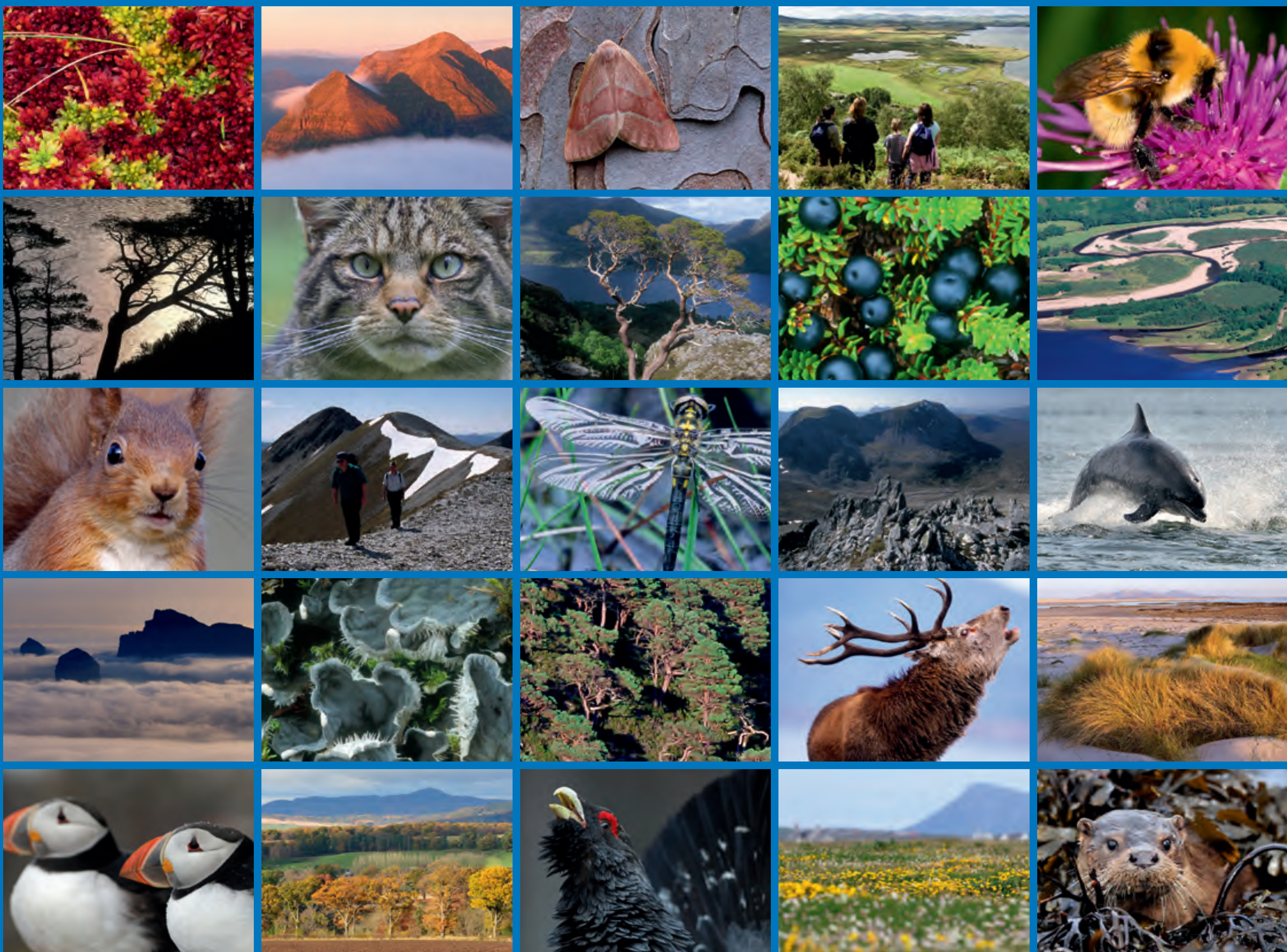
Scottish Natural Heritage
Commissioned Report No. 885

A review of red-throated diver and great skua avoidance rates at onshore wind farms in Scotland



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COMMISSIONED REPORT
Summary

A review of red-throated diver and great skua avoidance rates at onshore wind farms in Scotland

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Contractor: MacArthur Green
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Keywords

Red-throated diver; great skua; collision risk; avoidance rate.

Background

SNH's approach to the use of avoidance rates in collision risk modelling at onshore wind farms is set out in guidance on their website. SNH is committed to reviewing avoidance rates for individual species (or species groups) periodically, and as new information becomes available.

SNH has been provided with post-construction monitoring reports for operational wind farms in Orkney. This report reviews these new data in respect of red-throated diver *Gavia stellata* and great skua *Stercorarius skua*, along with other evidence for avoidance behaviours in these species.

Main findings

No divers or skuas of any species have been found as collision victims at any terrestrial wind farms within their breeding range in Scotland, Norway, Sweden, Finland or North America. One red-throated diver, presumably on migration, was a collision victim at a wind farm in Germany. Red-throated divers show strong macro-avoidance of offshore wind farms, and there is some evidence for (partial) displacement from breeding sites close to wind farm turbines.

Recent studies involving flight activity watches and carcass searches in Orkney were reviewed, and found to be well presented and based on sound methods. At an avoidance rate of 0.995, between 1.3 and 3 collision deaths would be predicted for each species, but no carcasses were found. The Orkney work therefore supports an avoidance rate of greater than 0.980, which is the value currently used for both species.

In light of the relatively small number of wind farms at which avoidance by these two species has been studied, a highly precautionary avoidance rate of 0.990 could be advised until the generality of the current results across other wind farm sites and designs has been established. However, it would also be consistent with evidence from Orkney, from other wind farms in Scotland and abroad, and with practice at marine wind farms, to adopt an avoidance rate of 0.995 for red-throated diver and great skua at terrestrial wind farms.

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1. INTRODUCTION

The SNH Collision Risk Model (CRM) (in its simplest form also known as the 'basic Band model' or 'Option 1') estimates how many birds might collide with wind turbines, if they show no avoidance behaviour when flying through the rotor swept area of a turbine. Birds show 'macro-avoidance' if they change flight path to avoid entering a wind farm, 'meso-avoidance' if they change flight path to avoid individual turbines when flying through a wind farm, or 'micro-avoidance' if they change flight path to avoid collision with a turbine blade when passing through the rotor swept area of a turbine (Cook *et al*., 2014).

Whenever possible, avoidance rates are calculated from data on numbers of birds actually killed by collision in relation to numbers predicted to be killed when using the Band model to obtain a no-avoidance collision estimate. This has been termed the 'within wind farm avoidance rate' by Cook *et al*. (2014). This term is used to indicate that macro-avoidance effects are not included in this avoidance estimate. The observed rate of bird flight activity – also termed 'flux' – at a wind farm cannot quantify macro-avoidance if that occurs at large distances from the wind farm (unless specifically studied using methods such as radar). Cook *et al*. (2014) use the term 'total avoidance rate' to indicate that this should include 'macro-avoidance' as well as 'within wind farm avoidance'. For many terrestrial birds macro-avoidance may be zero or negligible, but there is evidence for macro-avoidance, for example, in golden eagles (*Aquila chrysaetos*). Macro-avoidance is considered to occur at offshore wind farms, and is thought to be particularly strong in red-throated divers (*Gavia stellata*) (Furness *et al*., 2013) and northern gannets (*Morus bassanus*) (Cook *et al*., 2014). However, in contrast, gulls seem to show little or no macro-avoidance at offshore wind farms, so the behaviour is not a consistent feature of all seabird species (Cook *et al*., 2014).

SNH originally issued guidance that an avoidance rate of 0.95 should be used for sensitive bird species commonly identified in terrestrial wind farm planning applications. This figure was acknowledged as being precautionary and was based on expert opinion rather than monitoring data. It was felt that, as evidence became available from post-construction studies, this rate would be likely to be revised upwards. Empirical evidence was subsequently obtained from terrestrial wind farms indicating that avoidance rates were significantly higher than 0.95 for several species for which adequate data were available (Fernley *et al*., 2006; Pendlebury, 2006; Whitfield & Madders, 2006; Whitfield, 2009). As a result, the default value and some species-specific values were revised by SNH . A default 'within wind farm' avoidance rate of 0.98 was recommended, except for species where evidence indicated otherwise. Exceptions to the default value included geese, hen harrier (*Circus cyaneus*) and golden eagle, for which evidence supported a 0.99 avoidance rate as being precautionary and kestrel (*Falco tinnunculus*) and white-tailed eagle (*Haliaeetus albicilla*), for which the 0.95 avoidance rate was retained as it was felt they were particularly susceptible to collisions. SNH revised the guidance on goose avoidance rates further, recommending the use of an avoidance rate of 0.998, in 2013.

Garthe & Hüppop (2004) and Maclean *et al*. (2009) present some arguments in support of higher avoidance rates for certain seabird species rather than others. This was based on consideration of their ecology and morphology but, until recently very little work had been done on quantifying seabird avoidance rates on the basis of numbers of collision victims compared to predicted casualty rates. Gulls and gannets are among the seabirds considered most at risk of collision with offshore wind farm turbines (Furness *et al*., 2013) but, because carcass collection is impossible around marine wind turbines, it is extremely difficult to quantify avoidance rates of seabirds at offshore wind farms.

To improve the assessment of gull avoidance rates, Cook *et al*. (2014) identified 20 wind farm sites at which post-construction monitoring data were available that combine an estimate of the collision rate with an estimate of the rate of flux through the wind farm. For these sites it was possible to derive within-wind farm avoidance rates. Seventeen of these sites were onshore and three were offshore. From the data, Cook *et al*. (2014) estimated a within-wind farm avoidance rate applicable to the basic Band model of 0.9956 (S.D. 0.0004) for large gulls. They recommended use in the basic Band model of an avoidance rate of 0.995 for herring gull (*Larus argentatus*), lesser black-backed gull (*L. fuscus*), and great black-backed gull (*L. marinus*), with most of the data on which this conclusion was based coming from post-construction monitoring at terrestrial wind farms. From offshore studies, they recommended total avoidance rates (including macro-avoidance) for use in the basic Band model of 0.989 for northern gannet, and 0.992 for black-legged kittiwake (*Rissa tridactyla*).

JNCC *et al*. (2014) provide guidance on the use of avoidance rate estimates derived from the results presented in Cook *et al*. (2014) in collision risk modelling. JNCC *et al*. (2014) advise that avoidance rates should be given to three decimal places rather than rounded to two decimal places as was previous practice for almost all species. JNCC *et al*. (2014) also advise that precautionary total avoidance rates used in modelling should be 0.989 for gannet and kittiwake, 0.995 for herring gull, lesser black-backed gull and great black-backed gull. The lower avoidance estimate recommended for gannet and kittiwake was due to the lack of any species-specific data on within wind farm avoidance by these two species in the Cook *et al*. (2014) report, and therefore the need for a more precautionary estimate than for the large gull species. The advice indicates that the lower avoidance estimate, of 0.989, for gannet and kittiwake is to provide greater caution in the absence of species-specific data for these species, and does not suggest that gannets and kittiwakes show lower avoidance behaviour than shown by large gulls.

JNCC *et al*. (2014) provide guidance for appropriate avoidance rates for use in offshore CRM, despite the majority of data in Cook *et al*. (2014) being derived from terrestrial studies. It therefore would seem appropriate for the avoidance rates advocated in JNCC *et al*. (2014) to be applied also to terrestrial CRM and not only to offshore CRM. JNCC *et al*. (2014) specifically excluded skuas and divers from consideration because those taxa were not reviewed by Cook *et al*. (2014). They recommended continued use of 0.980 as a precautionary avoidance rate for skuas and divers until empirical data for those species have been evaluated, despite advocating an avoidance rate of 0.989 for gannet in the absence of any species-specific data on within wind farm avoidance of gannet. This makes the use of 0.980 for skuas and divers now look extremely precautionary and out of line with the values adopted for kittiwakes and gannets, and invites assessment of data on skua and diver avoidance rates from wind farms where appropriate monitoring studies have been carried out.

Post-construction surveys quantifying bird flux at terrestrial wind farms are usually carried out from vantage points outside the area to be observed, but ensuring that all observations are within 2 km. However, these methodologies rarely employ distance correction which means that the flux rates of birds (or population estimates) are likely to be underestimated. If the numbers of birds passing through the rotor-swept area of a turbine, and therefore the expected numbers of collisions, are underestimated, the derived avoidance rate will also be an underestimate. Since survey data at sites being considered for wind farm development are also likely to be affected by detection issues with distance from survey points, it is appropriate to use these underestimated avoidance rates in calculating likely impact on bird populations where survey data are similarly subject to this bias.

Two species of conservation concern which occur at some terrestrial wind farm development sites in northern Scotland and for which appropriate avoidance rates have not been assessed in detail are red-throated diver and great skua (*Stercorarius skua*).

Red-throated divers breed at freshwater lochs and pools in Shetland, Orkney, the Western Isles and much of north and west Scotland close to the coast. During the breeding season, from April to September, breeding red-throated divers feed at sea, commuting between freshwater nest sites and shallow marine feeding areas. At other times of year the species is essentially marine. Red-throated divers have a high wing loading and small tail, so fly fast but with low manoeuvrability. They may be at risk of collision with terrestrial wind turbines if a wind farm lies on their commuting routes between breeding lochs and marine foraging habitat.

Great skua is a globally scarce seabird that breeds on moorland and rough grassland mainly in Shetland and Orkney, but also in smaller numbers in north and west Scotland. It is gull-like, so might be expected to show broadly similar avoidance rates to large gulls, but great skuas differ from large gulls in having more powerful flight musculature (Caldow & Furness, 1993) and stronger tendencies towards predatory and piratical behaviour. Great skuas show individual variation in feeding behaviour and major differences in behaviour as breeders, failed breeders or immatures (Furness, 1987; Wade *et al*., 2014; Wade, 2015), so that individual exposure to risk is likely to vary considerably according to individual features and status. Such variation is likely in other bird species, but is particularly a feature of great skuas because of their highly specialised individual behaviour.

Breeding populations of red-throated divers and great skuas are features of several Special Protection Areas (SPAs) in Orkney which are close to terrestrial wind farms. Post-construction monitoring has been carried out at these wind farms which provides the opportunity to obtain novel information on avoidance rates of these species. Upton (2012 a, b; 2014 a, b, c) has provided data and calculations making a case for the appropriate within wind farm avoidance rate for red-throated diver and great skua to be increased from 0.98 to a higher value. This is based on species-specific data obtained from studies of red-throated divers over eight breeding seasons at Burgar Hill wind farm in Orkney, data from studies of great skuas at three wind farms in Orkney in 2012-14 (Burgar Hill, Hammers Hill and Hoy Community Turbine) and data from Burgar Hill in 2007-11. This paper reviews the case made by Upton (2012 a, b; 2014 a, b, c), considers whether measurements of avoidance rate are available from other wind farms, and the context of avoidance rates now thought appropriate for other species of seabirds. These considerations are then used to make a recommendation regarding avoidance rates to use for terrestrial wind farm assessments where red-throated divers or great skuas are present.

2. REVIEW OF UPTON (2012A, 2014A, B) AVOIDANCE RATE OF 0.99 FOR RED-THROATED DIVER

Upton (2012 a; 2014 a, b) reviews evidence gathered over eight breeding seasons (2007-2014), presents calculations, and from these makes a case that 0.99 would be a precautionary evidence-based avoidance rate for red-throated diver. Strictly speaking, SNH guidance recommends that avoidance rates should be calculated from observed numbers of birds killed at the operational wind farm in relation to numbers predicted to be killed by pre-construction observations of flight activity at the proposed wind farm site. However, in practice almost all estimates of avoidance rates have been based on observed numbers of birds killed at operational wind farms in relation to bird flight activity levels during the same time period of wind farm operation, as in Upton (2012 a; 2014 a, b). The reason to use pre-construction flight activity data is to include macro-avoidance effects in the estimation of avoidance rate. Birds that avoid a wind farm completely post-construction will not be included in the bird flux estimate for an operational wind farm, and so the true avoidance rate will tend to be underestimated when based on bird flux data from an operational site rather than on pre-construction data. However, if bird flux varies from year to year, and especially if bird flux shows a trend with calendar year, then application of pre-construction bird flux data may be inappropriate. The case made by Upton (2012 a) is based on data from a single wind farm site: Burgar Hill, Orkney. At that site, there were three breeding pairs in most years immediately before wind farm construction began, but after wind farm construction, one or two pairs of red-throated divers have bred each year very close to, and on the inland side of a row of six turbines, requiring birds to fly between the breeding loch and sea through or round the row of turbines. This suggests that pre-construction flight activity may have been higher than during the operational period. The paper is further supported by Upton (2014 a) which adds further evidence for the same site for 2013, and Upton (2014 b) which adds evidence from studies in 2014.

Carcass searches around five of the turbines were carried out following recommended methods and are well presented in Upton (2012 a; 2014 a, b). The papers make a good case for the search efficiency for carcasses of birds the size of red-throated diver being 100%. No diver carcasses were found in any year. Numbers of red-throated divers at risk were estimated from vantage point (VP) surveys in 2007 (19.75 hours), 2008 (63 hours) and 2012 (72.5 hours). These data were used by Upton (2012 a) to estimate from the basic Band model the numbers predicted to be killed per year by collision with turbines. The calculations are performed carefully, accurately, and in a precautionary manner. The main weakness with the conclusion reached is that it is derived from data for only a single breeding site holding only one or two breeding pairs each year. Red-throated diver flight lines reported in Upton (2012 a) indicate little evidence of macro-avoidance (in that birds frequently fly between the individual turbines on Burgar Hill), and this behaviour contrasts with suggestions from Smøla (Norway) reported in the next section, where there is thought to be a high level of macro-avoidance of the Smøla wind farm by red-throated divers breeding on that island. It is unclear which of these responses is more typical, and possibly the response depends on the individual personalities of the birds (since red-throated divers certainly vary considerably in their behaviour, for example some birds flying off when a human approaches and others remaining still on the nest). It is also unclear whether high macro-avoidance further reduces collision risk or whether birds that do fly between turbines do so because they are able to show high 'meso-avoidance'. However, in this regard, the avoidance rates indicated by the study at Burgar Hill are unlikely to be higher than those that would be derived from an equivalent study at a site such as Smøla, where macro-avoidance by red-throated divers appears to be much higher than at Burgar Hill. Data from 2013 and 2014 reach the same conclusions; no collisions by red-throated divers were observed despite continued flight activity at the site. A total of 3,393 flights at risk were estimated for the 2014 breeding season, and the accumulated data over all years predicted 3.8 collisions at an avoidance rate of 0.990 or 1.9 collisions at an avoidance rate of 0.995. Since no collisions were detected from carcass searches, the avoidance rate of 0.995 appears precautionary for this site (Upton 2014 b).

Breeding red-throated divers show very high site fidelity in Shetland, almost invariably breeding at the same pool year after year (Furness, 1983; Okill, 1992). Although site fidelity may be lower elsewhere (breeding numbers and distribution seem to vary more in Western Isles and Argyll than in Orkney and Shetland, Andrew Stevenson pers. comm.), this has the potential to mean that the behaviour of perhaps just four breeding adults would be used to make a recommendation that would apply to different birds at different breeding sites near to different arrangements of wind turbines. However, an important point that is mentioned by Upton (2012 a) but not explored in detail is that many of the birds observed from the VP surveys were non-breeding birds visiting breeding sites towards the end of the breeding season rather than the resident breeding adults. The extent of this activity of non-breeders can be assessed to some extent by looking at the VP data. In 2012, one pair nested successfully at Burgar Hill in 2012, rearing two chicks (Upton, 2012 a). In July of that year, 46 'at risk' flights were observed in 15 hours of observation while in August, 113 'at risk' flights were observed in 15 hours of observation. Data from other studies can be used to assess how many flights are likely to be made by one pair of chick-rearing breeding adults.

Based on a total of 76 hours of hide watches of breeding sites at Foula (Shetland), Furness (1983) reported that breeding adults made an average of 10 (range 4-17) trips from the nesting lochan to the sea per day while rearing chicks. The 80 trips observed occurred over a total of 76 hours of observation but not all trips were completed before observation periods terminated, so represent about one feeding trip per hour per breeding pair. Not every trip resulted in a fish being brought back to feed to the chick(s) and a few trips resulted in more than one fish being brought back, although in most cases red-throated divers are single-prey loaders. Davis (1972) reported 0.61 fish per hour carried back to nesting pools in Canada by chick-rearing red-throated divers. Reimchen & Douglas (1984) reported 347 foraging trips (averaging 60 minutes duration) during 646 hours of observation of chick-rearing red-throated divers in Canada, giving a rate of 0.54 trips per hour. In that paper they state that divers brought back fish to feed the chick at a rate of 0.54 fish per hour in one year of study but 0.71 fish per hour in the other year. However, they do not indicate whether some trips involved multiple fish or no fish being returned. Eriksson, *et al*. (1990) observed chick-rearing red-throated divers nesting in southern Sweden. Those birds commuted from nest sites on freshwater pools to feed on freshwater lakes, taking rather larger fish than the sandeels carried by red-throated divers feeding at sea off Foula. The Swedish birds made an average of seven feeding trips per pair per day, rather fewer than birds from Foula, suggesting some variation in behaviour between regions or countries depending on available fish prey and perhaps locations of nesting pools in relation to feeding areas. Hulka (2010) found that incubating red-throated divers sometimes left the eggs unattended for periods of tens of minutes, even during darkness, and suggested that they may leave nest sites when predators such as otters were near the nest; under such circumstances adults are likely to remain on the water rather than flying off. There is little to suggest that divers fly to and from nesting sites during darkness, although flight activity seems to be highest around dawn (Furness, 1983; Upton, 2012 a).

These studies indicate that breeding adults at the Burgar Hill site are likely to have made about one feeding trip per hour during chick-rearing, so that we might expect 30 trips of breeding adults to be observed in 15 hours of VP watches in July and August, whereas in fact 46 and 113 flights were observed in the 'at risk' zone. This suggests that a substantial proportion of the flights observed were by visiting non-breeding birds. The avoidance data presented in Upton (2012 a, 2014 b) therefore apply to a potentially large number of non-breeding individuals as well as to the very small number of local resident breeding birds.

The key result from Upton (2012 a) is the calculation of expected numbers of collisions from the basic Band model, and comparison with the empirical data showing no collisions at Burgar Hill wind turbines (Upton, 2012 a; Table 7). The expected number of collisions during 2007-2012 at an avoidance rate of 0.98 was 6.4. For an avoidance rate of 0.99 the expected number of collisions was 3.2, and at an avoidance rate of 0.995 the expected number of collisions was 1.6. Even if two or three diver carcasses had been missed during searches, the empirical data indicate an avoidance rate higher than 0.99. Upton (2012 a) also presents probability estimates to assess the likelihood that the zero collisions results from chance rather than high avoidance. These calculations further support the conclusion that avoidance rate is higher than 0.99, as do data collected in 2014 (Upton, 2014 b).

Had pre-construction flight activity data been used rather than flight activity data from the operational period, the estimated avoidance rate would most likely have been even higher, since there is evidence that breeding activity at the site was reduced due to construction disturbance (Meek *et al*., 1993), and has not recovered since (Upton, 2012 a). The data do provide a case for 0.990-0.995 being suitable and precautionary avoidance rates for red-throated diver based on species-specific data (and further supported by supplementary data collected in 2013 when again, no carcasses of divers were found). Nevertheless, the data do apply only to a single breeding site and a single wind farm, and that represents the main issue regarding the potential application of these data to other sites. In particular, the Burgar Hill wind farm consists of a single row of turbines rather than an array. It is possible that red-throated divers might be better able to avoid rotor swept areas of turbines in a single row rather than in an array.

3. EVIDENCE FOR RED-THROATED DIVER AVOIDANCE FROM OTHER STUDIES

One of 48 ring recoveries of red-throated divers ringed in Scotland was of a bird killed by flying into overhead wires (Okill, 1994). One red-throated diver was found (alive) impaled on a barbed wire fence that had been set up close to a nesting pool in Foula during the previous winter (R.W. Furness, unpubl.), and Sheila Gear (in litt.) reported finding two red-throated divers that had died as a result of collisions with fences in Foula. These deaths due to collision are consistent with the general conclusion that the birds most at risk of collision with power transmission lines are large birds with high wing loading and small tails (Janss, 2000) which fly fast but have little ability to suddenly change direction. Red-throated divers are close to the extreme of high wing loading and small tail size, and therefore will be highly vulnerable to colliding with objects that they cannot detect at a distance. However, this inherent vulnerability may make them show especially strong avoidance behaviour to reduce collision risk.

The Scottish Windfarm Bird Steering Group (SWBSG) does not hold any records of red-throated divers being killed by collision at any Scottish terrestrial wind farms (Claire Lacey, in lit.). However, a formal request for data was made to SWBSG for three sets of data:

- Data on estimated numbers of red-throated diver and black-throated diver *(Gavia arctica)*[1] collisions predicted by standard Band model assessments of pre-construction data on bird flight activity that might be killed at Scottish terrestrial wind farms where these values are not zero (for proposed wind farm sites whether wind farm was subsequently constructed or not);
- A list of constructed wind farms where post-construction monitoring has been carried out and where collisions were predicted based on pre-construction bird survey data, with the year of construction and number of years of post-construction monitoring of bird collision victims.
- Data on any records of red-throated diver or black-throated diver as collision victims found at any Scottish terrestrial wind farm (not just those listed in 2 above), and a list of which sites where collisions had been predicted have found no victims of these species.

In response to this request, no information was forthcoming from SWBSG.

Bright *et al*. (2006; 2008) considered that the main hazard of Scottish terrestrial wind farms for red-throated divers was displacement of breeding pairs through disturbance rather than collision. The main evidence they presented to support this was that Meek *et al*. (1993) had demonstrated that ‘breeding numbers of red-throated divers at a three-turbine wind farm site in Orkney declined as a result of disturbance during construction’. Meek *et al*. (1993) stated ‘the only species to have been adversely affected by the [wind farm] development was red-throated diver and its decline was probably the result of factors other than the operation of the aero-generators’. They reported that while red-throated divers were present on the breeding loch in the early morning while turbines were operational, they left the site when people arrived on site, indicating that their response was more likely to be to human disturbance rather than wind turbines.

Bright *et al*. (2006; 2008) reported that in 2007 there were 79 red-throated diver breeding areas (defined by 1 km buffer around nest sites) in Scotland that overlapped with terrestrial wind farm developments (though only 10 installed sites, 8 approved, and the majority in application or scoping at that time).

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[1] Black-throated diver was included as a closely-related species to red-throated diver, with similar flight characteristics and (assumed) similar susceptibility to wind farm collisions.

Wind turbines constructed at Foula, Shetland, were in areas of the island where flight activity of red-throated divers normally does not occur, so provide little indication of effects on divers (Sheila Gear, in litt.).

Dürr (2014) presents a tabulation of bird casualties found at terrestrial wind farms throughout Europe. The most recent update occurred in October 2014. There was one red-throated diver casualty (in Germany) and no other diver species out of 11,150 birds of about 270 different bird species. Red-throated divers do not breed in Germany, so this individual was presumably migrating through the country. Although this compilation is not complete for some countries, including the UK, it is based on a very large number of surveys of a very large number of different wind farms.

A review of bird casualties found in 68 studies at wind farms, which has been used to estimate total numbers killed at wind farms in the contiguous United States as 234,000 birds per year, reported about 3,500 birds of 220 species in the raw data, but these did not include any divers (loons) of any species (Loss *et al*., 2013). Similarly, Zimmerling *et al*. (2013) reported 1,297 carcasses of 140 species found at 43 wind farms in Canada monitored for collision victims; these did not include any divers/loons and none has been found as collision victims during updating of these data since that publication (Ryan Zimmerling, in litt.).

Rydell *et al*. (2012) reported that post-construction monitoring has found birds of 53 species as casualties at Swedish terrestrial wind farms, but these did not include either red-throated diver or any other species of diver. This is despite the widespread breeding distribution of red-throated and black-throated diver across much of Sweden, and migration of these species to and from breeding areas. One of the co-authors of that report, Martin Green (Lund University), provided further details in an email on 26 January 2015. He stated that as far as is known, there have been no collisions of divers at Swedish wind farms since the compilation of the Rydell *et al*. (2012) report, but also no studies of diver flight lines in relation to operational wind farms in Sweden, as divers have not been perceived as a collision risk at any existing Swedish wind farms. He did, however, indicate that there was some anecdotal evidence suggesting red-throated divers being displaced from breeding sites by wind farms.

Studies of red-throated divers breeding on the island of Smøla, Norway, have been carried out in relation to the construction and operation of a large terrestrial wind farm on that island. There were 23 red-throated diver nesting lochans on Smøla in 1999-2007, with about 10-13 pairs nesting in most years but a range between 9 and 20 pairs in particular years. Breeding success from 1999-2004 averaged 0.42 chicks per pair, which is similar to typical breeding success in Scottish populations (Halley & Hopshaug, 2007; Hulka, 2010). Smøla is about 18 km in diameter and approximately circular. In part of the island a wind farm of 20 2 MW turbines was constructed in 2001-02 with a further 48 2.3 MW turbines constructed in 2003-05. Before turbine construction began, three red-throated diver nest sites were within what became the wind farm area; all three nest sites were abandoned in the year in which construction occurred and were not reoccupied up until at least 2007 (Halley & Hopshaug, 2007). However, it is unclear whether these sites were abandoned due to the wind farm itself, or due to increased human disturbance consequent on the construction of new roads into this part of the island (Halley & Hopshaug, 2007). In over 46 hours of survey work in May and June 2007, not a single red-throated diver flight was seen through the wind farm area, which was considered to indicate strong avoidance behaviour because for at least four of the nest sites used in 2007 the most direct route between nest site and sea would be through the wind farm area (Halley & Hopshaug 2007). This appears to contrast with red-throated diver behaviour at Burgar Hill, where many flights occurred between turbines. This contrast may be at least in part because the extent of macro-avoidance at Smøla may have been overemphasised in the Norwegian reports. Studies of breeding red-throated divers elsewhere show that flight activity is generally very low in May and June because birds are mostly incubating and immature birds tend to arrive in breeding areas later in the summer. High levels of flight activity occur in July-August when breeding birds are bringing fish to nest sites to feed chicks and when immature birds visit breeding sites seeking possible breeding opportunities in areas with high breeding success (Furness, 1983; Reimchen & Douglas, 1984; Hulka, 2010; Upton, 2012 a). Therefore, the low flight activity of red-throated divers at Smøla may simply reflect the typical low activity levels of breeding adults at the time of year when observations were made, rather than avoidance behaviour. It is unfortunate that there are no data on red-throated diver flight activity at Smøla during the chick-rearing period in July-August. Other possibilities may be that red-throated diver behaviour is highly variable between individuals, or that divers are able to fly between turbines when presented with a single row (as at Burgar Hill) but are unwilling to fly through a grid of turbines (as at Smøla).

Some bird collision victims at Smøla wind farm were counted in 2005 and 2006, but from 2007-2010, trained dogs were used to assist in weekly searches throughout the year for collision victims in the wind farm area (Bevanger *et al*., 2010). The only mammalian scavengers on Smøla were American mink (*Neovison vison*), but gyr falcons (*Falco rusticolus*) were found to remove some smaller birds, especially willow ptarmigan (*Lagopus lagopus*). Nevertheless, 40% of monitored carcasses were not visited by any scavengers within four weeks, and no large birds were thought to be removed. Human search efficiency for bird carcasses was low due to the heathery habitat, with an estimated 50% of carcasses of small birds found, but was much higher when trained dogs were used. Over 20 species of birds were recorded as collision victims in 2005-2010, including 39 white-tailed eagles and 74 willow ptarmigan, but no red-throated divers were found (Bevanger *et al*., 2010). Therefore, although there are no reliable data on flight activity of red-throated divers through the wind farm at Smøla, there are around 10 pairs breeding on the island meaning they are within a few kilometres of the wind farm. The carcass survey study indicates an avoidance rate by red-throated divers that was effectively 100%.

There have not been any collisions of divers with wind turbines in Finland as far as is known (Teemu Lehtiniemi, in litt.), although there are some misgivings about possible impacts and perhaps especially effects of increased disturbance of breeding birds. Topping & Petersen (2011) modelled the cumulative impact of offshore wind farms on red-throated divers migrating through, and wintering in the Baltic Sea and North Sea near to Denmark. They inferred from the literature that there would be no collisions at offshore wind farms affecting the population, but that the strong avoidance behaviour would lead to a loss of foraging habitat from offshore wind farms and the area of 500 m surrounding these, a view also presented by Skov & Petersen (2011). Dierschke *et al*. (2012) also inferred that there would be no, or negligible, collision mortality for red-throated divers or black-throated divers, either in their breeding areas or during migration or winter, but that avoidance behaviour would result in habitat loss. They cited nine studies at offshore wind farms that indicated strong avoidance of offshore wind farm turbines by red-throated divers, with birds often staying one, and sometimes two or three, kilometres away from turbines. Studies at offshore wind farms (Table 1) indicate that red-throated divers are likely to show such strong macro-avoidance of turbines that collision risk at offshore wind farm turbines will be negligible.

Divers (loons) tend to fly low over the sea, so are at very low risk of collision with offshore or coastal wind turbines (Day *et al*., 2003). Those authors reported a flight height of 1-20 m (mean 4 +/- 1.6 m) for loons near Gambell, Alaska during winter. Flight heights over land are likely to be higher, increasing risk of collision with turbines. However, if red-throated divers show high macro-avoidance behaviour, tending to keep out of terrestrial wind farms as they do offshore, risk of collision would be reduced. Nevertheless, the considerable flight activity reported at Burgar Hill suggests that macro-avoidance is not always high. This may be because birds become habituated to the presence of wind turbines, or differ in individual behaviour, or are not deterred from crossing a single line of widely-spaced turbines

Table 1. Summary of maximum distance with detectable avoidance/displacement of red-throated divers from operating offshore wind farms.

Wind farm	Avoidance flying	Avoidance swimming	References
Utgrunden	avoidance	avoidance	Petterson (2002; 2003)
Nysted	-	>2.5 km	Petersen *et al*. (2006; 2008); Blew *et al*. (2008)
Horns Rev I	>900 m	>2 km	Christensen *et al*. (2003, 2004); Petersen *et al*. (2006); Petersen & Fox (2007); Blew *et al*. (2008); Danish Energy Agency (2013)
Alpha Ventu	-	>1-3 km	Bundesamt für Seeschifffahrt und Hydrographie (2012)
Egmond Zee	2-4 km	some	Krijgsveld *et al*. (2010; 2011); Leopold *et al*. (2011)
Gunfleet San	-	>1 km	Barker (2011)
Kentish Flats	Avoidance	>3 km	Percival (2009; 2010)
Thanet	-	some	Ecology Consulting (2012)
North Hoyle	-	>2.5 km	May (2008)

4. REVIEW OF UPTON (2012A, 2014A, C) AVOIDANCE RATE OF 0.99 FOR GREAT SKUA

Upton (2012 b) reviews evidence gathered over six breeding seasons (2007-2012) at Burgar Hill wind farm, one season (2012) at Hammars Hill wind farm and one season (2012) at Hoy community turbine. He presents calculations and, from these, makes a case that 0.99 would be a precautionary evidence-based avoidance rate for great skua. In this case, use of bird flight data from the operational period will be precautionary in that it omits birds that avoid the wind farm envelope by a wide margin (macro-avoidance), so will tend to underestimate the true avoidance rate to the extent that macro-avoidance occurs in this species. The paper is further supported by Upton (2014 a) which adds further evidence for the same three sites for 2013, and Upton (2014 c) which adds further evidence for the same three sites in 2014.

Carcass searches were carried out following recommended methods and are well presented in Upton (2012 b; 2014 a, c). The papers make a good case for the search efficiency for carcasses of birds the size of great skua being 100%. My own experience at great skua colonies is that when adult great skuas die (often as a result of fatal injuries during territorial fighting) the carcass is normally not scavenged by other great skuas. The species will very quickly eat other dead birds such as Atlantic puffins (*Fratercula arctica*) and kittiwakes and great skua chicks, but seems to avoid eating other adult great skuas, so great skua carcasses in colonies tend to remain intact for many months and eventually rot away. No great skua carcasses were found in any year. Numbers of great skuas at risk were estimated from vantage point (VP) surveys at Burgar Hill in 2012, at Hammars Hill in 2012 and at Hoy community turbine in 2008, 2010 and 2012. These data were used thoughtfully, and with the methodology fully explained and justified, by Upton (2012 b) to estimate from the basic Band model the numbers predicted to be killed per year by collision with turbines. The calculations are performed carefully, accurately, and in a precautionary manner.

The key result from Upton (2012 b) is the calculation of expected numbers of collisions from the basic Band model, and comparison with the empirical data showing no collisions at Burgar Hill wind turbines (Upton, 2012 b; Table 7). For all three sites and all years combined, the expected number of collisions at an avoidance rate of 0.98 was 7.52. For an avoidance rate of 0.99 the expected number of collisions was 3.76, and at an avoidance rate of 0.995 the expected number of collisions was 1.88. Even if two or three great skua carcasses had been missed during searches, the empirical data indicate an avoidance rate higher than 0.99. Upton (2012 a) also presents probability estimates to assess the likelihood that the zero collisions results from chance rather than high avoidance. These calculations support the conclusion that avoidance rate is higher than 0.99. The conclusion is further supported by additional data from the same sites in 2014 which adds to the evidence that an avoidance rate above 0.99 would be appropriate for great skua. In 2014, an estimated 5,523 flights at risk resulted in no detected collisions. The accumulated data over all sites and years predicted 5.5 collisions at an avoidance rate of 0.990 or 2.8 collisions at an avoidance rate of 0.995. These data suggest that, for these sites, an avoidance rate of 0.995 is precautionary (Upton 2014 c).

Had pre-construction flight activity data been used rather than flight activity data from the operational period, the estimated avoidance rate might possibly have been even higher. There is little evidence of macro-avoidance of wind farms by great skuas, but Sheila Gear at Foula describes that great skuas ‘appear to be well aware of where the turbines are and fly on a course that will avoid them’. The data from the three Orkney sites do provide a case for 0.99 or higher being appropriate as an avoidance rate for great skua based on species-specific data. Nevertheless, assessment of data from other sites would be appropriate to see if these results are consistent with evidence, even if only qualitative, from elsewhere. It is also relevant to consider whether collision risk might be higher during disputes between birds holding neighbouring territories, or where immature birds are attempting to establish a territory adjacent to an occupied territory. In such situations birds may engage in aerial chases and fights, where risk of collision may be higher than for birds commuting between colonies and foraging areas. Neither Burgar Hill nor Hammers Hill have many pairs of skuas nesting close to turbines, and risk may be greater if a wind farm is constructed close to areas disputed for territories.

5. EVIDENCE FOR GREAT SKUA AVOIDANCE FROM OTHER STUDIES

The Scottish Wind Farm Bird Steering Group does not hold any records of great skuas being killed by collision at any Scottish terrestrial wind farms (Claire Lacey, in litt.). However, a formal request for data was made to SWBSG for three sets of data in respect of great skua and Arctic skua (*Stercorarius parasiticus*)[2], identical to that already described for red-throated diver in Section 3.

In response to this request, no data were forthcoming from SWBSG.

A relatively small lattice tower turbine operated at South Ness in Foula, Shetland, for some years. The location at the southern extreme of the island on a short and intensively grazed sward of cliff-top grassland was as far away from skua breeding territories as it is possible to be on this small island. However, both great and Arctic skuas flew across this area in small numbers every day during the breeding season commuting between nesting territories and feeding areas. During each summer that I spent in Foula, I regularly walked past this turbine, and made casual checks for any collision victims, but I did not find any. Sheila Gear who resides in Foula and has a close interest in the seabird populations on the island also frequently passed this turbine without finding any skua casualties that could be attributed to collisions with the turbine. About 700 m away from the turbine, she did find several Arctic skuas with broken or severed wings and major impact injuries in the Bankwell area of Foula the regular breeding area for the nearest pairs of Arctic skuas to the wind turbine, but those birds appear to have been killed by collision with the plane as Bankwell is close to the southern end of the Foula airstrip and is on the flight line for landing and take-off. I have seen the plane hit and kill adult Arctic skuas with territories close to the airstrip. Like me, Sheila also did not find any great skua carcasses that could have been collision victims at the South Ness wind turbine. New, more modern, wind turbines were erected in the southern part of Foula in 2012. These were tested during the seabird breeding seasons of 2012 and 2013 and Sheila Gear monitored great skua behaviour as these new turbines operated. Sheila reported that 'most of the time bonxies appear to be well aware of where the turbines are and fly on a course that will avoid them. In poor visibility they fly steadily, close to the ground, apparently using it as a guide' (Sheila Gear, in litt.). No bird carcasses were found at these new turbines during their short period of operation (these turbines subsequently were damaged by severe winds and have been removed).

No casualties of any skua species were recorded in the extensive collation of European wind farm mortality data carried out by Dürr (2014).

Smaller species of skuas (jaegers) may migrate across the North American continent (Furness, 1987), but are unlikely to occur at North American wind farms in anything other than very small numbers. It is therefore not very informative that a review of bird casualties found in 68 studies at wind farms, estimated the total numbers killed at wind farms in the contiguous United States as 234,000 birds per year. This included about 3,500 birds of 220 species in the raw data, but these did not include any skuas (jaegers) of any species (Loss *et al*., 2013). Similarly, Zimmerling *et al*. (2013) reported 1,297 carcasses of 140 species found at 43 wind farms in Canada monitored for collision victims. These did not include any skuas (jaegers), and none has been found as collision victims during updating of these data since that publication (Ryan Zimmerling, in litt.).

The main breeding areas of great skuas are Shetland (probably now about 6,000 pairs but not censused recently), Orkney (about 1,500 pairs), the western isles (about 600 pairs), the small outer Faroe islands (about 500 pairs), glacial outwash plains of south-east Iceland

[2] Arctic skua was included as a related species with somewhat similar flight characteristics and (assumed) similar susceptibility to wind farm collisions.

(about 5,000 pairs), and Bear Island (about 400 pairs). There are no wind farms in Bear Island. Iceland has only one wind farm, with two Enercon E-44 900 kW turbines installed in February 2013 at Burfell Hydropower Station in upland south-west Iceland. This area, far from the coast, is unlikely to be visited regularly by great skuas. The Faroe Islands have four wind farms. Neshaga near Toftir on the large island of Esturoy is near to Torshavn. One turbine was constructed in 1993, there were three in 2005, five in 2012 and a sixth added in 2014. There is one turbine on the small island of Nolsoy near to Torshavn. Three turbines were erected at Myrunum, Vestmanna, in 2003. Thirteen turbines were erected at Husahagi near Torshavn in 2014. Although great skuas may occasionally pass any of these sites, they are all considerable distances from the main great skua breeding areas in the Faroes (which are mostly on small outer islands away from the main human settlement areas), so those wind farms are unlikely to be greatly informative about great skua avoidance rates. Although possible impacts on birds were considered during planning of these wind farms, there is no requirement for post-construction monitoring of bird collisions or flux at wind farms in the Faroes (S. Hammer, pers. comm.).

6. CONCLUSIONS

Upton (2012 a, b; 2014 a, b, c) presents a good case for the available evidence from studies at Orkney wind farms supporting the move to a precautionary avoidance rate of at least 0.99 for red-throated diver and great skua at terrestrial wind farms. An avoidance rate of 0.99 for these two species would also be supported by evidence from other wind farms in Scotland, and from wind farms throughout Europe and North America. No skua casualties have been reported from these, and only one instance of a diver casualty has been reported out of 11,150 bird carcasses sampled as killed at European wind farms. No divers were reported as casualties at any North American wind farms. There is strong evidence of macro-avoidance by red-throated divers of offshore wind farms, and some evidence for displacement of breeding divers by terrestrial wind farms which would tend to reduce collision risk further relative to predictions from measured pre-construction flight activity levels (although two pairs continue to breed close to the turbines at Burgar Hill so some pairs appear able to adapt to breeding close to turbines).

Calculations provided by Upton (2012 a, b; 2014 a, b, c) indicate that the avoidance rate of red-throated diver and great skua is almost certainly greater than 0.990, and probably greater than 0.995. Upton (2014 b, c) points out that at an avoidance rate of 0.995, the flight activity data predict between 1.5 and 3 deaths for both red-throated diver and great skua, yet none was found for either species. The recent review of seabird avoidance rates conducted by the BTO for Marine Scotland (Cook *et al*., 2014) made use of data derived predominantly from terrestrial wind farms. The consequent SNCB advice to use an avoidance rate of 0.995 for herring gull, lesser black-backed gull and great black-backed gull, and the use of indirect evidence to advise use of an avoidance rate of 0.989 for gannet and kittiwake at offshore wind farms, puts the evidence reviewed here for red-throated divers and great skuas into a wider context.

The evidence suggests there is little justification to advise a lower avoidance rate for red-throated diver and great skua at terrestrial wind farms than for gannet and kittiwake at offshore wind farms, and the avoidance rate is likely to be the same as that of the large *Larus* gull species. Therefore, it would be more consistent with the recommendation for large *Larus* gulls, and still apparently precautionary, to advise use of an avoidance rate of 0.995 for red-throated diver and great skua. This would also be consistent with the evidence from abroad. In light of the relatively small number of wind farms at which avoidance by these two species has been studied, and the fact that the Burgar Hill wind farm represents a single row of turbines so may not be a good model for wind farms where turbines are in a grid with several rows, it would be precautionary to advise the use of an avoidance rate of 0.990 until the generality of the current results across other wind farm sites and designs has been established. However, on balance and based on wider UK and international data as well as studies in Orkney, it seems more appropriate to align the avoidance rate for red-throated diver and great skua with that of large *Larus* gulls, at 0.995.

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