Rafting behaviour of Manx Shearwaters *Puffinus puffinus*

Wilson, L. J.[1]*, McSorley, C. A.[1a], Gray, C. M.[2], Dean, B. J.[1], Dunn, T. E.[1], Webb, A.[1] & Reid, J. B.[1]

**Correspondence author.*
Email: linda.wilson@jncc.gov.uk
[1] *Joint Nature Conservation Committee, 7 Thistle Place, Aberdeen AB10 1UZ, UK ([a]Current address: Scottish Natural Heritage, 1 Kilmory Industrial Estate, Lochgilphead, Argyll PA31 8RR, UK);* [2] *Countryside Council for Wales, Maes Y Ffynnon, Penrhosgarnedd, Bangor LL57 2DW, UK (Current address: Peak District National Park Authority, Aldern House, Baslow Road, Bakewell, Derbyshire DE45 1AE, UK).*

Abstract
Radio-telemetry data were collected on rafting Manx Shearwaters *Puffinus puffinus* at Skomer (southwest Wales), Rum (northwest Scotland) and Bardsey (northwest Wales) between 2003 and 2005. These were used to investigate whether Manx Shearwaters tend to raft adjacent to their breeding areas and whether rafts move closer towards shore as the evening progresses. On Skomer and Bardsey, there was a tendency for birds to raft in an area roughly adjacent to where they bred, although they did not raft exclusively opposite their breeding site. On Rum, birds breeding at two different locations appeared to show different preferences for rafting areas. However, it was difficult to draw conclusions from this, as signal coverage around the island was poor, and the breeding locations were close together. At all three islands, there was strong evidence that birds tended to move closer inshore as the evening progressed.

Introduction
Many nocturnal Procellariids form rafts, or dense flocks of birds, on the sea adjacent to their breeding colonies from late afternoon onwards, before coming ashore at nightfall (Brooke 2004). Species of shearwater known to engage in such rafting behaviour include Cory's Shearwater *Calonectris diomedea*, Streaked Shearwater *C. leucomelas*, Manx Shearwater *Puffinus puffinus*, Flesh-footed Shearwater *P. carneipes*, Great Shearwater *P. gravis*, Sooty Shearwater *P. griseus* and Short-tailed Shearwater *P. tenuirostris* (Brooke 2004). Nocturnal attendance at the colony is thought to be a predator avoidance strategy (Brooke & Prince 1991; Mougeot & Bretagnolle 2000; Keitt *et al.* 2004), but the function of rafting is unclear. It is possible that the birds have difficulty in timing their return to their colony from their distant foraging grounds to precisely coincide with nightfall, so they assemble in rafts until it is safe to come ashore (Warham 1996; Brooke 2004). Most Procellariids in nearshore rafts do not feed, or only do so if schooling fish are present (Lockley 1942; Warham 1990), but rafts may provide an arena for courtship behaviour and other social interactions, as well as maintenance behaviour such as preening and resting (Brooke 1990; Warham 1996).

Rafts can comprise thousands of birds and it is assumed that they include both breeding and non-breeding birds, as both visit the colony after nightfall (Furness *et al*. 2000). Anecdotal observations indicate that rafting birds are generally more restless during windy conditions, frequently flying and re-alighting to maintain position (Brooke 2004), suggesting that raft position is of importance to participating birds. It is thought that Manx Shearwaters may raft adjacent to where they come ashore and their rafts might tend to approach the shore, once darkness falls (Brooke 1990). Based on visual observations of birds coming ashore close to where they had been rafting, Furness *et al*. (2000) also assumed Cory's Shearwaters tended to raft opposite their breeding site.

Most observations of rafting have been anecdotal, and to our knowledge, there have been no detailed studies of rafting behaviour itself. Recently, we used radio-telemetry to determine how far Manx Shearwater rafts extend offshore, as part of a project to inform the issue of possible extensions to breeding colony Special Protection Areas into adjacent marine areas (McSorley *et al.* 2008; Wilson *et*

al. in prep.). In this paper, we use those data to further investigate whether Manx Shearwaters tend to raft adjacent to their breeding areas and whether rafts move closer towards shore as the evening progresses.

Methods

Detailed methods of the fieldwork can be found in McSorley *et al*. (2008) and Wilson *et al*. (in prep.). The main points are summarised here.

Study colonies: The study took place from May to August on the islands of Skomer (southwest Wales), Rum (northwest Scotland) and Bardsey (northwest Wales) (Figure 1a–c), during 2003, 2004 and 2005 respectively. These islands host the world's three largest Manx Shearwater breeding colonies (Skomer: 101,800 pairs, Rum: 120,000 pairs, Bardsey: 16,183 pairs (Newton *et al*. 2004)). On each island, we fitted radio-tags to breeding adults at a number of geographically distinct breeding areas, allowing us to test whether the location of the breeding area influenced raft location around the island. Four study breeding areas were chosen on Skomer, two on Rum and five on Bardsey (Table 1, Figure 1a–c). It was not possible to get a wide geographical spread of study sites on Rum, as the colony is confined to the high mountains, where access is difficult. An initial visit to each colony in May (during the incubation period) allowed the marking of potential study burrows, with adults from each being sexed using cloacal inspection where possible (Gray & Hamer 2001).

Radio-tag attachment and radio-tracking: Radio-tag attachment was carried out during a second visit in July (during the chick rearing period). A VHF radio transmitter (supplied by Biotrack Ltd) was attached to the two central tail feathers of one adult from each accessible, occupied study burrow. To reduce any adverse effects of the tag and the possibility of chick desertion, only the heaviest individuals, with chicks older than five days were tagged. Tags weighed 8.9 g on Skomer and 4.4 g on Rum and Bardsey, less than 2.5% (Skomer) or 1.3% (Rum and Bardsey) of average adult body weight. Tags were attached using either self-amalgamating tape (Skomer), or Tesa® tape (Rum and Bardsey). Adults were returned to their burrows immediately following the tagging procedure, which took less than ten minutes. At the end of the study, birds were recaptured and their tags removed. Some birds could not be recaptured and it was assumed that these would lose their tags during their subsequent post-breeding moult.

Table 1. The number of marked burrows and birds that were tagged and subsequently located rafting, for each Manx Shearwater *Puffinus puffinus* breeding site on each island.

Island	Breeding Site	Total no. of burrows marked	No. of birds tagged	No. of birds located rafting
Skomer	Pigstone	14	7	6
	The Wick	35	8	4
	Behind house	23	8	3
	The Neck	26	7	6
	Total	**98**	**30**	**19**
Rum	Hallival	45	18	11
	Askival	75	10	9
	Total	**120**	**28**	**20**
Bardsey	Cristin	9	2	2
	Nant	32	11	11
	Pen Cristin	35	9	9
	NW Fields	21	5	5
	South-end	7	3	3
	Total	**104**	**30**	**30**

Radio-tracking, using Sika receivers and five-bar rigid Yagi antennas (Biotrack Ltd), began on the first evening of tag attachment and took place on: 14 evenings between 15 and 29 July 2003 (Skomer); 15 evenings between 15 July and 6 August 2004 (Rum); and 18 evenings between 31 July and 19 August 2005 (Bardsey). Radio-tracking was conducted from three locations on Skomer and mainland Pembrokeshire (50–80 m above sea level (a.s.l.)), six locations on Rum (200–250 m a.s.l.), and five locations on Bardsey and mainland Gwynedd (100–160 m a.s.l.), although at any one time only two or, usually, three locations were used. Radio-tracking generally commenced 17.00–19.00 (GMT) and continued until the last detectable tagged bird returned to the colony (usually by 24.00). During this time simultaneous compass bearings for each detectable signal (bird) in the area were taken by two or three observers, following a coordinated tracking schedule (one bird every three minutes).

Analysis: Analyses were performed only on those birds that were thought to be rafting; data were checked prior to analyses and any bearings that were clearly incorrect, or were for birds that were travelling or foraging, were removed. This was determined by signal strength, notes taken by the trackers and comparison of signal direction between tracking locations. Compass bearings were corrected for magnetic north using the appropriate adjustment for each area. Bird locations were estimated by triangulation of corrected bearing data with LOAS™ 3.0.2 (Location Of A Signal) software © 1998–2004 (Ecological Software Solutions™). A maximum likelihood estimator was used for triangulation.

To test whether raft location around each island was influenced by birds' breeding locations, a quadrant was centred on the 'central study burrow' and rafting birds from each breeding area were classified according to which quadrant they fell within (i.e. whether they were located in rafts northeast, northwest, southeast or southwest of the island, or in the case for Rum, east or west). Observed and expected frequencies were compared using a Chi-squared test. The 'central study burrow' was defined as the geographical mean centre of all study burrows containing a tagged bird, using the central feature tool within Esri® Arcmap™ 9.2.

A Spearman rank correlation of raft distance against time was used to investigate whether rafts moved closer to the colony over time. The distance between each estimated raft location and the nearest point of land on the island ('raft distance') was calculated using the spatial join tool within Esri® Arcmap™ 9.2 and based on a polygon of the high water mark supplied by Ordnance Survey under licence [JNCC][100017995][2008].

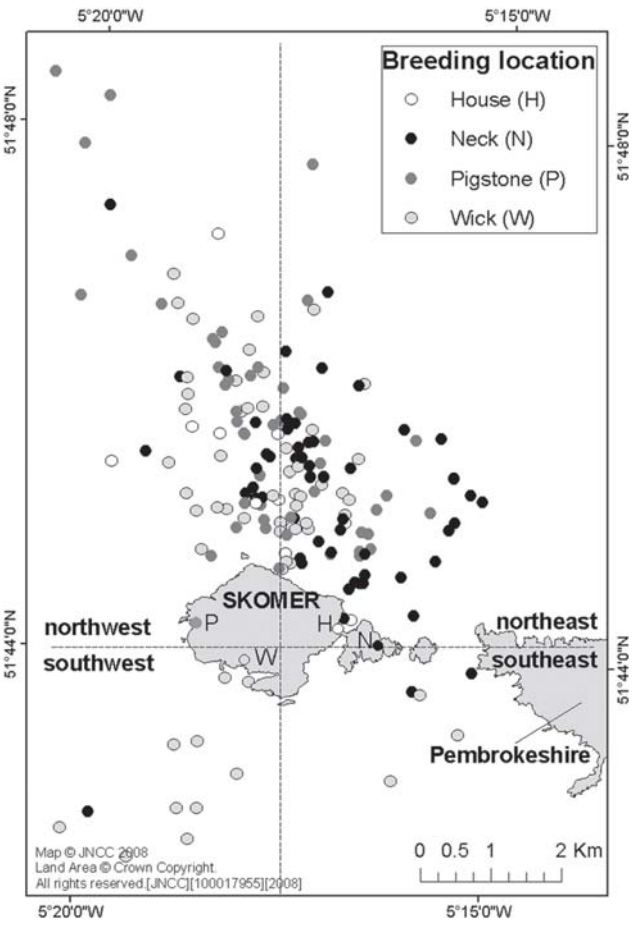

Figure 1a. Rafting locations of Manx Shearwaters *Puffinus puffinus* around Skomer, according to their breeding area. The position of each quadrant is shown, centred on the mean centre of all study burrows.

Results and Discussion

Thirty birds on Skomer, 28 on Rum and 30 on Bardsey, were fitted with a radio-tag, and of these it was possible to estimate raft locations for 19, 20 and 30 birds respectively (Table 1). Within Skomer and Rum, the sample of birds for which we were unable to estimate raft locations included individuals breeding at each of the study areas, making it unlikely that the lack of data from these birds biased our results. Six birds from Skomer and three from Rum were not detected at all after tag attachment, and of these, four (all from Skomer) were recaptured of which all had lost their tag. Therefore, it seems likely that our failure to detect some birds was due to tag loss, rather than because they were not in the vicinity of the colony. Tag loss was reduced during the Rum and Bardsey studies by having a more secure attachment using Tesa® tape and lighter tags. In the sample of birds for which we obtained raft locations, the sex ratio did not significantly differ from 50:50 (Skomer: 9m:9f, χ^2 = 0.11; Rum: 11m:7f, χ^2 = 0.56; Bardsey: 8m:7f, χ^2 = 0.17; P > 0.05, 1 df for all).

Of those birds located rafting, 58% (Skomer), 40% (Rum) and 93% (Bardsey) were located in rafts at least twice during the study period. Guilford *et al*. (2008) suggested that most breeding Manx Shearwaters on Skomer may not join rafts. This was based on data from birds fitted with global positioning devices which showed that some birds were some distance from the colony at nightfall. We were unable to estimate the number of evenings that birds visited the colony without rafting, as we were much more likely to detect birds that were rafting than birds which simply flew straight from their foraging grounds to their burrow (where the radio signal was not detectable except at close range). However, our data does not exclude the possibility that some birds attended their burrow without joining rafts beforehand, although we feel this would be a minority.

Figure 1(a–c), shows the rafting locations estimated from our analysis around each island, colour coded according to breeding location.

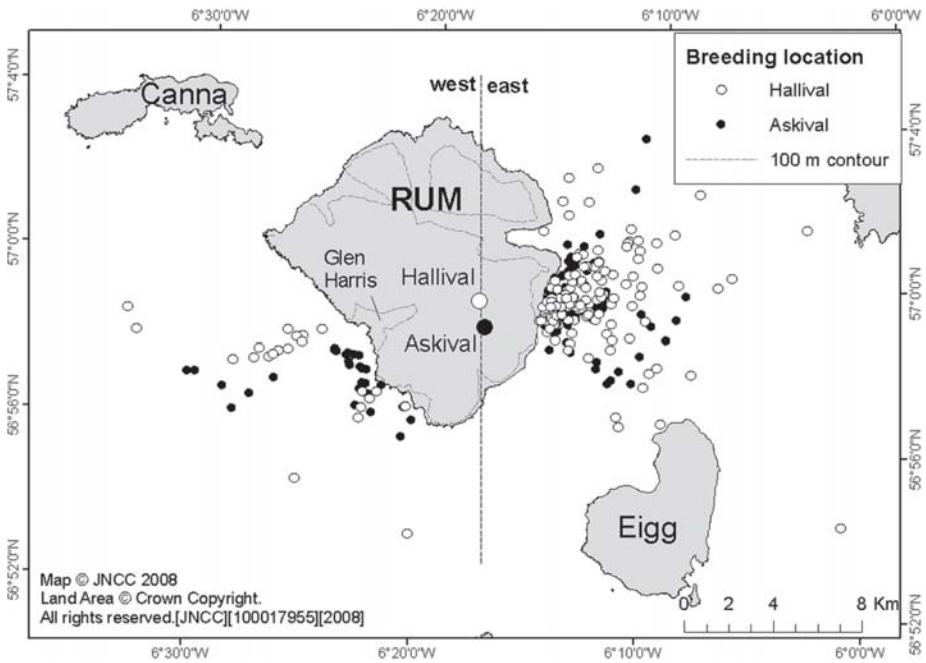

Figure 1b. Rafting locations of Manx Shearwaters *Puffinus puffinus* around Rum, according to their breeding area. The position of the line dividing the island into west and east is shown, centred on the mean centre of all study burrows.

Skomer (Figure 1a): No raft location data were obtained to the east or west of Skomer and sample sizes were small to the south. This was largely due to the island's topography interfering with signals from tagged birds and the locations of trackers (at the highest points on the island, falling in an east–west orientated line) making it difficult to triangulate to the east or west. Casual observations before nightfall, together with signals coming from these directions (but which could not be triangulated), indicated that birds were rafting in the areas for which we lacked data.

There was a significant difference in the observed and expected frequencies of raft locations in each quadrant for Skomer (χ^2 = 33.53, 9 df, P < 0.001, Figure 2a). Most raft locations were to the northeast (53%) and the northwest (37%). Birds breeding at Pigstone (in the west of the island) rafted most often to the northwest while birds breeding at the Neck (in the east of the island) were located more often to the northeast. Observations from birds breeding at the House (in the east of the island) were equally divided between the northeast and northwest. Almost all of the observations in the two southern quadrants were from birds breeding at the Wick (in the south of the island), although most of observations from the Wick were in the northeast quadrant.

As there were few observations to the south of Skomer, the Chi-squared test was repeated excluding raft locations to the southeast and southwest; there was still a significant difference (χ^2 = 11.29, 3 df, P < 0.05).

Thus, there was evidence that the location of the breeding area had some influence on raft location, with most of birds breeding in the east of the island, rafting to the northeast, most birds breeding in the west of the island, rafting to the northwest, and almost all of the raft observations to the south, being from birds breeding in the south.

Rum (Figure 1b): No raft location data were obtained to the north or south of Rum. On

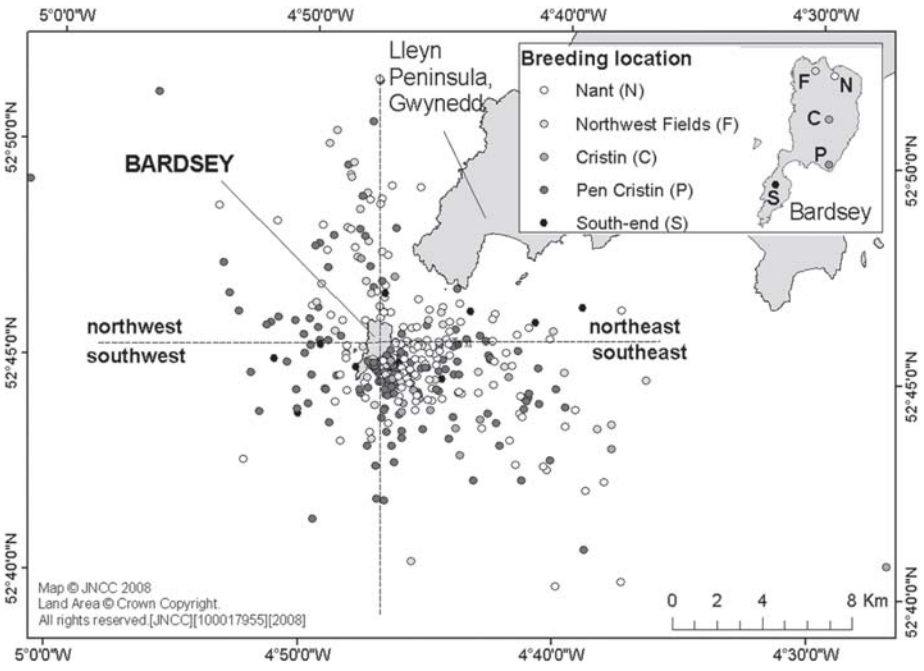

Figure 1c. Rafting locations of Manx Shearwaters *Puffinus puffinus* around Bardsey, according to their breeding area. The position of each quadrant is shown, centred on the mean centre of all study burrows.

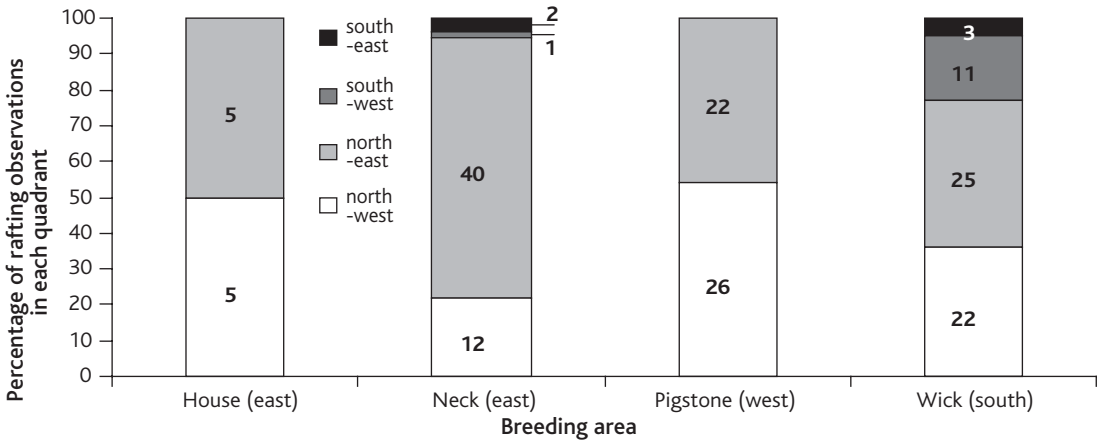

Figure 2a. The percentage of Manx Shearwater *Puffinus puffinus* raft locations in each of four quadrants around Skomer, in relation to breeding area (Pigstone, House, Neck and Wick). Quadrants were centred on the mean centre of all the study burrows. Bar numbers are frequency numbers.

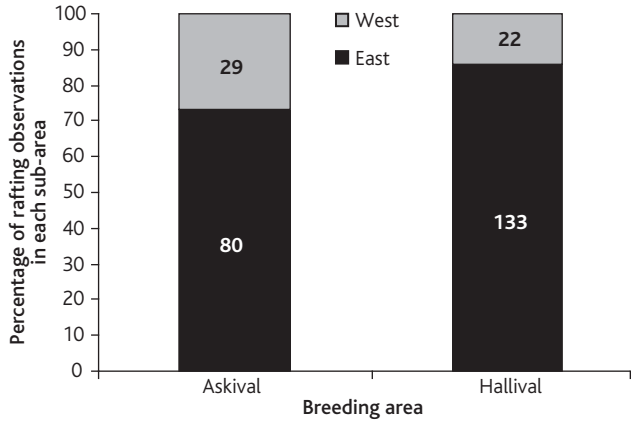

Figure 2b. The percentage of Manx Shearwater *Puffinus puffinus* raft locations in each of two areas around Rum, in relation to breeding area (Askival and Hallival). The dividing line between the two areas was centred on the mean centre of all the study burrows. Bar numbers are frequency numbers.

Rum, the position of trackers was limited due to access difficulties, and the surrounding topography allowed adequate signal coverage only to the west and the east. However, birds have been observed rafting to the north (S. Morris, Scottish Natural Heritage, pers. comm.) and our tracking indicated that birds were probably also rafting to the south.

Most (81%) raft locations were to the east of Rum, reflecting greater observer effort there. There was a significant difference in the observed and expected frequencies of raft locations between each breeding area, within the east and west areas (χ^2 = 19.14, 1 df, P < 0.01, Figure 2b). This is perhaps surprising considering the close proximity of the two breeding areas. Most (57%) of the westerly locations were from birds that bred at Askival and most (62%) of the easterly locations were from birds that bred at Hallival, although individuals from both breeding areas rafted both to the east and west of the island.

Birds rafting to the west of Rum may position themselves there so that they can reach their burrow by flying directly east up the Glen Harris valley system (Figure 1b) across land and around the back of the site. However, anecdotal observations suggested that some birds that rafted to the west gradually moved southwards and around to the east side of the island, presumably to access their burrow from the east. Thus, it seems that on Rum, topography and access routes to the burrow, as well as burrow location itself, may influence raft locations, particularly just prior to birds returning to their colony.

Bardsey (Figure 1c): The highest sample size of both rafting observations and tagged birds, and the most complete signal coverage achieved, was on Bardsey. There was a significant difference in the observed and

expected frequencies between each quadrant for Bardsey (χ^2 = 57.78, 12 df, P < 0.001). On Bardsey, most (56%) raft locations were to the southeast of the island, while the other quadrants each contained only 14–15% of raft locations (Figure 2c). Birds from all subcolonies (except South-end) appeared to show a preference for rafting to the southeast of the island, possibly because this provides the most sheltered area from wind and/or strong tidal currents. Once the southeast locations are accounted for, there was evidence that birds tended to raft adjacent to their breeding area, with birds breeding in the northeast (Nant) tending to raft to the northeast, birds breeding in the northwest (Northwest fields) tending to raft to the northwest, and birds breeding in the southwest (South-end) tending to raft to the southwest. In addition, most of rafting observations in the preferred southeast quadrant were from birds breeding in the southeast (Pen Cristin).

Do rafts move closer to shore over time?: There were no locations generated earlier than

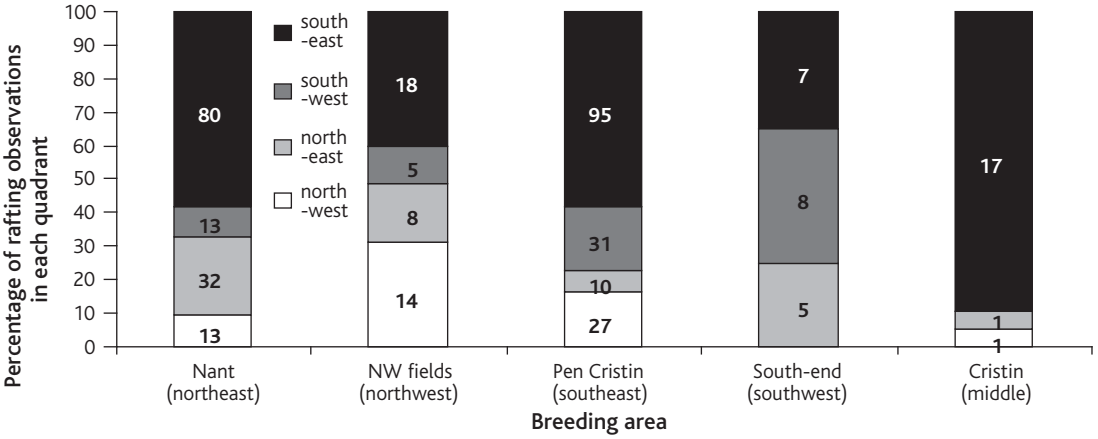

Figure 2c. The percentage of Manx Shearwater *Puffinus puffinus* raft locations in each of four quadrants around Bardsey, in relation to breeding area (Nant, NW fields, Pen Cristin, South end and Cristin). Quadrants were centred on the mean centre of all the study burrows. Bar numbers are frequency numbers.

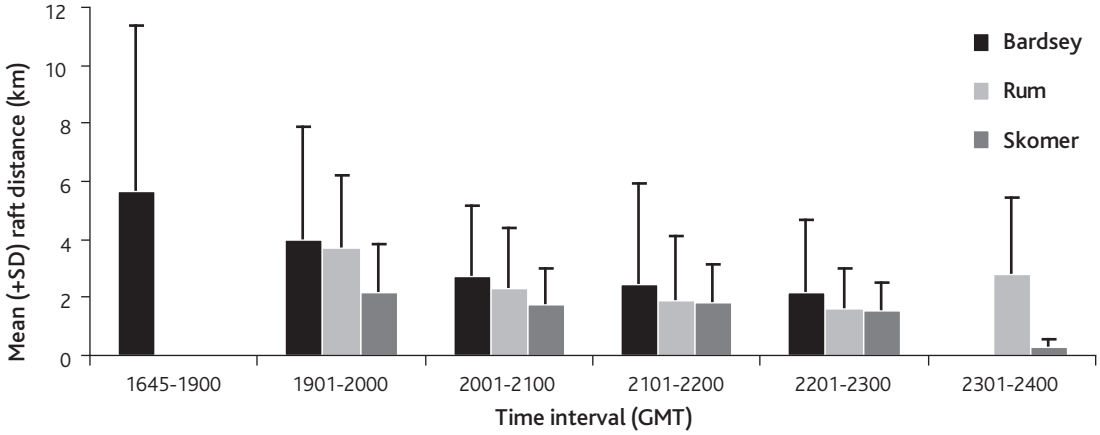

Figure 3. The mean and standard deviation (SD) of rafting distance (km) of Manx Shearwaters *Puffinus puffinus* from their breeding islands, at different time intervals over the evening.

19.00 (GMT) on Skomer and Rum, as birds did not start rafting within range of the trackers until at least 19.00 on Skomer and 19.30 on Rum. On Bardsey, the earliest locations generated were much earlier, at 16.45, reflecting the earlier onset of nightfall later on in the season, when the Bardsey study took place. On all three islands, there was evidence that rafting birds moved significantly closer to the colony as the evening progressed (Spearman Rank correlation: r_s = -0.19, n = 174, P < 0.01, Skomer; r_s = -0.13, n = 264, P < 0.05, Rum; r_s = -0.32, n = 385, P < 0.001, Bardsey) (Figure 3). Positioning closer to shore as darkness falls may allow a better assessment of the approach to the breeding burrow, which could be associated with assessing predation threat and local light levels. By reducing flight time to the burrow, temporary periods of reduced light levels, such as when moonlight is obscured by clouds, may be taken advantage of more readily.

Conclusion

This study highlights how radio-telemetry can be a useful tool to examine rafting behaviour. There was clear evidence from all three colonies that rafting birds tended to approach closer to shore as the evening progressed. The data also indicated that raft location around an island may be influenced by the location of the breeding area, although the situation was not clear-cut and data were confined to one season for each island. For Skomer and Rum, data were limited in some areas by poor signal coverage, making it more difficult to assess the true influence of breeding location on raft location. The rafts around Bardsey included a few birds which were feeding and although these birds were removed from the analysis, the presence of feeding birds might attract other birds and so influence the location of rafts. It is likely that other factors also influence raft location, such as weather conditions, local oceanographic variables, and access routes to the colony, and that the combined effect of such factors will vary between colonies. Around fairly small islands, such as the ones in this study, the choice of raft site may not be as crucial as around larger islands, as differences in travel time to the burrow from different raft locations around the island could be insignificant. Thus, a stronger influence of breeding location on rafting location might be more evident where colonies are on larger islands, such as with Cory's Shearwaters in the Azores archipelago.

Acknowledgements

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Late breeding by Great Cormorants *Phalacrocorax carbo*

Craik J. C. A.[1]* and Bregnballe T.[2]

**Correspondence author.*
Email: clive.craik@sams.ac.uk
[1] *Scottish Association for Marine Science, Dunstaffnage, Oban, Argyll PA37 1QA, UK;* [2] *National Environmental Research Institute, University of Aarhus, Department of Wildlife Ecology and Biodiversity, Kalø, Grenåvej 14, DK-8410 Rønde, Denmark.*

Abstract
Two distinct waves of synchronised breeding occurred at a colony of Great Cormorants *Phalacrocorax carbo* in west Scotland in 2007. The second wave led to young fledging in September, exceptionally late for this species locally. Evidence from elsewhere suggests that this second wave was not double-brooding (raising of two broods in one year by the same pair) but breeding by newly-arrived birds that had failed at a nearby colony earlier in the year.

Introduction
At a small colony of Great Cormorants *Phalacrocorax carbo* (hereafter 'Cormorants') in Scotland in 2007, there were two distinct waves of successful breeding separated by 2.5 to 3 months. In June, the normal fledging season, 47 young fledged from 18 nests. Then, in September, 28 young fledged from 14 nests in the same small area (details in Appendix 1). A well-synchronised pulse of many young fledging together so late in the year is unusual, at least in this part of Scotland where such an occurrence seems not to have been reported before. The first purpose of this short note is to place this event on record.

Our second objective is to consider whether these two waves were caused by the same pairs breeding for a second time (successful 'double-brooding'), or by incoming birds nesting in the same small colony area, or possibly a mixture of these. There were no ringing data to resolve this question directly. We therefore approach it indirectly by examining other records of late breeding in this and a closely related species. If it was genuine double-brooding, 14 of the original 18 pairs raised successful second broods. This percentage (78%) will be compared with similar measures from elsewhere.

Late breeding
Late breeding has been recognised as an aspect of Cormorant breeding behaviour at, at least, two colonies in continental Europe. In 1992 and 1993, the colony at Val Campotto in the Po