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Nocturnal flight activity of northern gannets *Morus bassanus* and implications for modelling collision risk at offshore wind farms

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ABSTRACT

Assessing the potential impacts of proposed offshore wind farm developments on seabird populations requires estimation of nocturnal flight activity of seabirds for input into collision risk models. One of the seabirds considered most at risk from collision with offshore wind turbines is the northern gannet *Morus bassanus*. The recommended correction for gannet nocturnal flight activity is currently a highly precautionary value. Here we use data from tracking studies to derive evidence-based correction factors for nocturnal flight activity of adult gannets during the breeding and nonbreeding seasons, and of immature gannets during the summer prospecting phase. Flight and diving activity of gannets was minimal during the night, astronomical and nautical twilight, for adults during the breeding season and nonbreeding season, and for immatures. Some flight activity occurred during the short period of civil twilight, but on average at about half the level seen during the day. Based on evidence from numerous tracking studies, we recommend that precautionary values of the nocturnal (sunset to sunrise) flight activity factor for estimating collision risk should be 8% of daytime flight activity during the breeding season and 3% of daytime flight activity during the nonbreeding season. Use of these evidence-based correction factors will improve the accuracy, and reduce the uncertainty of collision risk models, providing a more reliable assessment of the impacts of offshore wind farms on gannets.

1. Introduction

One of the key environmental issues facing developers of offshore wind farms in Environmental Impact Assessments is the impact that turbines may have on seabird populations as a consequence of mortality of birds that collide with rotating blades (Garthe and Hüppop, 2004; Furness et al., 2013). Bird collision mortality can be estimated using the Band collision risk model (Band, 2012). However, this requires an estimate of nocturnal flight activity as one of the model inputs. Seabird surveys at proposed offshore wind farm sites do not record the numbers of birds flying through the area at night, as visual (boat-based counts) or photographic (aerial) surveys are only practical during daylight hours. It is, therefore, necessary to use a correction factor, relative to daytime data, to allow for nocturnal flight activity of seabirds. Garthe and Hüppop (2004) assigned nocturnal flight activity scores to seabird species in five categories (scores of 1 to 5), based on existing limited evidence, their own judgement, and that of a panel of experts. They indicated that a score of 1 represented 'hardly any flight activity at night' while a score of 5 represented 'much flight activity at night'. These scores simply indicated that bird species that scored higher were likely to show more nocturnal flight activity than bird species that scored lower on the scale. Nevertheless Band (2012) advocated an arbitrary but precautionary translation of the Garthe and Hüppop (2004) scores for collision risk modelling as follows:

- 1 = 0% of daytime flight activity,
- 2 = 25% of daytime flight activity,
- 3 = 50% of daytime flight activity,
- 4 = 75% of daytime flight activity,
- 5 = 100% of daytime flight activity.

It is important to note that these suggested percentages were not based on evidence. It is also clear from Garthe and Hüppop (2004) that many of the scores for other seabird sensitivity metrics that they assigned were categorical rather than linear. Explicit examples are their scoring of population size; 1 ≥ 3million, 2 = 1–3 million,

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3 = 500,000–1 million, 4 = 100,000-500,000, 5 ≤ 100,000, and their scoring of flight altitude where scores 1 and 2 were based on median flight heights on a non-linear scale but scores 3 to 5 were based on 90th percentile flight heights on that scale.

One of the seabird species that appears most vulnerable to collision mortality at offshore wind farms is the northern gannet *Morus bassanus* (hereafter gannet) (Furness et al., 2013). The impact of collision mortality on gannet populations has been one of the primary concerns of recent planning applications for offshore wind farms. Band model calculations estimate a cumulative total of 2561 gannets per year may be killed by collisions at constructed and consented offshore wind farms in the United Kingdom sector of the North Sea (MacArthur Green, 2018). In relation to the Habitat Regulations Assessment (HRA) component of the planning application for Hornsea Two offshore wind farm, Natural England (2015) were unable to conclude beyond all reasonable scientific doubt that the estimated cumulative collision total for offshore wind farms would not have an adverse effect on the integrity of the Flamborough and Filey Coast proposed Special Protection Area (FFC pSPA) gannet population. In relation to East Anglia THREE offshore wind farm, The Planning Inspectorate (2017) stated "two key HRA matters were the focus of the Examination: The effect of the proposed development in combination with other offshore wind farms on the kittiwake and gannet features of the FFC pSPA". Therefore, estimated collision mortality of gannets has the potential to stop the considerable further development of offshore wind farms planned for the North Sea (The Crown Estate, 2018).

Garthe and Hüppop (2004) assigned a nocturnal flight activity score of two for gannets, based on evidence from Garthe et al. (1999, 2000, 2003) and Hamer et al. (2000), and this was converted to 25% of the daytime level by Band (2012). During mid-summer, the correction for nocturnal flight activity makes only a small difference to estimated numbers of collisions, since the night is short in mid-summer (Fig. 1). However, in winter the effect is larger: because the night is about twice as long as day during winter, the Band (2012) model estimates an additional 0.5 collisions at night for each collision during the day for an offshore wind farm located in the southern North Sea. Most offshore wind farms in Europe are in the southern North Sea. Gannet numbers in that region are low in summer and peak strongly during November (Stone et al., 1995; Furness et al., 2018), so the influence of nocturnal correction is likely to be close to the 0.5 nocturnal collisions per daytime collision. This means that an evidence-based correction for this parameter would be important in improving confidence in the estimated cumulative impact of collisions at offshore wind farms on gannet populations, especially where the cumulative total is close to a level that could result in consenting risk for further offshore wind farm developments.

Garthe and Hüppop (2004) did not provide an explicit definition of day and night. Collision risk modelling using the Band model defines day as sunrise to sunset and night as sunset to sunrise, with the

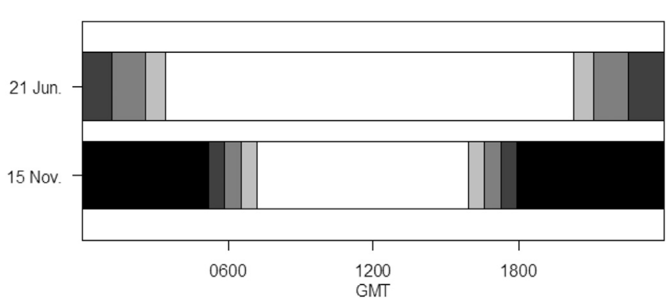

Fig. 1. Illustration of the differences in duration of night (black), astronomical twilight (dark grey), nautical twilight (medium grey), civil twilight (light grey), and day (white) at midsummer (21 June) and during peak migration of gannets through the southern North Sea (November) at 52°30′N 2°30′E, a typical location for a southern North Sea offshore wind farm. Times in GMT.

estimation of the times of sunrise and sunset derived from Forsythe et al. (1995). However, that definition of night contrasts with the official concept of 'twilight' and 'night'. 'Civil twilight' is defined as from sunset to the sun falling 6° below the horizon and in the morning from when the sun reaches 6° below the horizon until sunrise. 'Nautical twilight' is defined as the sun being between 6° and 12° below the horizon. 'Astronomical twilight' is defined as the sun being between 12° and 18° below the horizon, and 'night' is from then until the sun has risen back to 18° below the horizon. In the regions where gannets overwinter, the transition through twilight can be rapid. However, in summer, there may be no official 'night' at all, because astronomical twilight persists if the sun never falls more than 18° below the horizon (Fig. 1). This suggests that a more subtle definition of 'day' and 'night' is required than that used in Band (2012) to take account of the considerable variation in light levels between sunset and sunrise in summer, and especially at higher latitudes. Since gannets are visual predators (Garthe et al., 2000, 2003; Lewis et al., 2002), it is likely that flight activity is determined by the minimum light levels to allow foraging, commuting or migrating. Cleasby et al. (2015a) noted that gannet dives tend to be shallower close to sunrise and sunset, which supports the argument that diving at twilight is limited by the birds' ability to see their prey.

There are now many data sets showing flight activity levels of gannets at different times of day, both for breeding birds and for birds during the migration period and in winter. In this paper we assess the available evidence in order to provide evidence-based corrections for nocturnal flight activity of gannets for use in Band model collision assessments. This will give more accurate results than estimates based on the conversion of scores assigned by Garthe and Hüppop (2004). Here we consider data from throughout the range of the gannet. However, we focus on deriving appropriate corrections for use in examining impacts on gannets in the North Sea, the region with by far the largest number of constructed and proposed offshore wind farms (The Crown Estate, 2018).

2. Methods

We carried out a literature search, focused on Web of Knowledge and Google Scholar but also searching 'grey literature' (such as consultant reports and SNCB guidance documents) to find data on daytime and nocturnal flight activity of gannets. GLS logger data (from Garthe et al., 2012) were used in order to identify variation in flight behaviour according to the time of day. We considered activity data divided into 'day', 'civil twilight', 'nautical twilight', 'astronomical twilight', and 'night' (Fig. 1). We used Time and Date (2018) to extract timings of sunrise, sunset, civil, nautical, astronomical twilight and night appropriate for the location and date of each study.

We considered data derived from tags deployments: a) data from breeding gannets incorporated into Garthe and Hüppop (2004), b) data from breeding gannets collected since Garthe and Hüppop (2004), c) geolocator (GLS) data from gannets during the non-breeding season, d) data from tags on immature gannets (Jeglinski et al. unpublished data). Flight activity is frequently referred to as the percentage of each hour spent in flight. Several different types of tag have been used to infer at sea behaviours of seabirds. Travel speed of birds at sea derived from GPS tracking can be assigned to resting on the sea or to flying if there is a clearly bimodal distribution of travel speeds, with the faster mode representing flight (Grémillet et al., 2004). Few studies have used accelerometer data from tags, but these can aid interpretation of behaviour of birds (Warwick-Evans et al., 2015). Geolocator tags that have a salt-water switch provide accurate data for gannets because birds are either in the water (switch on) or flying (switch off), as it can be assumed that gannets are not on land during the nonbreeding season when away from the colony (Garthe et al., 2012). Some loggers record diving activity but not flight activity. Since gannets only dive from the air, and not from the sea surface, diving activity implies flight activity.