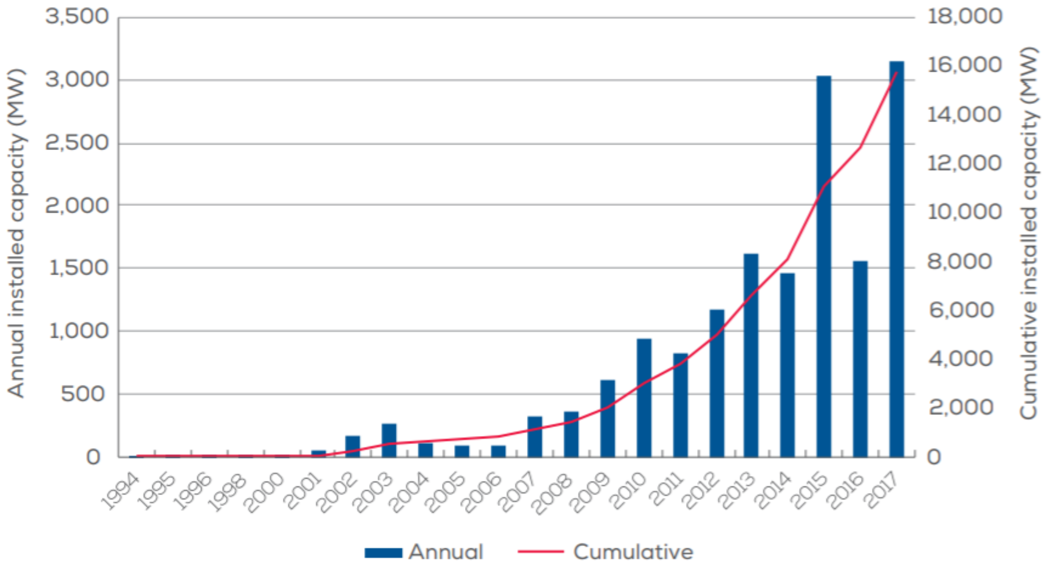

Figure 1. Cumulative and annual offshore wind energy installation in Europe. Source: WindEurope (2018).

Substantial additional offshore wind deployment is planned, with several European countries having ambitious plans for large-scale deployment in the near future. WindEurope predicts offshore wind market growth to accelerate until 2020, with an average annual capacity of 3-4GW per year being installed during 2018-2020 (WindEurope 2017). Development is predicted to occur predominantly in the North Sea: UK = 5.2GW, Germany = 3.6GW, Belgium = 1.5GW, Netherlands = 1.4GW and Denmark = 1.0GW (WindEurope 2017).

1.2 Why study red-throated divers?

Red-throated divers (*Gavia stellata*), breeding at high latitudes, migrate south to winter in entirely marine environments (Wernham *et al* 2002). Divers wintering in the southern North Sea breed in Siberia, Scandinavia and Greenland (Žydelis *et al* 2017). There is limited evidence that divers breeding at the southern edge of their range (Scotland, Iceland) head southwards after breeding but do not move as far as birds breeding further north (Ib Krag Petersen, Aevar Petersen, David Okill, Jim Williams, unpublished data). Ringing recoveries suggest juvenile and immature red-throated divers from Scotland and Iceland move further south (Okill 1994; Aevar Petersen, pers comm). Red-throated divers wintering in the North

[1] The Paris Agreement, adopted by consensus in 2015, is an agreement within the United Nations Framework Convention on Climate Change (UNFCCC).
[2] https://ec.europa.eu/clima/policies/eccp_en.

Sea and Baltic Sea are thought to feed predominantly on small fish such as herring (*Clupea harengus*), sprats (*Sprattus sprattus*) and sandeels (*Ammodytes marinus*) (Guse *et al* 2009). However, they are believed to be capable of switching to alternative small prey, if that is more widely available (Dierschke *et al* 2017). Red-throated divers favour shallow seas with a sandy substrate and, in winter, often aggregate in high densities around estuarine tidal fronts, such as occur in the German Bight and the Thames Estuary (Guse *et al* 2009; Heinänen *et al* 2016; O'Brien *et al* 2008; Skov *et al* 2016; Skov & Prins 2001).

Habitats favoured by red-throated divers are also ideal for offshore wind development. Many offshore wind farms are already operational, under construction or planned in areas such as the German Bight and Outer Thames Estuary. Red-throated divers are highly sensitive to anthropogenic activity and move away from ships and other structures, such as wind turbines, in the marine environment (Schwemmer *et al* 2011). There is substantial evidence of divers being displaced from marine areas following construction of offshore wind farms (Halley & Hopshaug 2007; Furness *et al* 2013; Mendel *et al* 2019; Petersen *et al* 2006, 2014; Percival 2014; Welcker & Nehls 2016; Dierschke *et al* 2016; Webb *et al* 2016; Heinänen, 2016; Dorsch *et al* 2016). As installed capacity rises in areas of red-throated divers, so the total cumulative number of divers in European waters that are displaced will increase. Given the projected growth in offshore wind over the next few years, a growing proportion of the European wintering red-throated diver population may be affected by offshore wind development.

1.3 Why study diver energetics?

Despite extensive evidence for displacement of red-throated divers from offshore wind farms, the consequences of displacement on individual birds, and the wider population as a whole, are unknown. Displacement and barrier effects (flying around a wind farm increases flight distance and time) increase energy expenditure and/or decrease energy intake through being displaced from preferred foraging grounds (Drewitt & Langston 2006). For displacement of red-throated divers to cause a change in population size, divers need to change their behaviour, choosing to move to a different marine area rather than the wind farm area. In turn, this would need to influence their ability to acquire prey in some way, altering their energetic budgets, resulting in a decrease in body condition. Individuals in poorer condition may not migrate, may have reduced breeding success or may even die. These demographic changes would lead to reductions in annual survival and productivity of the population and consequent decreased population growth rate and size (Dierschke *et al* 2017).

Whilst it is not possible to obtain empirical measures of all of these changes, it is possible to assess whether red-throated divers are already struggling to meet their energetic requirements and to maintain body condition during the non-breeding season. If individuals forage for only short periods each day, it implies they are easily able to find sufficient prey to meet their energetic requirements. From this, it could be inferred that they have capacity to increase time spent foraging, enabling them to meet the additional energetic demands caused by displacement and barrier effects. (This assumes that other processes, such as intra-specific density dependence, do not outweigh the benefits of spending longer foraging.) Conversely, if divers are already spending long periods foraging each day during the winter, they are unlikely to be able to markedly increase their time spent foraging following displacement and may not cope well with displacement.

Red-throated diver activity and energy budgets have never previously been investigated. During a recent expert workshop on red-throated diver displacement a research project was conceived specifically to investigate this (Dierschke *et al* 2017). This novel tagging project will, for the first time, obtain empirical data on time budgets, dive depth and frequency, and other key behavioural information, leading to an understanding of red-throated diver energetics. By attaching time depth recorder and geolocator tags to divers on their breeding grounds and then retrieving the tags the following year, information on dive frequency, duration and depth as well as approximate location can be obtained for the entire non-breeding season. From this, it can be inferred whether divers have the capacity to accommodate the additional energetic costs of displacement and barrier effects caused by offshore wind farm developments.

Current uncertainty about the environmental impacts of offshore wind development on red-throated divers has led to delays in the planning process and cancellation of offshore wind projects, e.g. London Array Phase 2[3]. Uncertainty around likely consent decisions for future offshore wind projects in areas of high densities of red-throated divers causes higher development and production costs and failure of governments to meet renewable energy targets. Evidence from this diver energetics study will reduce uncertainty about the potential energetic consequences of displacing red-throated divers, leading to reduced consent risk for future offshore wind development.

[3] http://www.londonarray.com/the-project-3/phase-2/.

2 Methods

2.1 Project aims and objectives

2.1.1 Project aim

To reduce consent risk for offshore wind development in areas of high red-throated diver density through improved understanding of diver energetic budgets in the non-breeding season.

2.1.2 Project objectives

1. Deploy and retrieve geolocator (GLS) and time depth recorder (TDR) tags on breeding red-throated divers in Finland, Scotland and Iceland.
2. From the tags, obtain empirical data on activity budgets of divers, particularly amount of time divers spend foraging.
3. Interpret the data to establish whether divers are energetically challenged in the non-breeding season.

2.2 Tag deployment

2.2.1 Study areas: why Finland, Scotland and Iceland?

Extensive discussion was held with the RTD Energetics Project Partners, particularly the scientists and the funders, to agree where best to try and tag breeding red-throated divers. The offshore wind industry who funded tag purchase, deployment and retrieval in Finland (Vattenfall, Ørsted and The Crown Estate) wished to see red-throated divers tagged that were likely to winter in areas of current or planned offshore wind development. Evidence from the German DIVER study (e.g. Žydelis *et al* 2017, www.divertracking.com) has shown that divers wintering in the eastern North Sea breed predominantly in Scandinavia but also in northern Scandinavia and Greenland. Working in any of these high arctic areas would be logistically very challenging and expensive and, since attaching time depth recorders to red-throated divers has never been undertaken previously, it was agreed we needed to work in more accessible areas. Ringing data from Finland indicated that red-throated divers breeding in Finland winter in the North Sea (Figure 2; Saurola *et al* 2013). Red-throated divers breed in many lakes in southern Finland that are accessible and logistically feasible to work at. Furthermore, the project partners knew of reliable and experienced ringers in Finland. Consequently, Finland was selected as a location for tagging divers, with fieldwork supported by funding from the offshore wind industry.

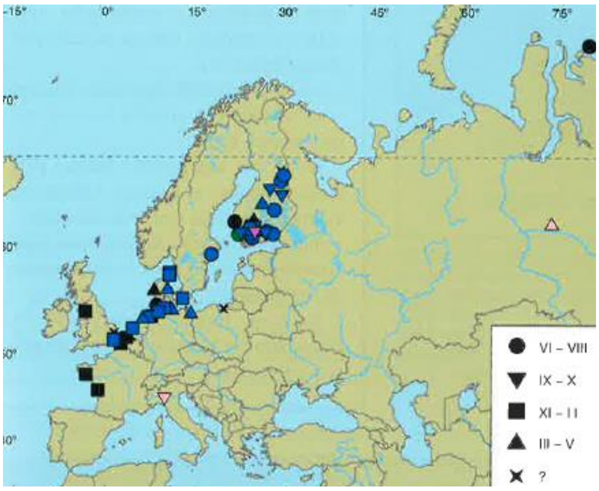

Figure 2. Recoveries of red-throated divers ringed in Finland (key indicates month of recovery). From the Finnish Ringing Atlas (Saurola *et al* 2013).

A second study area was selected in Scotland for two reasons. Firstly, investigating the foraging behaviour of a second population of divers that undergo a different migration strategy to Finnish divers (i.e. wintering relatively close to their breeding grounds (Okill 1994)) will broaden our understanding of diver energetics and when/where divers are most energetically-challenged. Secondly, JNCC had worked previously in both Orkney and Shetland and knew the experienced ringers who had ringed these populations of divers for many decades. Additionally, these ringers had worked previously with Ib Krag Petersen to successfully catch and attach geolocator tags to breeding red-throated divers in Orkney and Shetland. We were therefore confident that, by working with local ringers, we could catch and tag breeding red-throated divers in Orkney and Shetland. Whilst limited ringing and geolocator data indicate these divers to not winter in areas of current offshore wind development, the feasibility of logistics and the fact that these birds breed in the UK made this a preferred location for the main funder, BEIS's Offshore Energy SEA Research Programme, managed by Hartley Anderson Ltd.

In addition, a decision was made to contribute some GLS and TDR tags to a study that was already underway and funded in Iceland. The RTD Energetics Project gave seven TDR tags and ten GLS tags to Aevar Petersen for deployment on Icelandic breeding red-throated divers. Whilst Icelandic breeding birds are thought to winter in the vicinity of Iceland, i.e. not in areas of offshore wind development, and are also not UK breeding birds, the additional information gained from tagging a third population of divers that winter at high latitudes will provide more insight into variation in foraging behaviour and energetics of red-throated divers. It is currently unknown whether red-throated divers can forage at night; divers wintering at high latitudes around Iceland are the most likely of any wintering divers to forage at night due to the very short day-length in mid-winter.

2.2.2 Permits, licences and permission

Catching and tagging of red-throated divers in Scotland was undertaken with all licences, permissions and permits in place. David Okill and Jim Williams have BTO ringing licences (number 1461 and 1423, respectively). Additionally, both ringers have a permit allowing disturbance of Schedule 1 species, including breeding red-throated divers for the purpose of ringing and nest recording. All staff, contractors and volunteers working on the Red-throated Diver Energetics Project in Scotland were named on a Schedule 1 permit. Attaching tags to divers also requires a Special Methods Endorsement from the BTO. The Special Methods Technical Panel evaluated and approved our application to attach GLS and TDR tags to breeding red-throated divers. We wish to thank the BTO, the SMTP and Jez Blackburn for their assistance with this.

As far as possible, we avoided working within any Special Protection Areas in the Northern Isles. However, this was unavoidable on Hoy and so an Appropriate Assessment was undertaken by SNH. SNH's Natura Appraisal found that the mitigation measures included within the project design enabled a conclusion of no adverse effect on site integrity, and so permission to work within the Hoy SPA was granted. However, one important aspect of our study design was monitoring breeding success at control nest sites at which no tagging was undertaken. Therefore, SNH requested that we limit the number of nests within the SPA at which we attempted to trap divers to no more than 50% of active nests. This condition was met by tagging two birds on mainland Orkney, outside of any SPA. We wish to thank Kate Thompson and Glen Tyler of SNH for their assistance with enabling our study to go ahead.

Finally, we also obtained permission from the RSPB to monitor and tag breeding red-throated divers within their reserve on Hoy. We are grateful to Lee Shields and Iain Malzer for enabling us to work within the reserve and for sharing data on breeding success of divers on other RSPB reserves.

In Finland, all trapping and ringing of red-throated divers was undertaken with full permission, licences and permits in place. The Finnish ringing license allows trapping and ringing of bird species protected by the Nature Conservation Act with traditional metal rings. Trapping with temporary traps and nets does not require the permission of the land owner. However, a ringing license does not allow for tagging birds with GLS or TDR tags and for these purposes, specific permission was granted by the Centre of Economic Development, Traffic and Environment (licence number: VARELY/1055/2018). Some of the breeding sites were situated inside government-owned nature reserves and a permit for trapping inside these areas was received from the Metsähallitus, National Parks Finland (license number: MH1804/2018/06.06.02). Ringing license numbers for Petteri Lehikoinen and Roni Väisänen are 2787 and 2854, respectively.

In Iceland, the general ringing licence allows trapping and attaching of tags other than the traditional metal rings. All work was undertaken with a general ringing licence in place.

2.2.3 Capture methods

In Scotland, an initial search for red-throated diver nests was undertaken in May 2018 on Hoy, Orkney, and on mainland Shetland. A thorough search of known breeding sites allowed as many nests as possible to be found. This was greatly facilitated by the decades of experience of David Okill, Jim Williams and Stuart Williams. All nests were monitored (revisited and nest status recorded) at least once during the breeding season. A subset of nests was selected as suitable for attempting to catch breeding adults for tagging, based on how easy it was likely to be to catch divers at that site. Frequently, smaller lochs were favoured, enabling wader nets to be used to catch adults.

In Finland, nests of red-throated divers were found using observations from BirdLife Finland for 2010-2017 as well as valuable help from local red-throated diver ringers who provided detailed information on their study sites. Nest sites were selected for attempting to catch breeding divers for tagging by:

- preferring concentrations of nearby breeding lakes to enable several trapping attempts during one day and also to help relocate tagged birds the following year, even though individuals may switch breeding location between years;
- targeting study sites of local ringers to increase the potential to relocate tagged individuals in 2019. Local ringers go through their study sites early in the breeding season and note whether adults are ringed or not. Their help in relocating tagged individuals in 2019 will be extremely valuable;

- starting to capture breeding birds from the south coast of Finland, heading northwards, to avoid unnecessary travelling (especially in 2019). As the incubation period of divers is relatively short this allows allocating more time for capturing and avoiding spending time travelling between sites.

Breeding adult red-throated divers were caught at their nest sites/breeding loch using nest traps and/or wader nets. In one case, a diver was caught using a walk-in trap. In Scotland, tagging efforts were focussed on birds breeding on small lochans as these are most suited to catching with a wader net. This method of catching adult red-throated divers is least stressful to the birds as it is quick and efficient. Where this failed or was not feasible, a nest trap was used. In Finland, only nest traps were used; in Iceland both methods were used. When using nest traps, eggs were removed from the diver's nest and put into an incubator, while dummy eggs were placed in the nest (Figure 3). When deployed, the nest trap was monitored constantly by an observer. If the diver did not return to its nest within two hours (or less, in Iceland), the trapping attempt was aborted and no further attempt was made at that nest site for at least two days. In Finland, almost all divers nest on artificial rafts. Ringers used small inflatable boats to reach nests and deploy nest traps.

Figure 3. Untouched nest with one egg (on left) and a set trap with a dummy egg (on right). Photo: Petteri Lehikoinen.

Trapping was not attempted during early stages of egg laying, nor when chicks were very young (age <5 days). Early in egg laying, birds may abandon their nesting attempt due to disturbance and stress of handling. Early in chick rearing, the young chick(s) may not survive being left alone for longer periods after the tagged adult is released. Inadvertent disturbance of neighbouring diver nests was avoided by only attempting to trap divers where no other diver nests were in close proximity. Catching with mist nets in Iceland took place during chick rearing.

2.2.4 Types of tags deployed

Divers were fitted with leg-mounted archival time depth recorder (TDR) tags (Cefas G5 Standard Time Depth Recorder, dimensions: 8mm x 31mm, weight: 2.7g) and global location sensor (GLS) tags (Biotrack MK4083 Geolocator, dimensions: 17mm x 10mm x 6.5mm, weight: 1.8g) (Figure 4). These tags were selected for deployment because MK4083 have been successfully deployed on red-throated divers previously by Ib Krag Petersen and Jon Green has found the Cefas tags to work well. We considered deploying larger G5 TDR tags that have increased data storage capacity but wanted to be sure that divers carrying both GLS and TDR tags did not exhibit any detectable tag effects before deploying the larger tag.

Archival tags do require the tagged individual to be recaptured and tags removed to download data, which reduces the volume of data acquired, compared with remote-download tags. However, no remote-download tags were suitable for deploying on red-throated divers without either using a highly invasive approach (implanting GPS tags within the bird's body cavity) or attachment with a harness. The latter approach has been tried with red-throated divers previously but no birds wearing harnesses were resighted and it was assumed that mortality rate was 100%. Recapture of red-throated divers in subsequent years has worked well previously when GLS tags were deployed on this species in Iceland and Scotland (Ib Krag Petersen, pers comm). Divers are long-lived and have very high inter-annual nest site fidelity (Okill 1992), making finding and recapturing tagged individuals logistically feasible.

The TDR tags were set to sample pressure every six seconds and temperature every ten minutes for a 24-hour period with a four-day gap between sampling bouts. This sampling regime was chosen to maximise data obtained while ensuring that battery life was maintained to allow sampling throughout the whole year and that sufficient memory capacity remained. GLS tags were calibrated in northern Denmark in mid May 2018.

Figure 4. Geolocator (GLS) tag (left) and time depth recorder (TDR) tag (right) mounted on red darvic rings and attached to red-throated diver legs. Metal ID rings were put on the same leg as the GLS tag. Photo: Sue O'Brien.

Tags were mounted on 2mm thickness red darvic colour rings using cable ties and epoxy resin glue to ensure tags remained attached to the darvic ring (Figure 5). The rings were specially shaped to fit a red-throated diver leg, which is tapered and not symmetrical. Tags were mounted and attached according to BTO recommendations.

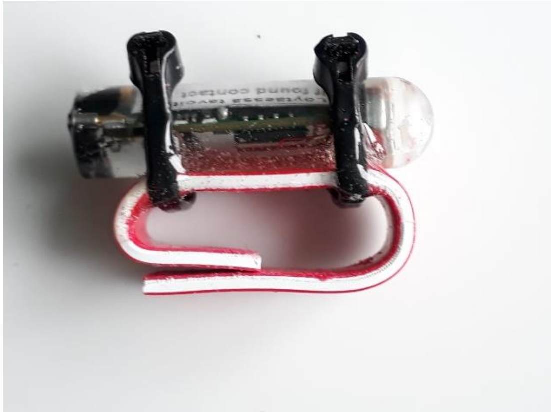

Figure 5. Cefas G5 Time Depth Recorder tag (TDR) mounted on a 2mm red darvic ring, specially shaped for fitting to a red-throated diver's tarsus. Photo: Sue O'Brien.

All divers had both TDR and GLS tags attached (Figure 6) as the combined information on both approximate location of an individual and its foraging behaviour is much more powerful than each in isolation. By knowing where individuals are, it is possible to obtain a much better understanding of what might be driving observed differences in foraging behaviour. However, information on an individual's location obtained from GLS tags is not precise, indicating a bird's location to approximately +/-150km. Figure 7 shows an example of geolocator data from red-throated divers, illustrating the level of precision that is likely to be obtained from tags deployed in 2018.

Red-throated divers are foot-propelled diving birds with highly adapted physiology for diving underwater. For such a species, attaching devices to their legs may create drag through the water, thereby reducing their ability to dive and forage. Following extensive discussion, RTD Energetics Project Partners agreed drag was likely to be minimised through mounting a tag on each leg, rather than two tags on one leg. We are also monitoring breeding success and body mass of tagged and untagged birds to look for any tag effects.

All birds were ringed with a metal ring with a unique number (e.g. BTO ring), if not already ringed. The GLS tag was placed on the same leg as the metal ring but above it on the leg, the TDR tag was on the opposite leg. Whether left or right leg carried the metal ring varied between area, e.g. generally Orkney divers carry a metal ring on their left leg whereas Shetland birds on their right leg. The darvic rings with tags mounted on them were attached to each leg and then glued closed with Loctite plastic glue. Morphometrics were also taken (body weight, wing length, culmen length, tarsus length and width). The combined mass of both tags was 0.3% of the mass of the lightest diver tagged.

Figure 6. A tagged red-throated diver on Hoy, Orkney, with the BTO metal ring and GLS tag on the diver's left leg and TDR tag on the diver's right leg. Tags were mounted on red darvic rings to facilitate identifying tagged individuals in the field. The laterally-narrowed shape of diver legs, requiring specially shaped rings, is also evident in this photo. Photo: Kerstin Kober.

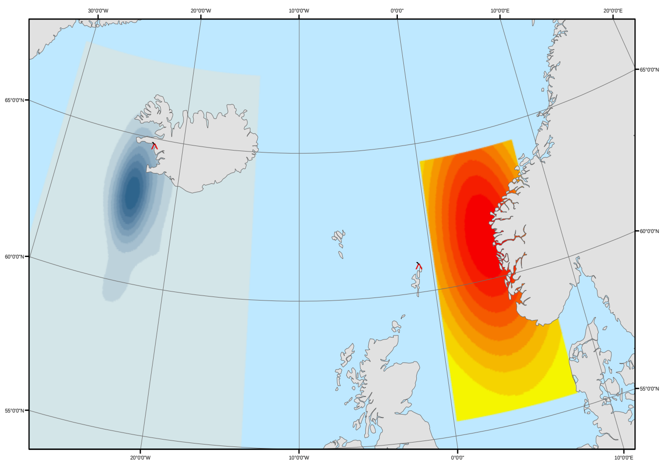

Figure 7. Example of geolocator data from divers tagged in Iceland (blue) and Shetland (red) showing areas used by divers during winter. Unpublished data from Ib Krag Petersen, Aevar Petersen and David Okill.

Recapture rates for red-throated divers carrying geolocators were reported to be approximately 50% based on previous work in Iceland and Scotland (Ib Krag Petersen and Aevar Petersen, pers comm). The minimum number of individuals from which dive behaviour is required, in order to have some understanding of variation among individuals' energetics, is 15 individuals (Francis Daunt and Jon Green, pers comm). Consequently, project partners agreed we should aim to tag at least 30 individuals in Scotland and another 30 in Finland. When ordering the tags, Biotrack and Cefas Technology Ltd provided 'free' tags with the 60 tags ordered. In consequence, we had more than 60 GLS and 60 TDR tags to deploy.

During the tagging process, any diver showing signs of stress would have been released immediately, without having tags or rings attached. However, none of the divers that were caught and tagged showed signs of stress and needed early release.

Only one individual in a pair was tagged in case tag effects reduced the ability of that individual to incubate or provision chicks. It was hoped if this did occur, that with only one bird tagged, the other individual in the pair could successfully fledge young. However, in some cases, both adults in a pair were caught (when using a wader net). In this case only one adult was tagged but both were ringed and morphometrics recorded.

Tagged individuals will be recaptured in 2019 and tags removed. GLS tag data will be used to establish approximate areas of use by tagged individuals, while TDR tag data will provide empirical information on dive frequency, depth, the proportion of time spent foraging at different times throughout the year and whether red-throated divers can forage at night.

2.2.5 Breeding success

Divers are asynchronous breeders with chicks hatching as early as late May and as late as August. Consequently, monitoring breeding success is challenging as, during any single survey, nest status can vary considerably. This asynchronous breeding requires many surveys of nest sites to be sure of nest status. Identifying if/when nests fail and whether a nesting attempt is a first attempt or a relay (second clutch) is difficult. Furthermore, determining when fledging occurs is almost impossible. Over the last four decades of monitoring red-throated diver breeding success on Shetland and Orkney, David Okill and Jim Williams have both classed nests as ‘successful’ when a chick is present that is at least three weeks old or ¾ the size of an adult bird. At this stage, chicks can generally avoid predators such as great skuas, unlike at the egg or small chick stage. However, even well grown chicks may not successfully fledge if adults are unable to successfully provision them.

Breeding success was determined by making multiple visits to nest sites during the breeding season and assessing nest status, i.e. scrape, eggs + incubation stage, chicks + approximate age. In Scotland, all nest sites were visited and eggs examined to determine incubation status, whereas in Finland, control sites were monitored from a distance and divers sat on eggs were not flushed. Similar methods were used in Iceland; some nests were visited, while others which were hard to approach were monitored from distance. Chicks with adults were monitored from a distance.

Incubation stage of red-throated diver nests was determined by floating eggs in water. This technique has been used for many species (van Paassen *et al* 1984). Fresh eggs remain horizontal on the bottom of the loch/lake whereas eggs that floated upright and emerge above the surface of the water are in an advanced state of incubation, close to hatching. A calibration of incubation stage does not exist for red-throated diver eggs so we used a calibration obtained for eider duck eggs, which have a similar incubation duration of approximately 26 days. Whilst this does not give a precise measure of incubation stage, it was sufficient to be able to avoid attempting to trap birds early in incubation. Age of chicks was estimated relative to the size of adults. A three-week old diver chick is approximately ¾ size of an adult bird.

2.3 Does trapping and tagging affect breeding success?

Tagging activities have the potential to alter the physiology and behaviour of breeding birds, with potential subsequent deleterious consequences on a number of traits, including reproductive parameters. As red-throated divers are known to be sensitive to human disturbance, there is a need to minimise, and monitor, these effects. Monitoring of lochs where breeding surveys and tagging activities are carried out allows this assessment. Preliminary analyses have therefore been performed on this year's dataset in order to assess whether our trapping and tagging activities had any significant negative effects on the probability of successfully rearing chicks. The results of these analyses will provide the basis for critical evaluation of the trapping methods used, as well as some useful insights and recommendations for future work.

Approximately 50 GLS tags have been deployed previously on red-throated divers, predominantly in Iceland but also in Scotland. No effect on breeding success was observed, although a systematic study was not undertaken (Ib Krag Petersen, pers comm). TDR tags have never been deployed on red-throated divers. Whilst no adverse effects from the tags are anticipated, it was important to undertake additional monitoring to look for any effect from birds either having to carry tags and/or the stress and disturbance of the trapping and tagging process.

A study to monitor diver breeding success, to assess any trapping and tag effects, was undertaken in Shetland and Orkney. Additionally, in Finland, local ringers kindly provided information on breeding success at control nests which also enabled a comparison of breeding success of nest sites with and without trapping efforts. A nest was described as successful if a chick at least ¾ grown was seen, as monitoring fledging was too labour-intensive and unfeasible.

Data on disturbance at control sites from Scotland and Finland are not directly comparable. In Orkney and Shetland, all nests were visited to check nest contents, resulting in birds being flushed from nests. Therefore, a control nest site in Scotland will still have suffered some level of disturbance. However, in Finland, control nests were not visited but were monitored from a distance. Using binoculars, birds were seen sitting on nests and were left undisturbed. At a few sites (n=6), nests were visited and birds were flushed but no trapping was attempted. For Finnish data these were treated as 'trapping attempted' nest sites. In other words, nest sites where birds were flushed from nests but no trapping activity was undertaken were treated as 'controls' in Scottish data but 'trapping attempted' in Finnish data. This anomaly will be corrected when undertaking a more rigorous analysis of any trapping and tag effects in 2019.

2.3.1 Scotland

Nest sites at which trapping was attempted and at control nest sites from Orkney and Shetland were included in a statistical analysis to investigate any difference in breeding success caused by trapping. Nest sites from mainland Orkney were not included in the analysis as sample sizes were small and including this data could introduce an additional source of variation, e.g. predators such as stoats are on mainland Orkney but are currently absent from Hoy. Additionally, a sufficient number of control nest sites were available from Hoy and Shetland.

In Scotland, surveys in May and early June 2018 identified sites where divers were nesting and nest status was recorded (see 2.2.5 Breeding Success, above). Nests were revisited on multiple occasions to monitor nest status until end of August 2018. Most visits occurred during three main monitoring sessions: i) third week of May; ii) first, second and third weeks of June; iii) third and fourth weeks of July. A nest was deemed occupied by breeding birds if clear evidence of nesting activity was observed on a loch, using at least two of the following criteria: clear scrape (a shallow depression created by a nesting diver in which eggs are laid), two individual divers present on a loch, incubating adult present, egg(s) or chick(s) present.

Divers at a proportion of these monitored nest sites were tagged in June and July 2018. Ideally, we would tag birds at a random sample of monitored nests, but this wasn't feasible as tagging efforts needed to be targeted towards birds and nest sites where capture (and recapture the following year) was likely to be easiest. This will minimise disturbance and stress for the birds and maximise the probability of recapturing birds and removing tags and darvic rings. Therefore, our sample of tagged birds will be biased towards those individuals that nest on small lochans which are easiest to catch. We felt it was more important to minimise stress on the birds and maximise recapture rate rather than undertake a study of optimal design. Loch size was included as a covariate in the analyses to minimise any effect that this bias might have.

Breeding success at tagged and untagged nest sites was compared, to test for a reduction in number of ¾ grown chicks (i.e. approximately three-weeks old) recorded at nest sites of tagged birds. A nesting attempt is considered 'successful' if it has produced at least one chick at least three weeks old. Red-throated diver chicks passing the three-week old threshold are more likely to fledge successfully (David Okill and Jim Williams, pers comm). 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 many years.

In order to investigate whether our trapping and tagging activities had any negative effects on the fate of red-throated divers' nests, we performed Generalized Additive Models (GAM) fitted with a binomial distribution of the response variable "Breeding Success" (nest was successful *vs*. nest failed) and a logit link function. Two categorical variables were considered in the models: "trapping outcome" (3 levels: trapping has not been attempted; trapping has been attempted but bird was not caught; trapping has been attempted and bird was caught) and "island" (2 levels: Orkney; Shetland). Stepwise model selection based on deviance tables indicated that including "island" did not significantly improve model fit (deviance = 0.05); therefore, this variable was not included in the final model. No interaction term was included in the final GAM model since initial data exploration did not reveal any apparent difference in trapping effect between islands, and there was also a risk of overparameterizing the model. Moreover, running a GAM including an interaction term between the two-level categorical variable "trapping attempt" (trapping has been attempted *vs*. trapping has not been attempted) and "island" did not reveal any significant effect of the interaction, which confirmed our predictions.

Estimated egg "laying date" was included as a continuous covariate in the models since initial data exploration suggested that this variable may be an important factor explaining variation in breeding success. Stepwise model selection also indicated that "laying date" decreased residual deviance of the model (deviance = -2.56).

The choice of the basis dimension for the smoothing term on "laying date" was made based on a trade-off between maximising model fit and ensuring smoothed patterns most correctly represent patterns observed in nature. Although using a higher basis dimension (up to degrees of freedom – 1) did increase model fit, it also produced a rather complicated smoothed pattern which, given the nature of the dataset and relatively small sample size, would not be expected to be detected as such. We therefore decided to use a more monotonous smoothed pattern with a basis dimension k of 3 for "laying date". However, both series of models (with k = 3 and k = df - 1) produced the exact same outcomes (see below).

Our final GAM model was therefore:

gam(Breeding Success ~ Trapping Outcome + s(Laying Date, k = 3), family = binomial)

Total sample size for this model was 61. Thirty-four nests had to be discarded from the analyses due to missing data for laying dates (n = 24) and/or unknown nest fates (n = 10) at time of last survey.

In addition, three additional explanatory variables were tested in separate models that only included birds that were successfully trapped, using GAMs and laying dates as a covariate: trapping duration, i.e. number of minutes the bird was subject to trapping and tagging disturbance (n = 22; p = 0.44); incubation stage at the time of trapping, determined by egg floating tests (n = 25; p = 0.19); trapping method, i.e. nest trap vs. wader net (n = 19; p = 0.99). Finally, the effect of loch size was tentatively tested on a restricted dataset due to missing data, running a GAM that included both "bird captured (yes or no)" and "laying date" as explanatory variables (n = 42; p = 0.44). None of these models revealed a significant effect on the probability of successfully rearing chicks.

Analyses were run in R 3.4.2. using the "mgcv" package.

2.3.2 Finland

In Finland, there was no systematic study to assess how breeding success might be altered by trapping of divers. However, nest sites at which trapping was carried out were monitored to check for nest failure. Nests at which trapping was attempted were revisited within a few days after trapping to record whether incubation had continued. Hatching and fledging success were also recorded on subsequent visits to nest sites at which trapping occurred. Additionally, information on breeding success at sites where no trapping occurred was provided by local Finnish ringers, from the Nuuksio area (provided by Veli-Matti Väänänen) and the Mäntyharju area (provided by Tuula Kyllönen). Kalevi Eklöf provided the details of breeding success in the Luumäki area. We are very grateful to Tuula, Veli-Matti and Kalevi for sharing this information. At this stage, these Finnish data have not been incorporated into a statistical analysis, but a chi-squared test indicated no difference in breeding success between trapped and control nest sites.

3 Results

All tags were deployed during the 2018 field season, except for one TDR tag that was found to be faulty. A total of 31 red-throated divers were tagged with both TDR and GLS tags in Finland, 17 divers were tagged in Orkney, 14 divers were tagged in Shetland and 12 divers were tagged in Iceland. Figure 8 shows locations of nest sites of tagged red-throated divers. It is not possible to include detailed information on locations of nest sites in Scotland in this report as this species has been targeted by egg collectors in the past and the ringers felt it unsafe to release detailed maps of nest locations.

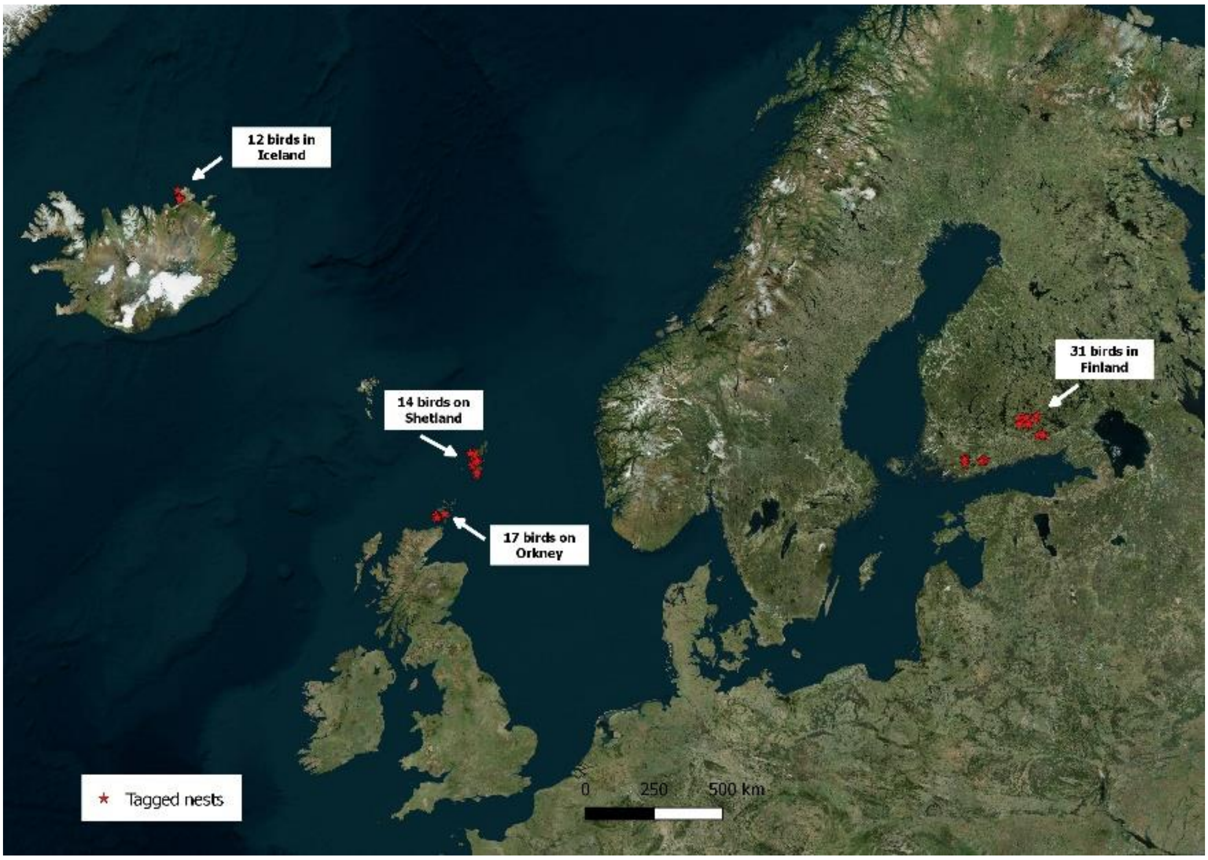

Figure 8. Location of 74 breeding red-throated divers that were tagged with GLS and TDR tags in Summer 2018.

3.1 Tagging summary

3.1.1 Finland

Divers were caught in four areas in southern Finland (see Figure 9). 31 red-throated divers were tagged with both TDR and GLS tags during 22 May to 10th June 2018. When approaching a nest to set a nest trap, the incubating diver usually returned to the nest within 30 minutes after the trap was set, although one individual returned within five minutes. If the incubating bird took off the water, it usually returned within 20-30 minutes but late in the day return times became prolonged. This could be due to very warm weather during the trapping season. In warm temperatures adults may rely on eggs staying warm without an adult sitting.

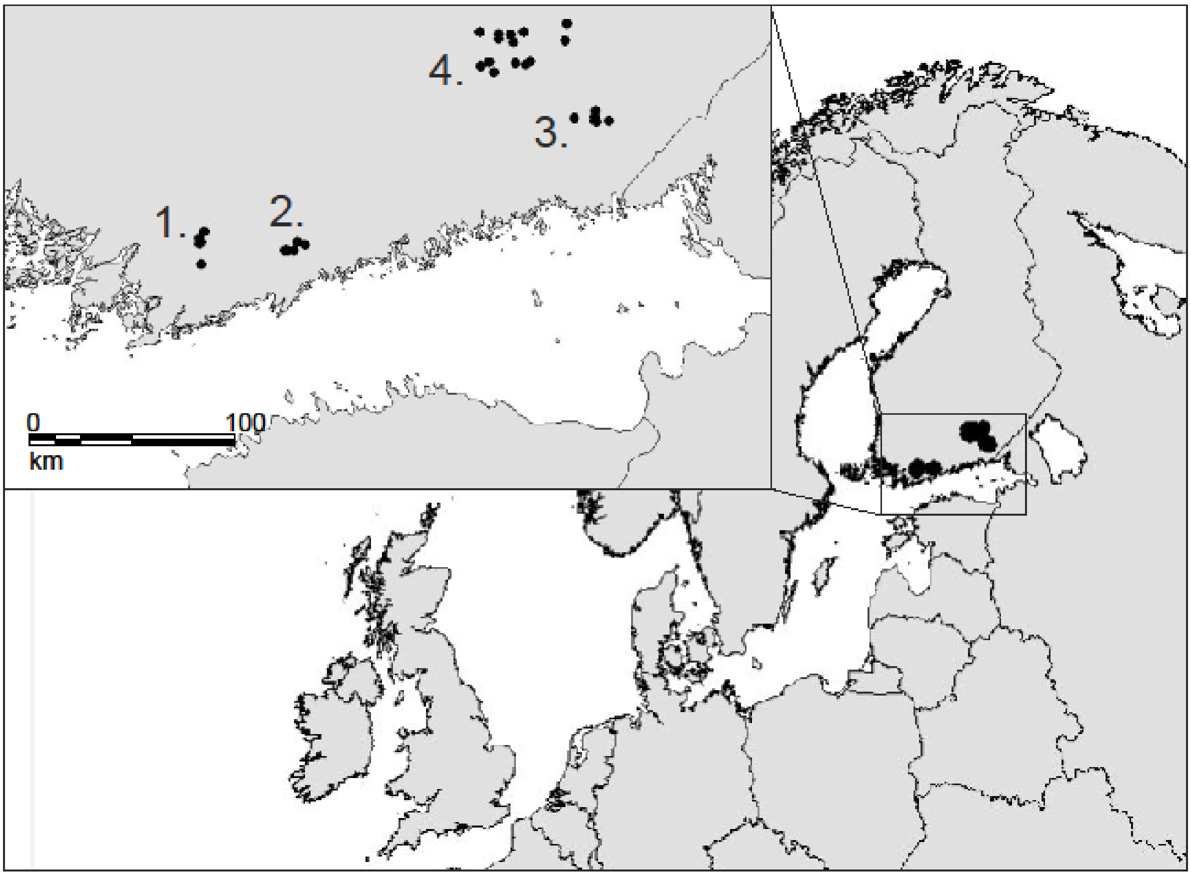

Figure 9. Geographical locations of tagging sites (black dots) in the southern Finland. The capturing areas are 1. Suomusjärvi (partly under monitoring of ringer Kalevi Eklöf), 2. Nuuksio National Park (under monitoring of Petri Nummi & Veli-Matti Väänänen), 3. Luumäki, 4. Mäntyharju area (study site of ringer Tuula Kyllönen).

All birds were caught using a nest trap; wader nets were not used in Finland. Success rate of catching divers with the nest trap was 84%, with six failed attempts. In two of these attempts, the bird escaped the trap after the release mechanism was triggered. Sex ratio of tagged birds was almost 50:50 with 15 tagged birds recorded as female and 16 as male, based on their morphometrics. Bird body mass ranged from 1.525kg to 2.29kg. In Finland, divers were in the hand for an average of 13 minutes (range 6-20 mins). Total time spent trying to trap a bird, from the bird first being flushed from the nest to releasing an individual was, on average 1:05 hrs (range 26 mins to 2:21 hrs).

3.1.2 Orkney

Tagging breeding red-throated divers on Hoy was challenging due to a particularly poor and late breeding season. Until 2017, red-throated divers on Hoy maintained relatively high and consistent breeding success and nest site occupation, with a mean of 58 nest sites (range 56-66 nest sites) occupied during the period 1998-2016. Since 2009, the number of occupied nests has always exceeded 60. However, in 2017 the number of occupied nests declined to 56 and 2018 was lower again, with just 49 occupied nests. Due to the poor breeding season, SNH requested that we only attempt to catch divers at no more than half of the active nest sites within the SPA and that we carefully monitor breeding success to look for any effect from tagging activity on breeding success. Originally, we had planned to deploy all Orkney tags on Hoy, but the poor breeding season meant we needed to deploy two sets of tags on mainland Orkney. These two nest sites were not far from Hoy and are highly likely to be part of the same population as Hoy breeding birds, i.e. tagging divers breeding on mainland Orkney will have no effect on results obtained from these tags.

Of the 17 birds tagged, three were caught using a nest trap and the remaining 14 were caught using a wader net. 73% of trapping attempts were successful on Orkney. Birds were in the hand for an average of 21 minutes (range 9-33 mins) and the entire capture (from setting a trap to releasing a bird) took an average of 1:12 hrs (range 12 mins to 2:30 hrs).

Six of the tagged birds were already ringed, five having been ringed as chicks and one as an adult. A further two birds were caught which were already ringed, that were not tagged. The ringed birds were surprisingly old, being aged 14-28 years, with the exception of one bird aged six. Additionally, a ringed diver that had died recently was known to be 36 years old. Another diver that was caught but not tagged was ringed as a chick in Shetland, suggesting the Orkney and Shetland populations are part of one larger population.

Of the 17 tagged birds, ten were thought to be female and seven male, based on their morphometrics (Okill *et al* 1989) but there may be some error using morphometrics to assign sex, especially for intermediate sized birds. The smallest bird caught weighed 1.42kg, the heaviest 2.185kg. The first bird was tagged on 8th June and the last on 9th July 2018. Two tagged birds were at sites at which no eggs were recorded as being laid, only a fresh scrape in preparation for nesting. Thirteen nests of tagged birds contained two eggs, the remaining two nests containing a single egg. Seven nests of tagged birds successfully raised chicks to at least three weeks of age (when probability of successfully fledging becomes high) whereas ten nests failed to produce chicks.

3.1.3 Shetland

Shetland had a relatively poor breeding season, but with a larger number of breeding pairs of red-throated divers than Hoy (Orkney), a sufficient number of birds were found to tag. The first individual was tagged on 5th June and the last on 21st June 2018. Eight birds were caught using traps on the nest and the remaining six birds were caught using a wader net. Out of 21 attempts to catch birds, 7 were unsuccessful, giving a success rate of 67% on Shetland. Birds were in the hand for an average of 15 minutes (range 10-20 mins) and the entire trapping process (from setting the nest trap up to releasing the bird) took an average of 55 minutes (range 16 mins to 2:15 hrs).

Two of the tagged birds were already ringed, one as a chick in 2001 and one as an adult in 2004. Nine tagged birds were recorded as female, five as male although since this is based on morphometrics (Okill *et al* 1989), this may be incorrect in some cases. The lightest bird weighed 1.47kg, the heaviest 2.11kg. All of the nests of tagged birds contained a clutch of two eggs, with the exception of one nest which had a single egg. Five nests of tagged birds successfully raised chicks to at least three weeks of age whereas eight nests failed to fledge any chicks. At one nest, breeding success was unknown.

3.1.4 Iceland

Some populations of red-throated divers breeding in Iceland have had reduced breeding success in recent years, whereas others have continued to have relatively high breeding success. This may be due to relying on different prey species which are differentially affected by climate change (Aevar Petersen, pers comm). A population with relatively good breeding success in north-eastern Iceland was used for this tagging study. A total of 12 divers were tagged in Iceland, although not all of these tags were purchased by the Red-throated Diver Energetics Project. The first diver was tagged on 26th May and the last on 2nd July. Seven divers were caught using nest traps and a further five using wader nets. Five tagged birds were thought to be female and seven male although since this is based on morphometrics it may be incorrect in some cases. Individual body mass varied from 1.42kg to 2.17kg. Six nests of tagged birds failed to fledge any young, two nests fledged a single chick and the remaining four nests successfully fledged two young.

3.2 Breeding success

Breeding success varied across the four study sites. Across Orkney and Shetland, a total of 102 red-throated diver nest sites were monitored by the Red-throated Diver Energetics Project during 2018, 48 on Hoy, nine on mainland Orkney and 45 on Shetland (Table 1). All nest sites were considered as occupied by breeding adults with an intention to nest, i.e. they at least produced a scrape even if they were not recorded as laying eggs. Data on breeding success from 12 nest sites in Iceland was available. In Finland, a total of 100 nest sites were monitored.

Table 1. Breeding success in Scotland, Iceland and Finland. Breeding success is measured as number of successful nests, as a percentage of total number of nests of known fate. Data from Iceland is only for nest sites with tagged birds and does not include any control sites.

Region	No. of nests monitored	No. of failed nests	No. successful nests	No. nests of unknown fate	Breeding success
Hoy (Orkney)	48	29	13	6	31%
Mainland Orkney	9	5	3	1	37%
Shetland	45	20	18	7	47%
Iceland	12	6	6	0	50%
Finland	100	38	62	0	62%

Breeding success, measured as a nest site producing at least one three-week old chick, was low across Orkney and Shetland. Combining sites monitored by the RTD Energetics Project with additional information from RSPB reserves on the Northern Isles, average breeding success across the northern isles was 38% for nest sites of known outcome (n=109). This is low when compared with a breeding success rate for southern Finland of 62% (n=100). The sample size from Iceland is too small to make a valid comparison.

In Finland, breeding productivity at the sites where trapping occurred in 2018 (excluding Nuuksio) has been reported to be 0.77±0.14 (SD) fledged young/pair in years 2008-2017 (Eklöf & Koskimies 2018). Regionally the productivity rates were 0.84±0.11 (SD) for Suomusjärvi, 0.70±0.14 (SD) for Mäntyharju region and 0.79±0.14 (SD) fledged young/ breeding pair for Luumäki (Eklöf & Koskimies 2018). Breeding productivity in Finland in 2018 seems to be broadly similar to other years, suggesting this was not a particularly good or bad season in Finland.

3.3 Does trapping and tagging affect breeding success?

A tagged red-throated diver, with the red darvic ring carrying a tag just visible below the surface. Photograph by Nick Moore.

3.3.1 Scotland

A statistical analysis was carried out on breeding success from nest sites at which trapping occurred and from control nest sites, from Hoy (Orkney) and Shetland. Note that control sites were also visited during the breeding season to assess nest status but that no trapping was attempted. On average, nests in Orkney were visited 4.2 times (range 1-9 times) (excluding non-intrusive visits) whereas nests on Shetland were visited 2.4 times (range 1-4 times). This differs to control nest sites in Finland, where nests were not visited but were monitored at a distance.

On Hoy, a total of 48 nests were monitored, with trapping attempted at 22 nest sites, although seven of these attempts failed to catch a bird. (Note, an additional two individuals tagged in Orkney were on the mainland and not on Hoy.) On Shetland, a total of 45 nests were monitored, with trapping attempted at 17 nest sites, of which 14 were successful.

Initial inspection of the data revealed that breeding success declined as the breeding season progressed (Figure 10).

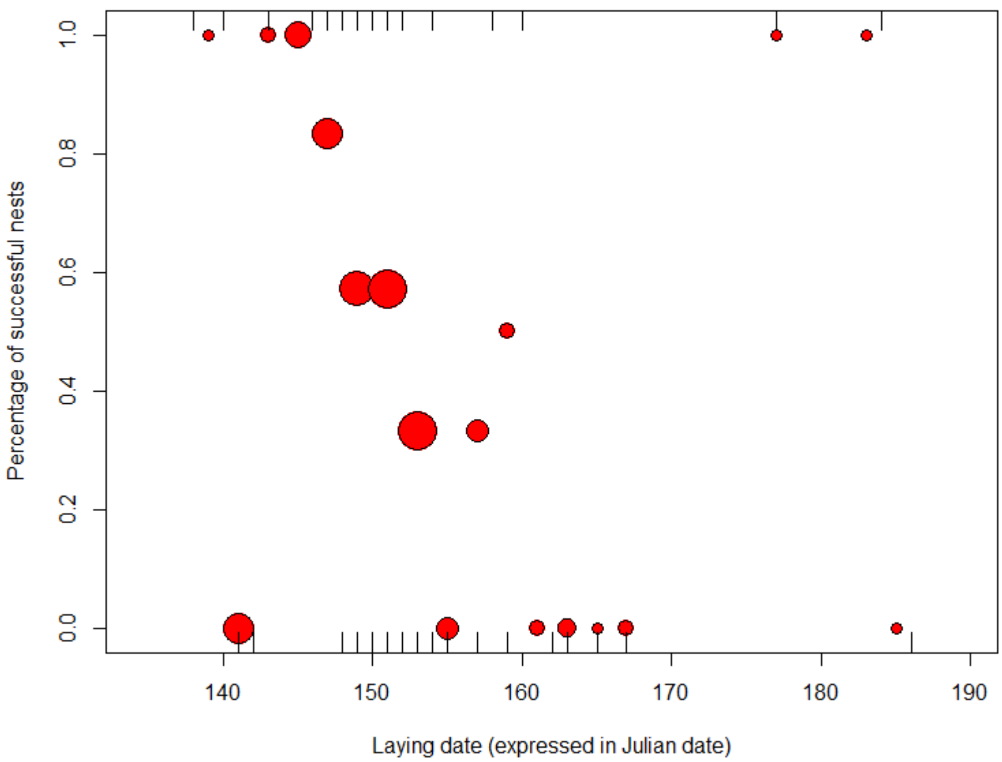

Figure 10. Variation in the percentage of successful diver nests in relation to estimated egg laying date, showing the percentage of successful nests declined as the breeding season progressed. Larger dots signify larger sample sizes. Vertical bars indicate where failed (0) and successful (1) nests occurred. Total sample size is 61 (i.e. number of nests for which there is data on both nest fate and egg laying dates).

Our final GAM model explained 5.93% of the residual deviance. Results indicated that none of the explanatory variables included in the model significantly explained variation in divers' breeding success (Table 2). Importantly, there was therefore no evidence that our trapping and tagging activities had any negative effects on breeding success of red-throated divers in Orkney and Shetland in 2018. Whilst the smoothing term (laying date) was non-significant (Table 2), it was felt beneficial to still use a GAM, rather than a GLM, since the percentage of successful nests did not vary in a strictly linear manner with laying date (Figure 11).

Table 2. GAM model output for Breeding Success ~ Trapping Outcome + s(Laying Date, k = 3) TAC: Trapping Attempted and bird Caught; TANC: Trapping Attempted but bird Not Caught. Laying date represents the smoothing term.

	Estimate	SE	Statistics	p-value
Intercept	0.10	0.34	-0.30	0.76
Trapping Outcome: TAC	0.16	0.58	0.27	0.79
Trapping Outcome: TANC	-1.59	1.19	-1.34	0.18
Laying Date	1.56	1.80	2.35	0.37

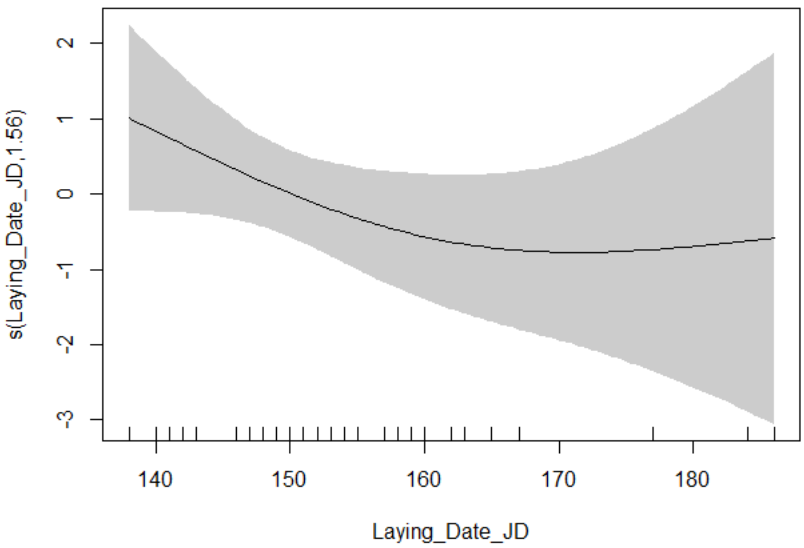

Figure 11. Plot from the final GAM model in which the proportion of successful divers' nests has been modelled as a smooth function of laying date (expressed as Julian date).

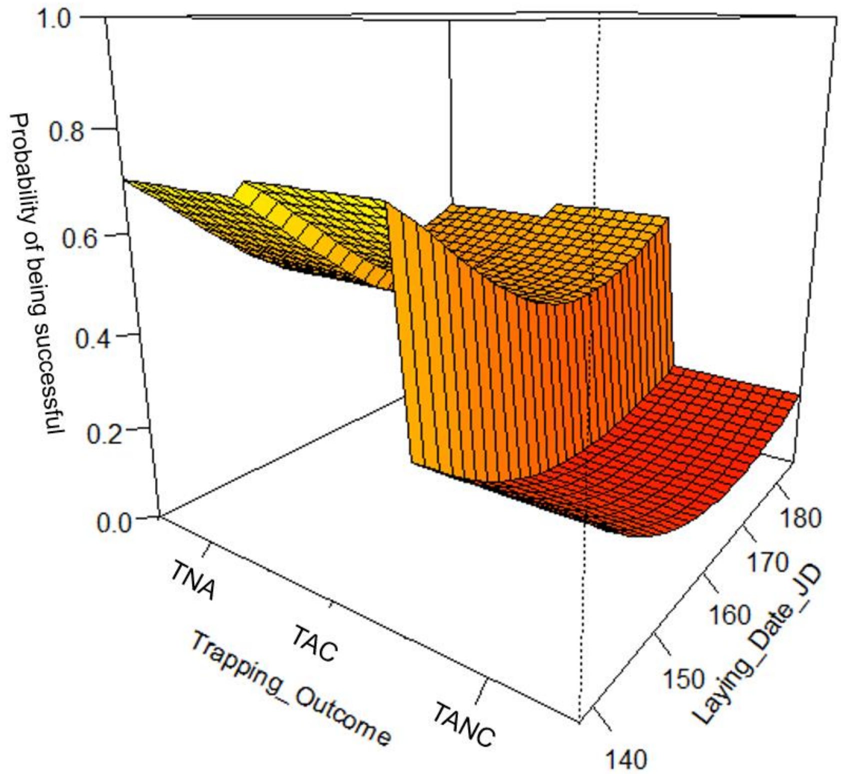

Figure 12. Three-dimensional plot presenting model predictions of the final GAM model on the response scale. Note that the GAM model did not reveal any significant effect of "trapping outcome"; this figure is useful however to evaluate the magnitude of effect sizes.

Figure 12 shows a small difference (slight increase) in breeding success between the percentage of successful nests where trapping was not attempted (TNA) and where trapping resulted in a bird being caught (TAC). There is a larger decline for trapping attempts which failed to catch a bird (TANC). This difference holds no matter when in the breeding season a nesting attempt begins, i.e. a similar reduction in breeding success with date occurs irrespective of whether any trapping was attempted or not. However, it is important to note that the GAM found no significant effect of trapping on the percentage of successful nests, as illustrated in a plot of the partial residuals (Figure 13).

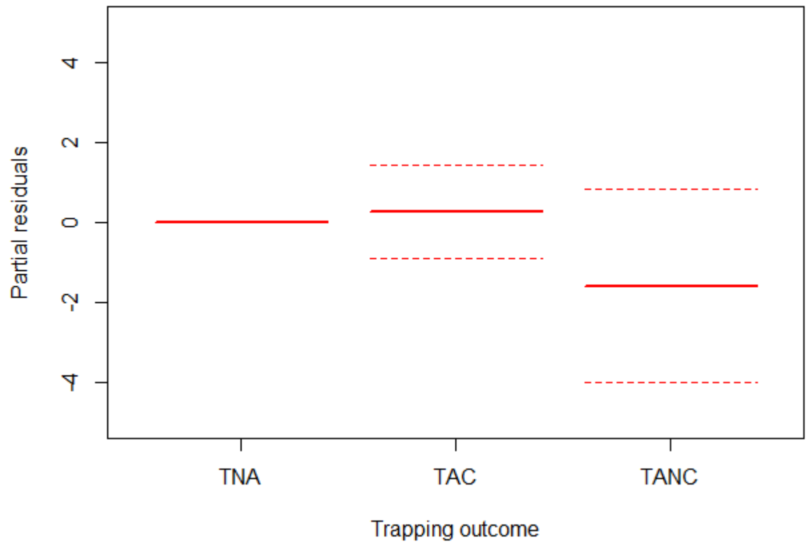

Figure 13. Partial residual plot for trapping outcome, showing the standard errors around TANC. Percentage of successful diver nests where birds were successfully caught (TAC; n = 19) and where trapping had not been successful (TANC; n = 5) are presented relative to the percentage of successful nests where trapping had not been attempted (TNA; n = 37).

3.3.2 Finland

Trapping was attempted at a total of 33 nest sites, at which 31 divers were tagged. A further six nest sites were visited, which may also have caused disturbance and potentially increased risk of breeding failure. At 85% of nest sites at which trapping was attempted or a nest visit was made, incubation continued for at least several days after trapping. Whilst no statistical analysis has been undertaken on breeding success data from Finland, the percentage of nests that successfully fledged chicks was similar, irrespective of whether any trapping or nest visits had occurred at that site: 59% at sites with trapping/nest visits; 64% where no trapping/nest visits occurred (Table 3).

Table 3. Breeding success for red-throated diver nests in Finland, where trapping was attempted, or nests were visited thereby creating disturbance, compared with control nest sites where no disturbance occurred. Breeding success was number of successful nests as a percentage of nests of known outcome.

	Disturbed nest sites	Control nest sites	Total
No. of successful nests	23	39	62
No. of nests failing	16	22	38
Unknown outcome	0	0	0
Total number of nests monitored	39	61	100
Breeding success	59%	64%	62%

When studying the effect of trapping on breeding success the nest site location should be taken into account as artificial rafts have been shown to increase breeding success and productivity (Nummi *et al* 2013). Breeding success on artificial rafts was not lower at nest sites where trapping was attempted, or nests were visited: 67% of 30 nests were successful where disturbance occurred, compared with 63% of 48 control nest sites.

For most nest sites there is no information on whether a success or failed nest was a first or second nesting attempt. However, for the Nuuksio nest sites, this was monitored. More disturbed nests failed during the first breeding attempt compared with undisturbed nests: 51% of 33 disturbed nests (where trapping was attempted, or nests were visited) failed during the first breeding attempt, compared with control nest sites where only 23% failed on a first breeding attempt.

In Finland, breeding productivity of the tagged pairs was 0.86 fledged young/pair, 0.91 for pairs with nest visits and 0.93 for control pairs, suggesting that productivity was not affected by trapping activity and other disturbance at the nest site.

One tagged bird from Finland was found drowned in a fishing net set in a freshwater loch. The bird was entangled in the net, but this was not thought to be caused by the tags.

3.3.3 Iceland

A systematic study to compare breeding success at tagged and control nest sites was not undertaken in Iceland. However, observations of nest success found breeding productivity to be slightly lower at nests where divers were caught and tagged (mean no. of chicks per nest = 0.8, n=10) compared with control nest sites (mean no. of chicks per nest = 1.08, n=60). This difference could be attributable to the small sample size of nest sites at which tagging occurred, rather than a real reduction in breeding success caused by tagging.

4 Discussion

4.1 Tagging

Deployment of the TDR and GLS tags was highly successful with all tags being deployed, with exception of one faulty TDR tag. A total of 31 divers were tagged in Finland, 31 divers in Scotland and a further 12 divers were tagged in Iceland. Whilst red-throated divers are a challenging species to work with, being highly sensitive to disturbance and stress, this study has shown divers can be caught by skilled experienced ringers. The success of tag deployment in 2018 bodes well for recapture of tagged birds in 2019.

4.2 Breeding success

Breeding success was low across the Northern Isles (Scotland), with an average breeding success across 109 monitored nests of 38%. In recent years breeding success in the Northern Isles has been declining. For example, mean breeding success on Hoy during the six years 2011-2016 was 55% (range 44-66%) but was only 13% in 2017 (Jim Williams & Stuart Williams, unpublished data). Figure 14, reproduced from Okill (2017), shows how numbers of successful pairs on Shetland has declined over the last two decades. This long-term decline can also be seen in the age of divers recaptured in 2018, that had been ringed as chicks, with most older than 14 years and several in their twenties. Given the availability of suitable nesting lochs that were unoccupied, this suggests that, for Hoy at least, recruitment has been poor for at least a decade and there is a shrinking and aging population of adult divers that are not being replaced by younger birds. The long-term monitoring of divers on Hoy and Shetland over such a long period (four decades) provides a rare and extremely valuable dataset to better understand red-throated diver population ecology in Scotland.

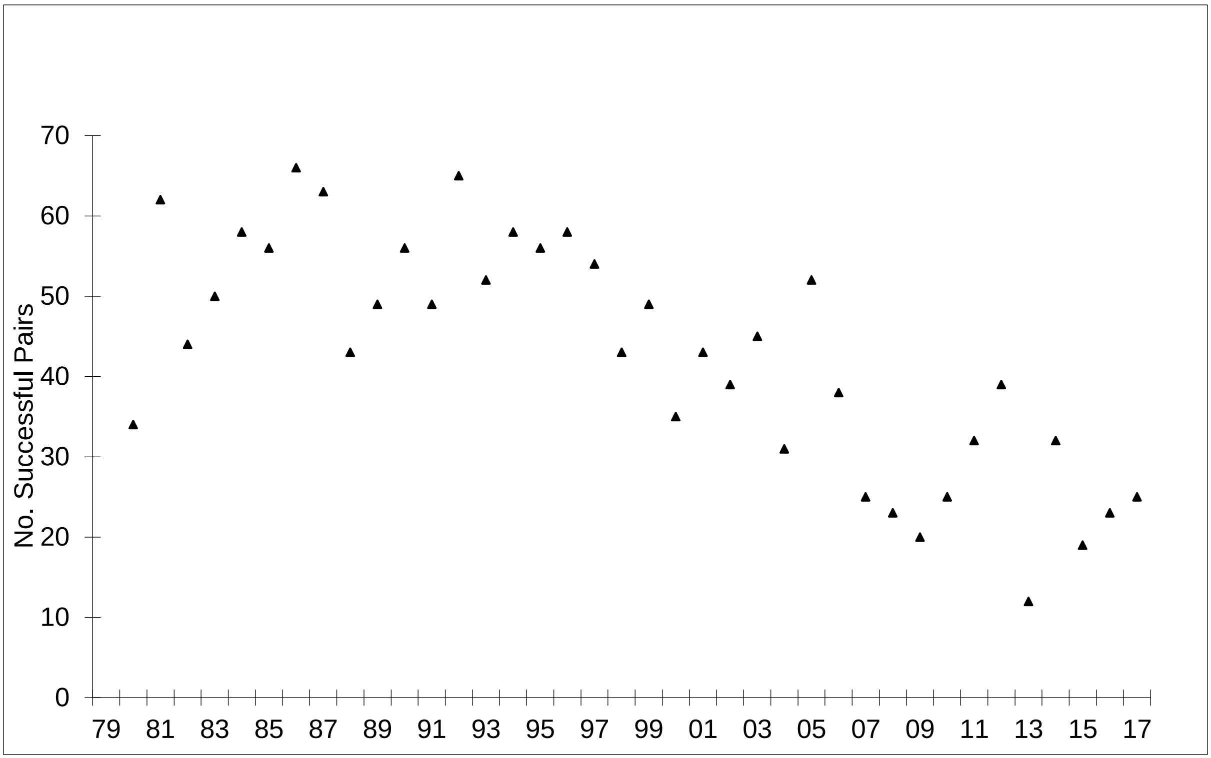

Figure 14. Number of pairs of red-throated divers successfully fledging young in Shetland, from 1979 to 2017 (reproduced from David Okill's SOTEAG report, 2017).

Breeding success was higher in Finland, with 62% of nests successfully producing chicks. There is evidence that artificial rafts raise breeding success for red-throated divers in Finland (Nummi *et al* 2013). However, breeding success for nest sites on artificial rafts was 64% so nests in other locations are not having lower breeding success than those on rafts, for nest sites monitored in 2018.

4.3 Tagging effects on breeding success

There was no discernable effect of tagging activity on breeding success in either Scotland or Finland. However, control nest sites in both Finland and Scotland may be subject to some level of human disturbance and thus may not be true controls. In Orkney and Shetland all nests were visited on at least one occasion and many more in most cases. In Finland, recreational activity on breeding lakes is thought to disturb breeding divers. Consequently, it may be more accurate to say tagging activity does not appear to increase numbers of nests failing, above that caused by background levels of human disturbance. In Alaska two diver species (Pacific loons *Gavia pacifica* and Yellow-billed loons *Gavia adamsii*) showed breeding success of 61% when captured with bow nets (spring traps) and 66% when captured with suspended dive nets, whereas 94% of the untagged pairs were successful (Uher-Koch *et al* 2015). Lehikoinen and Väisänen (2018) hypothesise that this may be due to low levels of human disturbance at Alaskan control sites. Tag and tagging effects are rarely assessed and/or published for foot-propelled diving birds, such as red-throated divers, but one study that investigated tag effects on cormorants found no effect (Ropert-Coudert *et al* 2009).

In Finland, the number of divers failing in their first breeding attempt and then relaying a second clutch was higher for nest sites with trapping activity, compared with control sites. In Alaska, yellow-billed and pacific divers avoided returning to continue incubation immediately after being trapped and during this period eggs became chilled or were predated (Uher-Koch *et al* 2015; Kenneth G. Wright, pers comm). Since overall breeding success for red-throated divers in Finland was not lower for nests with trapping activity, divers must be able to fully compensate the loss of the first clutch with higher success rates with their second clutch. However, survival of chicks fledged later in the year may be lower than those fledged earlier in the year, as seen in many other species.

There was a small, non-significant decrease in breeding success when trapping was attempted but was unsuccessful, compared with successful trapping attempts. This result could be caused by the very small sample sizes but might be due to birds that are more sensitive to disturbance effects being harder to catch.

There were several limitations of the statistical analysis undertaken to investigate tagging effects. For example, the final GAM model explained a relatively small part of the variation in the dataset and it is highly plausible that some important explanatory variables may not have been considered here, e.g. body condition, previous breeding history, age. We did not deem it relevant to control for the effect of trapping effort (i.e. number of nest visits) in our GAM model due to the apparent biased structure of the dataset; indeed, as nest monitoring stopped after recording a failure, nests that failed tended to have less nest visits than nests that were successful. In order to correctly control for the effect of trapping effort on the probability of a nest being successful, it would be necessary to relate each visit to a particular nest event (either observed as alive or dead), as done with survival (cox) analyses. Unfortunately, our dataset does not allow running survival cox analyses since the exact recordings of timing of nest failure (i.e. a 'death' in a survival analysis) are not available. Our data only indicate when a nest was last recorded as having viable eggs or chicks and when it had failed but we don't know when exactly the 'death' occurred. However, given the nature of the dataset and limited sample size, we have adopted a relatively simple, but sound and robust, analytical approach, by including a time covariate and using a model that is not overparameterised. Nevertheless, it would be extremely useful to perform further analyses as more data becomes available next year and there is more predictive power to test more complex hypotheses.

4.4 Recommendations for the 2019 breeding season

Ideally, in 2019 information on breeding success at nest sites should be collected in such a way that it is possible to separate trapping effects in 2019 from any effects caused by carrying tags for a year. Suggestions for improving methods for collecting information on breeding success in 2019, to enable better assessment of trapping and tag effects, are given below. For example:

- obtaining measures of body mass (as a proxy for body condition) of tagged and untagged birds in 2019, compared with body mass of tagged and untagged birds in 2018 should enable quantification of any tag effects on body mass;
- levels of disturbance at ‘control’ sites should be carefully monitored and recorded. Balancing the need to check nest status with numbers of nest visits needs consideration;
- additional surveys late in the season should be undertaken, if possible, to determine fates of all nest sites;
- record time taken for the birds to come back after being flushed from their lochs. This could be related to body condition indices, sex or age for example, and help clarify the apparent difference in breeding success probability between tagged and non-tagged birds;
- standardising numbers of visits to nests to be able to control for trapping effort and disturbance, and also to reduce the likelihood that failed nests were missed;
- set up camera traps at nests to record nest fates with time and date;
- ensure that information on laying date is collected for all nests, including non-tagged pairs. It may also be worth collecting data on incubation stage at time of trapping in a more systematic manner. This is important as a substantial number of nests had to be discarded from the analysis in 2018;
- next year’s breeding success monitoring should cover the entire breeding season, until all chicks are at least ¾ grown, to avoid discarding nest sites from the analysis due to them having an unknown fate.

5 Acknowledgements

We are grateful to The Crown Estate, Vattenfall, Ørsted and Hartley Anderson Ltd (BEIS Offshore Energy SEA Research Fund) for providing funding for this project. The Natural Environment Research Council (NERC) and University of Liverpool are providing funding, via the ACCE DTP, for a PhD studentship to analyse data collected during this project.

Jon Green and Francis Daunt provided valuable advice on scientific design of this project, including which tags to use and many other aspects. Special thanks to Jon Green for providing a peer review of the statistical analysis of tagging effects on breeding success.

Fieldwork in Scotland was made possible by the hard work of many people including Pete Ellis, George Petrie, Kerstin Kroeger, Karen Hall, Gus Routledge, Ruth Williams, Kerstin Kober, Moray Souter, Matt Parsons, Nick Moore, Thomas Cornulier, Julia Sutherland. We are also grateful to SNH (Kate Thompson and Glen Tyler) for their help with enabling us to work within Natura sites and to the RSPB (Lee Shields, Alan Leitch, Iain Malzer) for permission to tag and monitor diver nest sites on their reserves. In addition, thanks go to Jez Blackburn and the Special Methods Technical Panel for their help with obtaining permission to tag red-throated divers.

In Finland, the help of local ringers was invaluable, ensuring the success of this project. Pepe and Roni are most grateful to our field assistants Marc Illa Llobet and Jari Laitasalo for the aid throughout the field season and Tuula Kyllönen for her help in Mäntyharju region. Aleksi Lehikoinen and Jarkko Santaharju helped in the field work on a single day. Veli-Matti Väänänen, Petri Nummi, Jani Suua, Markku Vakiala, Kalevi Eklöf and Heikki Helle provided helpful advices for trapping sites and techniques. Breeding success data was provided by Tuula Kyllönen (Mäntyharju, also on control sites), Veli-Matti Väänänen (control sites in Nuuksio) and Kalevi Eklöf (Luumäki and Suomusjärvi). Teemu Lehtiniemi (BirdLife Finland) provided casual observation data for recognizing the suitable breeding sites. Tapio Aalto and Ritva Kemppainen (Centre for Economic Development, Transport and the Environment) provided the permission to use TDR and GLS tags for red-throated divers in Finland. Mikael Nordström and Aimo Saano (Metsähallitus, National Parks Finland) provided permission to tag birds inside state owned protected areas. Markus Piha and Jari Valkama (Ringing Centre - Finnish Museum of Natural History) gave valuable information on diver ringing, helped with the applications and provided metal rings for divers.

Work in Iceland, undertaken by Aevar, was greatly helped by Guðmundur Ö. Benediktsson. Funding for some of the tags deployed in Iceland was from the Icelandic Ministry for the Environment and Natural Resources.

6 References

Dierschke, V., Furness, R.W. & Garthe, S. 2016. Seabirds and offshore wind farms in European waters: Avoidance and attraction. *Biological Conservation*, **202**, 59-68.

Dierschke, V., Furness, R.W., Gray, C.E., Petersen, I.K., Schmutz, J., Zydelis, R. & Daunt, F. 2017. Possible Behavioural, Energetic and Demographic Effects of Displacement of Red-throated Divers. *JNCC Report No. 605*. JNCC, Peterborough. ISSN 0963-8091.

Dorsch, M., Nehls, G., Žydelis, R., Heinänen, S., Kleinschmidt, B., Quillfeldt, P. & Morkūnas, J. 2016. Red-throated Diver winter movements in areas with offshore wind farms. *Presentation at International workshop on Red-throated Divers, 24-25 November 2016, Hamburg.* http://www.divertracking.com/category/news/?lang=en_gb#

Drewitt, A.L. & Langston, R.H.W. 2006. Assessing the impacts of wind farms on birds. *Ibis*, **148**, 29-42.

Eklöf, K. & Koskimies, P. 2018: Kaakkurien kanssa 42 vuotta – Miten kaakkurit liikkuvat ja kuinka pesinnät onnistuvat? *Linnut-vuosikirja* **2017**: 118–121.

Furness, R.W., Wade, H. & Masden, E.A. 2013. Assessing vulnerability of seabird populations to offshore wind farms. *Journal of Environmental Management* **119:** 56-66.

Guse, N., Garthe, S. & Schirmeister, B. 2009. Diet of red-throated divers *Gavia stellata* reflects the seasonal availability of Atlantic herring *Clupea harengus* in the southwestern Baltic Sea. *Journal of Sea Research*, **62**, 268-275.

Halley, D.J. & Hopshaug, P. 2007. *Breeding and overland flight of red-throated divers* Gavia stellata *at Smøla, Norway, in relation to the Smøla wind farm.* NINA Report 297. 32 pp. http://www.nina.no/archive/ nina/PppBasePdf/rapport/2007/297.pdf. (27 January 2015)

Heinänen, S. 2016. Red-throated Diver habitat use in the German North Sea based on aerial survey data. *Presentation at International workshop on Red-throated Divers, 24-25 November 2016, Hamburg.* http://www.divertracking.com/category/news/?lang=en_gb#

Lehikoinen, P. & Väisänen, R. 2018. *The Red-throated Diver Energetics Project – Report of the field work in Finland 2018*. Unpublished report to JNCC.

Mendel, B., Schwemmer, P., Peschko, V., Muller, S., Schwemmer, H., Mercker, M. & Garthe, S. 2019. Operational offshore wind farms and associated ship traffic cause profound changes in distribution patterns of Loons (*Gavia* spp.). *Journal of Environmental Management*, **231**, 429-438.

Nummi, P., Väänänen, V.-M., Pakarinen, R. & Pienmunne, E. 2013: Red-throated diver in human disturbed habitats - artificial nesting rafts improve breeding success. *Ornis Fennica* **90**: 16–22.

O'Brien, S.H., Wilson, L.J., Webb, A. & Cranswick, P. 2008. Revised estimate of numbers of wintering red-throated divers *Gavia stellata* in Great Britain. *Bird Study,* **55:** 152-160.

Okill, D. 2017. *Report to SOTEAG on Red-throated Divers in Shetland*. Shetland Ringing Group.

Okill, J.D. 1992. Natal dispersal and breeding site fidelity of red-throated Divers *Gavia stellata* in Shetland, *Ringing & Migration*, **13**:1, 57-58, DOI: 10.1080/03078698.1992.9674016

Okill, J.D. 1994. Ringing recoveries of red-throated divers *Gavia stellata* in Britain and Ireland. *Ringing & Migration*, **15:2**, 107-118. DOI: 10.1080/03078698.1994.9674083

Okill, J.D., French, D.D. & Wanless, S. 1989. Sexing Red-throated Divers in Shetland, *Ringing & Migration*, **10**:1, 26-30, DOI: 10.1080/03078698.1989.9676003

Percival, S. 2014. *Kentish Flats Offshore Wind Farm: Diver Surveys 2011-12 and 2012-13.* Report to Vattenfall, by Ecology Consulting. https://corporate.vattenfall.co.uk/globalassets/uk/projects/redthroated-diver-2014.pdf.

Petersen, I.K., Christensen, T.K., Kahlert, J., Desholm, M. & Fox, A.D. 2006. *Final results of bird studies at the offshore wind farms at Nysted and Horns Rev, Denmark.* National Environmental Research Institute, Kalø.

Petersen, I.K., Nielsen, R.D. & Mackenzie, M.L. 2014. *Post-construction evaluation of bird abundances and distributions in the Horns Rev 2 offshore wind farm area, 2011 and 2012.* Aarhus University, Aarhus.

Ropert-Coudert, Y., Kato, A., Poulin, N. & Gremillet, D. 2009. Leg-attached data loggers do not modify the diving performances of a foot-propelled seabird. *Journal of Zoology* **279:** 294-297.

Saurola, P., Valkama, J. & Velmala, W. 2013: *Suomen rengastusatlas. Osa I. - The Finnish Bird Ringing Atlas. Vol 1. - Luomus ja ympäristöministeriö*, 549pp, ISBN 978-952-10-8572-7

Schwemmer, P., Mendel, B., Sonntag, N., Dierschke, V. & Garthe, S. 2011. Effects of ship traffic on seabirds in offshore waters: implications for marine conservation and spatial planning. *Ecological Applications*, **21**(5), 1851–1860.

Skov, H. & Prins, E. 2001. Impact of estuarine fronts on the dispersal of piscivorous birds in the German Bight. *Mar Ecol Prog Ser* **214**: 279–287.

Skov, H., Heinanen, S., Thaxter, C.B., Williams, A.E., Lohier, S. & Banks, A.N. 2016. Realtime species distribution models for conservation and management of natural resources in marine environments. *Marine Ecology Progress Series*, **542**, 221-234.

Uher-Koch, B.D., Schmutz, J.A. & Wright, K.G. 2015: Nest visits and capture events affect breeding success of Yellow-billed and Pacific loons. *The Condor: Ornithological Applications* **117**: 121–129.

van Päässen, A.G., Veldman, D.H. & Beintema, A.J. 1984. A simple device for determination of incubation stages in eggs. *Wildfowl*, **35**: 173-178.

Webb, A., Irwin, C., Mackenzie, M., Scott-Hayward, L., Caneco, B. & Donovan, C. 2016. *Lincs Wind Farm third annual post-construction aerial ornithological monitoring report.* HiDef Aerial Surveying Limited report to Centrica Renewable Energy Limited, CREL Ref LN-E-EV013-0006-400013-007.

Welcker, J. & Nehls, G. 2016. Displacement of seabirds by an offshore wind farm in the North Sea. *Marine Ecology Progress Series,* **554**: 173-182.

Wernham, C., Toms, M., Marchant, J., Clark, J., Siriwardena, G. & Baillie, S.R. 2002. *The Migration Atlas: Movements of the Birds of Britain and Ireland*. London: T & AD Poyser.

WindEurope. 2017. *Wind energy in Europe: Outlook to 2020.* www.windeurope.org

WindEurope. 2018. *Offshore Wind in Europe Key trends and statistics 2017*. www.windeurope.org.

Žydelis, R., Dorsch, M., Heinänen, S., Kleinschmidt, B., Morkūnas, J., Quillfeldt, P. & Nehls, G. 2017. High mobility of Red-throated Divers revealed by satellite telemetry. *From avian tracking to population processes 28 – 30 March 2017 | University of Warwick, UK.*