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Review of the migratory movements of Shelduck to inform understanding of potential interactions with offshore wind farms in the southern North Sea

Ros M.W. Green, Niall H.K. Burton and Aonghais S.C.P. Cook

BTO
Looking out for birds

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Report of work carried out by the British Trust for Ornithology on behalf of the Department for Business, Energy and Industrial Strategy's offshore energy Strategic Environmental Assessment programme.

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EXECUTIVE SUMMARY

1. Offshore wind farms (OWFs) may have a number of negative effects on waterbird populations. To inform the consenting process, the potential impacts of these key effects are assessed. A significant proportion of the north-west European population of Shelduck *Tadorna tadorna* migrate across the southern North Sea annually, and so may be exposed to these OWF effects.

2. The aim of this project was to provide an overview of the current knowledge of the migratory movements of UK populations of breeding and non-breeding Shelduck by conducting a literature review and analysing all Shelduck ring-recovery data from the British and Irish Ringing Scheme. Key knowledge gaps would then be identified, and recommendations for further work to fill these gaps would be made.

3. A literature review was conducted to find all sources of information on Shelduck distributions and movements within the north-west European population, with a focus on their migratory routes and timings, as well as their flight heights. The ring-recovery data were analysed in order to determine whether these could provide any further detail.

4. The results of the literature review found reasonable information on Shelduck distribution and the timings of their annual cycle. The majority of UK Shelduck migrate across the North Sea twice annually, travelling to and from a major moulting site in the Helgoland Bight. They generally leave Britain between late-June and early-August, and return any time between October and February. Those leaving pre-migration accumulation areas on the British west coast do so in large flocks on clear evenings with a favourable tail wind, usually around sunset, with the migration east happening overnight. In contrast, there is no clear information on when, where, or in what conditions Shelduck leaving the UK east coast migrate. Little is known about which individuals from the UK breeding range migrate to the Helgoland Bight, with some birds from the same breeding area remaining in the UK to moult, whilst others cross the North Sea to moult on the continent. It is also not currently possible to link individuals between their breeding, moulting and non-breeding areas, which makes it difficult to determine which individuals using the 32 designated SPAs that include Shelduck as a non-breeding feature are likely to interact with OWFs. No information on the specific migratory pathways was available from the literature review, and only one reference presented empirical data on Shelduck flight heights.

5. The results of the ring-recovery analysis broadly agreed with the information found during the literature review, confirming the north-west European distribution and the timings of movements within the annual cycle. It did not provide any extra information on the migratory pathways, speed of migration or flight heights.

6. Although the timings and final destinations of the Shelduck moult migration are relatively well documented, most primary literature is from the 1940s-1980s, with more contemporary literature suggesting the pattern may have changed in recent years. There is a need to update the knowledge on migratory routes and destinations in order to accurately assess potential OWF effects on the Shelduck population.

7. The biggest knowledge gaps are the lack of data on specific migratory routes across the North Sea, flight heights and what Shelducks' behavioural responses to offshore structures are. It is recommended that a tracking study is implemented to collect data to fill these knowledge gaps. The feasibility of a tracking study is discussed. Other knowledge gaps and recommendations are also outlined.

1. INTRODUCTION

1.1 Background

Offshore wind farms (OWFs) may have a number of negative effects on waterbird populations. These include the risk of collision with turbines, the OWF acting as a barrier to migrating or commuting birds, and displacement from preferred foraging (Drewitt & Langston, 2006; Furness, Wade, & Masden, 2013; Garthe & Hüppop, 2004; Masden *et al*., 2009).

To inform the consenting process, the potential impact of these key effects is assessed through an Environmental Impact Assessment (EIA) in relation to baseline populations from site to national and international levels. When preparing applications for Nationally Significant Infrastructure Projects (NSIP) under the Planning Act 2008, developers should also consider if the project is likely to affect an EU-designated site, and/or an EU-designated marine site, and undertake a Habitats Regulation Assessment (HRA) to identify sites and features which may be affected, and assess the potential for likely significant effects.

Assessing the potential effects of OWFs on migratory birds is hindered by a number of difficulties. While migration involves very large numbers of individuals, the bird surveys conducted to inform assessments are often inadequate to provide quantification of passage through particular sites. Some species will be missed because their migration is routinely at high elevation (Wernham *et al*., 2002), or because migration occurs at night or in weather conditions when surveys are not possible. Other species will be missed because migration occurs in a short time window, often as pulse events of short duration which are missed by the existing level of survey effort. Furthermore, migration routes and the numbers of birds migrating across sites may vary from year-to-year depending on environmental conditions (Newton, 2010). There have also been few studies that attempt to measure the flight heights of migrating birds (Gyimesi et al., 2017; Newton, 2010; Wright et al., 2012).

The north-west European population of Shelduck *Tadorna tadorna* is currently estimated at 250,000 individuals (Wetlands International, 2018), and breeds on or near the coast from France, Ireland and the UK through northern Europe to Scandinavia and the Baltic (Hagemeijer & Blair, 1997). The Shelduck is a large duck species, around 60 cm long, with a wingspan of ~120 cm and weighing between 703 and 1736 g in the UK (Patterson, 1982). They feed mostly on molluscs and other invertebrate prey, generally in intertidal regions, though terrestrial habitats may be used during the breeding season (Patterson, 1982). During the breeding season they remain in a monogamous pair with both individuals being strongly territorial, though 'territories' do not necessarily remain spatially stable throughout the season. 'Territories' are dependent on food, water and nesting burrow availability, and local breeding density, and vary greatly around the country. Generally a territory will include a nesting burrow (rabbit hole, nest box, hay/straw bale stack, under a shed) and an area of salt- or fresh-water with exposed mud (estuary, lagoon, river channel, lake, loch). The nesting burrow may be a couple of kilometres from the water and food source, with adults commuting between the two, and moving young chicks to the water source shortly after hatching. This generally leads to lower Shelduck densities in the breeding season compared to the non-breeding season, so no single site holds densities great enough for SPA designation. In the non-breeding season Shelduck are not territorial, so move to intertidal areas and co-exist with many other individuals of the species (Patterson, 1982).

Shelduck are a non-breeding feature of 32 Special Protection Areas (SPAs) in the UK (Stroud *et al.*, 2016; Figure 1), which have been designated on the basis that those sites hold more than 1% of the international population, or because the Shelduck are an important component of a non-breeding waterbird assemblage[1] There are no SPAs designated for **breeding** Shelduck in the UK; this is assumed to be because they breed at too low density for any single site to support more than 1% of the international breeding population (Figure 2).

The population distribution is widespread around the British and Irish coasts during breeding, passage and the wintering seasons, and has also been extending increasingly inland during the last 30 - 50 years. During the moulting period (late-summer) they can be found in flocks of hundreds of thousands at European coastal moulting sites (Blew *et al*., 2017; Goethe, 1961b, 1961a; Koffijberg *et al*., 2003; Meltofte, Blew, Frikke, Rösner, & Smit, 1994). While large moulting concentrations occur within Britain, notably on the Humber Estuary, The Wash, Bridgwater Bay in the Severn Estuary, the Firth of Forth (Frost *et al*., 2018), and the Mersey Estuary (Cheshire and Wirral Ornithological Society, 1999) many British and Irish birds move to the Helgoland Bight of the Wadden Sea, with very large numbers occurring in this area from mid-July to the end of August (Blew *et al*., 2017; Kempf & Kleefstra, 2013; Koffijberg *et al*., 2003; Meltofte *et al*., 1994; Patterson, 1982). Movements to these moulting sites, and those of continental and Scandinavian birds migrating to winter within Britain and Ireland (Wernham *et al*., 2002), potentially place birds at risk of barrier and collision effects with OWFs, particularly in the southern North Sea where numerous operational and planned OWFs are located (Figure 1).

There is thus a need for a better understanding of the migratory movements of Shelduck within the north-west European population, both with respect to their routes and timing, as well as their flight heights during migration. The aims of this project are to assess current knowledge of the species' movements, to provide information of use to assessment at individual wind farm, cumulative and strategic levels, and to provide recommendations to address outstanding knowledge gaps.

[1] http://jncc.defra.gov.uk/pdf/UKSPA/UKSPA-A6-27.pdf

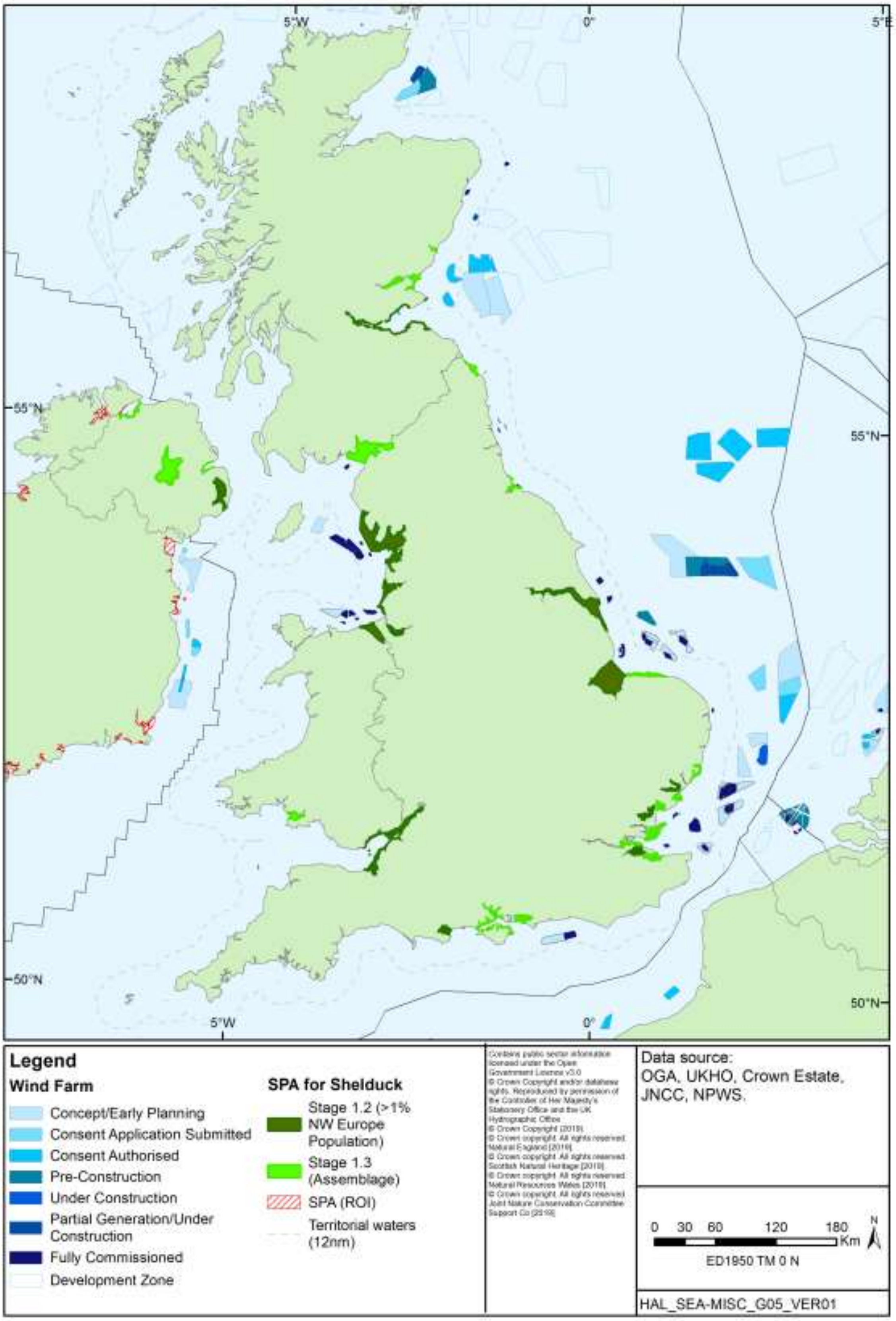

Figure 1. Map of Britain and Ireland displaying all offshore wind farm areas and the 32 SPAs for which Shelduck are a non-breeding feature.

1.2 Project aims

The aims of this project are to provide an overview of current knowledge on the migratory movements of UK populations of breeding and non-breeding Shelduck. In particular, the review provides:

i. A review of the literature on Shelduck distributions and movements within the north-west European population, highlighting existing knowledge of their migratory routes and timing, as well as their flight heights (if any);
ii. An analysis of ring-recovery data from the British and Irish Ringing scheme;
iii. A summary of key gaps in knowledge and recommendations for further work that could be conducted to fill these gaps, including considerations of the requirements for potential tracking studies.

2. METHODS

2.1 Literature Review

A systematic literature review was conducted using Web of Science, Google Scholar and the BTO's Chris Mead library. Either the species common name, 'Shelduck', or its scientific name*,' Tadorna tadorna'*, were used as primary fields, followed by one of the following: 'migration', 'movement', 'North Sea', 'flight height', 'flight', 'height', 'distribution', or 'Europe'. All search returns found in Web of Science and the BTO's Chris Mead library were read, and those that provided useful information on Shelduck distributions and movements within the north-west European population, highlighting information on their migratory routes and timing, as well as their flight heights (if any) were retained. At least the first 200 search returns in Google Scholar were assessed for the likelihood of containing information relevant to that outlined above, and retained if useful.

These references were combined with previously known sources of information on Shelduck distributions and movements within the north-west European population. These included recent atlases (Balmer *et al*., 2013; Hagemeijer & Blair, 1997) and reports from surveys, including the Wetland Bird Survey (WeBS) and its sister surveys in other countries that together feed into the International Waterbird Census (Blew *et al*., 2017; Frost *et al*., 2018; Kempf & Kleefstra, 2013; Koffijberg *et al*., 2003; Meltofte *et al*., 1994), as well as previous reviews of the species' movements (Patterson, 1982; Wernham *et al*., 2002; Wright *et al*., 2012).

All potentially relevant cited literature within those references found using the methods above were also checked, if accessible, to determine whether they contained relevant information.

2.2 Ringing Data

All Shelduck ringing-recovery data were extracted from the British and Irish Ringing Scheme databank. Recoveries are defined as those birds that were fitted with a unique identifying metal leg ring or colour-rings, and then subsequently recaptured or recovered, with the ring number or colour-ring combination reported to a ringing scheme. These data contained information on the original ringing and subsequent recovery location, date, age and sex of bird, capture method, duration between ringing and recovery date, and finding condition.

All ringing data were analysed using the "maprec" package (Robinson, 2018) in the statistical programme "R" (R Core Team, 2018), in order to identify the main directions of movement, considering whether these vary in relation to point of origin within Britain and Ireland, and assess the timing of these movements. The focus of the analysis was on data that represented movements across the North Sea, so those data that represented within-UK movements were excluded.

We also contacted all UK ringers with registered Shelduck colour-ringing schemes on European Colour-ring Birding[2], to request any data they may have on Shelduck movements across the North Sea. European Colour-ring Birding is a publically accessible website which lists all of the European avian colour-ringing projects that have been registered with the website. It does not contain an

[2]Shelduck colour-ringing studies registerd on European Colour-ring Birding are available at: http://www.cr-birding.org/colourprojects?tid_3=Common+Shelduck&tid_2=&tid=All&tid_1=2744&tid_4=All&tid_5=All

exhaustive list of all avian colour-ringing projects, but is generally accepted as the most comprehensive list of European colour-ringing projects available.

3. RESULTS

3.1 Literature Review

3.1.1 Background

During the literature review 61 reference sources were found that provided information on Shelduck distributions and movements within the north-west European population, highlighting existing knowledge of their migratory routes and timing, or presenting information on their flight heights. These spanned from 1942 to the present day, and provided information from all the countries within the known distribution of the north-west European population, as well as some information from the rest of the species' global range.

3.1.2 Population: distribution, estimates and trends

There are six recognised biogeographic Shelduck populations throughout the temperate latitudes of the Northern Hemisphere (Rose & Scott, 1994), with British and Irish breeding Shelduck being recognised as part of the north-west European breeding population (Stroud *et al*., 2001). This population extends from the western coast of Ireland, through Britain, along the European coasts of the English Channel and North Sea, up to Scandinavia and through to the Baltic coast (Balmer *et al*., 2013; Hagemeijer & Blair, 1997; Linton & Fox, 1991; Patterson, 1982).

The distribution of breeding and non-breeding Shelduck in Britain and Ireland is mainly coastal, with an increasing number of inland records over the last 30 – 50 years (Figure 2 and 3), where suitable habitats are available (Linton and Fox, 1991; Balmer *et al.*, 2013). This distribution is similar throughout the north-west European population, with a stronger tendency for coastal distributions on the continent (Hagemeijer & Blair, 1997).

The breeding and wintering relative abundances of Shelduck within Britain and Ireland are displayed in Figure 2. These relative abundances are calculated using those tetrads (2x2 km OS square) where Shelduck were found to be present in the appropriate seasons during the 2007-2011 Atlas survey. There are equal numbers of squares for each of the ten colour tones, so each tone represents one tenth of the species abundance. For example, the darkest colour tone indicates the 10% of squares with the highest abundance, and the palest tone indicates the 10% of squares with the lowest abundance. The tendency for coastal abundance and distribution is evident.

The distribution changes over time within Britain and Ireland are displayed in Figure 3. These suggest a generally increasing trend for inland records both in the breeding and non-breeding season, though it should be noted that the inland records in the non-breeding season (Figure 2b and 3b) are mostly in February, when Shelduck are returning to breeding sites or on passage from their coastal wintering areas.

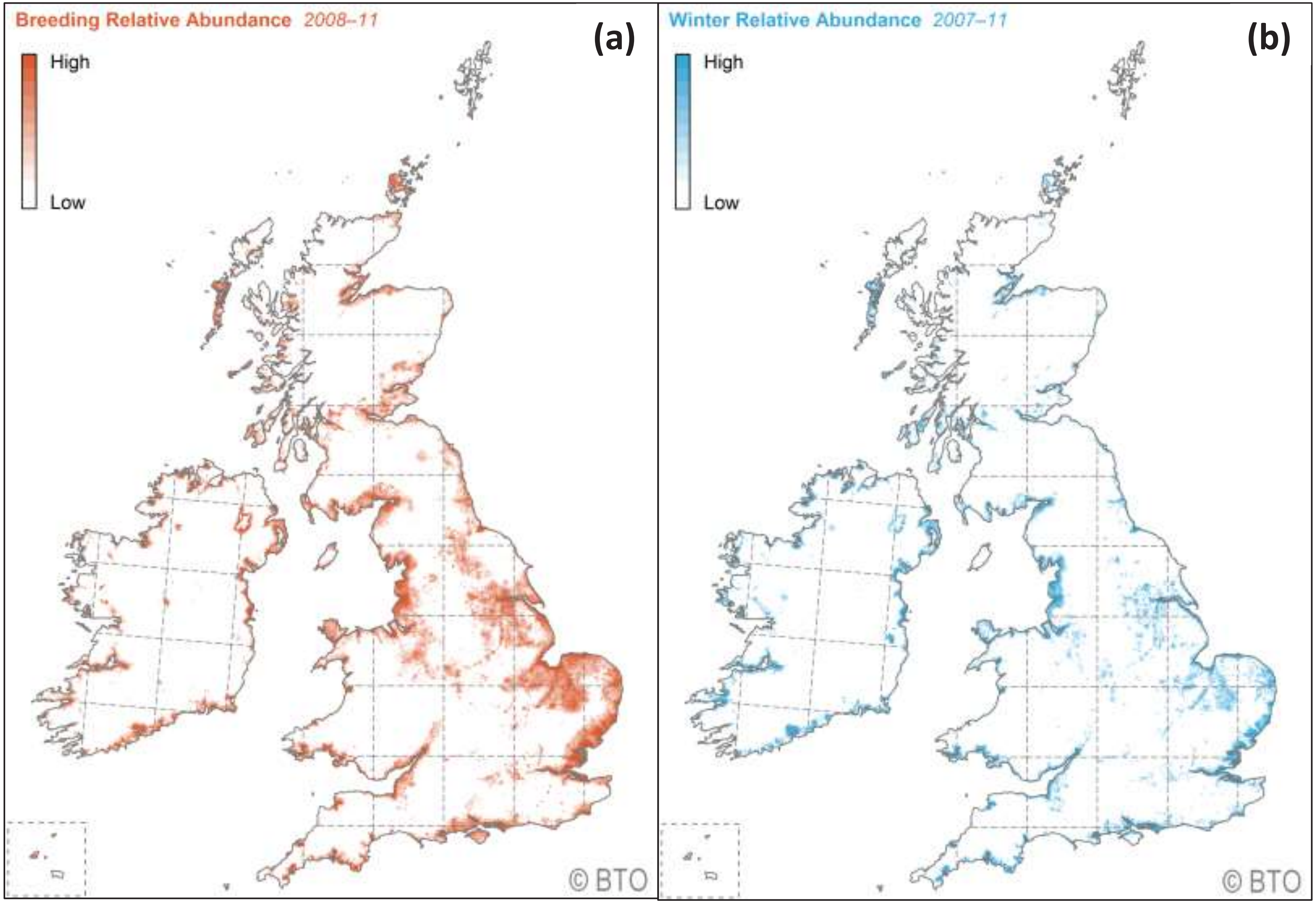

Figure 2 Relative abundance of the British and Irish Shelduck population during a) the breeding season; and b) the non-breeding season. Distribution maps from Bird Atlas 2007-11 which is a joint project between BTO, BirdWatch Ireland and the Scottish Ornithologists' Club. Maps reproduced with permission from the BTO.

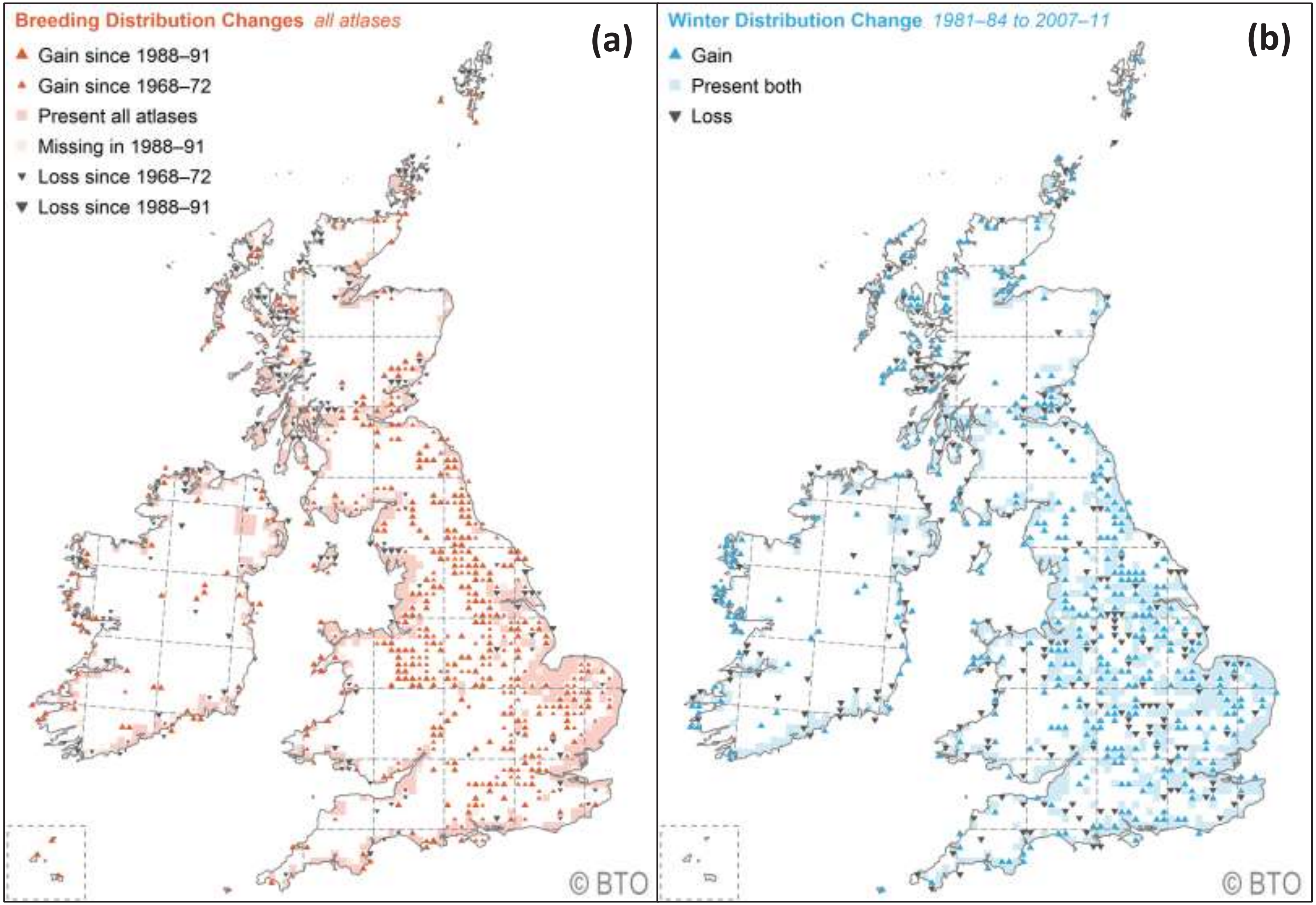

Figure 3 Distribution changes of the British and Irish Shelduck population over time in a) the breeding season; and b) the non-breeding season. Distribution maps from Bird Atlas 2007-11 which is a joint project between BTO, BirdWatch Ireland and the Scottish Ornithologists' Club. Maps reproduced with permission from the BTO.

The UK (England, Scotland, Wales and Northern Ireland) has approximately 15,000 breeding pairs (BirdLife International, 2015; Musgrove *et al*., 2013), and the Republic of Ireland has approximately 958. The combined British and Irish breeding population represents ~25% of the north-west European breeding population of 50,800 – 68,900 pairs (BirdLife International, 2015). In the non-breeding season, Britain (England, Wales and Scotland) has approximately 47,000 individuals distributed around the coast and inland (Frost *et al*., 2019), and Ireland (Northern Ireland and the Republic) has approximately 14,610. The combined British and Irish non-breeding population represents ~25% of the north-west European non-breeding population of 250,000 individuals[3]. Full details of breeding and non-breeding estimates over time can be found in the supplementary information.

Shelduck is listed as 'Least Concern' on the Global IUCN Red List (IUCN, 2018), and the European IUCN Red List (BirdLife International, 2015). This is based on European data that show Shelduck have a large range (almost all European countries), the population trends appear to be increasing, and the population size is also large (250,000 individuals). The trends reported for the north-west European population as a whole suggest there has been a 1.6% (± 0.35% SE) increase between 1967 – 2015[4] (BirdLife International, 2015). However, Shelduck is listed as 'Amber' under the Birds of Conservation Concern 4 list (Eaton *et al*., 2015), based on a reported 41% decline in the UK breeding population over 25 years, though the source of this figure cannot be verified. The most recent Breeding Bird Survey trend for the last 22 years (1995 – 2017) suggests the UK breeding population decline has been 9% over this period (Harris *et al*., 2019). For the UK non-breeding population, Frost *et al.* (2018) reports a 33% decline over the last 25 years, and a 23% non-breeding decline over the last 10 years. For a more full assessment of published population trends and estimates, please see the Electronic Appendix 2.

No peer-reviewed suggestions for this decline were found within the scope of this review, but Richard Hearn from WWT has suggested that a changing climate may be a factor, as is seen in many other duck species declines[5]. Holt *et al.* (2012) have suggested that climate shifts mean that more Shelduck remain on the continent for the winter, and so the British non-breeding population has declined as a result of fewer continental birds over-wintering in Britain. In contrast Stroud *et al.* (2016) review of the status of UK SPAs in the 2000s states that modelled impacts of climate change by 2050, under a medium emissions scenario, may increase spring passage numbers within the UK SPA suite for Shelduck, with poor confidence, by 25-50%.

3.1.3 Migratory routes and timings

Shelduck exhibit a different migratory strategy to most other migratory avian species, which migrate between separate breeding and non-breeding locations. Adult Shelduck instead migrate from their breeding grounds to a suitable moulting location, and then back to their breeding country for the remainder of the non-breeding period (Coombes, 1949; Goethe, 1961b; Hoogerheide & Kraak, 1942; Patterson, 1982). Juvenile Shelduck (birds in their first year) do not moult their flight or tail feathers, and so do not make this moult migration.

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3 http://wpe.wetlands.org/search?form%5Bspecies%5D=Tadorna+tadorna&form%5Bpopulation%5D=&form%5Bpublication%5D=10

4 http://iwc.wetlands.org/index.php/aewatrends

5 https://monitoring.wwt.org.uk/2015/04/uk-waterbirds/webs/shelduck-declining-in-the-uk/

During the moulting period Shelduck are completely flightless, and so are more vulnerable to disturbance and predation (Salomonsen, 1968). Extensive mudflat areas, or those with soft glutinous mud that is hard to move through, offer good protection from predation and human disturbance, whilst providing abundant food resources, and so are perfect sites for this moulting and feather re-growing period. There are several known sites that provide this habitat, with the majority of the British and Irish Shelduck population migrating to the Elbe estuary area of the Helgoland Bight in the German Wadden Sea (Bryant, 1978; Coombes, 1949; Eltringham & Boyd, 1963; Hoogerheide & Kraak, 1942; Patterson, 1982), which has extensive mudflats, whilst others remain in five known UK sites – Bridgwater Bay (Eltringham & Boyd, 1963), the Mersey Estuary (Cheshire and Wirral Ornithological Society, 1999), The Wash, the Humber Estuary and the Firth of Forth (Bryant, 1978). Any Shelduck that migrates from Britain or Ireland to the Helgoland Bight, or other areas of coastal Europe, has the potential to interact with OWFs.

Multiple sources suggest that British and Irish breeding Shelduck begin this migration in late-June or early-July, with immature birds (>1 year but not yet breeding) and adults that have failed to breed successfully leaving first, followed by successful breeders in late-July to early August, once ducklings have fledged (Bryant, 1978; Coombes, 1949; Patterson, 1982). Once Shelduck have reached their moulting grounds, the complete moulting and feather re-growing process normally takes between 25-31 days (Patterson, 1982). Those that migrate to the Helgoland Bight drop all their flight and tail feathers and remain in the area for ~12-14 days (Oelke, 1974), before spreading out into the rest of the Wadden Sea (Goethe, 1961b) to complete their moult. The peak counts of individuals in the Helgoland Bight (~100,000) are usually in late-July / early-August, confirming that most birds will have reached the area by this point (Goethe, 1961b; Kempf & Kleefstra, 2013). There is then a reported gradual return of Shelduck to Britain and Ireland (Coombes, 1949; Koffijberg *et al*., 2003), with birds potentially returning down the Dutch coast (Meininger & Snoek, 1992), to southern England first, and then moving further north and west throughout the winter (Evans & Pienkowski, 1982; Symonds, Langslow, & Pienkowski, 1984; Wernham *et al*., 2002; Wright *et al*., 2012) in order to return to their breeding areas by March. There is evidence to suggest that some birds may return directly to their breeding grounds after moulting, rather than returning gradually via the route suggested above (Goethe, 1961b; Symonds and Langslow, 1984; Cimiotti *et al*., 2013). Many continental breeding Shelduck also migrate to Britain and Ireland during the non-breeding season, presumably to take advantage of the milder winter climate (Symonds & Langslow, 1984; Wright *et al*., 2012).

Figure 4 represents the timing of the major periods of the Shelduck annual cycle. Darker colours represent the period in which the majority of the population are theoretically in that state. The breeding period refers to the time when individuals have paired up and are defending their breeding territory; the moulting period refers to the time after they have left their breeding territory on moult migration; the non-breeding period refers to the time when they have completed moult, but are not yet defending their breeding territory.

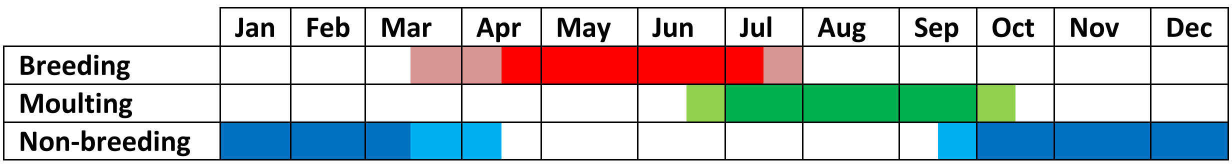

Figure 4. Illustration of the annual cycle of breeding adult Shelduck, split into the three major portions of their annual migratory cycle.

Within Britain and Ireland the Wetland Bird Survey (WeBS) is conducted annually, primarily throughout the non-breeding season, with count data at 2000+ wetland sites (5000+ sub-sites) collected at monthly intervals. The data from WeBS (Figure 5) are consistent with the annual cycle outlined above with counts being highest in January when both the British and Irish, and continental populations should be present on major wetland sites, and lowest in May when all adults should have dispersed to their breeding grounds, with some moving inland away from count sites, and continental breeders travelling back to the continent. There is a slight peak in July when adults aggregate in wetland areas before migrating to moult.

Figure 5 displays the monthly data trends for the 2017/18 WeBS data (Frost *et al*., 2018). The mean and range are presented for 2012/13 – 2017/18, with green bars representing the 2017/18 indices for each month. Indices are calculated and imputed to account for incomplete surveys at certain sites between years. Annual index values are expressed relative to the highest index in the most recent year, which takes an arbitrary value of 100.

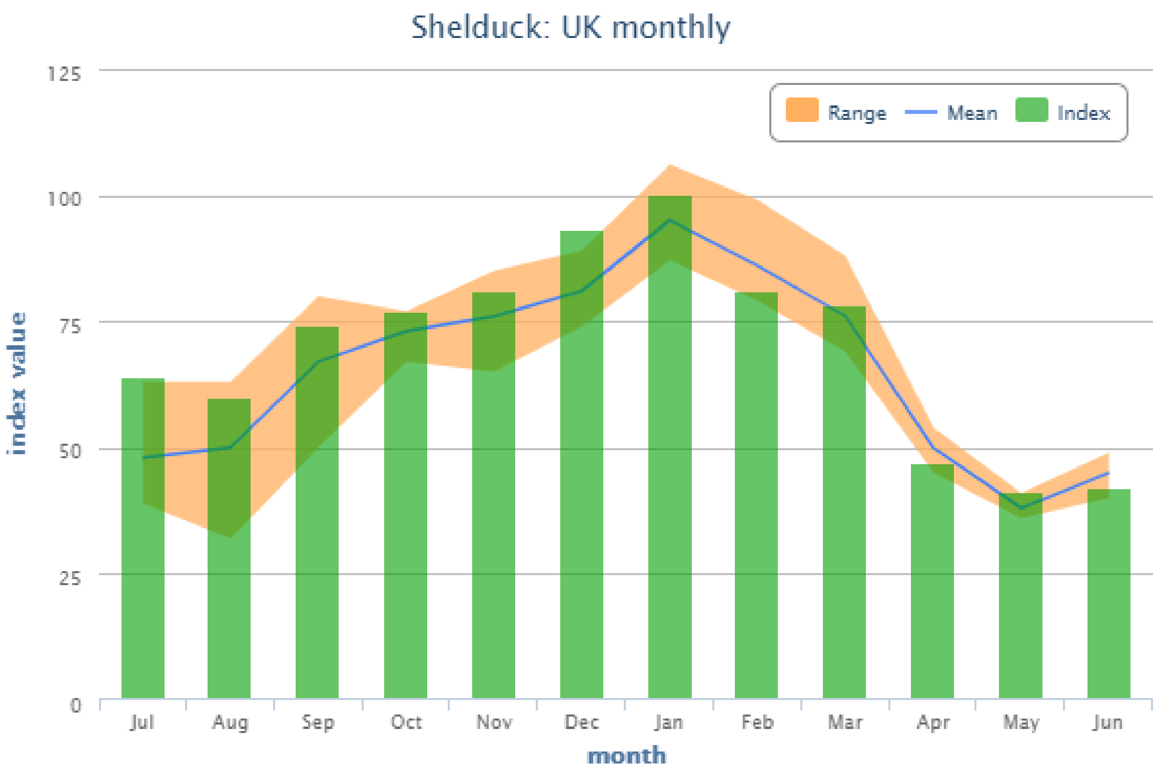

Figure 5. Monthly trends in Shelduck counts made during the Wetland Bird Survey 2017/18, and five year mean and range in count data. Figure reproduced from Frost *et al*. (2018) with permission from the BTO.

Specific departure routes / bearings of birds migrating from the east coast have not been reported, but those of west coast birds have been (Coombes, 1949, 1950; Eltringham & Boyd, 1963; Patterson, 1982). Coombes (1950) reports that Shelduck migrating from Morecambe Bay between the late 1930s and 1949 all left on an easterly bearing, flying over land, in a direction consistent with a flight to the Helgoland Bight, though no confirmation of their final destinations was made. Eltringham and Boyd (1963) reported a similar flight line towards the Helgoland Bight by birds leaving the Severn Estuary, with one being recovered dead on the Wash. Birds tended to leave in large flocks, on clear nights, with a favourable tail wind, at dusk (Morley, 1966; Patterson, 1982). Salomonsen (1968) reported that "Shelduck collect in flocks and then leave at sunset, probably covering the whole distance in a single night. The migration usually follows a straight line, these normally coastal birds crossing the mainland of England and Jutland"; it is not clear where Salomonsen gathered this information from, or what is meant by 'whole distance'. As he refers to "crossing the mainland", it is possible that his information is inferred from the west coast studies published by Coombes (1949, 1950) and Eltringham and Boyd (1963), as east coast birds would not have to cross the British mainland.

The timing of the moult and migration may be affected year-to-year by poor breeding seasons or poor weather, or in the longer-term by climate change. Goethe (1961a) reported that the moult period in 1954 was significantly extended into October compared to the years before and after, due to very rainy and cold weather, which may also have delayed birds' departure from Britain and Ireland. Salomonsen (1968) reported that in years when the breeding period is postponed, the moult is correspondingly delayed, with birds occasionally moulting some feathers before making the migration to the usual moult location.

Overall it seems the departure of British and Irish birds to the Helgoland Bight occurs between late-June and late-August each year, with a concentrated period in July, with birds essentially making a direct flight from their departure point. Birds return more gradually between October and January.

3.1.4 Flight heights / speed

Very few references containing Shelduck flight height information were found during the literature review. Only one contained detailed direct observational information, with a reasonable sample size (Kruger & Garthe, 2001), with one other suggesting they agreed with these findings, though not actually reporting direct figures on Shelduck (Fijn *et al*., 2012). Two further studies suggested that they collected Shelduck flight height data, but did not report the figures due to low sample sizes (Rothery *et al*., 2009; Heiss, 2016), and one final report that summarised all Shelduck tracking studies to 2017 reported that none had successfully collected flight height data (Gyimesi *et al*., 2017).

Kruger and Garthe (2001) observed all birds migrating away from Wangerooge Island, Germany, for 52 days between 1 September and 15 November 1999. They categorised the flight height of birds into four height bands: Low (sea level to 1.5 m), Medium (1.5-12 m; eye level of observer from top of island cliff), High (12-25 m), Very High (25 m+), and recorded the wind direction at the time. They observed 1,013 Shelduck in total, and found that 75% flew in the 'low' height band when flying into a headwind (23% medium, 2% high), but when flying with a tail wind the preference was to fly in the 'high' height band, with 51% doing so (15% low, 1% medium, 3% very high).

The other study that corroborated these results was Fijn *et al.* (2012). They observed birds passing a gas production platform (K14) in the North Sea, approximately 80 km west-north-west of the Dutch coast, and categorised all flights into height bands comparable to Kruger and Garthe (2001). Shelduck were only recorded incidentally during a visit in September, and categorised with the 'other ducks' when flight heights were reported. The figures suggest that all 'other ducks' passing K14 remained below 3 m. However, those 'other ducks' recorded by radar passing a near-by wind farm (OWEZ) were recorded flying at 20 m ± 10 m. It should also be noted that this study did not collect data between mid-June and the last day of August 2010; this is the period through which the concentrated part of the moult migration would be occurring.

Only one reference to Shelduck flight speed was found, with seven measurements being reported between 57-61 mph (91-98 kmh), with a 60 mph (96 kmh) average (Morley, 1966; Patterson, 1982).

These measurements were taken by timing the flight of migrating Shelduck between 2 known points in Bridgwater Bay in 1964, and calculating the flight speed between them. The known points could have been as much as 14 miles apart, so the flight speed estimates made may not necessarily be accurate.

3.1.5 Moult location shift

It has been noticed recently that there may be a shift in the favoured moulting location of Shelduck within the Wadden Sea. Kempf and Kleefstra (2013) have reported an apparently new significant moulting aggregation within the Dutch Wadden Sea (see figure 9, point 6), with ~66,000 birds counted in August 2012, which corresponds to a similar drop in the count totals within the Helgoland Bight (see figure 9, point 7). Meltofte *et al.* (1994) reported a shift in local site preference within the Helgoland Bight away from Knechtsand towards Scharhörn, due to the near-complete erosion of Knechtsand island, which could no longer provide protection for birds in poor weather. It seems the current shift towards the Dutch Wadden Sea may also be driven by habitat suitability for moulting birds.

3.1.6 Tracking studies

We found information on eight Shelduck tracking studies in total. All of these have collected some form of location data on Shelduck movements, though none have successfully collected data on flight heights or speed. Also none are known to have collected data on a Shelduck movement across the North Sea. A summary of each study, with the device type, attachment methods, and result reporting type, is outlined below for reference.

1) Oelke (1974) mounted radio-tracking devices using harnesses to five adult individuals in the Wadden Sea, to track their movements during the moulting period. He found that they generally moved 3–8 km between feeding and resting areas, and seemed to drift passively on the tide when resting. He estimated that they only stayed in the Knechtsand area for 12-14 days.
2) The Royal Belgian Institute of Natural Sciences tagged five adult Shelduck in Belgium in 2009 using GPS PTT tags. The attachment methods and results are unreported, and the study has only been reported in brief by Gyimesi *et al.* (2017). Data are potentially available if purchased.
3) Staff from the Research and Technology Centre (FTZ) and NABU in Germany equipped 11 Shelduck with GPS-satellite tags in order to track their movements around the Wadden Sea. The attachment method is not known, but data was retrieved for an entire annual cycle, so it is likely that harnesses were used. No data have been published, other than conference proceedings from the 37th annual meeting of the Waterbird Society (Cimiotti *et al*., 2013) and, in turn, by Gyimesi *et al.* (2017).
4) The Royal Belgian Institute of Natural Sciences tagged two juvenile Shelduck in Belgium in 2014 using GPS-GSM tags, apparently using harnesses (interpreted from photograph). The results are unreported, though the data could potentially be purchased. The study has only been reported in brief by Gyimesi *et al.* (2017).
5) The Royal Belgian Institute of Natural Sciences tagged eight adult male Shelduck in Belgium in 2015 using GPS-GSM tags, apparently using harnesses (interpreted from photograph). The results are unreported, though the data could potentially by purchased. The study has only been reported in brief by Gyimesi *et al.* (2017).
6) The BTO in collaboration with WWT tagged 30 adult Shelduck during the non-breeding period on the Severn Estuary SPA, using GPS-UHF tags. These were attached via glue mount

to the back feathers/skin. Partial data were retrieved from 29 birds on winter movements around the estuary and surrounding land, though these have not been publicly reported. The resolution of the GPS data received is not sufficiently high enough to calculate flight height or speed.

7) Wang *et al.* (2018) tagged 14 adult Shelduck in Mongolia in July 2017, using GPS-GSM tags fitted with a harness, in order to track their autumn migration from moulting areas in Mongolia to wintering areas on the Chinese coast of the Yellow and East China Seas. Location data were received from 10 birds, and reported in the paper. The tags were programmed to record altitude and velocity, but no flight heights or speeds were reported.
8) Leander Khil from St. Martins Lodge, Austria, tracked 2 adult Shelduck from July to September 2018 using 25g GPS-GSM Ornitela OT-25 tags attached using a harness, in order to track their moult migration from Neusiedler See-Seewinkel National Park, Austria[6]. One of these birds died 1 month after tagging with suspected botulism, whilst still in the original tagging area. The other migrated overland to Hamburg, Germany, before being predated by a fox one month after tagging.

[6] Movebank study - https://www.movebank.org/movebank/#page%3Dstudies%2Cpath%3Dstudy522309921

3.2 Ringing Data Analysis

3.2.1 Background

We identified 1501 recovery records of Shelduck from the British and Irish Ringing Scheme, between 1908 and 2017. All of the recoveries were either of Shelduck (i) ringed in Britain and Ireland and recovered within Britain and Ireland; (ii) ringed in Britain and Ireland and recovered on the continent; or (iii) ringed on the continent and recovered within Britain and Ireland. Figure 6 displays a summary of these data for each country within the north-west European range of the Shelduck. Yellow figures display the number of Shelduck ringed in each country that have subsequently been recovered anywhere; this figure does not include those Shelduck that were ringed, but never recovered afterwards. White figures display the number of Shelduck recovered in each country. This gives a general overview of the amount of ringing and recovery activity within each country, and the level of interchange between Britain and Ireland, and the continent. The majority of continental recoveries come from the Netherlands and Germany, which is to be expected given the Wadden Sea moulting sites, and few recoveries extend beyond the documented bounds of the north-west European population. This confirms what is reported within the literature.

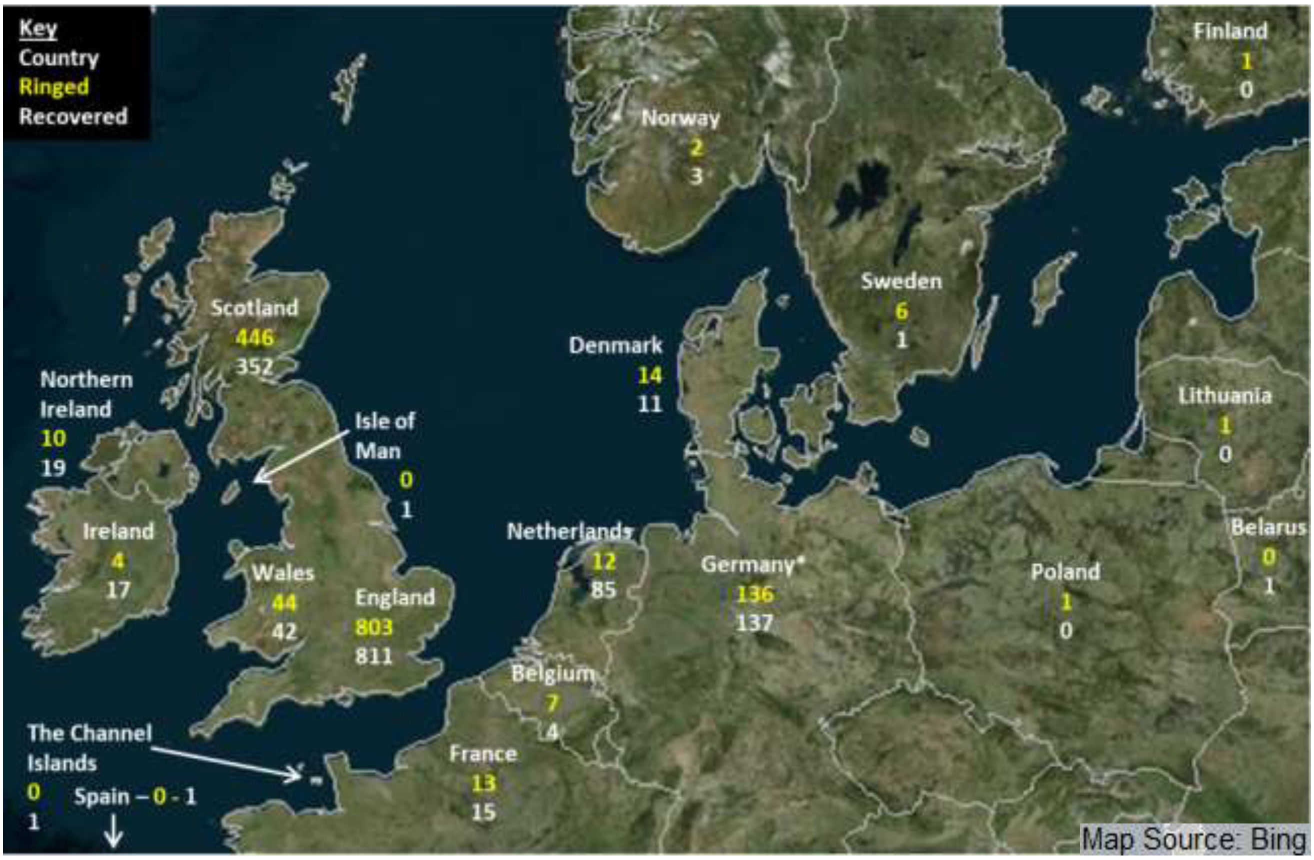

Figure 6. Ringing and recovery data for Shelduck from the British and Irish Ringing Scheme between 1908 and 2017. Yellow figures display the number of Shelduck that have been ringed in each country and subsequently recovered, and in white those that have been recovered within each country. *German records + birds reported as coming from/to the North Sea.

Figure 7 displays the location of all recovery points across Europe. This matches the preferred distribution of Shelduck that is reported in the literature, showing a mainly coastal distribution with fewer inland records. It also suggests that Shelduck found within Britain and Ireland at any time of year very rarely travel beyond western Europe.

Figure 7. The locations of all recoveries of Shelduck recorded by the British and Irish Ringing Scheme between 1908 - 2017.

In the ringing data the finding condition of each recovered bird was also reported, so it was known whether the Shelduck were recovered alive (i.e. caught by ringers), freshly dead (i.e. shot and immediately recovered), or found after a period of time (>1 week; i.e. found on tideline). Table 1 summarises these data, and displays the finding areas, age classes, and finding conditions. These data mirror what would be expected given the literature review, with few juvenile movements being recorded across the North Sea. Records from the 'UK/ROI' include birds ringed or recovered in England, Wales, Scotland, Northern Ireland, Republic of Ireland, or the Isle of Man; records from the 'continent' include birds ringed or recovered in Belarus, Belgium, Channel Islands, Denmark, Estonia, Finland, France, Germany, Lithuania, North Sea, Norway, Poland, Spain, Sweden or The Netherlands; Adult refers to the age at recovery which would be >1 year; juvenile refers to the age at recovery which would be <1 year.

Table 1. Summary of Shelduck recovery data by ringing and recovery area, age class and finding condition.

	(1) Ringed UK/ROI –> recovered UK/ROI	(2) Ringed UK/ROI –> recovered continent	(3) Ringed continent –> recovered UK/ROI
Adult	**850**	**246**	**171**
Alive	406	18	22
Freshly dead (<1 week)	138	65	33
Long dead (>1week)	306	163	116
Juvenile	**196**	**15**	**23**
Alive	24	1	2
Freshly dead (<1 week)	58	8	9
Long dead (>1week)	114	6	12
Total	**1047**	**260**	**194**

For the purposes of this review, the focus of interest was on recoveries that represented movements across the North Sea. Those data representing within UK/ROI movements were therefore filtered out from further analysis. This left 260 movements of birds ringed in the UK/ROI and subsequently recovered on the continent (Table 1, column 2), and 194 movements of birds ringed on the continent and recovered in the UK/ROI (Table 1, column 3). For those birds that were discovered after an extended period of time (Table 1: Long dead (>1 week)), there is some uncertainty around the finding location, as birds may have been moved from the location where they originally died (i.e. by ocean currents, predators or humans). Therefore, when analysing movements across the North Sea, only birds found alive or freshly dead were considered, leaving 92 movements from the UK/ROI to the continent and 66 movements from the continent to the UK/ROI.

3.2.2 Movements across the North Sea

When all recoveries that represent movements across the North Sea, for birds recovered alive or freshly dead, are mapped by season the pattern again corroborates that reported in the literature (Figure 8). The majority of continental recoveries made of British or Irish ringed birds occur during the moulting and immediate post-moulting period (August – November), whilst the majority of British or Irish recoveries made of birds ringed on the continent occur during the winter months, when continental birds over-winter in Britain and Ireland, or have returned to their breeding areas after moulting on the continent.

However, the temporal resolution of these data do not provide any more detailed information on specific migratory paths than the literature. The quickest recovery that represents a movement across the North Sea was of an adult female ringed at Icklesham, Sussex, UK, and recovered alive 58 days later at De Haukes, Noord-Holland, The Netherlands. A straight line route between these two points passes through three operational OWFs, but the data available cannot confirm what route was actually taken.

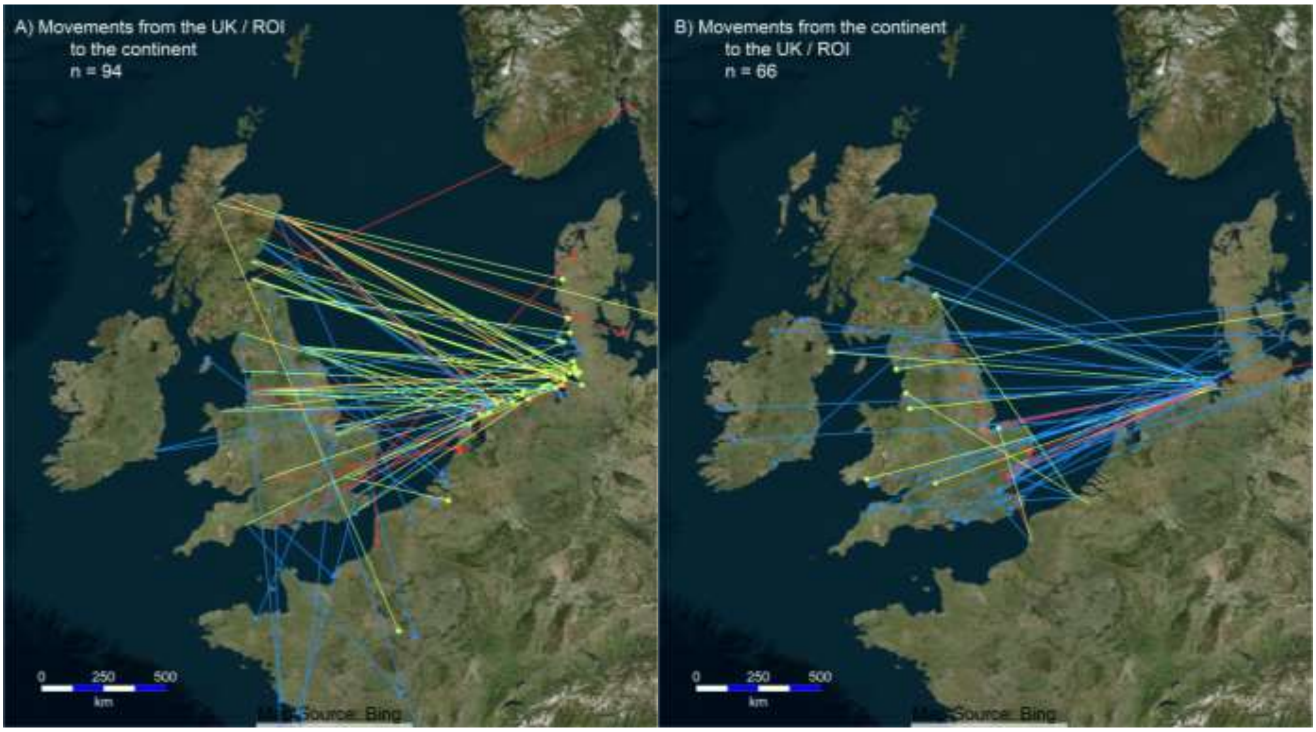

Figure 8. Sheldvck movements across the North Sea. These are colour coded by the period of the annual cycle for: A) birds ringed in the UK and recovered alive or freshly dead on the continent; and B) birds ringed on the continent and recovered alive or freshly dead in the UK. The recovery location is represented by a dot at the end of the line. The breeding period (in red) is defined as April-July; the moulting period (in pale yellow) is defined as August-November; the wintering period (in blue) is defined as December-March.

3.2.3 Annual cycle

The ringing recovery data also broadly agree with the British and Irish breeding Shelduck annual cycle as reported in Patterson (1982). When only considering recoveries of those birds originally ringed during the breeding season (April-July), and recovered live or freshly dead, it can be seen that very few of these birds are recovered on the continent between November and August each year, but that many recoveries are made during September and October. This matches the pattern reported in the literature, with British and Irish breeding Shelduck being expected in the Helgoland Bight between July and October, but not outside this period. The lack of recoveries during July and August is likely due to the fact they are incredibly wary whilst in active wing moult, and so will not enter areas where they can be recovered easily. Monthly recovery maps of British and Irish breeding Shelduck can be found in Appendix 1.

3.2.4 Colour-ringing projects

There are currently five registered colour-ringing schemes within the UK on cr-birding. The registered contact for all of these was emailed, and responses were received from three. One has not yet responded, and the other is no longer contactable through the email addresses provided (and it appears the scheme is no longer being managed). Of the three respondents, one had received no recoveries of their birds on the continent, one had only received one (to Trischen, Germany after

204 days), and the other had had one from Denmark, two from the Netherlands and one from France. None of these reports provide any more detailed information on migratory pathways or timings across the southern North Sea than can be found in the literature or from ringing recovery data.

4. DISCUSSION

4.1 Introduction

Through this review it can be concluded that a significant proportion of the British and Irish breeding, and north-western European wintering, Shelduck populations cross the North Sea at least twice annually. It is likely that those birds breeding within Britain and Ireland will pass offshore wind farm (OWF) areas on migration, and may therefore be exposed to various OWF effects. For birds breeding in Britain and Ireland, the most likely period of interaction with OWFs is between mid-June and early-August, when they make a directed flight to their moulting grounds in the Wadden Sea. They may also interact with OWFs on their return journey between October and January. Between October and February, Shelduck that breed on the continent and over-winter in the UK will also cross the North Sea twice. A proportion of these birds will make use of the SPAs designated for Shelduck, and so are also taken into account when considering OWF developments (Wright *et al.* 2012).

It should be noted that much of the information found on Shelduck migration is from the 1940s-1980s. Since this period, most new Shelduck literature has cited the original publications when discussing migration, or has been focussed more on estimating the size of the north-west European population, rather than studying the migration directly. It is possible that the migration patterns of Shelduck may have changed since the 1980s, as suggested by Kempf and Kleefstra (2013) with regards to the shift in moulting location within the Wadden Sea. Using the technologies now available to us, it would be possible to collect more detailed information on migration routes, from a range of locations. Collecting data of this sort could contribute significantly to an updated understanding of Shelduck migration, and fill some long-standing knowledge gaps (e.g. origin of Shelduck at certain moulting locations).

No high resolution spatial or temporal data are available through the literature or recovery data to determine the routes Shelduck take across the North Sea, and whether their current routes pass through operational or planned OWFs. There are also very few data available to inform accurate collision risk models for Shelduck, with information on flight heights and speed in particular being deficient.

4.2 Offshore Wind Farm Effects

Of the four most common potential OWF effects (barrier effects, collision, displacement and indirect habitat change) it would appear that Shelduck are unlikely to be subject to displacement or indirect habitat change, given the nature of their mainly terrestrial ecology. It is possible that they could be vulnerable to collision risk, though the evidence suggests their general flight heights at sea would keep them below rotor height. They may be vulnerable to barrier effects, given the majority of the population migrates across the North Sea twice annually, though their propensity to avoid OWFs has not yet been quantified.

They are most likely to be subject to collision and barrier effects when crossing the southern North Sea on the way to and from the moulting grounds in the Wadden Sea, though individuals crossing the English Channel or Irish Sea may also be exposed to these effects. If Shelduck exhibit similar avoidance behaviour to that observed in Common Eider (Masden *et al*., 2009), the presence of multiple OWFs on their migratory routes could cause increased energetic costs, as the Shelduck have to fly further to avoid the OWFs. This extra energetic cost has the potential to reduce individual survival, thus reducing the survival rate of the population as a whole over time. If productivity is not high enough to combat decreased adult survival, then the population will reduce over time. These increased energetic costs could be particularly pronounced in years with poor weather or food availability. The government target to produce 30GW of energy from offshore wind by 2030 (HM Government, 2019) has the potential to place many OWFs within the known area of Shelduck migration, as outlined by Wright *et al.* (2012). This increase in OWFs has the potential to produce cumulative barrier effects throughout the southern North Sea, which may lead to cumulative population level effects in future.

Shelduck may be less at risk of collision with turbine blades, as the reported flight heights suggest they will mainly remain below 25m, which is below the rotor sweep zone of most OWF turbines (Kruger & Garthe, 2001). However, there are far too few quantitative data to assess what the actual collision risk may be, so it cannot be stated what the level of risk is. However, it can be stated that if more OWFs are built to meet the 30GW target, this will increase the statistical likelihood of a Shelduck being exposed to collision risk during migration. For onshore wind farms only two known reports of Shelduck collision fatalities in Europe have been reported (Wang *et al*., 2015), though it is likely that the level of collision risk for Shelduck will differ between onshore and offshore wind farms.

Shelduck are unlikely to be subject to direct displacement by OWFs, since most of these are built outside their normal range, though cable installation through intertidal habitats and at landfall has the potential to cause displacement of Shelduck, and the prey species they eat from within the mud (Patterson, 1982).

4.3 Population Size

The British conservation status of Shelduck has been determined based on the reported breeding population decline of 41% over the last 25 years (Eaton *et al*., 2015), though the source of this figure is not clear. The data produced by the Breeding Bird Survey (BBS; ~4,000 1-km squares monitored annually) states that the breeding population trend for Shelduck between 1995 – 2017 is -9% [n=154, LCL = -47%, UCL = 42%] (Harris *et al*., 2019), which has been a more-or-less stable estimate for 7 years (see supplementary trend information). The most recent estimate of actual UK (England, Scotland, Wales, Northern Ireland) breeding population size is 15,000 pairs (Musgrove *et al*., 2013); this has been extrapolated from data collected during surveys conducted between 1988-91 (Gibbons *et al*., 1993) by the smoothed CBC/BBS joint trends for England - see Musgrove *et al.* (2013) methods section 1 for further information. Generally there seem to be fewer data available for Shelduck numbers in the breeding season than in the non-breeding season, which may contribute to the lack of designated breeding sites for the species. In order to provide better information on the status of the UK breeding Shelduck population, more regular, targeted surveys may be necessary.

The annual Wetland Bird Survey (WeBS) provides more up-to-date figures on the size of the non-breeding Shelduck population, which will make changes over time more easily assessable. This is particularly relevant given the Shelduck SPA suite is designated for non-breeding Shelduck only (Frost *et al*., 2018, 2019; Musgrove *et al*., 2011).

4.4 Moulting Location / Timing Shifts

From the literature and ringing data it is not possible to conclude where individuals from certain breeding locations migrate to moult, or which non-breeding sites these birds return to. There is a suggestion that the birds moulting in Bridgwater Bay, UK, are breeding individuals from Ireland, west Wales or south-west England, due to the lack of evidence of westerly migrating birds in July, but birds from these locations have also been recovered in the Wadden Sea (Eltringham & Boyd, 1963; Goethe, 1961b). Bryant (1978) suggested that birds moulting in the Forth may be immature, non-breeding individuals, or failed breeders, given the earlier than average peak in moulting birds, but again there are no empirical data to support this suggestion. The possible origins of the birds that moult in The Wash, the Humber Estuary and the Mersey Estuary are less clear.

It would appear that some breeding individuals from around the entire UK distribution migrate to the Wadden Sea to moult (see Figure 8), whilst other individuals from the same breeding locations remain within the UK to moult. Without further investigation it will not be possible to determine what the migratory links between breeding sites, moulting sites and SPA non-breeding sites are, or the extent to which these routes may lead to Shelduck interacting with OWFs.

The recorded shift in moulting site away from the Helgoland Bight and towards the Dutch Wadden Sea could have implications for the migratory routes taken by Shelduck. If Shelduck fly a straight line trajectory from their British departure point to their Wadden Sea moulting site, then a shift in destination could change which OWFs they interact with. Given the east-west orientation of the Dutch/German Wadden Sea, the straight-line route to these areas for birds departing from Ireland, Wales or southern England is unlikely to significantly change which OWFs Shelduck interact with. However, it may change which OWFs birds leaving from northern England and Scotland interact with. There are also small moulting sites known within the Danish Wadden Sea (Figure 9, point 8.) and in the southern Netherlands (Figure 9, point 5); if British birds shifted their moult location to these more northerly or southerly areas in future it could change Shelduck migratory trajectories more substantially. See Figure 9 for detail on where the currently known major moulting sites are.

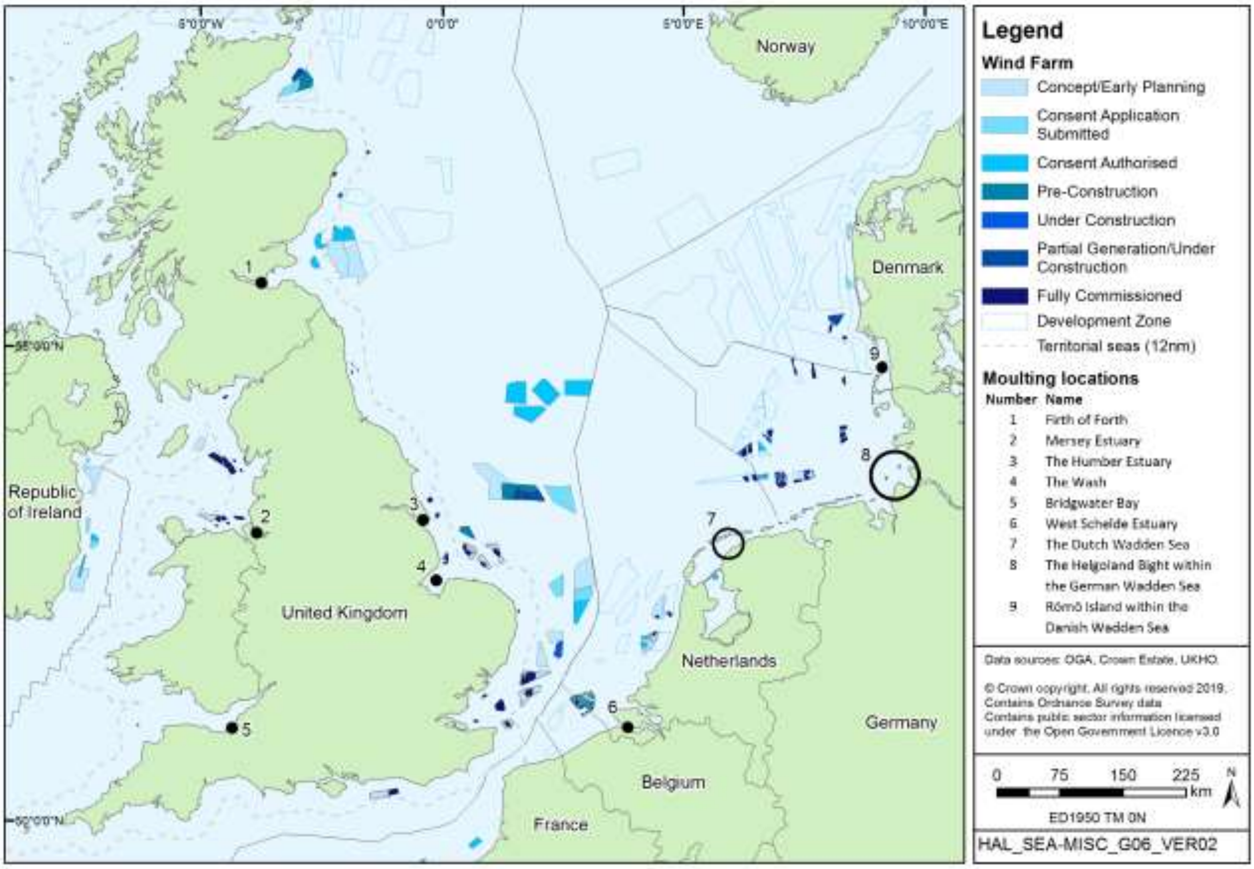

Figure 9. The major known moulting locations for Shelduck within the north-west European population. Large aggregations (50,000+ individuals) are indicated by open circles, with smaller aggregations being marked with dots.

The timing of annual movements to moult locations may also be affected by climate change. Barrett (2011) and others have recorded shifts in the annual arrival and departure dates of Shelduck from the breeding grounds, and have shown a correlation between these shifts and changes in climate (Barrett, 2002, 2011). The current data available are likely too few and low resolution to accurately assess small scale changes in migration timing of British and Irish Shelduck driven by climate change, but the potential for timing shifts should be considered when planning monitoring for this species (i.e. incorporate temporal survey buffers around the currently documented migration period).

Laursen *et al.* (2010) states that Shelduck trends in the Wadden Sea are not significantly correlated with winter conditions expressed by the North Atlantic Oscillation index or the water temperature in the North Sea in April, suggesting Shelduck winter survival and reproductive success are independent of the conditions currently found in the Wadden Sea. However, they also suggest that climate driven changes in sediment composition within the Wadden Sea could change which areas are suitable for Shelduck, and their usual food resources. Climate change has the potential to effect the timing and location of Shelduck moult migration, so regular searches for updated information on the migration pattern should be made.

4.5 Flight Heights

The results found during the literature review suggest that there are too few data available to conclude with certainty what Shelduck flight heights at sea are. From the data found Shelduck could be at risk of collision when flying in tail winds (at altitudes of >25m), but generally they will remain below 4m above sea level which is well below the area of rotor collision risk. These data are only based on one study conducted from land in 1999 (Kruger & Garthe, 2001), and one other with a small sample size conducted from offshore structures in 2010 (Fijn *et al*., 2012), so further studies should be conducted before assuming that these results can be applied to all individuals and weather conditions.

If Shelduck are taken to be representative of 'other ducks' as defined by Fijn *et al*. (2012), then it may be possible to review flight height data from other similar duck species, and draw comparisons. Kruger and Garthe (2001) found that 92% of surveyed Eider *Somateria mollissima* (n=4,241) flew below 12m above sea level (asl) in headwinds, and 100% flew below 25m asl. In tailwinds the Eider tended to fly slightly higher, with 33% (n=10,164) flying between 12 – 25m asl, but still none flew above 25m asl. Common Scoter *Melanitta nigra* displayed a similar flight height tendency, with 99% (n=4030) flying below 12m asl in headwinds, and 11.3% between 12 – 25m in tailwinds, with only 5 Scoter of 6754 observed flying above 25m. Fijn *et al*. (2012) observed similar flight heights, with 'other ducks' (Shelduck, Eurasian Wigeon, Common Teal, Red-breasted Merganser) and 'sea ducks' (Eider, Common Scoter, rails) rarely being recorded above 20m asl.

If the minimum height for collision risk at an offshore wind turbine is 25m, with most offshore turbines being much higher than this, then it can be assumed that sea ducks in general are at low collision risk, since a very small percentage fly above 25m. However, despite a reasonable Eider and Scoter sample size in Kruger and Garthe (2001) study, the results of this single study from a single location at the coast should not be extrapolated to the southern North Sea as a whole. Fijn *et al*., (2012) states that the sample size for 'other ducks' and 'sea ducks' was low, so these at also unlikely to be wholly representative.

4.6 Ringing / Colour-Ringing / Tracking Data

The ringing and colour-ringing data available provided useful corroboration of what was found within the literature, but did not provide any appreciable extra information. In particular, the recovery data did not provide higher resolution data on temporal movements across the North Sea, and could not show what the actual spatial movements across this area were.

Tracking data that have been published so far do not capture any movements across the North Sea, and have not provided information on flight height or speeds. It would appear that the results of some tracking studies have not been published (German and Belgian studies), so it may be possible that the data collected during these could fill certain knowledge gaps, but those data are not currently accessible.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Knowledge Gaps

Given the information that has been gathered during this review, there are still several knowledge gaps with regards to Shelduck movements across the southern North Sea. These are:

1) There are no empirical data on the specific routes Shelduck take across the North Sea, or how long their migration across this area takes.

2) There is no detailed information on where Shelduck depart from when migrating across the North Sea. It is not known if they migrate straight from their breeding locations as individuals, migrate a short distance to local estuaries before departing as small flocks, or migrate longer distances to major estuaries and depart as large flocks. There is evidence to suggest the latter is true for west coast breeders, but little evidence of patterns of movement along/from the east coast.

3) There is little information on which individuals moult in which locations. It is not known whether birds from the entire UK breeding distribution migrate across the North Sea, or whether certain local populations remain in the UK to moult, and so do not interact with OWFs.

4) It is not known which individuals make use of non-breeding SPA sites. It is possible that birds from the entire north-west European distribution could use UK SPA sites during the non-breeding season.

5) There are few data on Shelduck flight heights, and only one data source from 1966 on flight speed.

5.2 Recommendations

Given these knowledge gaps, we now make the following recommendations in order of priority:

1) Track Shelduck from the UK using GPS-GSM devices to collect high resolution spatial and temporal data on their migratory paths across the North Sea to their moulting site, and thus potential connectivity with and responses to offshore wind farms within the southern North Sea during these movements. The tracking devices could also be used to collect data on flight height and speed. Further information on the feasibility of this recommendation is outlined in 5.3.

2) Request a summary of movements and further information on study methodologies from researchers who have tracked Shelduck on the continent. It is thought that these tracking projects were not successful, but it is unknown why this is the case. It is possible that movements across the North Sea were recorded, but not reported. It is also possible that device attachment methods were used that yielded poor quality tracking data, so it would be good to avoid using these techniques in future tracking studies.

3) Analyse any available monitoring data (site records, tracking data, BirdTrack data, EIA data etc.) on Shelduck migratory behaviour against environmental data (tidal, wind, precipitation, moon-phase etc.) to see if there are any predictable conditions in which Shelduck migrate. If a pattern is discovered then this could be used to target future surveys more accurately.

4) Continue to monitor the shift in Wadden Sea moulting location in case this leads to changes in the current migratory routes. This may inform which offshore areas Shelduck are likely to pass through, and help target further monitoring of key areas. The UK moulting sites could also be monitored as an increase in the number of Shelduck using these locations could indicate a reduction in the number migrating across the North Sea. Climate change and natural environmental processes are likely to change the suitability of various habitats throughout the north-west European distribution, which may cause Shelduck migratory routes to change concurrently.

5) Analyse all Shelduck recoveries within the EURING databank, and from European Shelduck colour-ringing schemes not held in the British and Irish Ringing Scheme database. This may provide extra information on the general movement patterns along the European North Sea coast after the moulting period, and help elucidate where European birds depart from to reach the UK in the non-breeding season.

5.3 Tracking Study Feasibility / Constraints

As outlined in section 3.1.8, there is precedent for successfully tracking Shelduck using digital devices, though the sample sizes to date have been small.

In order to collect high resolution spatial data on Shelduck movements through OWF areas, it is necessary to use GPS devices on a high fix rate (1 second to 5 minutes), as the birds are likely to move through these areas extremely quickly. Assuming Shelduck fly at 96 kmh^{-1} (Morley, 1966; Patterson, 1982), it would be possible for them to pass directly through the smallest operational OWFs (i.e. Scroby Sands) in ca. 45 seconds. Therefore, a fix rate of approximately one minute should give a high enough resolution to detect behavioural responses to operational OWFs, and show routes that pass through proposed areas.

Due to UK licensing requirements, devices must be lighter than 3% of the body mass of the individual being tagged. Shelduck have a reported weight range of 703-1736 g (BTO unpublished data), so to remain within the 3% weight threshold for all birds that might be caught the device must remain under 21 g.

The intention of this data collection would be to capture information on all North Sea crossings made by an individual. In order to do this the GPS device would need to be attached for at least six months, to capture the outward and return migration to the Wadden Sea. The standard method for long-term deployments of this nature on birds would be to attach the tag using a body harness. Due to welfare concerns, licences are not issued to fit harnesses to any duck species within the UK, though some European licensing authorities have issued licences for this in their own countries. Therefore, the only device attachment method possible for Shelduck in the UK is for short-term deployments of devices attached to skin or feather. Given evidence from previous studies that used this attachment method, and the fact that birds are likely to be in active body moult before they migrate across the North Sea, we do not predict that deployments, under UK licence, would be capable of capturing data for more than the outbound migratory flight to the Wadden Sea.

Given the possible attachment method, and the likelihood that the tag will be shed by the time the bird reaches the moulting ground, we do not expect to be able to retrieve the device and download data directly from it. The device must therefore be capable of transmitting data remotely. There are several possible transmission methods and device types that are capable of doing this (satellite, PTT, GSM etc.), but only GSM transmission devices can remain under the 21 g weight threshold.

We therefore need a tag that is less than 21 g, is capable of transmitting GPS data over the GSM network whilst taking one minute fixes, and can be attached to the birds' feathers or skin directly. There are effectively three known suppliers that can deliver a tag that meets these requirements, but we recommend Ecotone as the best supplier to meet the needs of this recommendation. Ecotone produce GPS-GSM tags at 21g that can be fitted in the correct manner, and are capable of collecting high resolution GPS data (down to 1 minute fixes for short intervals), altitude data (to sufficient resolution) using barometric pressure sensor and GPS, speed and accelerometry information. They can also be programmed to collect data at a higher rate whilst they are flying, which allows battery to be conserved before the migration in order to have enough energy to collect high frequency data during the migration.

The final challenge will be catching individuals to tag. Given the short-term nature of the deployment, and the aims of the project, these need to be individuals that are imminently going to cross the North Sea, are likely to pass operational OWFs, are not in active body moult at the attachment site, and are in good enough body condition to tag (i.e. healthy). We have identified several potential sites where it may be possible to capture birds fitting these criteria, mostly along the Suffolk and Kent coastlines.

It is thus proposed that a pilot study should be undertaken to:

- Provide data to assess the routes and timing of movements of Shelduck during the early summer period on their migration between the UK and moulting sites in the Dutch/German Wadden Sea;
- Provide data to assess the flight height and flight speed during these movements;
- Assess potential connectivity with offshore wind farms within the southern North Sea during these movements;
- Assess methodologies for a wider study, and tag performance.

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APPENDIX 1. Recovery maps for British breeding Shelduck i.e. those originally ringed in Britain and Ireland during the breeding season (April-July). Recoveries are displayed by month of finding, to illustrate the distribution changes throughout the year, and separated into the main periods of the annual cycle

A1.1 Breeding season recoveries of British and Irish breeders – April to July: the majority of Shelduck should be breeding

A1.2 - Moulting season recoveries of British and Irish breeders – August to November**:** the majority of Shelduck should be moulting or on the continent

A1.3 Wintering season recovering or British and Irish breeders – December to March: the majority of Shelduck should have returned to Britain and Ireland for the winter

 

Images: Edmund Fellowes. Cover image: Edmund Fellowes

Review of the migratory movements of Shelduck to inform understanding of potential interactions with offshore wind farms in the southern North Sea

The aim of this project was to provide an overview of the current knowledge of the migratory movements of UK populations of breeding and non-breeding Shelduck by conducting a literature review and analysing all Shelduck ring-recovery data from the British and Irish Ringing Scheme. Key knowledge gaps are identified, and recommendations for further work to fill these gaps made.

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