Marine Policy ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at SciVerse ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Individual consistency in the foraging behaviour of Northern Gannets: Implications for interactions with offshore renewable energy developments

L.M. Soanes [a,*], P.W. Atkinson [b], R.D. Gauvain [c], J.A. Green [a]

[a] School of Environmental Sciences, University of Liverpool, Liverpool L69 3GP, UK
[b] British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU, UK
[c] Alderney Wildlife Trust, St Annes GY9 3TA, Alderney, Channel Islands

ARTICLE INFO

Article history:
Received 18 February 2012
Received in revised form
23 August 2012
Accepted 23 August 2012

Keywords:
Environmental impact assessment
Tidal power
GPS tracking
Home-range area

ABSTRACT

With recent EU directives requiring that Europe must achieve 20% of its energy from renewable sources by 2020 the development of offshore wind, tidal and wave technologies is gaining momentum, increasing pressure on our already vulnerable marine systems and organisms. All EU countries are required to have Environmental Impact Assessment (EIA) guidelines in place for such developments and whilst tracking studies of marine predators have been recommended to aid EIAs, they are as yet not a requirement. This study tracked Northern Gannets breeding on Les Etacs, a stack immediately offshore Alderney, Channel Islands, to determine their use of both local and international waters and examine the consistency between an individual's foraging trips. The 15 Northern Gannets that made at least two foraging trips foraged in three different territorial waters and their combined home-range area overlapped with nine potential offshore marine renewable energy developments. Repeatability between the first and second foraging trips made by an individual was apparent when considering the direction travelled and the maximum distance travelled from the colony, but not when considering the percentage overlap in core foraging areas, trip duration, or the total trip distance suggesting individuals did not appear to be dependent on specific foraging areas. Our findings highlight the need to consider all important seabird colonies which forage in the range of potential offshore developments and to use tracking technology to determine which colonies may be affected by such developments and the colony's dependence on these areas. Tracking studies of birds from important seabird colonies should form an integral part of the EIA process for marine renewable developments.

1. Introduction

The potential capacity of Europe's offshore wind energy generation is enormous and is expected to play a big part in helping EU countries meet the target set by the European Commission for all member states to achieve 20% of their energy from renewable sources by 2020 (Directive 2001/77/EC). The UK is leading the rest of Europe in offshore renewable energy generation with 517 MW capacity in place or to be completed by the end of 2011 and industry experts are forecasting that the UK will achieve up to 23 GW capacity by 2020 [1]. Whilst not yet at the same scale of development as offshore wind technology, tidal and wave energy developments are also gaining momentum [2]. By January 2010 the UK had 0.85 MW of wave energy and 1.55 MW of tidal stream installed. Due to the technological support available in the UK and the abundant wave and tidal stream resource it is considered that by 2020 a large share of European marine renewable energy installations (MREIs) will be in UK waters [3].

Due to the short time scale in which offshore wind farms have been developed and the fact that there are very few sites where the effects of MREIs can be assessed there are few scientific studies on the environmental effects such developments may have [4]. Potential impacts such as the effect that MREI developments may have on coastal processes [5], on fish and seabed communities [6], and with reference to birds; direct mortality [7], disturbance of feeding areas and displacement [8,9], migration routes [10] and costly avoidance behaviours [11,12], have generally been inferred from existing technologies and developments. Any offshore developments in the EU are subject to environmental monitoring which should be undertaken prior to and post installation of devices [13]. In the UK the Crown Estate has an established research body, the Collaborative Offshore Wind Research into the Environment (COWRIE), to develop and test the guidelines for environmental monitoring for offshore MREIs. COWRIE have set strict standards and guidelines for the boat-based and aerial monitoring of seabirds and cetaceans in

* Corresponding author. Tel.: +44 151795 4658.
E-mail address: louise.soanes@liv.ac.uk (L.M. Soanes).

0308-597X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpol.2012.08.006

potential test site areas based on the methodology of Camphuysen et al. [14] and more recently refined by Maclean et al. [15] Any potential MREI developments in the UK are required to meet these standards before consent for development is given.

Due to the availability of new and more affordable technologies such as thermal cameras, satellite and GPS data loggers, radar etc. and the increased use of such technology in the monitoring of marine organisms [16–19], there has been a greater interest in the application of these technologies to the monitoring of the environmental impacts of MREIs [20–22] particularly with regard to a seabirds [23–25]. Desholm et al. [26] highlighted the advantages that remote techniques can provide in collecting bird data applicable to environmental impact assessments. For example, they can be used during darkness and reduced visibility, across extended time periods, over a larger spatial extent and remotely in offshore regions. Louzao et al. [27] combined vessel-based monitoring and tracking studies to determine the habitat use of Cory's Shearwaters *Calonectris diomedea* and concluded that the integration of tracking and vessel-based survey data provided a wider understanding of the predictability of aggregation and the key oceanographic habitats of this species at multiple spatial scales. Vessel-based surveys provided a large-scale perspective of the population level distribution and habitat associations while tracking data provided more fine-scale and detailed information at the individual level. Inger et al. [28] suggested that to allow for full biodiversity impacts of MREIs to be assessed there exists an urgent need for additional multi- and inter-disciplinary research in this area ranging from engineering to policy. As a result of the increased interest and use of these tracking technologies a further report was published by COWRIE in 2009, advocating the use of remote technologies in the environmental monitoring of MREIs. This concluded that tracking studies, thermal cameras and the use of radar should be complimentary, in certain instances, to existing aerial and boat-based survey methods though this is not yet a requirement [15]. Another factor to consider in favour of the use of tracking studies is that the foraging ranges of some species have the potential to cross national boundaries and be affected by offshore developments under the control of other governments and therefore subject to a different set of environmental monitoring standards [13]. For example Pettex et al. [29] found that Northern Gannets *Sula bassunus* (from here on referred to as "Gannet") breeding on Rouzic Island France, foraged in three different territorial waters, the UK, the Channel Islands and France.

The potential adaptability of seabirds to changes or disturbance in their foraging areas will depend on the location of the colony and habitat preferences [30,31], the physiological constraints of a species [32,33], competition from nearby colonies [34] and individual foraging behaviour. An additional advantage of the use of tracking studies is that they can be used to assess the potential specialisation and/or adaptability of individual birds from within a population, and the implications of this can then be scaled to the population level. Several studies have revealed that individual seabirds do exhibit repeatability in the foraging sites they visit. Irons et al. [35] found that 24 out of 26 Black-legged Kittiwakes *Rissa tridactyla* that were tracked remotely at a North sea colony over 13 day returned repeatedly, with an average of 19 trips, to the same areas to forage. Likewise a study on Gannets breeding on the Bass Rock in Scotland suggested that individuals learnt and remembered the locations of feeding sites and used that knowledge on subsequent foraging trips. By contrast the foraging areas of Gannets breeding on Great Saltee (UK), were much less similar, with highly variable distances to destinations, no differences in bearings among individuals and no significant repeatability in distance travelled [36].

It may be in an individual birds interest to exhibit variable and adaptable foraging behaviour if it relies on mobile prey species. Alternatively individuals that exhibit highly repeatable foraging behaviour may save time and energy in searching for prey and therefore be more able to provide for their offspring and themselves. Tracking studies may help to reveal the plasticity in the behaviour of individuals, colonies and species. Such knowledge can then be applied to assess the potential impacts MREIs may have on particular species, colonies or individuals.

This study focused on the Gannet population located in the territorial waters of the Channel Island of Alderney (49.5° N, −4.0°E). This population of approximately 6900 pairs breed on two islets within Alderney's territorial waters, this population was one of the reasons that led to the designation of the area under the Ramsar Convention in 2005. In response to proposals for the development of Alderney's waters as a tidal power site in 2006 and 2007, environmental baseline boat- and land-based surveys were conducted according to COWRIE guidelines to record seabird and cetacean activity [37]. The EIA report found little foraging activity of Gannets in the proposed test site areas. While this may not be surprising, given that this species has a foraging range of up to 440 km and foraging trip duration of up 20.5 h [38], it may not have been possible to fully evaluate the use of this area with a vessel-based approach. Those that were recorded in these surveys were likely to be breeding in the Channel Islands. However, Alderney's waters are well within the foraging range of the southernmost colony of Gannets, on the French islet of Le Rouzic where 11,500 pairs of Gannet breed [39]. A disadvantage of using only vessel- and land-based surveys is that they provide no information on the breeding locations of the Gannets recorded. Breeding Gannets were GPS-tracked with the aim of determining the main foraging areas of this population and to quantify their use of local waters (within the test site area) as well as waters outside of the Channel Islands legislative control, particularly considering that there are currently 13 MREI development sites located within the potential foraging range of Alderney's Gannet colony [40–42]. The similarity of foraging trips made by each individual was also examined to allow a preliminary assessment of the repeatability of foraging behaviour of individuals from this colony.

2. Methods

2.1. Data collection

IgotU GT-120 GPS data loggers (Mobile technology, UK) were attached with waterproof tape (Tesa, Extra Power) [43] to the tail feathers of 23 chick-rearing Gannets breeding on the offshore stack Les Etacs, Alderney, Channel Islands on the 6th June 2011 and recovered 3, 4 or 5 days later. Birds were selected at random and gender was not determined. Loggers were set to record a position every two mins during deployment which was later interpolated to every 10 s using the R package "Trip"

2.2. Home-range analysis

The term "home-range" for the purposes of this study refers to "a minimum area in which an animal has some specified probability of being located" [44]. Home range estimates were derived from tracking data using the R package "adehabitatHR" to calculate the 50% utilisation distribution of a pooled sample of the first two foraging trips. This 50% utilisation distribution corresponds to the smallest area in which the probability to relocate the animals is equal to 0.50 and is considered to be the most heavily used area known as the area of core use [45,46]. The 95% utilisation distribution was also calculated; this is considered the area of active use and the minimum area where 95% of all fixes are located. In all cases home-range areas were calculated using the bivariate normal kernel (the ad hoc method [47]). The 50% core area of use and the

95% area of active use were also calculated for each individual's first and second foraging trips.

The foraging behaviour of Gannets has previously been divided into categories; (1) out flight, (2) return flight, both (1) and (2) usually characterised by high flights speeds and high sinuosity, (3) diving for prey, (4) drifting on the sea surface, usually after feeding, and (5) hunting or search flight (characterised by medium flight speeds) [48]. Whilst we do not attempt to define the different foraging behaviour of Gannets tracked in this study, we suggest that the 50% core area of use is likely to represent core foraging areas based on the rational of Gremillet et al. [34] that a Gannet actively exploiting a prey patch will spend more time in a given area than when commuting between feeding patches. The 95% area of active use is likely to include all types of foraging behaviour including out and in-bound flight to and from the colony, which can be used to infer important flight paths that may be affected by MREIs. As we are using the predicted 50% core area to represent core foraging areas we removed darkness hours from any foraging trips (between 22:00 and 04:00 BST) to remove fixes where Gannets were sat on the sea at night and therefore not actively foraging. We compared the home-range areas predicted when these night time fixes were left in the analysis and when they were removed and found very little difference in the predicted areas, with 70.3% overlap in the 50% core foraging areas, but for the purposes of this paper night-time fixes remain removed.

2.3. Relationship of foraging areas to offshore renewable energy developments

Using ArcMap 9.3 the core foraging area and area of active use of the pooled sample of the first two trips made by our tracked Gannets and the core foraging area and area of active use of each individual foraging trip that was made by these Gannets was plotted along with the locations of potential offshore wind and tidal power developments at various stages of planning and consent on the South Coast of England [40,41] and the Normandy Coast of France [42]. We then determined the number of potential offshore developments within the pooled sample's core foraging area and area of active use, and also noted how many of the core foraging areas and areas of active use of individual foraging trips overlapped with potential development sites.

2.4. Foraging trip characteristics and repeatability

From our sample of successfully tracked birds we calculated foraging trip duration, total trip distance and the maximum distance travelled from the colony for the first two trips made by each Gannet using ArcMap 9.3. The value of each of these variables for the second trip was plotted as a function of the value for the first trip and Pearson's correlation was performed in Minitab (Version 15). We also used Bland and Altman's approach [49] of measuring agreement in methods (in this case between the first and second foraging trip made by an individual) to analyse our data. In this procedure, the mean of each foraging characteristic (foraging trip duration, total trip distance and maximum distance travelled from colony) for the first and second

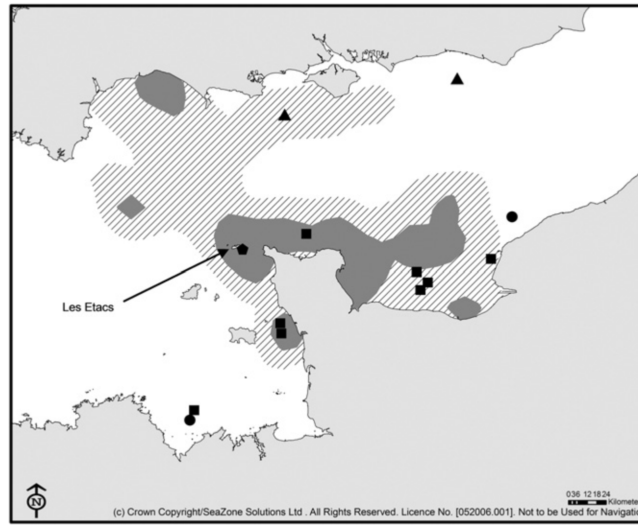

Fig. 1. Home range areas predicted from 15 Gannets tagged on Les Etacs, Alderney (dark grey = core foraging area; black hatch = area of active use) and locations of offshore renewable energy developments (pentagon symbol = Alderney tidal power site, square symbol = concept/early planning stage development, triangle symbol = round 3 wind farm, circle symbol = consent application submitted).

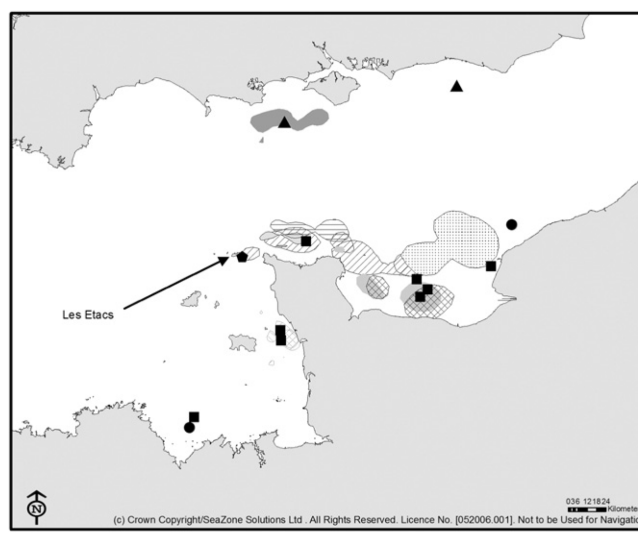

Fig. 2. Core foraging areas of the 10 individual foraging trips made by 8 Gannets that overlapped with renewable energy developments. (pentagon symbol = Alderney tidal power site, square = concept/early planning stage development, triangle = round 3 wind farm, circle = consent application submitted).

Table 1
Summary of mean (±SD) foraging trip data recorded in this study compared to foraging trip data recorded from chick-rearing Gannets at other UK and French colonies.

	Les Etacs, Alderney	Rouzic Island, Brittany [57]	Bass Rock, Scotland [58]	Grassholm, Wales[59]
Number of Gannets tracked	17	20	13	23
Foraging trip duration (h)	17.6 (±6.5)	17.8 (±8.6)	21.5 (±6.7)	25.1 (±17)
Total trip distance (km)	289 (±115)	479 (±206)	440 (±234)	370 (±251)
Maximum distance travelled (km)	106 (±43)	100 (±35)	155 (±65)	–

Please cite this article as: Soanes LM, et al. Individual consistency in the foraging behaviour of Northern Gannets: Implications for interactions with offshore renewable energy developments. Mar. Policy (2012), http://dx.doi.org/10.1016/j.marpol.2012.08.006

foraging trips was calculated, as was the difference between them. This calculated difference was then plotted as a function of the mean of that characteristic. Visual comparison of the systematic bias (the overall mean difference) and its limits of agreement (confidence intervals) with the plotted data and zero, within the Brand–Altman plot, revealed whether or not there were consistencies in the foraging characteristics between the first and second foraging trips made by an individual. The difference in direction travelled of the first and second foraging trip made by each individual from the colony to the centre of its core foraging area was determined using the circular statistic Watson Williams *F*-test [50] in Oriana for Windows 1.06 (Kovach Computing Service, Pentraeth, UK). The percentage area overlap ($\pm$SEM) in the core foraging area and the area of active use between the first and second trips made by each individual was also calculated using ArcMap 9.3. After testing for normality a two sample *t*-test in Sigmaplot 11.0 was used to test if there were significant differences in the time spent foraging of those individuals whose core foraging areas overlapped compared to those whose areas did not overlap.

3. Results

Of 23 birds tracked, 17 were recaptured and the loggers retrieved; two others were sighted again at the colony but not recaptured. Access to the birds was limited due to logistical difficulties in accessing the field site and to limit disturbance to the breeding birds. This meant that further re-sighting or recapture opportunities were not available. Individual Gannets made 1–4 foraging trips during the deployment period, with 15 individuals making at least two trips and these data were used in the majority of analysis. The mean foraging trip duration of all trips undertaken

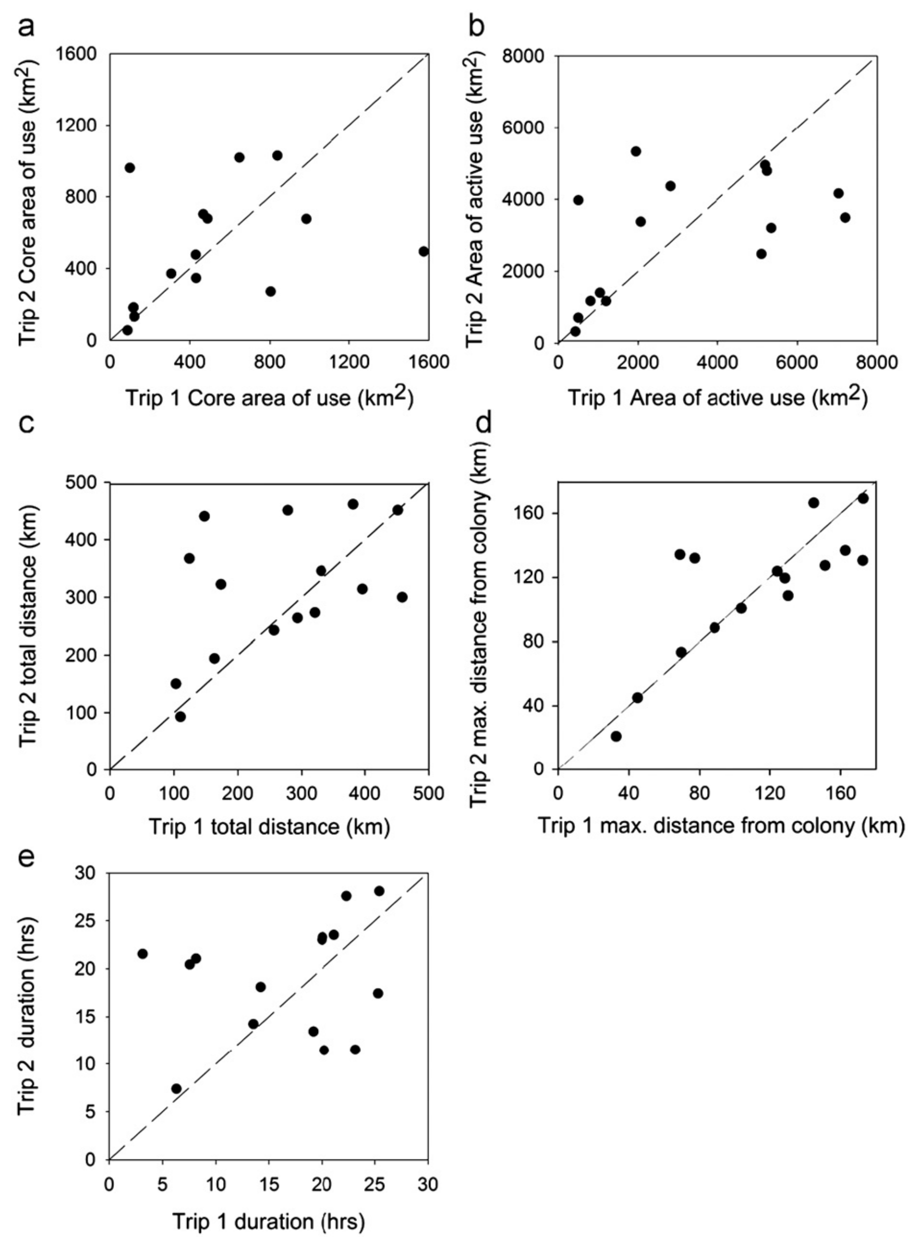

Fig. 3. Comparison between the first and second foraging trips made by 15 Gannets, comparing (a) the core area of use and (b) the area of active use, (c) average foraging trip distance, (d) maximum foraging distance from a colony, and (e) trip duration. Dashed line indicates the line of equality. The only parameter with significant correlation was maximum distance from colony.

by the 17 birds tracked was 17.6 ($\pm$ 6.5) h (Table 1), and mean time spent at the colony between trips was 19.5 ($\pm$ 2.0) h (n=15).

3.1. Relationship to offshore renewable energy developments

The core foraging area of the pooled sample of the first two trips made by 15 Gannets overlapped with five MREI sites (four in French waters and the Alderney tidal site), whilst the area of active use overlapped with nine MREI sites (seven in French waters, one in UK waters and the Alderney tidal site). When examining the predicted core foraging areas of the first and second foraging trips made by each individual Gannet we found that five individuals had one foraging trip that overlapped with a proposed offshore wind development, two individuals had both their first and second trip overlapping with an offshore wind farm development and one individual had one foraging trip that overlapped with the proposed tidal power development site in Alderney. When considering the wider area of active use, five individuals had one foraging trip that overlapped with proposed offshore wind developments, and nine individuals had both trips overlapping. Of the 23 foraging trips that overlapped with offshore wind developments 17 also overlapped with Alderney's tidal power development site (Figs. 1 and 2).

3.2. Foraging trip characteristics and repeatability

When comparing the foraging characteristics of an individual a significant correlation was found between the first and second foraging trips when considering the maximum distance travelled (R=0.789, n=15, $p<0.001$), indicating repeatability between the first and second foraging trips for the maximum distance travelled by an individual (Fig. 3d). However, no significant correlations were found between the first and second foraging trips when considering the core foraging area, the area of active use, total distance travelled from the colony, and trip duration (Fig. 3). Suggesting little repeatability between the first and second foraging trips when considering these characteristics. However, no significant difference was found in the direction travelled by an individual on its first and second foraging trips (Fig. 4) indicating significant repeatability between trips in the direction travelled by an individual.

The Bland–Altman plots plotted to test the agreement between the first and second foraging trips made by an individual revealed that the systematic bias (mean difference expressed as a percentage of the mean value of each foraging characteristic) was close to zero with large limits of agreement (confidence intervals) and large variability in data points for all foraging characteristics; percentage overlap, trip duration, and total distance travelled, suggesting low repeatability with the exception of maximum distance travelled from the colony which revealed relatively small limits of agreement (Fig. 5).

When examining the percentage overlap between the first and second foraging trip made by each Gannet we found that on average there was 16 $\pm$ 5% overlap in the core foraging area, with 10 individuals exhibiting some area overlap between trips, and on average 25 $\pm$ 3% overlap in the area of active use, with all 15 Gannets having some overlap in area between their first and second foraging trips. Individuals that exhibited overlap in their core foraging areas did not spend significantly more or less time on foraging trips compared to those that exhibited no overlap ($p>0.05$).

4. Discussion

Foraging trip duration and the maximum distance travelled were comparable to those recorded at other UK and French

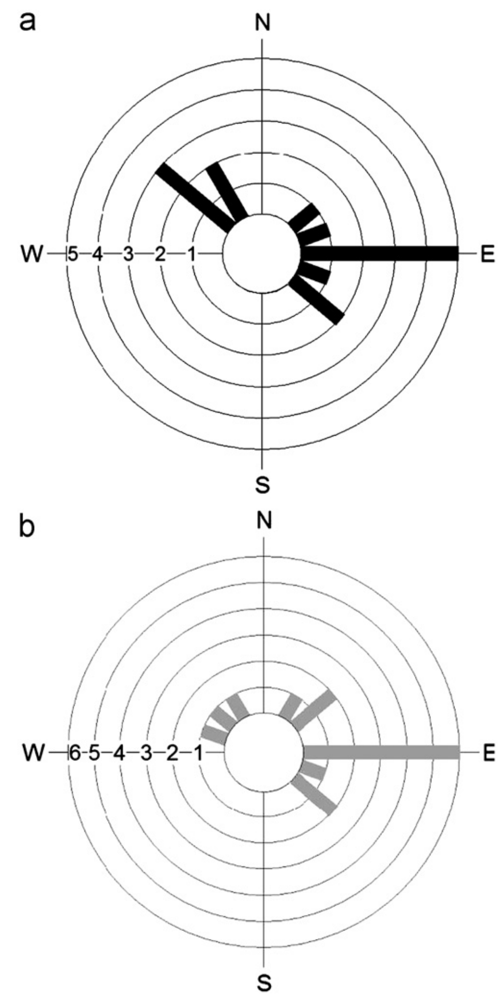

Fig. 4. The bearings of (a) the first foraging trip (b) the second foraging trip made by 15 Gannets. Number of trips made in each direction are represented by the frequency bars.

colonies [29,38,51] whilst mean foraging trip distance was lower compared to all other colonies (Table 1). The conclusions drawn in this study are based on the tracking data of 15 Gannets from a colony of 6900 pairs so we cannot assume that all foraging areas used by the colony were revealed. However, it is interesting that foraging trips were made in four discrete locations; (1) to the south coast of England, (2) south towards Jersey (3) eastwards around the Cherbourg peninsula and (4) towards the French coast of Le Havre (Figs. 1 and 2).

The pooled core foraging area predicted from analysis of the first two trips of 15 Gannets revealed that this area overlapped with three French MREIs at the concept or early planning stage of development and the Alderney tidal power development site (Fig. 1). When examining the core foraging areas of individuals, over half of all birds sampled (8 individuals) had core foraging areas that overlapped with proposed MREI developments (Fig. 2). Of these eight individuals, six overlapped with developments in French waters, one in UK waters. We recorded only one out of 15 individuals whose core foraging area overlapped with the proposed Alderney tidal power development, compared to 9 individuals whose area of active use overlapped with the site. Since the core area represents where the individual spends 50% of its time [46], it represents the most heavily used and most likely foraging areas for the Gannet [34]. Therefore whilst most Gannets breeding on Les Etacs do spend time within the proposed Alderney test site area, they are likely to be using this area as a flight path to and from the

ARTICLE IN PRESS

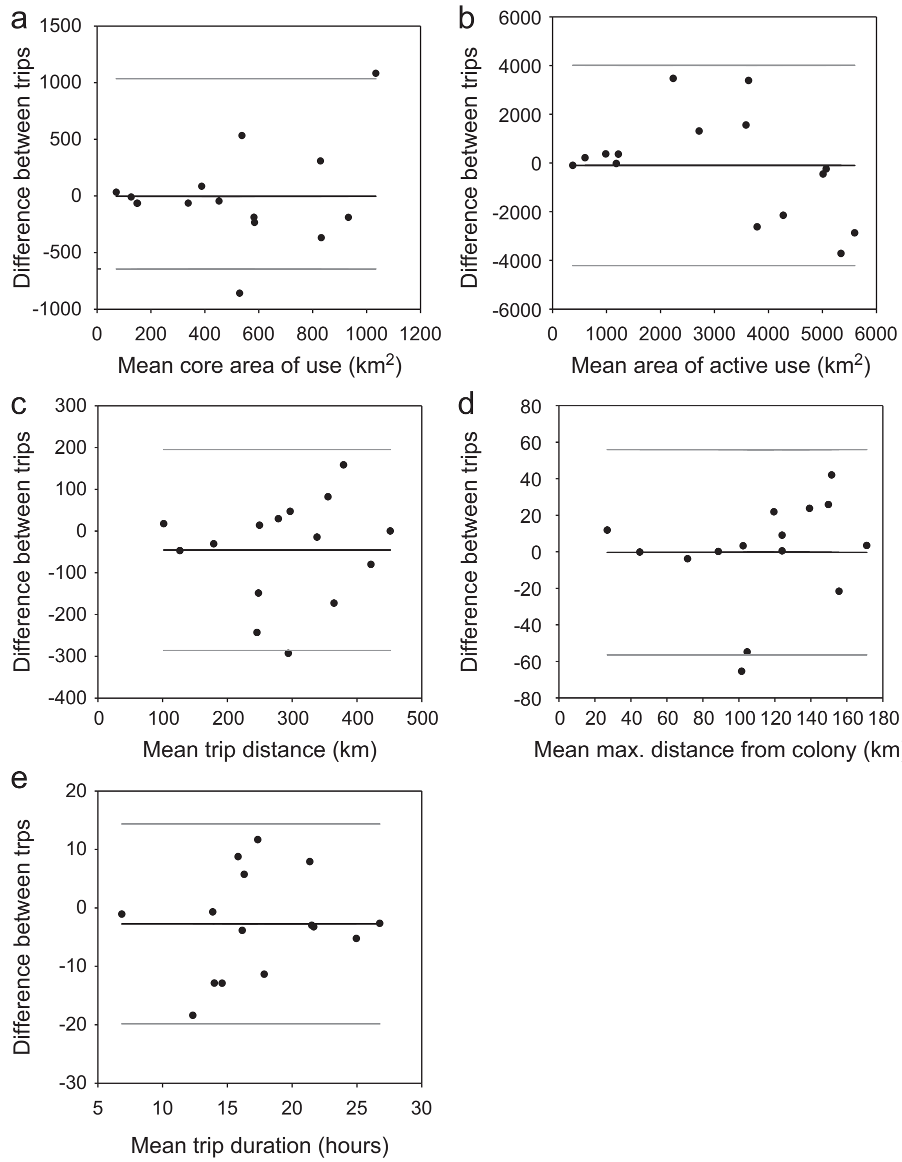

Fig. 5. Bland–Altman plots of the difference observed in the predicted core area of use and the area of active use, trip distance, maximum distance travelled and trip duration between the first and second foraging trip made by individual Gannets ($n=15$), as a function of mean home-range area, foraging trip distance, maximum distance travelled and trip duration. The black line shows the overall mean difference between trip 1 and trip 2 and the grey lines the overall mean standard error (± 1.96) between trip 1 and trip 2.

colony rather than as an important foraging area. These results highlight the need to look at the "bigger picture" when considering the effects that offshore renewable energy developments may have on seabird populations and for increased collaboration not just nationally, but within Europe when considering the effects of offshore renewable energy developments. This is particularly important as there are wide variations between requirements placed on developers in individual member EU states to fund and prepare environmental impact assessments [13].

We propose that as part of the integrated monitoring approach as proposed by COWRIE [53] that tracking studies of seabirds at important colonies within the range of offshore wind farm developments should also be a requirement, to provide valuable information on a colony's use of an area and dependence on particular areas, and that this data should be made freely available to multiple regulatory bodies. Tracking studies can be relatively cheap to conduct with the GPS loggers used in this study costing less than £50 and can provide useful information on the foraging behaviour of a colony in shorter time scales, which can be useful in identifying potentially important foraging areas or for identifying colonies that may be at most risk early on in the EIA process compared to boat-based and aerial monitoring. For example when analysing the foraging tracks of Gannets tracked in this study along with those tracked from the nearby colony of Rouzic [29], it seems likely that Gannets recorded on the boat-based surveys of Alderney's waters conducted in 2006-07 were Gannets breeding on Les Etacs rather than Rouzic island, even though Alderney's waters are well within the foraging range of both colonies. We can only conclude this as tracking data are available for birds from both colonies.

Although not significant for all individuals, when examining the foraging behaviour of the Gannets in this study a quarter of those tracked exhibited some overlap with an average of 16% overlap in their core foraging areas and 25% overlap in their areas of active use. Similarities were also found between the first and second trips made by an individual in the maximum distance they travelled and the direction in which individuals travelled but no significant relationship between the first and second foraging trips when

Please cite this article as: Soanes LM, et al. Individual consistency in the foraging behaviour of Northern Gannets: Implications for interactions with offshore renewable energy developments. Mar. Policy (2012), http://dx.doi.org/10.1016/j.marpol.2012.08.006

considering foraging trip duration and the total trip distance. These results suggest that individual Gannets appear not to be particularly dependent on any specific sites and that there is significant variation in the amount of time an individual spends searching for food. Furthermore, individuals that did show overlap in their foraging areas did not show a reduction in time spent foraging, thus suggesting no particular advantage to re-visiting the same foraging area on consecutive trips. However this is a preliminary conclusion based on just two foraging trips per individual, and further work in this area may reveal more information on the consistency of foraging trips within individuals. At the population level, there is a general consistency in the broad areas that they forage within (Figs. 1–3) with four main areas used. The repeatability of an individual's foraging behaviour has been demonstrated in previous studies [35,54] whereas others report changes in foraging behaviour. For example, Torres et al. [55] found that the white-capped albatross *Thalassarche steadi* had highly variable and adaptable foraging destinations in response to fisheries.

Tracking studies allow us to gauge how much any particular colony, or individual, may depend on certain foraging areas. Our study has revealed that important foraging areas can be relatively easily identified and related to proposed MREIs and we have provided baseline data, prior to any installation, of the foraging behaviour of this colony. It appears that the waters around Alderney are not heavily used foraging areas for the Gannets breeding there, with them being more likely to be affected by obstructions to their flight path around the colony rather than underwater installations. This pilot data set indicates that the population could potentially be more affected by MREI developments in French waters rather than the Alderney tidal power development. However behaviour may change between years so further years of tracking should be conducted to further support this finding. Few studies have investigated how individuals may adapt to disturbances in their preferred foraging areas as a result of MREIs but tracking studies again can provide an ideal resource to further the understanding in this field using a Before-After-Control-Impact approach [56]. We recommend that the tracking of important seabird colonies that may use the same waters of any proposed MREIs become an integral part of the EIA, along with more international collaboration on the EIA process.

Acknowledgements

This project was jointly funded by a Doctoral Training Grant from the Natural Environment Research Council and the Alderney Commission for Renewable Energy. We would like to thank Alderney Wildlife Trust volunteers for the assistance with this work, particularly Liz Morgan and our boat skippers Phil Murray, Dave Venn and Darron Machon. Permission to carry out field work was granted by the States of Alderney and the Channel Island Bird Ringing Scheme gave PWA and LMS permission to ring the Gannets and attach loggers to the birds.

References

[1] RenewableUK. State of the industry report Onshore and offshore wind: progress update. UK: RenewableUK; 2011.
[2] Rourke FO, Boyle F, Reynolds A. Tidal energy update 2009. Appl Energy 2010;87:398–409.
[3] Willow C, Valpy B. Wave and tidal energy in the UK, state of the industry report. UK: RenewableUK; 2011.
[4] Gill AB. Offshore renewable energy: ecological implications of generating electricity in the coastal zone. Jf Appl Ecol 2005;42:605–615.
[5] Lampkin DO, Harris JM, Cooper WS, Coates T. Coastal process modelling for offshore wind farm environmental impact assessment: best practice guide. London: COWRIE Limited; 2009.
[6] Linley ESA, Wilding TA, Black K, Hawkins AJS, Mangi S. Review of reef effects of offshore windfarm structures and their potential enhancement and mitigation. Report from PML Applications Ltd and the Scottish Association for Marine Science to the Department for Business, enterprise and Regulatory Reform (BERR), Contract No: RFCA/005/0029P, Scotland; 2008.
[7] Sugimoto H, Matsuda H. Collision risk of white-fronted geese with wind turbines. Ornithol Sci 2011;10:61–71.
[8] Perrow MR, Gilroy JJ, Skeate ER, Tomlinson ML. Effects of the construction of Scroby sands offshore wind farm on the prey base of Little tern Sternula albifrons at its most important UK colony. Mar Pollut Bull 2011;62: 1661–1670.
[9] Kaiser MJ, Elliott A, Galandi M, Rees EIS, Caldow R, Stillman R, et al. Predicting the displacement of common scoter Melanitta nigra from benthic feeding areas due to offshore windfarms. London: COWRIE Limited; 2002.
[10] Griffin L, Rees E, Hughes B. The migration of whooper swans in relation to offshore windfarms. London: Report prepared by the Wildfowl and Wetland Trust for COWRIE Limited; 2010.
[11] Perrow MR, Skeate ER, Lines P, Brown D, Tomlinson ML. Radio telemetry as a tool for impact assessment of wind farms: the case of Little Terns Sterna albifrons at Scroby Sands, Norfolk, UK. Ibis 2006;148:57–75.
[12] Masden EA, Haydon DT, Fox AD, Furness RW. Barriers to movement: modelling energetic costs of avoiding marine wind farms amongst breeding seabirds. Mar Pollut Bull 2010;60:1085–1091.
[13] Holmes SC. Wind energy—environmental impact assessment: the UK experience and the EU perspective. In: Anderson M, editor. Wind energy conversion. UK: BWEA; 1996. p.143–7.
[14] Camphuysen KC, Fox TA, Leopold MM, Petersen IB. Towards standardised seabirds at sea census techniques in connection with environmental impact assessments for offshore wind farms in the U.K. Royal Netherlands Institute for Sea Research; 2004.
[15] Maclean IMD, Wright LJ, Showler DA, Rehfish MM. A review of assessment methodologies for offshore windfarms. Report BTfO: British Trust Ornithology Report commissioned by COWRIE Ltd.; 2009.
[16] Johnson GD, Erickson WP, Strickland MD, Shepherd MF, Shepherd DA, Sarappo SA. Collision mortality of local and migrant birds at a large-scale wind-power development on Buffalo Ridge, Minnesota. Wildlife Soc Bull 2002;30:879–887.
[17] Gauthreaux Jr. SA, Livingston JW. Monitoring bird migration with a fixed-beam radar and a thermal-imaging camera. J Field Ornithol 2006;77: 319–328.
[18] Steer J. Bioacoustic monitoring of New Zealand birds. Notornis 2010;57: 75–80.
[19] Langton R, Davies IM, Scott BE. Seabird conservation and tidal stream and wave power generation: information needs for predicting and managing potential impacts. Mar Policy 2011;35:623–630.
[20] Zaugg S, Saporta G, Van Loon E, Schmaljohann H, Liechti F. Automatic identification of bird targets with radar via patterns produced by wing flapping. J R Soc Interface 2008;5:1041–1053.
[21] Scheidat M, Tougaard J, Brasseur S, Carstensen J, Petel TV, Teilmann J, et al. Harbour porpoises (Phocoena phocoena) and wind farms: a case study in the Dutch North Sea. Environ Res Lett 2011;6:10.
[22] Carstensen J, Henriksen OD, Teilmann J. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). Mar Ecol Progr Ser 2006;321: 295–308.
[23] Desholm M, Fox AD, Beasley PDL, Kahlert J. Remote techniques for counting and estimating the number of bird-wind turbine collisions at sea: a review. Ibis 2006;148:76–89.
[24] Fox AD, Desholm M, Kahlert J, Christensen TK, Petersen IK. Information needs to support environmental impact assessment of the effects of European marine offshore wind farms on birds. Ibis 2006;148:129–144.
[25] Desholm M, Fox T, Beasley P. Best practice guidance for the use of remote techniques for observing bird behaviour in relation to offshore windfarms: REMTECH-05-2004 Report commissioned by COWRIE Ltd.; 2005.
[26] Desholm M, Fox T, Beasley P. Best practice guidance for the use of remote techniques for observing bird behaviour in relation to offshore windfarms: REMTECH-05-2004 Report commissioned by COWRIE Ltd.; 2005.
[27] Louzao M, Becares J, Rodriguez B, Hyrenbach KD, Ruiz A, Arcos JM. Combining vessel-based surveys and tracking data to identify key marine areas for seabirds. Mar Ecol Progr Ser 2009;391:183–197.
[28] Inger R, Attrill MJ, Bearhop S, Broderick AC, Grecian WJ, Hodgson DJ, et al. Marine renewable energy: potential benefits to biodiversity? An urgent call for research J Appl Ecol 2009;46:1145–1153.
[29] Pettex E, Bonadonna F, Enstipp MR, Siorat F, Gremillet D. Northern gannets anticipate the spatio-temporal occurrence of their prey. J Exp Biol 2010; 213:2365–2371.
[30] Wakefield ED, Phillips RA, Matthiopoulos J. Quantifying habitat use and preferences of pelagic seabirds using individual movement data: a review. Mar Ecol Progr Ser 2009;391:165–182.
[31] Wakefield ED, Phillips RA, Trathan PN, Arata J, Gales R, Huin N, et al. Habitat preference, accessibility, and competition limit the global distribution of breeding black-browed Albatrosses. Ecol Monogr 2011;81:141–167.
[32] Daunt F, Benvenuti S, Harris MP, Dall'Antonia L, Elston DA, Wanless S. Foraging strategies of the black-legged kittiwake Rissa tridactyla at a North Sea colony: evidence for a maximum foraging range. Mar Ecol Progr Ser 2002;245:239–247.

Please cite this article as: Soanes LM, et al. Individual consistency in the foraging behaviour of Northern Gannets: Implications for interactions with offshore renewable energy developments. Mar. Policy (2012), http://dx.doi.org/10.1016/j.marpol.2012.08.006

[33] Shaffer SA, Costa DP, Weimerskirch H. Foraging effort in relation to the constraints of reproduction in free-ranging albatrosses. Funct Ecol 2003;17: 66–74.
[34] Gremillet D, Dell'Omo G, Ryan PG, Peters G, Ropert-Coudert Y, Weeks SJ. Offshore diplomacy, or how seabirds mitigate intra-specific competition: a case study based on GPS tracking of Cape gannets from neighbouring colonies. Mar Ecol Progr Ser 2004;268:265–279.
[35] Irons DB. Foraging area fidelity of individual seabirds in relation to tidal cycles and flock feeding. Ecology 1998;79:647–655.
[36] Hamer KC, Phillips RA, Hill JK, Wanless S, Wood AG. Contrasting foraging strategies of gannets Morus bassanus at two North Atlantic colonies: foraging trip duration and foraging area fidelity. Mar Ecol Progr Ser 2001;224: 283–290.
[37] Entec. Seabird and Ceteacen survey for tidal power development in Alderney. UK: Entec Consultancy; 2008.
[38] Votier SC, Grecian WJ, Patrick S, Newton J. Inter-colony movements, at-sea behaviour and foraging in an immature seabird: results from GPS-PPT tracking, radio-tracking and stable isotope analysis. Mar Biol 2011;158: 355–362.
[39] Siorat F, Rocamora G. Changes in numbers and distribution of the Northern Gannet (Morus bassanus) on Rouzic Island, (Reserve naturelle des Sept-Iles, Bretagne), France 1939–1994. Colon Waterbirds 1995;18:172–178.
[40] ENECO. Navitus Bay wind Park Infrastructure Planning (Environmental Impact Assessment) Regulations 2009. Rotterdam: Eneco; 2009.
[41] Eon. Rampion offshore wind farm scoping report. Helsby: RSP Group PLC; 2010.
[42] Dossier de Presse: Installation de 3000 MW d'eoliennes en mer. La Grenelle Environnement; 2011.
[43] Wilson RP, Putz K, Peters G, Culik B, Scolaro JA, Charrassin JB, et al. Long-term attachment of transmitting and recording devices to penguins and other seabirds. Wildlife Soc Bull 1997;25:101–106.
[44] Worton BJ. Kernel methods for estimating for utilization distribution in home-range studies. Ecology 1989;70:164–168.
[45] Ford RG. The analysis of space use patterns. J Theor Biol 1979:125–155.
[46] Calenge C. Exploring habitat selection by wildlife with adehabitat. J Stat Software 2007;22:1–19.
[47] Worton BJ. A convex hull-based estimator of home-range size. Biometrics 1995;51:1206–1215.
[48] RHE Mullers, Navarro RA, Daan S, Tinbergen JM, HAJ Meijer. Energetic costs of foraging in breeding Cape gannets Morus capensis. Mar Ecol Progr Ser 2009;393:161–171.
[49] Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res 1999;8:135–160.
[50] Batschelet E. Circular statistics in biology. New York; 1981.
[51] Hamer KC, Phillips RA, Wanless S, Harris MP, Wood AG. Foraging ranges, diets and feeding locations of gannets Morus bassanus in the North Sea: evidence from satellite telemetry. Mar Ecol Progr Ser 2000;200:257–264.
[53] Walls RJ, Pendlebury CJ, Budgey R, Brookes K, Thompson P. Revised best practice guidance for the use of remote techniques for ornithological monitoring at offshore windfarms. Cowrie: Cowrie; 2009.
[54] Bearhop S, Phillips RA, McGill R, Cherel Y, Dawson DA, Croxall JP. Stable isotopes indicate sex-specific and long-term individual foraging specialisation in diving seabirds. Mar Ecol Progr Ser 2006;311:157–164.
[55] Torres LG, Thompson DR, Bearhop S, Votier S, Taylor GA, Sagar PM, et al. White-capped albatrosses alter fine-scale foraging behavior patterns when associated with fishing vessels. Mar Ecol Progr Ser 2011;428:289–301.
[56] Smith EP, Orvos DR, Cairns J. Impact assessment using the before-after-control-impact (BACL) model—concerns and comments. Can J Fish Aquat Sci 1993;50:627–637.
[57] Gremillet D, Pichegru L, Siorat F, Georges JY. Conservation implications of the apparent mismatch between population dynamics and foraging effort in French northern gannets from the English Channel. Mar Ecol Progr Ser 2006;319:15–25.
[58] Hamer KC, Humphreys EM, Magalhaes MC, Garthe S, Hennicke J, Peters G, et al. Fine-scale foraging behaviour of a medium-ranging marine predator. J Anim Ecol 2009;78:880–889.
[59] Votier SC, Bearhop S, Witt MJ, Inger R, Thompson D, Newton J. Individual responses of seabirds to commercial fisheries revealed using GPS tracking, stable isotopes and vessel monitoring systems. J Appl Ecol 2010;47:487–497.

Please cite this article as: Soanes LM, et al. Individual consistency in the foraging behaviour of Northern Gannets: Implications for interactions with offshore renewable energy developments. Mar. Policy (2012), http://dx.doi.org/10.1016/j.marpol.2012.08.006