

FIRST BIOLOGGING RECORD OF A FORAGING RED-THROATED LOON *GAVIA STELLATA* SHOWS SHALLOW AND EFFICIENT DIVING IN FRESHWATER ENVIRONMENTS

JAMES DUCKWORTH^{1*}, SUSAN O'BRIEN², RONI VÄISÄNEN³, PETTERI LEHIKONEN⁴,
IB KRAG PETERSEN⁵, FRANCIS DAUNT⁶ & JONATHAN A. GREEN¹

¹*School of Environmental Sciences, University of Liverpool, Liverpool L69 3GP, UK* *(james.duckworth@liverpool.ac.uk)

²*Joint Nature Conservation Committee, Inverdee House, Baxter Street, Aberdeen AB11 9QA, UK*

³*Avescapes Oy, Vihdintie 3-5 B 21, 00320, Helsinki, Finland*

⁴*The Finnish Museum of Natural History, University of Helsinki, Helsinki 00100, Finland*

⁵*Department of Bioscience, Aarhus University, DK-8000 Aarhus C, Denmark*

⁶*Centre for Ecology & Hydrology, Edinburgh EH26 0QB, Scotland*

Received 26 July 2019, accepted 23 October 2019

ABSTRACT

DUCKWORTH, J., O'BRIEN, S., VÄISÄNEN, R., LEHIKONEN, P., PETERSEN, I.K., DAUNT, F. & GREEN, J.A. 2020. First biologging record of a foraging Red-throated Loon *Gavia stellata* shows shallow and efficient diving in freshwater environments. *Marine Ornithology* 48: 17–22.

Recently, Red-throated Loons *Gavia stellata* (RTL) have been the subject of increased interest due to their negative interactions with shipping, offshore wind farms, and other marine industry activities. This has driven a desire to quantify the behaviour and ecology of this understudied species, particularly during the non-breeding season. To achieve this, Time Depth Recorder (TDR) and Global Location Sensor (GLS) tags were deployed on individuals from several European locations. Due to an incidental mortality, one set of tags was retrieved early. The single set of tags recorded activity from June to August 2018. The TDR collected records for 14 d, providing the first ever biologging data on RTL foraging in Europe. The bird was tagged 90 km from the coast; therefore, it only used freshwater lakes and was never recorded entering saltwater. The individual mostly undertook shallow dives, with maximum and mean depths of 20 m and 5.4 m, respectively. Foraging constituted 22.9% of total activity during the sampling period. The RTL had diel foraging patterns, with dives being shallower and more frequent at times of “twilight” compared to “daylight.” These results provide novel information on an RTL’s diurnal patterns of water depth usage and foraging effort during the summer, demonstrating the potential of data loggers to provide key insights into the foraging ecology of this species

Key words: Red-throated Loon, Finland, foraging, time depth recorder, geolocator

INTRODUCTION

In recent years, Red-throated Loons *Gavia stellata* (RTL) have received increased attention because of their vulnerability to habitat loss from construction of offshore renewable energy structures and shipping (Garthe *et al.* 2004, Schwemmer *et al.* 2011, Mendel *et al.* 2019). Previous studies have provided insight into many important aspects of RTL ecology, including diet (Reimchen *et al.* 1984, Guse *et al.* 2009), foraging (Eriksson *et al.* 1991, Skov *et al.* 2001), and behaviour (Polak *et al.* 2007). As a result of research on diet, RTLs are known to be generalist piscivorous foragers (Eriksson 1985, Morkünè *et al.* 2016, Kleinschmidt *et al.* 2019), with prey that vary by geographic area (Guse *et al.* 2009). RTLs breed on freshwater ponds and lakes of different sizes during the summer, feeding on either freshwater (Eriksson *et al.* 1990, Eriksson *et al.* 1991) or marine prey (Reimchen *et al.* 1984, Rizzolo *et al.* 2015), with proximity to the coast being the likely driver of habitats used.

Recent advances in biologging techniques have facilitated a greatly improved understanding of aquatic top predator ecology and behaviour, especially winter behaviour and migrations (Rutz *et al.* 2009). Much of our current knowledge of RTL ecology is derived from empirical data collected by observing birds at a distance

(Eriksson *et al.* 1990, Eriksson *et al.* 1991, Rizzolo *et al.* 2015, Uher-Koch *et al.* 2018). However, RTLs breed at low densities (Solovyeva *et al.* 2017) and are highly sensitive to disturbance both at sea (Mendel *et al.* 2019) and at their breeding lakes (Rizzolo *et al.* 2014), limiting our ability to gain a full understanding of their ecology. Biologging techniques, which require few visits to an individual and relatively little disturbance, provide an ideal approach to answer specific questions about RTL foraging, water depth usage, and energetic budgets over long periods. However, this must be measured against the substantial difficulty of recapturing an RTL. Regardless, for a relatively under-studied species such as the RTL, even single biologging records can provide proof of concept for this approach (Sequeira *et al.* 2019).

During a larger project looking at breeding and non-breeding season energetics and foraging behaviour (O'Brien *et al.* 2018), a single Time Depth Recorder (TDR) and light-based Global Location Sensor (GLS) were recovered from a bird drowned in a gill net at the end of summer, three months after deployment. The data downloaded from these loggers provided the first biologging record of a foraging RTL in Europe, allowing estimates of diel patterns of depth usage and foraging behaviour. Here we (1) determine whether this individual remained in freshwater habitats during the breeding

season, (2) describe water depth usage and diving strategy, and (3) quantify diel patterns of diving.

METHODS

Study area

The bird was tagged at its nest site on a lake in Mäntyharju, southern Finland, on 04 June 2018, 90 km from the coast.

Deployment of loggers

In southern Finland, most RTLs in the study area nest on artificial rafts on small lakes (Nummi *et al.* 2013). Nests of RTLs were approached, causing the incubating diver to flush from the nest, following which a nest trap was laid to capture the bird on its return. Trapping was not attempted during the early stages of egg laying, nor when chicks were less than five days old (O'Brien *et al.* 2018). The single diver in this study was tagged on 04 June 2018 and found dead on 14 August 2018. After trapping, the pair continued incubation until 07 June, but on 08 June the nest had been abandoned. The pair laid a second clutch to a new nest by 25 June. This clutch failed by 25 July, when no divers were present at the breeding lake.

A Time Depth Recorder (TDR; Cefas G5 Standard TDR, dimensions: 8 mm × 31 mm, weight: 2.7 g) was attached to one 1.5 mm thickness plastic ring using cable ties and epoxy resin glue; the ring was then placed onto the leg of the RTL. A light-based GLS (Biotrack MK4083 Geolocator, dimensions: 17 mm × 10 mm × 6.5 mm, weight: 1.8 g) was attached to a plastic ring using the same methods as for the TDR tag and was fitted on the diver's other leg (for full methodology, see O'Brien *et al.* [2018]).

TDRs were programmed to sample barometric pressure as a proxy for depth every 6 s for 24 h, with a 4-d gap between sampling days. These sampling intervals were chosen to allow samples of dive behaviour to be gathered across the year, without impacting the ability to detect individual diving events. TDRs recorded dives with an accuracy of 0.1 m. GLS tags were set to record maximum light levels and saltwater immersion every 10 min (each 10-min record contained a number between 0 and 200, where 200 represents the tag being constantly immersed), for every day of deployment. The RTL was classified as being in saltwater when the GLS tag recorded any number greater than three (Fayet *et al.* 2016).

Data analysis

The baseline surface reading of a TDR can change over an extended study period (Elliott *et al.* 2009). A custom script was created (Appendix 1, available on the website), which shifted the dive profiles to set the barometric readings such that the surface was set to 0 m. The minimum value for the detection of a dive at each recording interval was 0.5 m, and only dives where the maximum depth exceeded 1 m were considered for analyses. These limits helped exclude any non-foraging dives or residual error from the shifting baseline (Falk *et al.* 2000).

The dives were analysed using a custom script in R (Appendix 1), and the following values were estimated for each dive: dive duration (duration of the dive event from first to last recording

> 0.5 m), maximum dive depth (lowest depth reached in dive), and surface time (time spent on the surface between the end of the dive and start of the next dive). The bottom time (the duration of time spent at depths deeper than 75% of the maximum dive depth; Tremblay *et al.* 2003) was also calculated for dives longer than 18 s. Dives shorter than 18 s would only have one or two data points due to the tag sampling frequency; therefore, the results would always have bottom times greater than half of the total dive length. Due to the resolution of dives, classification of dive shape was not possible.

To further define diving strategy, dives were classified into bouts, defined as a series of dives where the maximum surface time between each dive was less than 60 s. A 60-s cut-off was chosen based on the decreased frequency of surface times above 60 s (Fig. 1). Bouts with greater than four dives were defined as foraging bouts (Mehlum *et al.* 2001). Dive depth consistency (difference in maximum dive depth between the current and previous dive) was calculated for all dives within a foraging bout to determine whether dives within a foraging bout had similar depths.

To estimate the proportion of time spent foraging in relation to the time of day, we classified dives as occurring during “daylight” or “twilight”. For each dive, sun elevation angles were generated with the R package “oce” (Kelley *et al.* 2019) for the location of capture.

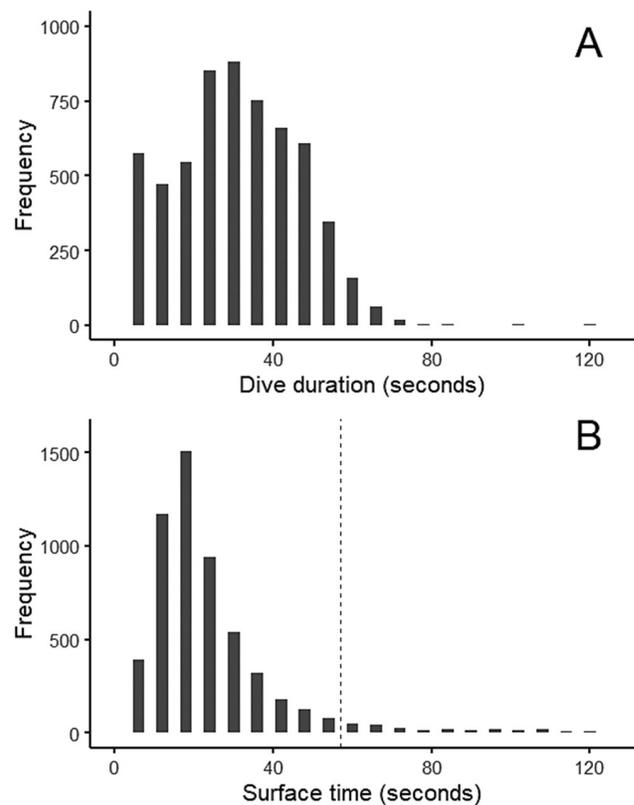


Fig. 1. (A) Frequency of dive durations across the study. The longest dive was 90 s. Each bar represents a 6-s interval. (B) Frequency of surface times between dives. The vertical dashed line shows the cut-off value, where dives with surface times below 60 s were considered to be within the same dive bout. No surface time above 120 s had a frequency greater than 20. Each bar represents a 6-s interval.

Location of capture was used to derive the sun elevation angle; because the bird was captured and recovered during the breeding season in the same part of Finland, it was assumed not to have left the area between initial tagging and being found dead. “Daylight” was defined as any sun angle above 0, and “twilight” was defined as a sun angle between 0 and -12 (Regular *et al.* 2011). Due to the high latitude of the study site and the time of year, < 1% of the records on the TDR and < 1% of recorded dives were at sun elevation angles below -12. Therefore, “night” was excluded, and all analyses of diel patterns include only “daylight” and “twilight” dives and timings.

The ratio of variances between maximum dive depths at “twilight” and “daylight” was high ($F = 3.007$, $P < 0.001$). Therefore, a Wilcoxon signed rank test was used to explore differences in maximum foraging depths reached during “daylight” and “twilight”. A Chi-squared test was used to test whether dives occurred uniformly across “daylight” and “twilight”, using expected values calculated from the proportion of “twilight” and “daylight” experienced by the bird. All data analyses and statistics were performed in R version 3.5.1 (R Development Core Team 2018). All means are given as \pm standard deviation.

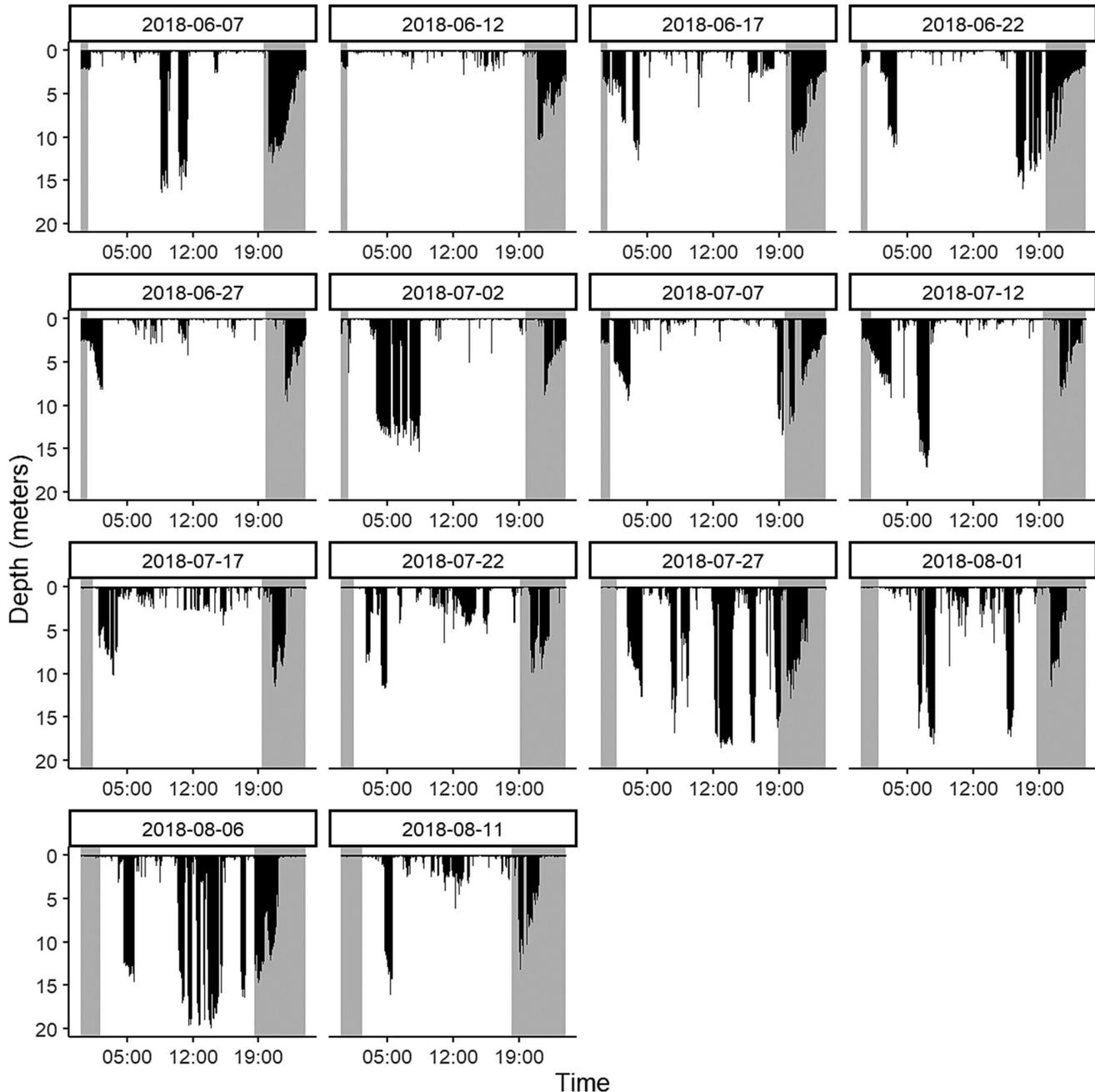


Fig. 2. Dive profiles of the Red-throated Loon (RTL) for the 14 d the Time Depth Recorder was active. The line represents the depth of the RTL at a given time. Shaded areas show times when the sun elevation angle was below 0.

RESULTS

Data were gathered from 07 June 2018 to 11 August 2018, for a total of 14 d and 66 d of TDR (Fig. 2) and GLS recordings, respectively. The GLS tag revealed that the saltwater immersion sensor had no positive readings for the duration of the study. This suggests that the bird never entered the marine environment and spent the entire deployment period on land and in freshwater habitats.

There were 5947 dives (Fig. 1A) and 687 dive bouts throughout the duration of the study: 235 bouts were classified as foraging and included 88% of all dives, whereas 22.9% of the time when the TDR was recording data was spent in a foraging bout. The RTL undertook an average of 425 ± 98 dives and 17 ± 6 foraging bouts per day with an average maximum dive depth of 5.4 ± 4.3 m (Fig. 3) and an overall maximum dive depth of 20 m. Foraging dive bouts comprised a highly variable number of dives, with an average of 22 ± 35 dives, but with 119 bouts containing < 10 dives. The longest bout had 339 dives and lasted 212 min. The mean surface time between dives within a foraging bout was 21.3 ± 10.5 s (Fig. 1B). Subsequent dives within a foraging bout differed in their maximum dive depth by 0.7 ± 1.4 m. The proportion of time at the bottom depths of the dive across dives longer than 18 s was 0.61 ± 0.18 .

Mean maximum dive depth during “daylight” hours (6.2 ± 5.1 m) was greater than during “twilight” hours (4.4 ± 2.9 m) ($W = 3957800$, $P < 0.001$). Dive frequency changed based on light levels ($X^2 = 1868.8$, $df = 1$, $P < 0.001$; Fig. 3), with the proportion of dives at twilight occurring more frequently than would be expected by chance. “Daylight” was recorded for 76% of the study and for 52% of the dives; “twilight” was recorded for 24% of the study and for 48% of the dives (Fig. 3).

DISCUSSION

This study used biologging technology to provide the first empirical data on RTL foraging depth and behaviour. In the bird studied, we found that dives were always < 20 m deep and varied according to light conditions, with dives tending to be shallower and more frequent during lower light levels. The RTL was capable of undertaking extended bouts of diving, lasting over three hours. Additionally, this study provides empirical evidence of an RTL foraging solely in freshwater environments. Together, these data generate interesting hypotheses regarding the foraging behaviour of Red-throated Loons.

A previous study found that bouts where the maximum dive depths were within 10% of the preceding maximum dive depth could be classified as benthic (Tremblay *et al.* 2000). Here, the average difference between subsequent maximum dive depths was slightly > 10% of the average maximum dive depth for all dives, which was 5.4 m. This suggests that, although there was some consistency in the depths to which the RTL dove, it is unlikely that the RTL was using a solely benthic foraging strategy. Moreover, the loon was found in a lake with a maximum depth of 29 m, which exceeds the maximum dive depth recorded across the study period. This implies that the dives were likely pelagic and/or that any benthic dives were in the shallower areas of the water.

Our results are consistent with data on RTLs from TDRs recovered by D. Rizzolo (pers. comm.), who recorded shallow dives (median 2.49 m, range 1.1–10.80 m) and a slightly deeper maximum dive

depth of 26.9 m. Winter observations of RTLs have revealed high densities of these birds at inshore marine areas with water depths < 20 m (Petersen *et al.* 2010). Together, these results indicate that the lack of deeper dives is likely due to physiological diving constraints or prey preference, rather than being limited by water column depth. However, analysis of more RTL diving profiles is needed to fully characterize the diving behaviour of this species in various habitats (Sequeira *et al.* 2019).

The reason for the observed increased rate of foraging during the twilight hours is unknown. One hypothesis is that there was an increased presence of prey in the shallower, more accessible areas of the lake, due to either lower oxygen levels at deeper depths (Kersten *et al.* 1991) or more favourable light conditions closer to the surface. An increased number of fish in the shallower areas could also provide an explanation for shallower dives at twilight. Additional research could explore whether dive shapes change over the different light levels of the day. This could be determined using a higher-frequency TDR setting to gain more recordings per dive (Schreer *et al.* 2001).

Other than laying a second clutch (Okill 1994), little is known about the activities of RTLs following a failed breeding attempt. Here, we demonstrate that a Finnish RTL can use an entirely freshwater habitat for foraging during the breeding season, and continue to remain in freshwater following two failed clutches. This behaviour is likely a consequence of the large distance of the breeding site from the coast. Other studies have shown that, during the non-breeding season, RTLs are entirely dependent on the marine environment (Guse *et al.* 2009, Morkünè *et al.* 2016); therefore, seeing one on freshwater during the winter is exceptional. This seasonal pattern suggests that RTLs are exposed to different stressors during different periods of the annual cycle, which dictates where they reside (Eriksson *et al.* 1990, Rizzolo *et al.* 2015). For this reason, with a better understanding of their year-round ecology and movements, RTLs could become a good multisystem indicator of habitat health (Cairns 1987).

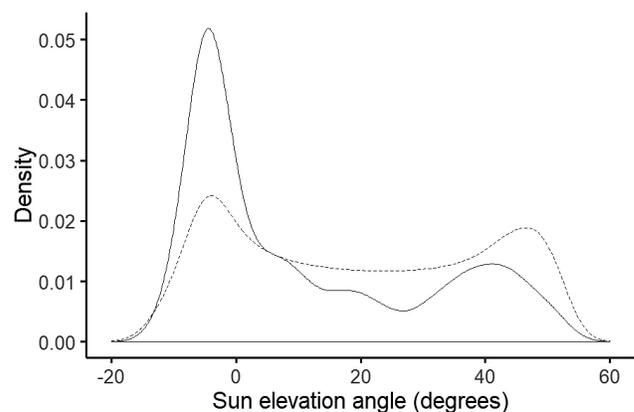


Fig. 3. Density graph showing timings of Red-throated Loon (RTL) dives relative to sun elevation angles, where the solid line represents the density of dives recorded from the recovered TDR at observed sun elevation angles through the deployment period, and the dashed line represents the density of time spent by the RTL at a sun elevation angle across the study period. Smoothing parameter: $h = 3$ for both densities.

ACKNOWLEDGEMENTS

All trapping and ringing of Red-throated Loons was undertaken with full permission, licenses, and permits in place. Specific permission for the work was granted by the Centre of Economic Development, Traffic and Environment (License Number: VARELY/1055/2018). Ringing license numbers for Petteri Lehtikoinen and Roni Väisänen were 2787 and 2854, respectively. We would like to thank the funders of the project: the Natural Environment Research Council (NERC), the Joint Nature Conservation Committee (JNCC as CASE partner on the PhD studentship to JD), the UK Department for Business, Energy and Industrial Strategy's offshore energy Strategic Environmental Assessment Programme, the Crown Estate, Vattenfall, Ørsted, and Equinor. We would also like to thank Marc Illa, Tuula Kyllönen, and Jari Laitasalo, who worked in the field, and Jani Volanen, who found the bird and returned the tags. D. Rizollo provided important comments that improved our paper.

REFERENCES

- CAIRNS, D.K. 1987. Seabirds as indicators of marine food supplies. *Biological Oceanography* 5: 261–271.
- ELLIOTT, K.H. & GASTON, A.J. 2009. Accuracy of depth recorders. *Waterbirds* 32: 183–191.
- ERIKSSON, M.O.G. 1985. Prey detectability for fish-eating birds in relation to fish density and water transparency. *Scandinavian Journal of Ornithology* 16: 1–7.
- ERIKSSON, M.O.G., BLOMQVIST, D., HAKE, M. & JOHANSSON, O.C. 1990. Parental feeding in the Red-throated Diver *Gavia stellata*. *Ibis* 132: 1–13.
- ERIKSSON, M.O.G. & SUNDBERG, P. 1991. The choice of fishing lakes by the Red-throated Diver *Gavia stellata* and Black-throated Diver *G. arctica* during the breeding season in south-west Sweden. *Bird Study* 38: 135–144.
- FALK, K., BENVENUTI, S., DALL'ANTONIA, L., KAMPP, K. & RIBOLINI, A. 2000. Time allocation and foraging behaviour of chick-rearing Brünnich's Guillemots *Uria lomvia* in high-arctic Greenland. *Ibis* 142: 82–92.
- FAYET, A.L., FREEMAN, R., SHOJI, A. ET AL. 2016. Drivers and fitness consequences of dispersive migration in a pelagic seabird. *Behavioral Ecology* 27: 1061–1072.
- GARTHE, S. & HÜPPOP, O. 2004. Scaling possible adverse effects of marine wind farms on seabirds: developing and applying a vulnerability index. *Journal of Applied Ecology* 41: 724–734.
- 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.
- KELLEY, D., RICHARDS, C. & CHANTELE, L. 2019. 'oce': R Package version 1.1-1 [Available online at: <https://CRAN.R-project.org/package=oce>. Accessed 20 June 2019].
- KERSTEN, M., BRITTON, R.H., DUGAN, P.J. & HAFNER, H. 1991. Flock feeding and food intake in Little Egrets: the effects of prey distribution and behaviour. *Journal of Animal Ecology* 60: 241–252.
- KLEINSCHMIDT, B., BURGER, C., DORSCH, M. ET AL. 2019. The diet of red-throated divers (*Gavia stellata*) overwintering in the German Bight (North Sea) analysed using molecular diagnostics. *Marine Biology* 166: 77.
- MEHLUM, F., WATANUKI, Y. & TAKAHASHI, A. 2001. Diving behaviour and foraging habitats of Brünnich's guillemots (*Uria lomvia*) breeding in the high-arctic. *Journal of Zoology* 255: 413–423.
- MENDEL, B., SCHWEMMER, P., PESCHKO, V., ET AL. 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.
- MORKÜNĒ, R., LESUTIENĒ, J., BARISEVIČIŪTĒ, R., MORKŪNAS, J. & GASIŪNAITĒ, Z.R. 2016. Food sources of wintering piscivorous waterbirds in coastal waters: a triple stable isotope approach for the southeastern Baltic Sea. *Estuarine, Coastal and Shelf Science* 171: 41–50.
- NUMMI, P., VÄÄNÄNEN, V., PAKARINEN, R. & PIENMUNNE, E. 2013. The Red-throated Diver (*Gavia stellata*) in human-disturbed habitats - building up a local population with the aid of artificial rafts. *Ornis Fennica* 90: 16–22.
- O'BRIEN, S., RUFFINO, L., LEHIKONEN, P. ET AL. 2018. *Red-Throated Diver Energetics Project - 2018 Field Season Report*. JNCC Report No. 627. Peterborough, Canada: Joint Nature Conservation Committee.
- OKILL, J.D. 1994. Ringing recoveries of red-throated divers *Gavia stellata* in Britain and Ireland. *Ringling & Migration* 15: 107–118.
- PETERSEN, I.K., NIELSEN, R.D., PIHL S., ET AL. 2010. LANDSDÆKKENDE OPTÆLLING AF VANDFUGLE I DANMARK, VINTEREN 2007/2008. Working Report from DMU, Aarhus University. Frederiksborgvej, Denmark: The Danish Environmental Research Institute.
- POLAK, M. & CIACH, M. 2007. Behaviour of black-throated diver *Gavia arctica* and red-throated diver *Gavia stellata* during autumn migration stopover. *Ornis Svecica* 17: 90–94.
- R DEVELOPMENT CORE TEAM. 2018. *R: A language and environment for statistical computing*. Vienna, Austria. R Foundation for Statistical Computing. [Available online at <https://www.R-project.org/>].
- REGULAR, P.M., HEDD, A. & MONTEVECCHI, W.A. 2011. Fishing in the dark: a pursuit-diving seabird modifies foraging behaviour in response to nocturnal light levels. *PLoS One* 6: e26763.
- REIMCHEN, T.E. & SHEILA, D. 1984. Feeding schedule and daily food consumption in Red-throated Loons (*Gavia stellata*) over the pre fledging period. *The Auk* 101: 593–599.
- RIZZOLO, D.J., SCHMUTZ, J., A., MCCLOSKEY, S.E. & FONDELL, T.F. 2014. Factors influencing nest survival and productivity of Red-throated Loons (*Gavia stellata*) in Alaska. *The Condor*: 574–587.
- RIZZOLO, D.J., SCHMUTZ, J.A. & SPEAKMAN, J.R. 2015. Fast and efficient: postnatal growth and energy expenditure in an Arctic-breeding waterbird, the Red-throated Loon (*Gavia stellata*). *The Auk* 132: 657–670.
- RUTZ, C. & HAYS, G.C. 2009. New frontiers in biologging science. *Biology Letters* 5: 289–292.
- SCHREER, J.F., KIT, M.K. & HARA HINES, R.J.O. 2001. Comparative Diving Patterns of Pinnipeds and Seabirds. *Ecological Monographs* 71: 137.
- 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: 1851–1860.

- SEQUEIRA, A.M.M., HEUPEL, M.R., LEA, M.A. ET AL. 2019. The importance of sample size in marine megafauna tagging studies. *Ecological Applications* 29: e01947.
- SKOV, H. & PRINS, E. 2001. Impact of estuarine fronts on the dispersal of piscivorous birds in the German Bight. *Marine Ecology-Progress Series* 214: 279–287.
- SOLOVYEVA, D., PARUK, J., TASH, J., ET AL. 2017. Post-breeding densities, population sizes and lake size partitioning of loon species in western Chukotka, Russia. *Contemporary Problems of Ecology* 10: 621–631.
- TREMBLAY, Y. & CHEREL, Y. 2000. Benthic and pelagic dives: a new foraging behaviour in rockhopper penguins. *Marine Ecology Progress Series* 204: 257–267.
- TREMBLAY, Y., CHEREL, Y., OREMUS, M., TVERAA, T. & CHASTEL, O. 2003. Unconventional ventral attachment of time–depth recorders as a new method for investigating time budget and diving behaviour of seabirds. *Journal of Experimental Biology* 206: 1929–1940.
- UHER-KOCH, B.D., KOCH, J.C., WRIGHT, K.G. & SCHMUTZ, J.A. 2018. Comparative nest survival of three sympatric loon species breeding in the Arctic. *Journal of Avian Biology* 49: e01671.
-