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Scroby Sands Ornithological Monitoring

Assessing the potential impact of the proposed wind farm upon Little tern *Sterna albifrons*: the construction phase 2004

January 2005

EXECUTIVE SUMMARY

Over the period October 2003 to August 2004 E.ON UK (formerly PowerGen) Renewables Offshore Wind Ltd. constructed a wind farm comprised of 30 high capacity turbines on Scroby Sands, a dynamic sand bar system approximately 3km offshore of Great Yarmouth, Norfolk.

The development is located directly offshore from the Great Yarmouth North Denes Special Protection Area (SPA), designated as a result of the presence of the largest colony of Little Tern *Sterna albifrons* in the UK, protected and managed by the Royal Society for the Protection of Birds (RSPB). Little terns are an endangered species and are in long-term chronic decline in the UK, reducing by some 27% between 1985-87 and 2000. From 1983 to 2001, North Denes regularly held over 200 breeding pairs, >10% of the UK total and around 2% of the European population.

An Appropriate Assessment of the likely impact of the proposed wind farm concluded that although Little terns used Scroby Sands when feeding, the impact of the wind farm on local bird populations was likely to be of moderate significance at most. Such is the importance of the site and its species that Department for Environment, Food and Rural Affairs (DEFRA), after discussion with English Nature (EN), instructed that monitoring of Little terns be undertaken to validate these conclusions. Determination of any impact relied on the suitability and rigour of the monitoring techniques employed. Suitable methodologies were developed after further consultation with the Royal Society for the Protection of Birds (RSPB).

The primary aim of this project was thus to monitor the impact of the proposed wind farm upon Little terns, although impacts on other bird species, of which **38** species have been recorded during the study thus far, were to be included as a matter of course.

The work was to be divided into several areas before and after construction:

- Feeding studies i.e. spatial and temporal distribution of foraging birds;
- Breeding colony studies – focusing on chick feeding ecology;
- Prey studies i.e. spatial and temporal distribution of prey at sea;
- Bird strike studies; which were to be added after construction.

The two years (2002 and 2003) prior to construction were to form a baseline against which future change relative to the presence of the wind farm could be evaluated. Monitoring following piling and during turbine construction was undertaken in 2004. Post-construction impacts may be evaluated in monitoring conducted in 2005 and 2006.

Reversing the pattern of the previous 20 years, in all years of the study thus far Little terns have not breed in numbers at North Denes. In 2002, the colony was destroyed by a single act of vandalism, although a small number of pairs (c. 7) managed to persist and fledge chicks (c.5). In 2003, helicopter patrols were thought to displace birds before breeding was attempted, although 10 pairs did eventually nest, fledging just 2 chicks. In 2004, 40 nests were put down over the course of the protracted season but no chicks fledged. With 1996, this became the worst year on record for the colony. In all years, Little terns established at Winterton some 12km to the north, where they had formerly bred and which is included in the SPA. In 2002, a minimum of 124 pairs

raised a minimum of 43 chicks, whereas in 2003, 233 pairs fledged 447 chicks, the greatest number of chicks raised from a single colony in the UK since records began in 1969. In 2004, 150 nests were put down, but all failed, which was mainly attributed to the lack of prey, although disturbance and predation were also thought to play a role. A comparison between the two colonies was made to promote further understanding of Little tern breeding and feeding ecology, which was deemed essential to ultimately assess the impact of the proposed wind farm.

In all years monitoring was conducted throughout the breeding season (May/June-August) of Little terns, with the following recorded approximately every two weeks:

- Numbers of birds at different sampling stations across both study sites;
- Parameters of foraging activity including dive and fish capture rate;
- Provisioning rate to chicks;
- Density and population dynamics of available prey, particularly fish.

A small surface tow net, sampling the upper 30cm of water was specifically developed to sample the invertebrate and fish prey available to Little terns. This net has been towed 340 km during the course of the study and a total of 46 potential prey species, including 14 fish species, have been captured. Of these, clupeid fish – Herring *Clupea harengus* and Sprat *Sprattus sprattus* – the crustacean *Idotea linearis* and the Ghost shrimp *Schistomysis spiritus* were by far the most numerous. Young-of-the-year (YOY) clupeid fish were overwhelmingly the most important dietary item and form the mainstay of tern breeding success.

In accordance with the known distribution of spawning and nursery areas of Herring and Sprat, Scroby appears to be by far the most important nursery area for clupeids along the stretch of coast sampled (including into North Norfolk). What are thought to be locally born Herring appear in the first samples in May at about 30mm in length. Peak numbers of Herring are recorded in June, before numbers rapidly decline perhaps as these fish move further offshore. Little tern breeding is thought to be closely tied in with the seasonal pattern of Herring, with chick development occurring in the peak phase, with fledging prior to decline of fish density. Sprat spawn offshore and larvae appear to be transported into the area through residual drift. Sprat appear in samples at about 15 mm in June, reaching a smaller peak of abundance than Herring by late July before again disappearing almost completely from samples in August. Late or re-nesting terns, particularly if these have moved colony may rely on this later peak in Sprat although they may still experience difficulty in finding enough food for chicks.

During the period of occurrence, the fish are patchily distributed and are considerably more abundant inshore (up to 2 individuals per m^{-2}), with the best sites immediately adjacent to the North Denes colony and Caister. Coupled with less inter-annual fluctuation than other sites – Winterton for example appears to be dependent on overspill from Scroby – this makes North Denes the colony location of choice. Within Scroby, the concentration of fish at North Denes and Caister is almost certainly because these sites tend to have more turbid water, which is thought to bring the fish closer to the surface and within reach of the terns. Terns as well as fish are thus significantly associated with more turbid water. Consequently, during surveys in 2002 and 2003 Little terns were encountered in largest numbers immediately adjacent to both colonies and were only sporadically recorded in small numbers over Scroby Sands themselves, typically early and late in the season before and after breeding.

However, increased use of Scroby Sands was recorded in 2004, with the largest number of birds yet encountered at a site recorded in the southern part of Scroby in early season. Moreover, birds were recorded on several occasions on the outer edge of Scroby near the wind farm, where they had never been recorded before. Birds did therefore not appear to be displaced from using Scroby as a result of turbine construction. Changes in the nature of Scroby including the formation of a subsidiary sand bar through the wind farm appear to have offered birds additional foraging grounds, perhaps especially for invertebrates. An increase in quantity and/or quality of foraging area may thus be tempered by the potential for greater risk of collision of birds with turbines. The continued use of radio telemetry, developed for use on Little terns for the first time in the UK during this study, is seen as a key tool in the assessment of this risk during any post construction monitoring. Combined with further data gathering on the flight height of Little terns, the relative amount of time spent at risk may be determined.

Colony location and foraging success are closely tied in with fish abundance. Whilst the latter is an essential prerequisite of successful breeding, breeding performance may also be constrained by disturbance and predation of eggs and chicks. When fish prey is abundant, birds forage significantly closer to shore and enjoy a significantly higher rate of dives producing fish. By far the lowest rates of the latter (c. 30% of peak rates) were recorded in 2004 in accordance with a virtual failure of recruitment of young-of-the-year Herring. The shortage of prey was so severe as to mean metabolic constraints came into operation and nesting birds which had already adapted to the conditions by laying a reduced clutch size (0.5 egg less than average) were forced to abandon their nests. Radio telemetry showed that birds in 2004 travelled over twice as far in forging bouts lasting twice as long in 2003, with the maximum distance traveled in a single foraging bout a staggering 25 km. Radio-tagged birds spent an average of 72% of their time foraging compared to 56% in 2003 even when they had chicks to feed. When nesting, birds appear to be tied to home ranges of around 4 km^2. In 2004, after failure, some birds ranged widely within average ranges of 25 km^2 incorporating the entire stretch of coast between North Denes and Winterton, seemingly in an attempt to exploit any available food supply.

Although inter-annual variation in recruitment of YOY clupeids is a known phenomenon and to be expected, particularly according to the North Atlantic Oscillation (NAO), virtual failure of Herring in 2004 was thought to be exceptional, if only because of the unprecedented failure of the Little terns, which appear to depend on Herring recruitment. Without further data, an analysis of possible explanations of the lack of YOY could only be speculative, although this did reveal potential for removal of adults perhaps through commercial activity and a NAO-temperature-phytoplankton-zooplankton-Herring larvae link. Moreover, recent research on the impact of underwater noise from pile driving on fish with both avoidance and mortality, indicated a potential for a short-term impact of piling of the turbines conducted in November-December 2003, in what is the documented critical spawning and initial development period for Herring in the area.

With no reason to suggest that successful fish spawning and recruitment has not occurred over the winter/spring of 2004/05, coupled with the prospect of a return of chicks fledged from Winterton in 2003 to the area for the first time, pro-active wardening and protection using all available means has been planned at both the prospective North Denes and Winterton colonies.

Final Report

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1. INTRODUCTION & AIMS

Over the period October 2003 to August 2004 E.ON UK (formerly PowerGen) Renewables Offshore Wind Ltd. constructed a wind farm comprised of 30 high capacity turbines on Scroby sands, a dynamic sand bar system approximately 3km offshore of Great Yarmouth, Norfolk.

The wind farm is located directly offshore from the Great Yarmouth North Denes Special Protection Area (SPA) and Site of Special Scientific Interest (SSSI). The former designation results from the presence of the largest colony of Little terns (*Sterna albifrons*) in the UK, comprising around 10% of the UK population. The colony is protected and managed by the Royal Society for the Protection of Birds (RSPB).

In the planning stages, an Appropriate Assessment of the likely impact of the wind farm upon the Little tern colony and other species known to use the area was undertaken (Percival & Percival, 2000) using information from bird surveys conducted in 1995 (Ecosurveys Ltd., 1995) and 1999 (Econet Ltd., 1999). This assessment concluded that although Little terns used Scroby sands as a feeding area, the impact of the wind farm on local bird populations was likely to be of moderate significance at most.

However, such is the importance of the site that the Department for Environment, Food and Rural Affairs (DEFRA), after discussion with English Nature (EN), consented the application for the construction of the turbines with the proviso that continued monitoring of Little terns should be undertaken to validate the conclusions of the Appropriate Assessment. This is in accordance with the recommendations of Percival (2000), that, as a result of the general paucity of detailed information on the impact of offshore wind farms, a precautionary approach should be undertaken with schemes including detailed monitoring of species of concern. The monitoring requirements suggested by EN/RSPB were supplied as Annex 3a and 3b with the consent, and are reproduced here as Terms of Reference in Appendix I.

Monitoring was designed with the primary aim of assessing the impact of the proposed wind farm upon Little terns. This forms the primary aim of the project documented here and previously (ECON, 2003). Prior to construction (i.e. in the 2002 and 2003 seasons), monitoring was to be divided into three areas of work:

1) Feeding studies i.e. spatial and temporal distribution of Little terns over Scroby sands and the area surrounding the colony and foraging behaviour at sea;
2) Breeding colony studies – focussing on chick feeding ecology and provisioning rate to chicks. Information on general colony development and parameters success was also to be made available to the project by the RSPB;
3) Prey studies i.e. spatial and temporal distribution of the prey resource available to birds at sea.

Post-construction (i.e. in 2004 at least), an additional area of work was to be added;

4) Bird strike studies.

During all phases, potential impacts on other seabird species throughout the period of study were to be included as a matter of course.

In 2004, the turbines were brought on line after the completion of the breeding season, after which the birds quickly disperse away from the area. Thus, the turbines were not in full operation whilst Little terns were present. Consequently, bird strike studies focused on continuing to attempt to assess the use of the wind farm and the area in general by Little terns through the use of radio telemetry of a small number of individual birds, as well as through more general bird surveys.

In all years of the study thus far breeding colony studies and (at least) foraging behaviour at sea was also conducted at Winterton, some 10km north along the coast, which forms part of the SPA. This was in order to obtain a better understanding of the foraging ecology of Little terns and the factors affecting reproductive success. Knowledge of such factors remains rather limited and was thought to be essential to allow a thorough evaluation of the impact of the wind farm at Scroby to be made, thereby achieving the primary aim of this project. Moreover, in every year of the study birds attempted to nest at Winterton typically in response to displacement from North Denes for one reason or another.

This report documents all monitoring conducted in 2004, referring to data gathered in 2002 and 2003 where appropriate.

2. BACKGROUND INFORMATION

2.1 Potential impact of the Scroby wind farm upon birds

As outlined in previous reports, the proposed wind farm at Scroby farm could have a positive, negative or neutral impact upon the Little tern colony at North Denes.

Potential negative impacts include:

- Direct strikes of birds upon turbines;
- Displacement of birds from important foraging grounds (i.e. habitat loss);
- Changes in the nature of important foraging grounds as a result of the presence of structures anchored to the sea-bed, thereby changing local geomorphological processes.

Prior to construction of the turbines, it was thought that changes in the nature of the foraging grounds, represented the most important likely impact (ECON, 2003). Moreover, in theory, it was suggested that any type of impact could be mitigated at least through action ‘in kind’ by:

- Modification of beach habitat;
- Proactive wardening and protection;
- Changes in commercial fishing activity i.e. exclusion zoning of important areas;

- Provision of fish habitat.

Of these, the latter was deemed to be the most appropriate and important.

In contrast, positive impact may result from enrichment of existing foraging grounds or creation of new foraging habitat as a result of the presence of structures anchored to the sea-bed, all resulting in an increase in the nature and/or availability of the Little tern prey resource. Fish find structures particularly attractive and the species richness as well as the abundance and distribution of fish may change to the benefit of Little terns. Moreover, through changes in local conditions leading to deposition, the size and shape of the sand bar and thus area of shallow water supporting fishes available to Little terns may also increase. The potential for increased abundance of fishes as a result of reduced fishing effort within a wind farm area is thought not to apply to Scroby as little commercial-scale fishing appears to be undertaken in the immediate area.

A neutral impact may result from no detectable change of the wind farm upon any aspect of individual foraging ecology and/or the prospects of individual mortality, with no knock-on effect to the population level i.e. reduced numbers of nesting birds and chicks fledged etc.

2.2 Advances in the assessment of the impact of offshore wind farms upon birds

Offshore wind is a developing industry set to burgeon rapidly in the coming years as the UK government is committed to a target of 10% of its energy use being generated from renewable sources by 2010, with the majority coming from wind-generated electricity of which 60-70% could come from turbines sited offshore (DTI, 1999). The first round of offshore wind farm environmental statements revealed difficulties in assigning importance to potential development areas and quantifying and mitigating likely impacts upon birds as well as other marine wildlife. This was primarily due to the lack of basic, scientifically rigorous data on the distribution, abundance and patterns of movement, especially upon species of conservation concern.

In response to the undeniable need for more data, a number of initiatives were begun. Of particular relevance to the proposed wind farm at Scroby was the joint project between the RSPB, Wildfowl and Wetlands Trust (WWT), Joint Nature Conservation Committee (JNCC) and ECON upon breeding tern foraging ranges in North-West England and East Anglia (Allcorn *et al.*, 2004) Several species of tern including Sandwich *Sterna sandvicensis* and Common *S. hirundo* terns as well as Little terns breed in internationally important numbers in the areas proposed for offshore development in the UK. The aim of the study was thus to provide good information on potential tern movements in these areas with a view to making general recommendations on the siting of turbines. Such information was critical to meet the requirements of the Strategic Environmental Assessment (SEA) as well as aiding site-specific Environmental Impact Assessments (EIA's). Monitoring was undertaken by both aerial (plane) and ship surveys in 2003.

It was concluded that Little terns consistently foraged less than 3km offshore and were thus likely to be unaffected by most wind farm developments. However, Sandwich and Common terns had a significant offshore component within their foraging ranges and that overlap with wind farm developments at 8km and considerably beyond this distance was likely. The potential impact of these remained difficult to evaluate and further surveys from 8-13km offshore was recommended.

The second strand of work that has developed in relation to wind farms has been that of survey methods. Although accepted methods to survey birds at sea have been in existence for some time (e.g. Komdeur *et al*., 1992), a distinct need for standardisation of sampling methodologies across the offshore wind farm industry was recognised, as this would enable comparable data gathering across developments and should result in a reduction of individual sampling effort whilst providing the level of information required to inform the EIA process for offshore wind farms.

For this purpose the Crown Estate in the UK, under the umbrella of the Collaborative Offshore Wind Research into the Environment (COWRIE) see (http://www.thecrownestate.co.uk/35_cowrie_04_02_07.htm) awarded a contract to the Royal Netherlands Institute for Sea Research (NIOZ) to conduct '*A Comparison of Ship and Aerial Sampling Methods for Marine Birds, and their applicability to Offshore Windfarm Assessments*'. The draft report was discussed at a workshop held at Aberdeen University on 24th November 2003 for invited participants. Dr Martin Perrow (MRP) from ECON was in attendance. The results of the workshop were posted on the web in April 2004 (Camphuysen *et al*., 2004). A key outcome was that aerial and ship surveys are not mutually exclusive techniques but should be seen as compatible depending on the objectives and nature of the target area and species concerned. The tack of the initial project brief was thus changed to move towards standardised census techniques and a series of recommendations as to how surveys from either platform are best conducted is presented in the final report (http://www.thecrownestate.co.uk/35_cowrie_marine_bird_survey_methodology_04_02_07).

Surveys at Scroby are based on this standard methodology, with a transect of 300 m set either side of the boat (see 4.1.2 below). With standard methods no attempt is made to calculate the absolute density of flying birds, so the numbers seen form a relative density estimate or catch-per-unit effort (CPUE).

3. STUDY DETAILS

3.1 Study area

The study area covered the full extent of Scroby sands potentially utilised by birds nesting at North Denes and that to be occupied by the wind farm (Fig. 1).

The twelve sampling stations and sample grid were established in the 2002 season and used subsequently. This followed the agreement with the RSPB that 30% more survey points – as compared to the surveys in 1995 (Ecosurveys Ltd., 1995) and 1999 (Econet Ltd., 1999) – be introduced with further effort directed at the eastern edge of the sands. The inshore points of the sample grid corresponded to the landmarks of Great Yarmouth, North Denes, Caister and California. The distance between inshore points and the western edge of the sands was 3km, with points on the eastern edge fixed a further 2km away. The exception was at California in the North where the eastern point was shifted to 2km offshore to sample the shallow waters of Caister Shoal. The western edge point was 3km away, maintaining the 5km between inshore points and those furthest offshore. The actual position of these points is shown in Fig. 1 and Table 1.

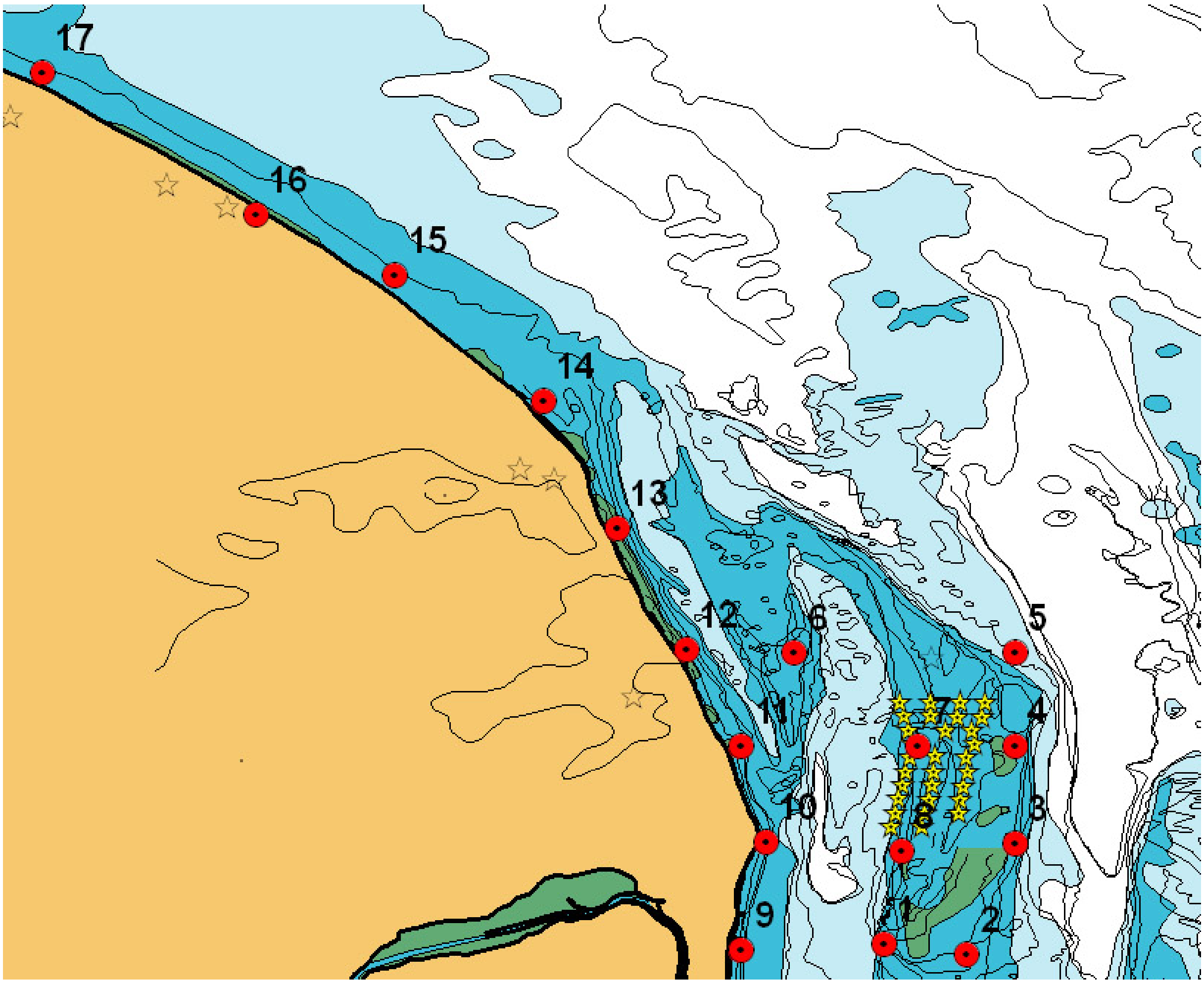

Figure 1. Map showing the twelve sampling sites at Scroby as well as additional sampling sites (13-16) in the Would including Winterton (site 14). The location of the turbines at Scroby are shown by yellow stars.

In 2002, a range of supplementary sites were sampled in the area known as the Would which includes Winterton, as far north as Eccles. This included inshore and the equivalent offshore locations. In 2003, it proved impossible to undertake the same level of supplementary surveying as a result of time constraints. No offshore sites equivalent to those at Scroby were sampled in 2003 as at a result of the total absence of Little terns and the general rarity of fish (a maximum of 4 individuals were recorded at all sites combined on any occasion) at these points in 2002.

Consequently, just the four inshore sites (1A, 2A & 4A with 3A adjusted one km from Sea Palling to Waxham to ensure equidistant spacing between sample points to become 3B) with the addition of a further inshore site at Hemsby (9A), which is equidistant (c. 3km) between Caister (the further north of the 'Scroby' sites) and Winterton (Table 1, Fig. 2), were sampled. The Hemsby site was easily sampled with little time cost on course to Winterton and provided sample coverage of the entire 15 km of coast between Yarmouth and Winterton. For ease of reference, these additional sampling stations were numbered from 13 to 17 from south-east to north-west in 2004 (Table 1).

Table 1. Latitude and longitude of all survey sites in the entire study area including Scroby and the Would. From each shore identification point sites are listed from west to east i.e. inshore to offshore.

Study zone	Shore identification	Site number	Latitude (northings)	Longitude (eastings)
Scroby	Yarmouth	9	52 35.96	01 44.43
		1	52 36.05	01 46.50
		2	52 35.90	01 47.70
	North Denes	10	52 37.51	01 44.79
		8	52 37.40	01 46.75
		3	52 37.50	01 48.40
	Caister	11	52 38.91	01 44.43
		7	52 38.90	01 47.00
		4	52 38.90	01 48.40
	California	12	52 40.29	01 43.63
		6	52 40.25	01 45.20
		5	52 40.25	01 48.25
	Hemsby	13[1]	52 42.06	01 42.63
Would	Winterton	14[2]	52 43.89	01 41.56
	Horsey	15[3]	52 45.72	01 39.41
	Waxham	16[4]	52 46.58	01 37.39
	Eccles	17[5]	52 48.64	01 34.28

[1] formerly 9A, [2] formerly 1A, [3] formerly 2A, [4] formerly 3B, [5] formerly 4A

However, time constraints dictated that sites north of Winterton (Horsey, Waxham and Eccles) could only be sampled sporadically (once in mid June in the case of the latter two sites). Moreover, with the delayed usage of Winterton by Little terns, bird counts and prey resource sampling was started over a month later than at Scroby. However, from mid June, sampling at both Scroby and the Winterton were conducted at similar times and the same number (nine) of sampling occasions was ultimately made.

In 2004, the same sites were sampled as in 2003, although sampling to Winterton had to be limited to three occasions, once each in May, June and July. Sites north of Winterton could only be sampled once in both May and June (see 4.1.1 below).

3.2 Timing of study

In 2004, the study commenced on 7th May, virtually to the day the study had begun in 2003 (6th May). The last visit was undertaken on 13th August, a week earlier than in 2003 (21st August), following the southward migration of the vast majority of Little terns from the study area. Moreover, a final planned survey in the week beginning the

23rd August was repeatedly cancelled as a result of a period of unseasonal and extremely bas weather. A total of 35 visits covering the various aspects of the project (with 8 surveys at sea, 12 foraging observations, 5 catching birds and 10 undertaking telemetry) were undertaken during the study period (cf 37 in 2003 and 23 in 2002). The timing of individual visits is documented in the methods for each aspect below. The frequency of field visits varied from daily during intensive periods, especially involving radio telemetry (see 4.2 below), to a maximum of 14 days at the end of the study period.

3.3 Details of vessel and personnel

All offshore work was conducted from the chartered 'Girl Kayla' a registered 12m work- and fishing boat operating from Gorleston, skippered by Paul Lines (PL), Chair of the East Anglian Fisheries Association. The boat used was very similar in build and features (e.g. Digital Global Positioning by Satellite [dGPS] system, accurate depth sounder and necessary safety equipment and appropriate procedures) to the 'Sea Venture' which had been used in previous studies and was unavailable as this was otherwise engaged in duties associated with the wind farm development.

Prey studies at sea were undertaken by Dr Martin Perrow (MRP) of ECON and PL, with MRP conducting all bird counts. Radio telemetry at sea was undertaken by MRP assisted by PL and Dan Brown (DB) an excellent field ecologist and surveyor retained by ECON. Colony studies were undertaken by MRP and Eleanor Skeate (ERS), a further ecologist at ECON.

Radio tags were fitted by Jennifer Smart (JS) assisted by Mark Smart (MS), under licence A4776 issued by the British Trust for Ornithology (BTO) (see 4.2.3 below). Both JS and MS were also named under Schedule 1 license No. 20041121 (to disturb protected species by observation for the purpose of science and education) issued to MRP by EN under the Wildlife & Countryside Act 1981 (amended by the Environmental Protection Act 1990). Birds fitted with radio tags were captured under license to the ringing team led by the Reverend Arthur Bowles of Great Yarmouth (see 4.2.2 below).

4. METHODS

4.1 Surveys of birds at sea

4.1.1 Number and timing of surveys

Counts were undertaken over one day at Scroby at intervals between 6-22 days (mean = 14 days). A total of 8 survey visits were undertaken at Scroby. The dates of the surveys are documented in Table 2.

Surveys were generally begun between 07.00 and 09.00hrs and continued to between 16.00 and 20.00hrs, with the speed of operation depending on the state of the tide and the time taken to process the samples obtained in the prey studies (see 4.3 below). Surveys were undertaken across a range of tides and conditions and the route around the study area was varied wherever possible, in order to sample at least the inner (12-9), middle (1, 6-8) and outer (2-5) sample points (see Fig. 1) at different times of day. At Winterton, including Hemsby *en route* (see 3.1 above), sampling was started 10 days later than at Scroby, as it became clear that Little terns were not concentrated at North Denes but had also been observed along the coast (see 5.1.2 below). It was not possible to sample at Winterton with the same frequency as in 2003 and intermittent sampling throughout the sample period coinciding with every second visit to Scroby was undertaken. Bird counts and prey studies were thus undertaken on three occasions at intervals of 24 and 36 days respectively (Table 2).

Bird counts and sampling of prey were also undertaken at Horsey, Waxham and Eccles on the 17th May and 10th June coinciding with sampling at both Scroby and Winterton. The timing of these surveys allowed prey densities available to birds at the supplementary colony at Eccles to be evaluated in comparison to Winterton and North Denes.

Table 2. Calendar of bird counts and prey studies.

Task	**Site**	**Visit**							
		1	2	3	4	5	6	7	8
Bird count & prey studies	Scroby	7 May	17 May	4 Jun	10 Jun	30 Jun	16 Jul	22 Jul	13 Aug
	Winterton		17 May		10 Jun		16 Jul		
	Eccles		17 May		10 Jun				

4.1.2 Survey technique

The same methodology employed has been used throughout the study including 2004. Namely, at each survey station on each occasion, all birds that could be seen were recorded by eye supplemented by the use of high-resolution Leica binoculars (8x in 2002 and 10-15 x 40 in 2003 and 2004) particularly to confirm species identity. All counts on all occasions were undertaken by the same person (MRP) to avoid operator bias. Each count was undertaken over a single 10-minute period, with the operator moving around the boat to cover 360^0. Counts were routinely conducted as the vessel was moving whilst trawling for prey. Using the relationship between platform and eye height of the observer, it was estimated a distance of 300m from the observer could be readily and routinely seen. This is further than the 200m estimated during previous surveys (Ecosurveys Ltd., 1995; Econet Ltd., 1999). However, this value was arbitrarily derived and 300m was considered to be a more realistic value, particularly as this is the standard distance used for strip-transect counts (http://www.crownestate.co.uk/cgi-bin/estates/marine/windfarms/marinebirds.cgi). Consequently, direct comparison of the numbers of birds seen in counts in all years was thought to be justified.

The methodology used produces a count, which is most appropriately thought of as an *index of abundance* and thus *an index of use*. In order to put these numbers into context of other studies, it was also desirable to calculate the density (D) of birds.

This was possible as when traveling at 3.5 knots over a 10 minute count period, the boat was effectively sampling a 1000 m long by 2 x 300 m wide strip transect, which is a standard method of estimating bird densities at sea (http://www.crownestate.co.uk/cgi-bin/estates/marine/windfarms/marinebirds.cgi).

Density could thus be simply calculated using:

$$D = N/L(2W) \qquad \text{(eq.1)}$$

where N = number of birds, L= length of transect and W is width of transect.

In practice, the estimation of density should be treated with extreme caution as most of the birds sampled within transect were not resident, but simply passing through. This is particularly true of flying birds, which comprised all the terns recorded as well as the majority of other species, with the exception of most of the auks. Consequently, all the birds recorded are unlikely to occur at the same time within transect, thereby overestimating density. In this case, the *snapshot* technique in which birds are recorded in an instantaneous fashion at intervals during the sampling period is preferred. However, this may not lend itself well to situations where birds are at particularly low density.

4.1.3 Foraging behaviour of Little terns

As during previous seasons, the foraging ecology of Little terns was evaluated primarily using a shore-based telescope (see 4.4.2 below). However, the location, distance from shore and behaviour, especially when foraging, of any Little terns seen at sea, even outside count points, was routinely recorded. Observations also extended to actively foraging terns of any species.

4.2 Radio telemetry of Little terns

4.2.1 Plan of action

The attachment of radio tags to Little terns in 2003 as part of this study had not been undertaken in the UK before. Whilst there were a number of technical problems in attaching tags to Little birds, with negative impacts upon the behaviour of the birds, these mostly stemmed from the initial supply of inappropriate tags. There is no evidence that handling itself was responsible as all birds initially behaved normally (ECON 2004). This is contrary to the experiences of Brubeck *et al*. (1981) who suggested that handling of individuals of the very closely related Least tern *Sterna antillarum* following capture at the nest to fit patagial tags was the cause of an increased frequency of nest desertion. In our case, any birds exhibiting aberrant behaviour did so after a period of days, often it seems in relation to loss of the aerial.

However, with the affected birds there was also some evidence of a chronological reduction in the level of aberrant behaviour, with the first two birds fitted with tags showing the more extreme response. This suggested some 'learning' process in tag attachment even in the hands of experienced workers. This is not surprising giving the novelty of attachment to a poorly known species with poorly understood anatomy.

The experience with tail-mounted tags suggested these were completely inappropriate for Little terns. The central feathers of the forked tail appear too short (c. 4-5cm) for effective tag attachment, and there may be an issue of unbalancing this fast-flying and diving species, no matter how small and light the tag and aerial. The fact that at least one and probably both tags fitted were shed very quickly illustrates the strain the tags exerted on the tail feathers.

In contrast, birds fitted with correctly designed back-mounted tags largely exhibited normal behaviour patterns and maintained good condition, with one of the tagged individuals raising 2 chicks, which were thought to have fledged. Despite this, there was thought to be scope for improvement and it was suggested that little or no trimming of the feathers to attach tags should be undertaken as i) there was potential for this area to stay wet longer than it might after immersion during diving, with consequences for thermal insulation and ii) the bird may be able to preen under the tag to some extent. Although it was possible this could enhance the chances of the tag being shed, this was deemed acceptable partly as experience shows tags are retained far longer than the life of the battery.

The work undertaken in 2003 also suggested that there could be sex related differences in the response to tagging. Massey *et al*. (1988), again working on Least tern in the US, showed that male birds (four individuals) fitted with back-mounted tags illustrated a number of behavioural abnormalities, which included absence for several days, reluctance to undertake normal nesting duties and shifts in habitat preferences. Admittedly, this could simply have been due to inappropriate handling or the relatively large size of the tags used (weighing 1.8 g, approximately 3% of body weight).

Consideration of the relative roles of male and female birds suggested that if a female responded unfavourably to tagging, it could be disastrous for any eggs or young chicks – the female undertaking the bulk of incubation. However, with greater attraction to both eggs and chicks, females may resume normal duties more rapidly after handling and tagging. Males on the other hand, being less directly tied to eggs and young chicks may show greater tendency to relax normal duties. If so, this could have great impact on the incubating female, forcing her to forage for herself (as she is often fed by the male particularly in early incubation) and leaving the eggs or young chicks at risk from predators and the vagaries of the weather. Moreover, as the male is typically responsible for the bulk of food provisioning to chicks particularly in early development, this may ultimately have negative consequences for chick survival. Overall, any sex-related differences in the response to tagging, clearly needed to be carefully monitored.

The study in 2003 thus concluded that with modification to some aspects of tagging procedure, it was worthwhile that the advantages of radio tagging to provide invaluable data in the assessment of the habitat use of Scroby and the wind farm, and to further knowledge of Little terns which may considerably enhance the ability to conserve the species effectively, far outweighed the potential disadvantages. The BTO, EN and RSPB seemingly took the same view and the appropriate licensing was granted (License No. A4776).

However, a number of technical issues still had to be overcome, not least with the high incidence of failure of the tags, especially in relation to limited battery life. There was also the issue of the range over which tags could be detected. Following discussions with Biotrack, it was agreed that a slightly heavier, but longer-lived (up to 28 days) battery (Ag 376) should be trialled. Previously unused tags fitted with the shorter-lived (maximum of 19 days) Ag 379 (although these would have to be re-fitted) tags were also to be used. Experiences in 2003 had shown that birds carrying tags fitted with ground plane aerials, which reputedly enhance signal detection especially at greater range, had apparently suffered no ill effects[1]. However, it was considered that the weight of tags with ground planes (1.1 g) meaning the birds were carrying around 2% body weight should not be exceeded by any tag of whatever combination of features. Thus, tags with heavier batteries should also not be fitted with ground planes. In total, fifteen tags (as in 2003) of three designs were to be used:

- Five (re-fitted) PIP2 tags with shorter-lived Ag 379 batteries
- Five (one re-fitted, four new) PIP2 tags with shorter-lived batteries and a further ground plane aerial
- Five (new) PIP2 tags with longer-lived Ag376 batteries.

It was planned to compare the performance of these different tags of similar weight (0.8-1.1g tags). As in 2003, it was planned to fit tags to birds in batches of 5 tags to cover the entire period of incubation and chick development (at least 40 days in the life of each breeding attempt).

With the potential for high tag failure rate, as much data gathering as possible was to be undertaken immediately after the tags had been fitted. For this reason, a second researcher (Daniel Brown-DB) was trained and employed to cover for MRP when unavailable. In order to maximise the amount of data gathered as much time and financial resources as possible were to be allocated to this part of the project.

As work in 2003 had demonstrated that birds could travel considerable distances (at least to 9.35 km) and at considerable speed (mean of 25 km hr^{-1}) reaching > 2 km offshore, meant that any tracking was likely to be more effectively achieved from a smaller, faster-moving boat than the more standard vessel that had previously been used. Consequently, it was planned to use a rigid-hulled inflatable boat (RIB) fitted with a large outboard engine capable of speeds of up to 30 knots hr^{-1}.

4.2.2 Capture of adults

The capture of adult Little terns at the nest for attachment of radio tags had first been successfully undertaken in the UK in this study in 2003 and similar methods were used in 2004.

For the bulk of captures the same simple wire-mesh walk-in trap composed of two chambers as designed and built by the ringing group led by the Reverend Arthur Bowles and comprised of Kevan Brett, Tony Leggett and David Parsons, was used. At North Denes on one occasion a wooden trap with a remotely-operated door (via radio

[1] This was largely restricted to one female which had successfully raised chicks

signals) provided by Mark Smart of the RSPB was also used. This proved to be temperamental and was abandoned after the initial trial.

Unlike at Winterton in 2003 when nests were selected by searching through areas of the colony, in 2004, at both North Denes and Winterton specific nests were targeted. At North Denes, only a few nests were available at any one time, the location of which was known by RSPB staff protecting the colony as well as by MRP. At Winterton, monitoring of individual nests had been undertaken by ECON in relation to another project monitoring the impact of the Happisburgh to Winterton sea defences upon shore nesting birds, commissioned by the Environment Agency (Skeate & Perrow *in prep*. and see ECON 2001). Here, it was planned to monitor the response of tagged birds in relation to untagged 'control' birds close-by. As a result of the nature of the trapping in which 2/3 nest traps were used in a small area typically resulting in the simultaneous capture of two adult birds, it provided an ideal opportunity to tag (and colour ring) a bird from one nest and simply colour ring another, thus allowing any behavioural response to tagging to be potentially separated from simply handling the bird. Birds not captured and handled at nearby nests provided the potential to monitor true controls.

At the beginning of the study only nests with apparently complete clutches that had undergone at least half the incubation period of around 20 days were selected. This was to reduce the risk of any birds abandoning the nest as a result of handling, although this had not been a problem in the study in 2003. However, with the rapid decline in nests (see 5.1.2 below) as a result of wholesale nest failure, a decision to attempt to trap any birds with nests at North Denes was taken. This had full support of the RSPB.

On each occasion, traps were placed over the nest containing eggs, with ringers retiring to the dunes (c. 75-100m) to observe. A bird generally returned to a nest within a few minutes, typically landing and walking around and pressing against the trap as it attempted to brood the eggs. There was considerable individual variation in behaviour, with some birds finding the entrance rather easily and quickly and others vainly attempting over 10 minutes or more. With some, the position of the trap was adjusted to aid access. This was mostly successful. With two or more traps, even if a bird had entered and settled in one trap, this was left for a period in the hope that a further bird would enter a second trap. If after a period of few minutes this had not occurred, an attempt was made to catch the settled bird. Moreover, where a bird(s) was settled, this was allowed to warm the eggs for a minimum of 10 minutes before any attempt at capture.

A ringer then set off to capture the bird (Plate 1). Birds generally flushed into the larger chamber where it could be captured by reaching in through a further hinged door in the roof. On a few occasions, the adult simply escaped through the door of the trap. This was mostly achieved by individuals that had positioned themselves directly facing the door as they incubated, which in turn appeared to be related to wind direction with a preference for facing into the breeze. Where the adult had quickly settled, a further attempt was made following re-positioning of the trap: otherwise the trap was placed on another nest. The welfare of the eggs and birds was paramount and with any concern that the eggs of any nest might become chilled any attempt to capture the adult was abandoned. With variable air temperature on the different occasions trapping was attempted, the minimum attempt period was about 20 minutes stretching to 30 minutes or more at higher air temperatures. In all cases that an adult was held for tag attachment, its partner settled to incubate the eggs.

Plate 1. Ringer collecting an adult Little tern from a walk-in nest trap

Plate 2. Ringing an adult Little tern

With the ultimate abandonment of nesting at North Denes (as well as Winterton – see 5.1.1 below), an attempt to capture birds not associated with nests was also made towards the end of the study, again with full support and cooperation of RSPB staff, who collaborated with the ringing team. A 'Whoosh net' was used on the foreshore to target loafing birds. Both of the birds captured in this manner were subsequently fitted with tags.

A total of 17 adult birds were captured on five separate occasions (22^{nd}, 26^{th} & 30^{th} June and 2^{nd} and 14^{h} July - Table 3), with 9 at North Denes and 8 at Winterton. Of these, all 9 of the North Denes birds were tagged, with 5 of the 8 tagged at Winterton. All birds were ringed (Plate 2) with a metal ring on the right leg where none was already present. At Winterton, a yellow over black colour ring was placed on the left leg. This contrasts with the yellow ring used on the left leg of adults (Plate 3) and the yellow ring placed on the right leg of chicks in 2003. Colour rings were not used on birds from North Denes. Five birds, including four that were subsequently tagged, had been previously marked as pulli from North Denes from 1994 to 2000 (Table 3).

In the hand, birds were generally both silent and docile in the hand, struggling little and only occasionally attempting to peck. The bill was very flexible and able to flex at the tip under muscular control. The eyes were noticeably large and bulging (Plate 3).

A number of measurements including weight were taken from all birds (Plate 4). There was considerable individual variation in these measurements, particularly in relation to weight, wing and tail fork length (Table 3). Combined with previous experiences it is now thought that the sex of the birds is most reliably indicated by tail fork difference, with apparent males having longer outer tail feathers (mean[±1SE] = 43.0 ± 2.2, range = 37-50 mm) than females (mean[±1SE] = 30.6 ± 1.1 mm, range = 24-36.2 mm).

Males also seem to have longer wings (mean[±1SE] = 180.8 ± 0.8 mm cf. 177.0 ± 1.1 mm) and bills (mean[±1SE] = 31.1 ± 0.6 mm cf. 29.6 ± 0.5 mm) and weigh more (mean[±1SE] 56.0 ± 1.3g cf. 52.7 ± 0.9 g) than females. However, all these measurements overlap (male wing length male range = 178-183 mm cf. female range = 172-183 mm; male bill length range = 29-33 mm cf. female bill length range = 27.4-32.5 mm; male weight range = 51-60 g cf. female weight range = 49-58 g). In other words, the smaller birds with shorter bills, wings and especially tails are most likely female with the largest birds with long wings, bills and especially tails are most likely male.

These patterns reported here reinforce the data on the nominate race *albifrons* in North-Western Europe (i.e. the same race as that in East Norfolk) presented in Cramp & Simmons (1985), which also suggested males tend to have longer wings (mean = 181mm, range = 176-187, n=16), a longer tail fork (mean = 44.5mm, range = 36-49, n=6) and longer bills (mean = 30.2mm, range = 27.8-33.1, n=13), than females: wings (mean = 175 mm, range 167-180, n=19), tail fork (mean = 36.1 mm, range 29-41 mm, n=10) and bill (mean = 28.7 mm, range= 26.7-30.8 mm, n=17). However, although supported by the literature, with no absolute test of the sex of the bird, any statements regarding sex differences should be treated with some caution.

Table 3. Details of tags and biometrics of captured and tagged Little terns in 2004.

Date	Site	BTO ring No./types	Retrap first ringed	Frequency	Tag type	Brood patch	Weight (g)	Bill length (mm)	Wing length (mm)	Tail fork (mm)
22nd June	ND	NW09890		7.1	Ag376	3 (M?)	54	29.0	182	39.0
26th June	W	NV91042 Y/B Left	02/07/98	5.5	Ag379 RF+GP	3	51	30.1	181	24.0
	W	NW09891 Y/B Left				3 (M?)	51	32.7	180	37.0
	W	NW09892 Y/B Left		13.9	Ag376	3 (M?)	56	30.6	183	40.0
	W	NV91076 Y/B Left	24/06/98	9.4	Ag379	3[1]	52	32.5	175	28.0
	W	NV80812 Y/B Left	29/06/94			3	53	31.3	179	32.0
	W	NW09893 Y/B Left		7.0	Ag379	3	49[2]	30.0	172	35.0
	W	NW09894 Y/B Left				3[3] (M?)	58	31.5	182	50.0R 46.0L
	W	NW09895 Y/B Left		2.9	Ag379 GP	3[4] (M?)	57[5]	33.0	178	43.0
30th June	ND	NW09896		12.0	Ag376	**?**	58	30.8	183	31.0
	ND	NW09897		c.9.0 (blue-grey)	Ag379	**?**	58	31.4	175	26.8
	ND	NW09898				**?**	54	29.0	175	28.6
2nd July	ND	NV82475	26/06/95	8.2	Ag376	**?**	49	27.8	174	26.8
	ND	NW09899		10.2	Ag376	**?**	51	28.0	182	30.1
	ND	NV80731	29/06/94	0.7	Ag379 GP	3	52	28.3	180	36.2
14th July	ND	NW09900		6.4	Ag379 RF	3	51	27.4	174	35.0
	ND	NV95791	26/06/00	4.7	Ag379 RF	**?** (M?)	60	29.9	180	49.0
	ND	NW09927		11.0	Ag379 GP	**?**	54	28.8	174	33.5

Notes
[1] This bird also had brownish crown feathers
[2] Five fish (probably 4 larval clupeids and 1 sand eel) were disgorged upon capture
[3] Relatively small brood patch
[4] Large brood patch
[5] Two sand eels were disgorged

What is also now clear is that the presence of a brood patch appears to be a poor indicator of sex, as all birds appear to have one, although this may be larger in females. This is not unexpected given that females take the bulk of incubation with males contributing an individually variable proportion. Indeed, the fact that males share incubation means that they may also be caught by the nest trap method. In fact, it may be that the initial flushing of what is most likely to be the female bird from the nest as the trap is laid, may mean that this triggers nest changeover behaviour and the first bird to land and attempt to incubate is disproportionately (compared to time spent incubating) male. However, with greater initial investment in eggs females may tend to persist more in gaining access to the trap and the eggs.

4.2.3 Tag attachment

Following capture of a bird and whilst measurements were being taken, the tag was prepared for fitting. The wires protruding from the tag were pressed together and the receiver used to confirm the tag was working and the position of the signal generated by its frequency on the dial of the receiver. A layer of solder was then applied over the wires using a gas-powered soldering iron. After this had set, Plastidip was applied to seal and waterproof the tag.

As recommended from previous experience (ECON 2004), the feathers on the back of the bird were only very lightly trimmed to preserve their insulating properties and the position of the tag complete with its muslin backing material tested on the back of the bird. A layer of cyanoacrylate Superglue was then applied to the backing material and the tag pressed on to the back of the bird (Plate 5). The site of attachment was then sprayed with Superglue activator, which aims to remove air bubbles and allow rapid setting. The fine mist produced had the effect of temporarily wetting the feathers around the tag. The bird was then prepared for release by being held up into the wind. Birds were very relaxed and either continued to grasp the fingers of the worker or to sit quietly before flying off. All birds were seen to shake in the air before flying towards the sea, where they were thought likely to bathe. After confirmation that the tag was still working and its position on the receiver dial, thus recording any immediate ‘drift’, the birds were left to acclimatise for at least 24 hours before any telemetry was attempted.

4.2.4 Telemetry

As a result of previous experience, telemetry of fast-flying birds was to be conducted from aboard a rigid-hulled inflatable boat (RIB) capable of high speed (to 30 knots hr^{-1}). This was to be supported by some telemetry from shore, largely to confirm that tags were still working and birds were behaving normally.

With the reduced life and relatively high failure rate of tags reported in 2003 (see 4.2.1 above), as much telemetry as possible following tag attachment was undertaken. However, this was dogged by a number of technical difficulties centred on the lack of availability of a RIB, the independent failure of both the RIB and the receiving equipment necessitating repair of both and ultimate replacement of the former, unseasonally rough weather and the abandonment of many nests causing birds to range widely (see 5.6.3 below). The latter prompted an attempt to use a second receiver at North Denes beach on one occasion (13th July).

Initial checking on tags and tagged birds was undertaken on 25th and 28th June followed by tracking at sea on 29th June and 1st, 2nd, 6th, 13th, 14th, 19th and 20th July. The latter two sessions were spent fruitlessly searching in excess of 20 km of coastline for any tagged birds. Tracking sessions lasting between 5-7.5 hours (excluding travel time) were undertaken in the period between 07.30 to 17.00 hrs.

Plate 3. A radio-tagged adult Little tern.
Note the colour ring on the left leg.

Plate 4. Taking measurements from an adult Little tern.

Plate 5. Detail of the back-mounted radio tag and aerial attached to a Little tern.

Plate 6. Radio tracking from a rigid hulled inflatable boat in 2004.

Tracking sessions were limited by operator fatigue, equipment failure and most frequently by running out of fuel, although the maximum load was carried on all occasions.

Tracking typically involved two personnel, with one (MRP or DB) operating the receiver with the other (PL) skippering the vessel and recording data (Plate 6) Unfortunately, interference from the engine meant that this had to be switched off if a clear signal was to be received from a tagged bird. Thus, the RIB had to stop whilst the receiver operator scanned with the aerial to find a signal. At the start of each session, each potentially live tag was checked for a signal. Where none was received from a particular tag, a number of attempts were made over several hours to locate it. This was undertaken during periods of inactivity whilst following a bird with a tag that was providing a signal.

When following a bird, the receiver operator continually moved the aerial to obtain the maximum signal strength corresponding with the direction of the bird from the RIB, the position of which was fixed by dGPS. This was recorded as a bearing from the known position. Distance (m) was estimated from the signal strength relative to the maximum value of around 1km at full volume and gain. Where the bird was relatively close, a number of fixes could be obtained in this manner over a relatively short time scale. On 21 occasions (5.7% of fixes) the signal was received from amongst a number of foraging birds, which aided fix location. These 'near visual' fixes were supported by actual sightings of a tagged bird on 17 occasions (4.6% of all fixes). Visual sightings were so rare partly as the tag and particularly the aerial could not be seen unless at very close range, even with binoculars. As noted in the previous year of study, signals comprised of intermittent 'pips' and 'squeaks' produced by most of the tags, occurred when the bird was diving. On the 60 occasions this occurred (16.3% of all fixes), the bird was classed as feeding (fishing).

Where the bird moved out of range, the engine of the RIB was started and a course thought likely to intercept the bird was taken. This became more successful over time as the operators began to better understand the habitat use of the birds. After travelling quickly to close the gap between operators and the bird, the engine was cut and a search for the signal initiated. Where successful, the tracking procedure was continued. Where unsuccessful, further searches were made until the bird was either re-located or declared lost. At this point, a scan of other frequencies was undertaken. If another bird was nearby, then this was followed. If not, a search for any tagged bird was initiated. Apart from the early period (i.e. 29th June) when some birds were associated with nests at Winterton, the search for birds began at North Denes followed by the wider Scroby area before moving onto Winterton and then further north to Horsey and even Eccles. On a few occasions where the RIB tracking session had finished, additional searches of other sites were also undertaken on foot after a journey to the site by car, in an attempt to better understand the movement of birds between sites along the coast.

All birds with signals on a particular day were continuously tracked for between 1 - 305 minutes (mean [±1SE] = 49 ± 14 mins), compared to 59-188 minutes (mean = 132 mins) in 2003 (Appendix II). Much of the difference was thought to be caused by the mobility of the birds in 2004, with most not tied to a nest apart from in the early part of the study, i.e. 29th June when tracking was undertaken solely at Winterton, where at least some birds were associated with nests.

4.2.5 Analysis of telemetry data

In 2003, when telemetry was conducted from a larger vessel (Sea Venture), it was possible to record the actual position of the bird by plotting the bearing and distance from the receiver of each fix, onto the vessel's dGPS plotter. In 2004, without this facility, an intermediate analytical step of estimating the position of the bird at each fix was required. This was most readily achieved by the use of the same plotter aboard the Sea Venture when the vessel was in port. Calculation of the minimum distances travelled between fixes and thus during each foraging bout was then possible.

Basic outputs of the telemetry data were thus:

- % time spent in different activities – at nest, foraging, loafing and flying above the beach typically as a result of disturbance of varying sorts;
- Number and duration of foraging bouts;
- Distance travelled between fixes in a foraging bout – also converted to flying speed (km hr^{-1});
- Minimum, maximum and mean distance (m) of fixes from shore.

The time (BST) state of tide and time from nearest low or high water, wind direction and strength (Beaufort scale) and wave state (rank scale from 0-mirror to 5-whitecaps over 1m height) were also routinely measured during each tracking period. High and low water periods were classified as occurring for a maximum of 90 minutes after the high or low peak had been reached as this incorporated any slack water period. Unfortunately, there was insufficient data from slack water periods to test for any differences in foraging parameters according to tidal state in 2004, unlike in 2003. However, it was possible to test for differences between years in duration of foraging bout (min), distance travelled (m), the mean, maximum and minimum foraging distance from shore and flying speed (km hr^{-1}) using non-parametric Mann-Whitney U-tests.

Telemtry data was also analysed using two pieces of software: ESRI® ArcMap™ 9.0, and Ranges 6 v1.2202, a dedicated package for the analysis of wildlife telemetry data. The co-ordinates were initially imported into ArcMap and displayed on a digitised version of the Admiralty Chart for Norfolk, provided by SeaZone Solutions Limited (Licence No. 112004.006). Outliers were rectified where possible and any erroneous fixes were eliminated (2 fixes on bird 12). Coordinates for the Norfolk coastline were exported from ArcMap into Excel, converted into OSGB 1936 using a co-ordinate converter (TM_LL Workbook, © Alan Morton) and imported into Ranges for use as a base map. The co-ordinates of all fixes (grouped by bird) were similarly exported into Excel, converted into OSGB 1936, and imported into Ranges in the same way.

Ranges software was then used to plot 100% minimum convex polygons (MCPs) around the fixes collected for each bird. This method involves joining up the outer location fixes to create a polygon, which may then be used as an estimate of the bird's range. Other outputs from the programme include an estimated maximum range area and a range span. The maximum, minimum and mean distances from a set of defined focus co-ordinates (either the nest site, or the beach where the bird was tagged) were also calculated. Birds with less than 25 fixes (i.e. 10.2 and 5.5) were excluded from the analysis. A tracking resolution (the smallest distance that can be recorded between adjacent locations) of 100m was used to allow for error in both estimating the distance of the bird from signal strength and calculating the location of the bird from a distance and a bearing. Plotting MCPs is a widely used method of estimating an animal's range (Mohr, 1947; Harris *et. al*., 1990), although there is the disadvantage that the shape and area of the polygons can be heavily influenced by outlying locations. However, in this case the inclusion of the outermost fixes was seen to be essential in ascertaining potential use of the wind farm area by foraging Little terns.

4.3 Prey studies

4.3.1 Development of a suitable methodology

Following discussions with the Centre for Fisheries and Aquatic Sciences (CEFAS) during the 2002 season, a more specific net than an adapted Riley net (Plate 7) to sample the available prey resource of Little terns was sourced, manufactured and developed.

As before, the net was to sample the upper 30 cm of water surface, which appears to be the limit that may be fished by Little terns, derived from the fact that this 22-24cm (with a 4-6cm tail) bird does not appear to immerse much below the surface of the water even when plunge-diving.

In brief, the *larval tow net* developed for use from 2003 onwards is comprised of a rectangular tubular stainless steel frame filled with lead with internal dimensions of 92 cm x 30 cm, with a 2 m long net of 5 mm mesh. Two vanes of 220 mm by 150 mm at an angle of 15 ° (from vertical) are seated on the dorsal side of the net (Plate 8). Such a net had been used during larval fish studies by CEFAS in the past.

In order to calibrate the larval tow net against the modified Riley net used throughout 2002, both nets were towed simultaneously (Plate 8) at all sites at Scroby on five occasions (6th and 26th May, 2nd and 11th June and 31st July) during the 2003 season. This was undertaken in periods of both 'high' and 'low' fish density to provide a suitable range of comparison. The catches in the two 'legs' of the Riley net fitted with different mesh sizes (9mm and 3mm stretched) were pooled as one catch for comparison against the larval tow net. The data from the resulting 60 paired tows was compared using linear regression following the $\log_{10} + 1$ transformation of the numbers captured. This resulting in the following relationship:

For fish $y = 1.197\,x + 0.1113$ $R^2 = 0.78$ $p < 0.001$ (eq. 2)

where y = number in the Riley net and x = number in the larval tow net.

The density (individuals [ind.] m^{-2}) of both fish and invertebrates was also calibrated between the two nets in the same manner:

For fish

$y = 6.7754\,x + 0.0009$ $R^2 = 0.74$ $p < 0.001$ (eq.3)

For invertebrates

$y = 2.2481\,x + 0.00001$ $R^2 = 0.94$ $p < 0.001$ (eq.4)

where y = density in the Riley net and x = density in the larval tow net.

Plate 7. Deploying the Riley net in 2002.

Plate 8. Larval tow net (foreground) and Riley net in action.

Applying these conversion factors to data collected in 2002 allowed a direct comparison of prey numbers and densities between all years.

4.3.2 Sampling at sea

Sampling the prey resource available to Little terns was conducted in the same manner as previously described (ECON 2003, 2004). Namely, two tows were conducted at each sampling station, each over 500 m to and from the centre point fixed by dGPS. Tows were therefore conducted over a total of 1km at each station, with the net sampling 1000 m x 0.92 m = 920 m^2 at each station. On each occasion, the net was towed at a speed of 3-3.5 knots. During towing, an average depth was recorded by an on-board echo sounder. In 2002 and 2003, upon completion of the tow, the net was hauled alongside the boat with a mechanised hauler. In 2004, with the use of a different but similar vessel hauling was undertaken by hand. As the net was lifted from the water an estimation of water clarity was made by recording the depth at which the frame of the net could no longer be seen (i.e. analogous to the standard Secchi disc method) (Appendix III). Once on board the net was inverted and a careful search for retained animals undertaken (Plate 7). All jellyfish were simply counted and returned to the water. Any fish and invertebrates conceivably falling prey to Little terns were immediately preserved in 70% industrial methylated spirit (IMS) and labelled appropriately. A rough count of any fish and invertebrates was made as they were preserved and recorded.

On some occasions in 2003 some fish and invertebrates were kept fresh on ice before return to the laboratory where they were measured and weighed before being preserved in the normal way. This was to investigate the effects of preservation on length and weight parameters (see 4.3.3 below).

4.3.3 Sorting and identification of samples

All specimens preserved in the field were identified as far as possible and measured to the nearest mm body length (fork length for fish) and weighed to the nearest 0.001g. Identification of invertebrates was undertaken using Hayward & Ryland (2000). Fish were identified using Wheeler (1969) as well as Hayward & Ryland (2000). It proved impossible to separate the larvae of Herring (*Clupea harengus*) and Sprat (*Sprattus sprattus*) from preserved specimens prior to the development of the ridge of scales on the ventral keel on Herring. The generic term ‘clupeid’ (‘whitebait’ in fishing parlance) was thus used for these specimens. However, at beyond 3cm, it was generally possible to separate the two species and this was undertaken wherever possible.

In 2003, an attempt was made to quantify the change in length and particularly weight of preserved specimens and to allow the ‘fresh’ biomass, and thus the biomass available to Little terns, to be better estimated. In order to achieve this a total of 40 fish and 112 invertebrates of a variety of species were put on ice immediately after capture and kept in the same state for <24 hrs being being measured (total length for invertebrates and fork length for fish) and weighed to the nearest 0.001g. These specimens were then preserved in the standard manner (i.e. in 70% IMS - see 4.3.2

above) for the same duration of time that specimens were normally preserved before being identified, that is, a few days.

Whereas length remained unchanged, the weight of the preserved specimens decreased sharply after preservation. The relationships between preserved weight and fresh weight of those groups of reasonable sample size were as follows:

For clupeid fish (n=28)

$y = 0.9477x + 0.185$ $R^2 = 0.988$ $p < 0.0001$ (eq.5)

For *Idotea* (n=63)

$y = 1.0202x + 0.0175$ $R^2 = 0.849$ $p < 0.0001$ (eq.6)

For shrimps (n=21)

$y = 0.9908x + 0.0567$ $R^2 = 0.995$ $p < 0.0001$ (eq.7)

The length to weight relationships of preserved specimens of sufficient sample size to obtain a meaningful relationship, were as follows:

For clupeid fish (n=331)

$y = 2.438x – 4.8812$ $R^2 = 0.623$ $p < 0.0001$ (eq.8)

For *Idotea* (n=272)

$y = 2.8041x – 5.0184$ $R^2 = 0.924$ $p < 0.0001$ (eq.9)

For ghost shrimp *Schistomysis spiritus* (n=110)

$y = 5.1392x – 7.2648$ $R^2 = 0.695$ $p < 0.0001$ (eq.10)

The true fresh biomass of individual preserved specimens taken in any year (i.e. in 2002 and 2004 as well as 2003) was then calculated using relationships between preserved weight and fresh weight (eq.'s 3-5 above), with the relationships for clupeids, *Schistomysis spiritus* and *Idotea* being applied to any fish, shrimp and all other invertebrates respectively, in the absence of sufficient samples of other species being available.

4.3.4 Statistical analysis

At Scroby, the relationship between fish density (pooled from the two tows) and depth and water clarity was explored using the Spearman rank correlation coefficient using all sites on all occasions (n=96) and just the four inner sites (n=32). The approach of mixing samples from different sampling occasions was justified on the grounds of the large variation in catch between sites and particularly occasion during the season.

Fish density and any variable(s) with which it was significantly correlated were then correlated with the number of Little terns recorded at a station (n=96).

4.4 Breeding colony studies

With the risk of disturbance to a Schedule 1 species during breeding colony studies MRP was in receipt of a Schedule 1 license (no. 20041121) issued by English Nature the responsible authority.

4.4.1 Colony development

Close liaison was maintained with RSPB staff, notably Mark Smart the Little tern Project Manager and the three full-time seasonal wardens – Kat Allen Navarro, Christina Turtle and Emma Clayton – as well as John White of EN, with specific responsibility for Winterton. RSPB staff and their volunteers monitored the North Denes colony closely, undertaking virtually daily counts of nests and monitoring the individual progress of individual nests and pairs (Allen Navarro *et al*. 2004). Following the formation of the ultimately larger colony at Winterton (see 5.1.1 & 5.1.2 below), the RSPB undertook some nest counts as well as normal wardening duties. Any information gathered was subsequently made available to this project.

Moreover, the initial development of any colonies in what has become known as the East Norfolk population, from its northernmost location at Eccles to Winterton, some 12.6 km to the south was largely undertaken by Skeate *et al*. (2004) in a project for Halcrow on behalf of the Environment Agency as part of the programme of monitoring to determine the impact of the offshore reefs between Eccles and Sea Palling. In this process, supplementary information was also gathered for the current project. Neil Bowman also passed on information in relation to the development of the colony at Eccles.

Observations of foraging birds and chicks at both North Denes and Winterton were generally undertaken without counting of nests this being routinely undertaken by the RSPB/EN. However, supplementary information on the development of the colony, particularly at North Denes, where the number of nests was small was gathered during these observation periods.

4.4.2 Foraging behaviour

At both North Denes and Winterton on each occasion, observations of foraging birds were made over all states of tide and at various times from 10.45 hrs until 18.00 hrs. Six visits were made to both North Denes and Winterton beginning in late May and extending into July (Table 4).

Table 4. Calendar of foraging observations.

Task	Site	Visit					
		1	2	3	4	5	6
Foraging observations	North Denes	25 May	01 Jun	16 Jun	25 Jun	12 Jul	26 Jul
	Winterton	23 May	06 Jun	22 Jun	14 Jul	17 Jul	26/27 Jul

The numbers of birds followed depended on the numbers foraging. In total, between 5-28 observations or foraging events were made at North Denes, excluding 26th July when no observations could be undertaken as no birds were present (see below). This includes repeat observations on the same individuals or members of a pair especially in early June when only a few pairs were present. Between 6-32 observations were made at Winterton on any one occasion. Total observation time on each visit varied from 37 to 121 minutes (mean [±1SE] = 71.6 ± 15.1 mins) at North Denes and 19 to 109 minutes (mean [±1SE] = 49.4 ± 13.2 mins) at Winterton. Lower foraging times were inevitably caused by the infrequent foraging of a small number of birds (Appendix IV).

Observations were initiated by scanning for foraging birds with binoculars and a telescope. If no birds were visible, patrols over a limited area of beach (c. 1km) were undertaken. This continued until birds were located. With few birds present at both sites some time often elapsed before observations could begin. At North Denes on 26th July no birds were located after several hours and no observations could be undertaken (see above).

Foraging Little terns were identified by their specific flight patterns and actions. In brief, foraging Little terns patrolled relatively low over the sea (c. 3-8m above the surface) typically adopting a head-down attitude (Plate 9). Upon locating prey, the bird hovered rapidly (Plate 10) for a few seconds before swooping to the surface or diving at high speed to immerse just below the surface. Hovering was generally conducted into the wind. Swooping to splash upon the surface occurred at a moderate (c. 45^o) angle and appeared to be particularly directed to invertebrates at the surface, but may also have been used to capture fish on the surface where the speed of a dive would take the bird past the prey. Sudden swooping without diving to pick prey off the surface (‘surface pick’) in the manner of marsh terns (*Chlidonias* spp.) was also noted (Plate 9).

Dive height and action varied with wind speed and conditions and perhaps with the type of prey and its distance below the surface, but was always undertaken more or less 90^o to the surface. Birds ‘sailed’ with wings held back in a strong wind and/or perhaps where prey was near the surface, but also plunge-dived at great speed with wings held in ‘dart’ style. The latter technique may have been used where prey was a rapidly swimming fish further below the surface. Upon emerging from the water after a dive the bird shook itself vigorously in flight as it dealt with any prey captured.

All observations of foraging birds were undertaken with a 30x magnification Kowa TSN telescope. Where a foraging bird or bird leaving the colony which was generally a precursor to foraging activity, had initially been detected by either eye or binoculars, this was first located within the telescope. The bird was then followed until it was lost from sight or had successfully captured prey and was returning to the beach to attend the nest or feed a partner or simply rest (loaf). With very few chicks hatched at Winterton and none hatched at North Denes, birds were generally feeding themselves during foraging bouts and not returning to shore to feed chicks. On occasion, particularly at North Denes in early June, a bird returning to the beach, perhaps feeding a partner visible to the observer, was kept in sight and observations could then continue with the same bird.

During the timed (secs) observation of a foraging bird, a number of data were recorded in a foraging sequence of search → locate prey → attack prey → handle prey. At any stage of the sequence after prey location the bird may continue, abort or fail. Abortion of a hover simply involved the bird discontinuing hovering and moving on, whereas an aborted dive involved the bird pulling out just prior to immersion. In both cases, birds typically resumed searching immediately.

Plate 9. Characteristic head-down attitude of foraging and hovering (inset) Little tern.

Plate 10. Little tern emerging from a lagoon with an invertebrate at North Denes.

The following data were thus recorded (see Appendix IV):

- Time (BST), state of tide and time from nearest low or high water (with tidal state as specified in 4.2.4 above);
- Wind direction and strength (Beaufort scale);
- Wave state (rank scale from 0-mirror to 5-whitecaps over 1m height);
- Number of aborted hovers and dives;
- Total number of foraging attempts;
- Number of completed dives, surface splashes and surface picks;
- Number of completed attempts that were successful, unsuccessful or unknown;
- Number of successful attempts with fish, invertebrate or unidentified prey;
- Details (type and size) of any prey captured;
- Approximate distance of foraging from shore;
- Outcome of observation i.e. bird lost from view or activity of bird following foraging.

From this, the number (and proportion) of successful dives relative to attempts begun or completed, relative to time (as a rate) could be determined.

At greater distance (>200m) and with small prey or when the bird was facing away from the observer, it became more difficult to determine whether prey had been successfully captured or not. A clue to successful prey capture was the tendency of successful birds to keep lower to the water whilst shaking and dealing with prey. Where there were no such clues, the event was classed as 'unknown'. Otherwise, prey was generally visible briefly in the bill before being swallowed or carried for display or presentation to a partner or chick. The prey was measured relative to bill length followed by its identification into basic categories of 'fish' or 'invertebrate'. With greater size and silver colouration it was relatively straightforward to determine when a fish was the prey. Where identity could not be confirmed, any prey was classified as 'unidentified'. In previous years, when the bird observed foraging was a parent, the capture of a fish also typically resulted in its transport to the shore and the waiting chick(s). This often afforded a further chance to confirm the identity and size of the prey. Generally, fish were readily separated in 'clupeid' or 'sand eel' from the very different length to width dimensions of these different taxa. In 2004, with little transport of prey back to the beach, identification relied on the briefest glimpse of prey captured at sea before it was swallowed.

Overall, it was considered likely that when fish were the prey a low proportion were missed. Indeed, when calculating the rate of dives resulting in the capture of fish per minute (dive $fish^{-1}$ min^{-1}) seen to be an important foraging parameter, it was assumed that if dives were known to be successful but the prey was unidentified this was something other than a fish. Thus, the dive $fish^{-1}$ min^{-1} rate may be conservative. Moreover, it is plausible that some attempts successfully resulting in the capture of small invertebrate prey were classed as unsuccessful. Whilst this may be of relevance to the dietary intake of adults, it was of little relevance to breeding productivity as invertebrates were rarely presented to chicks (ECON, 2003. 2004).

Statistical analysis was performed to examine seasonal patterns of various parameters of foraging within each colony and to compare differences between the colonies, based on five observation occasions at North Denes and six at Winterton. Variables tested included distance from shore (m), completed dives (actually all 'attacks') min^{-1} and dives producing $fish^{-1}$ min^{-1}. It was assumed that all birds observed were foraging (i.e. would take prey as it became available). For birds entirely in transit, the distance at which the bird was lost from view was still taken as a minimum estimate of foraging distance from shore as these birds were assumed to be travelling to foraging grounds.

As a result of some of the data failing the Kolmogorov-Smirnov test for normality even after log_{10} transformation, non-parametric Kruskal-Wallis tests were used to explore seasonal trends for 2004 within a colony. Any differences between the colonies in 2004 were explored with Mann-Whitney U-tests after all data for all occasions were pooled (irrespective of seasonal patterns) as a result of the relative paucity of data for some variables (particularly relating to the small number of birds at Yarmouth). Finally, inter-annual differences for any parameter within a colony were tested with Kruskal-Wallis tests after pooling all data within any given year.

4.4.3 Chick feeding behaviour

No chicks were observed at North Denes, with only four known to hatch at Winterton (Allen Navarro *et al*. 2004) (see 5.1.1 below**)**, with at least another suspected to have been hatched by the radio-tagged bird, female 9.4 (Table 3). Of the chicks observed by the RSPB, one pair of chicks were present on 22nd June during foraging observations and it is thought that a foraging bird returning to the beach presented to one of these chicks on one occasion (bird ref. 86 - Appendix IV). However, these chicks were not seen again and unlike other years, no routine observations of chick provisioning could be made.

5. RESULTS

5.1 Colony development

5.1.1 North Denes

Little terns are reported to have begun arriving in Norfolk from 22nd April (Allen Navarro *et al*. 2004). Numbers at North Denes fluctuated over the subsequent weeks, reaching a peak of 70 on 11th May. The fences around the north and south colonies along with the information cabin were erected on May 14th by a team of RSPB staff, volunteers and a team from E.ON Renewables. Whilst there seemed to relatively few birds on shore around the colony in this period, good numbers of birds were observed at sea from the first survey onwards, with 55 on 7th May, increasing to 164 by the 17th May (see 5.2.1 below). Despite the apparently relatively low number of birds the first nest was discovered on 25th May (Allen Navarro *et al*. 2004). At this stage, a good number of birds were present (counts of 60 and 102 were recorded on the beach during foraging observations), with 13 and 10 individual birds on the ground in the

North and South colonies respectively. Much courtship feeding of females on the beach and at sea was also observed.

This first nest was apparently deserted by the 28th May, with the single egg left in the nest. A further nest was discovered by 2nd June, whereafter nests were continually present until 18th July, although no more than five nests were active until 30th June, which signalled a rapid increase in nesting activity with 16 nests recorded on 1st July (Allen Navarro *et al*. 2004). This appears to be linked to the loss of nests at Winterton (see 5.1.2 below). In this period of activity, a large number of birds were occasionally observed on the beach during telemetry sessions, including around 250 at around 10.00am on the 6th July, although this had reduced to 130 just over an hour later.

Predation reduced the number of active nests to five between the 4-6th July, with 16-17 again present between 7th-10th July. By the 13th however, there were only two nests, reducing to one on the 17th July and then none by the 18th. A lot of birds were still present however, with 250 recorded on 14th July, with an equivalent number of birds at Winterton (see 5.1.2 below), perhaps representing a large proportion of the whole East Norfolk population. Birds appear to have abandoned North Denes as a whole soon after with just 3 birds seen in the survey at sea on 22nd July (see 5.2.1 below) and none present during attempted foraging observations on the 26th July (see 4.4.2 above).

There was thus a minimum of 40 nests within the colony over the season, with a strong preference for the south (31 nests -77.5%) compared to the north (9 nests - 22.5%) colonies. A few more nests were recorded outside the colony fence, which were lost to high tides on 8th and 9th July, virtually as soon as they were laid. Of the official 40 nests, only one (2.5%) is thought to have hatched, although no chicks (or evidence of chicks) were seen. Predation is thought to be the most important cause of clutch loss, with 22 (55%) of all nests thought to have been subject to predation. Of these, 18 (82%) losses were attributed to foxes *Vulpes vulpes*, with positive identification of tracks/remains in 32% (7) of cases. Fox predation generally occurred in a small number of 'events'. For example, overnight on 6-7th June, two of the three clutches present were taken, with the remaining nest predated the following night. A six-strand electric fence was erected in the south colony only where the losses had occurred on the 9th June, to protect further nests that had set up including during the day a few hours after the predation event. The next event was on 17th-18th June with two nests lost, followed by the loss of 10 nests over two nights between 3rd-5th July. With the lack of tracks as a result of rain it was not absolutely certain that a fox was the culprit, although as on 17th-18th June, part of the electric fence was broken/knocked over suggesting a similar large predator that had struggled to enter or more probably, leave. Other predators known to have occurred (either seen or tracks/sign found) in and around the colony, which may have caused some losses included Hedgehog *Erinaceus europaeus*, Brown rat *Rattus norvegicus*, Carrion crow *Corvus corone* and the ubiquitous large gulls.

Only one nest (2.5%) was officially recorded as 'washed out' on a high tide on 7th-8th July, although inundation was known to have caused the loss of a few nests outside the colony on 10th &11th July. It thus seems likely that at least some of the nests lost in the final two 'events' on 7-8th July and 9-11th July (five and eight nests respectively) could be attributed to high tides. However, at least one and two nests respectively were recorded as predated and so it is possible that predation also made an important contribution to the 'unknown' category. Overall, the fate of 30% of all nests (12) was ascribed to the latter. Three (7.5%) nests were deserted, with eggs (one in two cases and two in another) simply abandoned. The cause of desertion is not known although disturbance by either humans or predators is possible, with a lack of food (see 6.1.5 below) a further possibility. A tagged bird is thought to have been taken by a raptor and another tern was found crushed by a mammal (see 5.6.1 below) and it is possible that some nest losses were caused by the mortality of at least one of the adult birds. It is also possible that a number of the relatively large number of nests whose fate was 'unknown' were also deserted with the undefended eggs subsequently taken by avian predators (obvious tracks of mammals would have caused these nests to be described as predated by such).

5.1.2 Winterton

A larger early season count of birds was made at Winterton than at North Denes with 180 birds present on 6th May. Although there is a report of the first nest on 20th May (Allen Navarro *et al*. 2004), it is not clear by whom this was reported. However, this could relate to the abandoned nest containing one egg discovered by MRP/ERS during foraging observations on 23rd May. Only a small number of birds were present (maximum count of 13) although several pairs were either displaying or involved in courtship feeding. Good weather over the weekend with a large number of visitors to Winterton may have played a part in the abandonment of the nest and the relative lack of birds. A conversation with John White (EN) the following day led to the erection of protective fencing within a few days (i.e. later than the 20th May reported by Allen Navarro *et al*. (2004). It is also clear that the report from the latter of 30 or so nests present from the 24th May at Winterton is incorrect as no nests were recorded during the survey on 26th May by ECON as part of work in relation to the impact of the coastal defence works (Skeate *et al*. 2004). However, a number of nests, potentially as many as reported, were observed to be present on 6th June on the visit by MRP/ERS to conduct foraging observations (see 4.4.2 above).

It thus appears that nesting at Winterton was triggered by the presence of protective fencing and also perhaps by the loss of the initial nests at North Denes (28th May, 6-7th and 7-8th June). Whatever the case, the expansion of the colony was incredibly rapid and by the 14th June at least 150 nests were present with all but one of these within the protective fencing from groynes 59-65 (Table 5). On 22nd June, a pair of young chicks, which had to be from one of the earliest nests, was observed during foraging observations and by RSPB staff (Allen Navarro *et al*. 2004). Unfortunately, these were not seen again.

The count from the next survey on 24th June indicated that a disturbance event had displaced virtually all birds from the area of the colony between groynes 59-61, immediately to the north of the roped track that allows access to the beach through the colony. The site of 13 (from 45 individually monitored nests) inactive nests was re-found by Skeate *et al*. (2004). Of these, there was no visible sign of eggs in 10 (77%), although broken eggshell was found at one (8%) and single half-buried eggs were found at a further two (15%). This indicates that at least some birds abandoned their eggs and nests. The fact that this pattern was not repeated throughout the colony suggest a localised disturbance event had occurred, perhaps a human, dog or some other ground predator entered the area, possibly taking some eggs and causing other clutches to be abandoned. An increase in the number of nests to the south of groyne 64 and beyond the colony boundary indicated that a few of the pairs appeared to have re-nested in this area. The protective fenceline was subsequently extended to accommodate these. On 27th June, another pair of young chicks was seen by RSPB staff (Allen Navarro *et al*. 2004), but like the first pair were not seen again.

Table 5. Numbers and location of Little tern nests at the Winterton colony in detailed counts conducted by Skeate *et al*. (2004).

Location	Date		
	14th&15th June	24th&26th June	16th July
G57-58	0	0	0
G58-59	1	1	0
G59-60	14	0	0
G60-61	24	1	0
G61-62	31	0	0
G62-63	15	14	0
G63-64	20	7	0
G64-65	17	21	0
G65-fence	19	15	0
Fence –cafe	9	6	0
Total	**150**	**65**	**0**

Following the first disturbance event with some subsequent re-settlement, a precipitous decline in the number of active nests was then observed, with only around 40 nests present on the 29th June with just a handful by the 1st week of July (Allen Navarro *et al*. 2004). No nests were present at Winterton by 16th July (Table 5, Skeate *et al*. 2004). Some of the displaced birds appear to have settled at North Denes, as there was an increase in nesting activity here in early July (see 5.1.1 above). It is possible some birds also re-nested at Eccles although data from this site is more limited (see 5.1.3 below).

Despite the loss of nests the numbers of birds remained high until the middle of the month, with 87 on 1st July, 140 on 2nd, 187 on 8th July, 200 on 13th and 250 on 14th all recorded during telemetry sessions. Thereafter, numbers fluctuated both between and within the day with the use of alternative areas. For example, on 16th July, Skeate *et al*. (2004) only recorded three Little terns over the sea at Winterton, with a loafing flock of 200 birds just to the north between groynes 43-44. In contrast, the bird/prey survey conducted earlier in the day recorded 147 birds using the beach at Winterton (see 5.2.1 below). On the 19th July, the flock was divided with 176 on the beach at Winterton with 139 at the new site. By the end of the month, numbers had declined and there appeared to be influx of other birds from elsewhere with no birds at Winterton and two groups in the area to the north, with 79 (including 4 juveniles possibly from the North Norfolk colonies) between groynes 42-43 with a further 57 between groynes 38-39. All birds appear to have left the area completely by 11th August with no records of Little terns on the survey of Skeate *et al*. (2004) between Eccles and Winterton.

Finally, it is of note that this area, known as Bramble Hill, tends to support a few pairs of Little terns which are separate from any colony at Winterton itself. However, these tend to fail and 2004 was no exception when one pair laid two eggs, which subsequently disappeared (Skeate *et al*. 2004).

5.1.3 Eccles

Skeate *et al*. (2004) recorded Little terns at Eccles from 12th May onwards . On 26th May, several pairs of birds amongst the 34 recorded were involved in nest prospecting and scraping behaviour. Twenty-seven nests were present by 14th June. Numbers were reported to gradually increase, probably boosted by birds that had been displaced from Winterton, culminating in a record total for the site of 47 nests by early July and a peak count of 300 birds on 11th July (Neil Bowman *pers comm*.).

Two nests are thought to have been lost as a result of the incubating adult being taken by a Kestrel. Predation by the latter was then thought to be the main cause of death of the 1-2 chicks thought to have hatched from the remaining nests (Neil Bowman *pers comm*.). Ultimately, no chicks survived to fledge.

Three active nests containing eggs were still present on 16th July (Skeate *et al*. 2004) with around 100 birds still present in the area, although not associated directly with the colony. On 19th July, a count of 82 birds loafing on the beach was made during a search of the area for tagged birds. Remarkably, the same three nests were still active on 27th July, illustrating that these were most probably the product of re-nesting birds originally from either Winterton or perhaps more likely North Denes. By this date, chicks have normally fledged or even left the UK with their parents for the wintering grounds. Neither these nests nor any adult birds were present on 11th August (Skeate *et al*. 2004). Indeed, no Little terns at all were recorded between Eccles and Winterton (see 5.1.2 above), suggesting southward migration from the area had occurred.

5.2 Distribution and abundance of Little terns

5.2.1 North Denes and Scroby

In 2002 and 2003 Little terns were only recorded at only 6 (50%) and 5 (42%) respectively of the 12 sampling stations (42%) covering Scroby over the study period (2003 is displayed in Fig. 3). The peak count of birds combined on one date at all stations was relatively low in both years, being 54 in 2002 and just 23 in 2003. Both statistics contrast with the situation in 2004 when Little terns were recorded at every sampling station and the maximum number of Little terns encountered was 164 in mid-May, with 157 (96%) of these at Site 1 in the southern part of Scroby (Fig. 4) associated with a large number of other species, especially Common terns and assorted gull species all foraging together (Plate 11) on what appeared to be a spawning aggregation of *Schistomysis spriritus* (see 5.5.1 below).

The next highest total was 55 birds on the first sampling occasion in early May, with these mostly divided between the northerly outer sites at Site 5 and Site 4. It is of note that birds had not been recorded at either of these sites before, during surveys in 2002 and 2003 (Fig. 3). The use of these sites in early season may be linked to the expansion of the sand bank through the wind farm site (Plate 12).

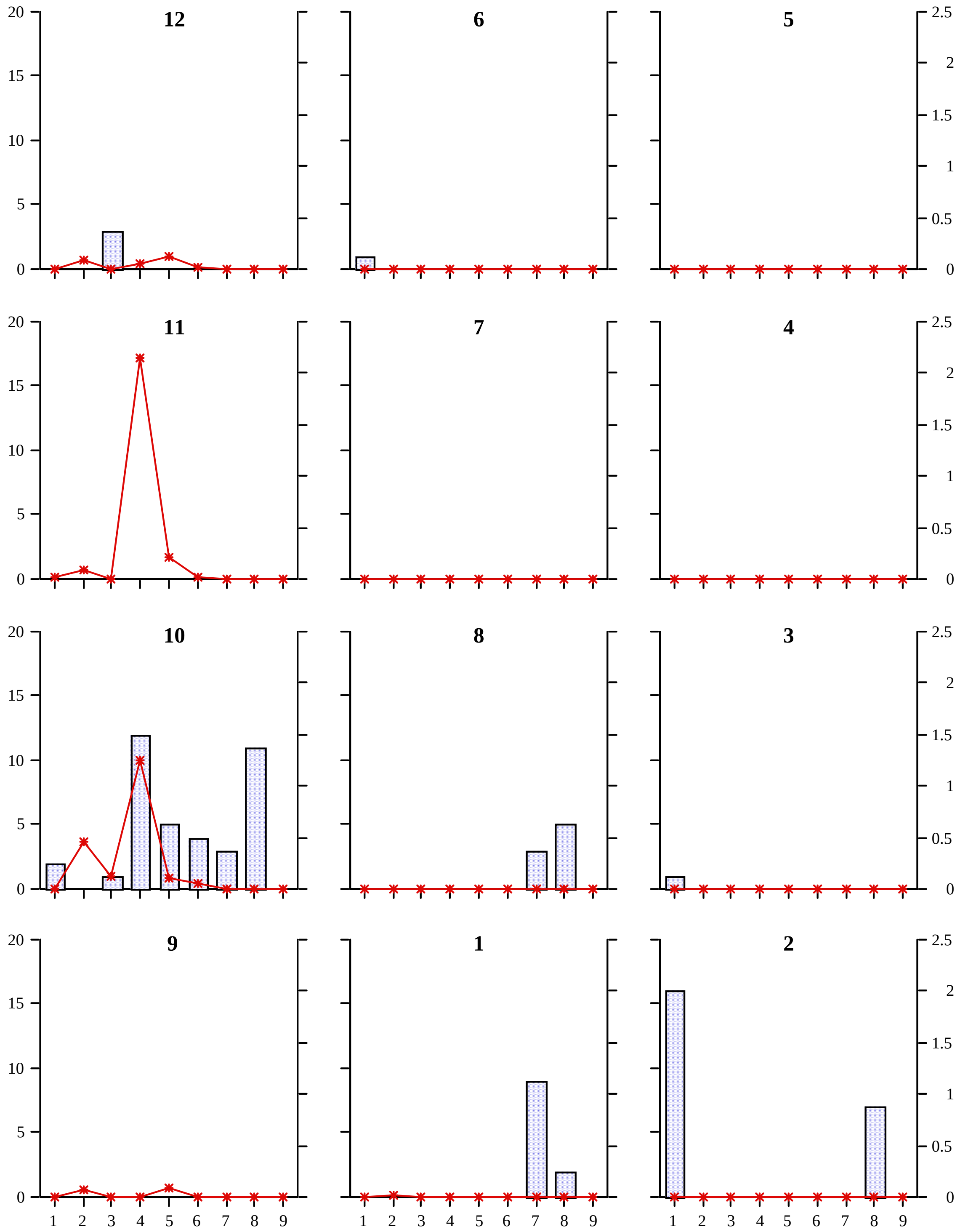

Figure 2. Seasonal variation in the numbers of individual Little terns (bars) recorded and the density (ind. m^{-2}) of fish (red line) at each sampling point at Scroby in 2003.

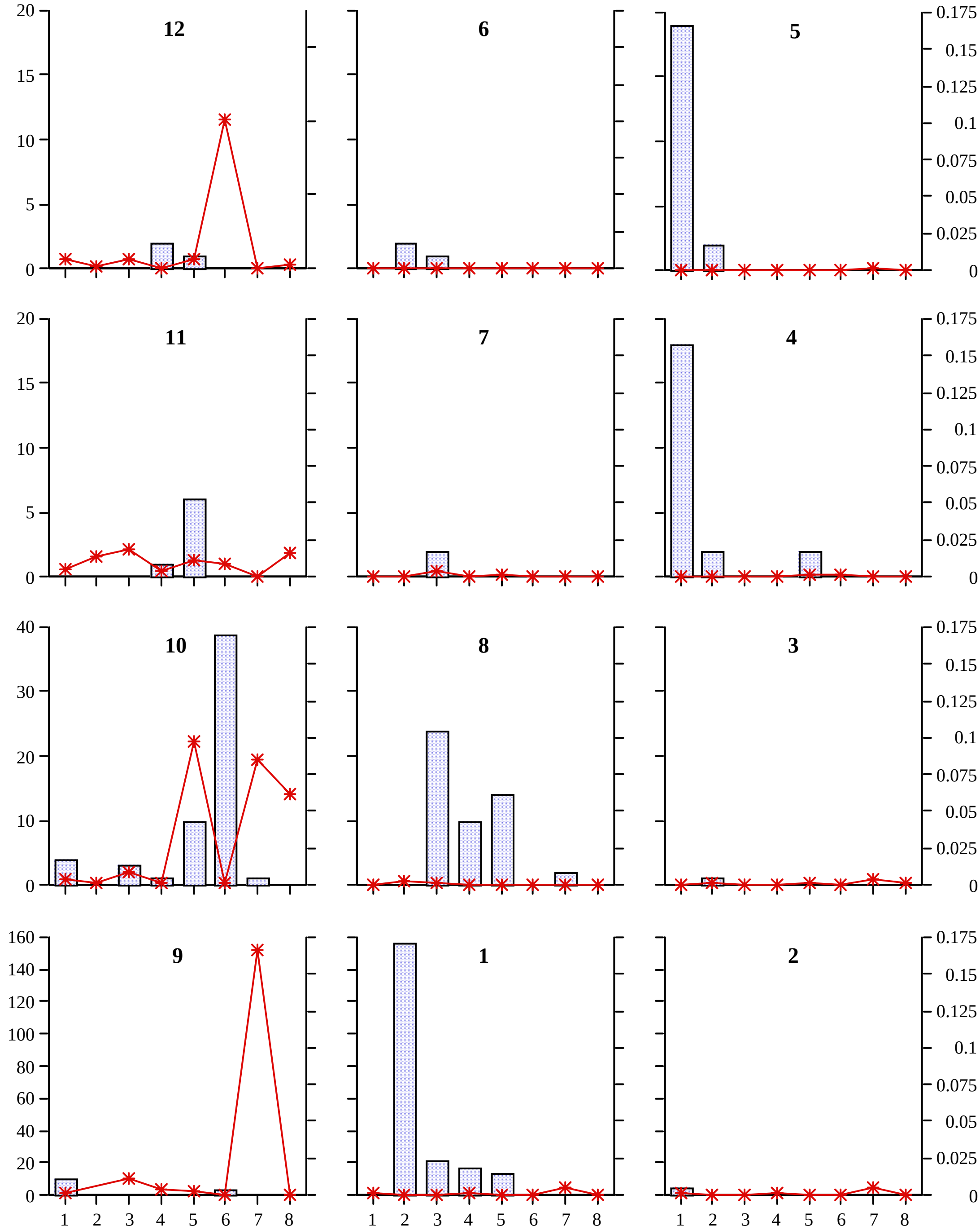

Figure 3. Seasonal variation in the numbers of individual Little terns (bars) recorded and the density (ind. m^{-2}) of fish (red line) at each sampling point at Scroby in 2004.

Plate 11. Feeding aggregation of gulls and terns at Site 1 in the south of Scroby on 17th May 2004.

Plate 12. Overview of Scroby Sands and the wind farm (top – taken 6th October 2004) with detail of the subsidiary sand bar forming through the wind farm (bottom – taken 6th July 2004). From aerial photographs taken by Air Images Ltd. during seal surveys.

The maximum total recorded immediately offshore of the colony at North Denes (Site 10) was of similar magnitude to 2002 (39 compared to 47) with a peak at similar time late in the season (mid to late July), contrasting with the situation in 2003 when only a small number of birds (<12) were present from mid-June onwards. In 2004, the peak coincided with the increase in the number of breeding pairs (see 5.1.1 above). Unlike 2003, the number of Little terns recorded at a site was not correlated with fish density by pooling all sites on all occasions ($r_s = -0.03$, n=96, p=ns) or just including inner (9-12) sites ($r_s = -0.08$, n=32, p=ns). However, like 2003, Little tern numbers were significantly negatively correlated with water clarity, when all sites were included ($r_s = -0.36$, n=95, $p<0.001$), but not when just using inner sites ($r_s = -0.28$, n=32, p=ns). This pattern indicates the relationship is influenced by the tendency of the waters in the middle and outer sites to be rather clear (Appendix III).

Outside of surveys, large numbers of birds were recorded at North Denes, loafing on the beach. This included 250 on the 6th July and a similar number on 14th July. The bulk of these were likely to be failed breeders from the attempt at Winterton (see 5.1.2 above). A similar but lower-key scenario was observed in 2002, when up to 74 adults were seen on the beach on 16th July, when just c. 4 nests were present (ECON 2003). In 2003, large numbers of adults and juveniles from the successful colony at Winterton were present on the beach on July 28th (c. 175 at roost) and 1st August (minimum of 232) (ECON 2004).

5.2.2 Winterton and the Would

Few bird and prey surveys could be undertaken in the Would in 2004. Both in mid May and early June when surveys were conducted all along the coast from Yarmouth to Eccles, were very few Little terns (<7) recorded at sea at any of the five (Hemsby, Winterton, Horsey, Sea Palling and Eccles) sites in the Would. Such low numbers contrast with those recorded subsequently at both colonies at Eccles from mid May onwards (up to 100 birds -see 5.1.3 above) and Winterton in early May and then again in mid June (up to 150 nests i.e. 300 birds – see 5.1.2 above). It is perhaps revealing that even when the colony was at its peak at Winterton in mid June, only 22 birds were recorded using the beach from the vessel at sea. The peak count of birds was 147 on the beach in mid July, after the colony had failed. The pattern of use contrasts with 2003 when the number of birds recorded in surveys at sea rose steadily from June (54) to early July (125) as the colony developed. The peak count of 148 on 28th July coincided with juveniles foraging for themselves.

In 2004, it appears that birds from both Winterton and Eccles were not consistently foraging in the inshore waters around the colonies (see 5.1.2 & 5.1.3 above).

5.3 Distribution and abundance of other birds

A total of 34 other [than Little tern] species (compared to 27 in 2003) were recorded in counts during the study period (Tables 6 & 7, Appendix V). These included three species of tern as well as Little tern, seven species of gull and ten species of waders amongst a mixture of true seabirds, migrating shorebirds and other species more typically associated with terrestrial habitats. A number of more unlikely species were also recorded at sea including Kestrel, Carrion crow, Woodpigeon, Swift, Swallow and Sand martin. As in 2003, there was a paucity of the latter around the breeding colony at California, although as birds were present until 30th June at least some may have bred. Fulmars also breed in the soft cliffs of this area and small numbers of these birds (<5 individuals) were frequently encountered in inshore waters adjacent to the colony, although odd individuals were recorded at a high proportion (>70%) of the other sites (Plate 13).

Table 6. Maximum number and corresponding density (individuals [ind.] km^{-2}) of all bird taxa recorded during counts at Scroby and the Would in 2004.

Bird species	Scientific name	Scroby		Would	
		Maximum number	Density (ind. km^{-2})	Maximum number	Density (ind. km^{-2})
Fulmar	*Fulmarus glacialis*	5	3		
Gannet	*Morus bassanus*	26	15.6		
Cormorant	*Phalacrocorax carbo*	6	3.6	1	0.6
Common Scoter	*Melanitta nigra*	3	1.8		
Kestrel	*Falco tinnunculus*	1	0.6		
Oystercatcher	*Haematopus ostralegus*	6	3.6	2	1.2
Ringed Plover	*Charadrius hiaticula*			2	1.2
Sanderling	*Calidris alba*			6	3.6
Dunlin	*C. alpina*	6	3.6	8	4.8
Bar-tailed Godwit	*Limosa lapponica*			1	0.6
Whimbrel	*Numenius phaeopus*				
Curlew	*N. arquata*	2	1.2		
Redshank	*Tringa totanus*	1	0.6		
Turnstone	*Arenaria interpres*	1	0.6	2	1.2
Common Sandpiper	*Actitis hypoleucos*	2	1.2		
Arctic Skua	*Stercorarius parasiticus*	1	0.6	1	0.6
Mediterranean Gull	*Larus melanocephalus*	1	0.6		
Black-headed Gull	*L. ridibundus*	12	7.2	13	7.8
Common Gull	*L. canus*	2	1.2	2	1.2
Lesser Black-backed Gull	*L. fuscus*	42	25.2	1	0.6
Herring Gull	*L. argentatus*	48	28.8	17	10.2
Great Black-backed Gull	*L. marinus*	6	3.6	1	0.6
Kittiwake	*Rissa tridactyla*	12	7.2		
Sandwich Tern	*Sterna sandvicensis*	26	15.6	53	31.8
Common Tern	*S. hirundo*	50	30	6	3.6
Arctic Tern	*S. paradisaea*			1	0.6
Little Tern	*S. albifrons*	157	94.2	147	88.2
Guillemot	*Uria aalge*	4	2.4	1	0.6
Feral/racing Pigeon	*Columba livia*	15	9	2	1.2
Woodpigeon	*C. palumbus*	1	0.6		
Swift	*Apus apus*	25	15	1	0.6
Sand Martin	*Riparia riparia*	4	2.4		
Swallow	*Hirundo rustica*	2	1.2		
Carrion Crow	*Corvus corone*			1	0.6

Table 7. Maximum number and corresponding density (individuals [ind.] km^{-2}) of all bird taxa recorded during counts at Scroby and the Would in 2003.

Bird species	Scientific name	Scroby		Would	
		Maximum number	Density (ind. km^{-2})	Maximum number	Density (ind. km^{-2})
Fulmar	*Fulmarus glacialis*	8	4.8		
Gannet	*Morus bassanus*	4	2.4	10	6.0
Cormorant	*Phalacrocorax carbo*	4	2.4	1	0.6
Eider	*Somateria mollissima*			4	2.4
Common Scoter	*Melanitta nigra*	70	42.0	2	1.2
Oystercatcher	*Haematopus ostralegus*	4	2.4	3	1.8
Ringed Plover	*Charadrius hiaticula*	1	0.6		
Grey Plover	*Pluvialis squatarola*	1	0.6		
Large sandpiper spp.	*Calidrid* spp.	5	3.0		
Dunlin	*Calidris alpina*	1	0.6		
Bar-tailed Godwit	*Limosa lapponica*			1	0.6
Common Sandpiper	*Actitis hypoleucos*			1	0.6
Arctic Skua	*Stercorarius parasiticus*	1	0.6		
Mediterranean Gull	*Larus melanocephalus*	3	1.8		
Little Gull	*L. minutus*			1	0.6
Black-headed Gull	*L. ridibundus*	20	12.0	21	12.6
Common Gull	*L. canus*	3	1.8	1	0.6
Lesser Black-backed Gull	*L. fuscus*	50	30.0	6	3.6
Herring Gull	*L. argentatus*	55	33.0	15	9.0
Great Black-backed Gull	*L. marinus*	3	1.8		
Kittiwake	*Rissa tridactyla*	2	1.2	1	0.6
Sandwich Tern	*Sterna sandvicensis*	73	43.8	5	3.0
Common Tern	*S. hirundo*	16	9.6	4	2.4
Little Tern	*S. albifrons*	12	7.2	148	88.8
Guillemot	*Uria aalge*	3	1.8		
Swift	*Apus apus*	2	1.2		
Sand Martin	*Riparia riparia*	5	3.0	2	1.2
Swallow	*Hirundo rustica*	1	0.6		
Chiffchaff	*Phylloscopus collybita*	1	0.6		

Plate 13. Fulmars are frequently encountered at California where a small number breed in the soft cliffs.

Plate 14. Herring (above) and Lesser Black-backed gulls are ubiquitous in their distribution at Scroby Sands.

Plate 15. Numbers of Sandwich terns increase towards the end of the season when birds leave the North Norfolk breeding colonies.

Plate 16. Common scoters occur sporadically in small to medium flocks passing through Scroby and the Would during summer surveys.

As in 2003, Little terns achieved the highest density figure of any species at both North Denes and Winterton, with only Lesser Black-backed and Herring gulls and Common terns (Sandwich terns in 2003) exceeding counts of >20 ind. km^{-2}, much the same as in 2003. Maximum numbers of birds were broadly in line with those in 2003 and thus the large numbers of Lesser Black-backed and Herring gulls seen on some surveys in 2002 (counts >100 birds) may be seen as exceptional rather than typical.

The more abundant species including Herring (Plate 14) and Lesser Black-backed gulls and Common and Sandwich terns were ubiquitous in their distribution (100% of sites) and although they could be encountered anywhere at any time, the terns especially varied considerably in numbers between sites and between occasions. Common terns were most common in the south of Scroby (mean of 17 ind. per occasion at Site 1 with a maximum of 50 birds, compared to mean values of <1-5 at all other sites). This is in keeping with the greater proximity of this site to their breeding colony at Breydon Water. The peak count (26 ind.) of Sandwich terns was also at Site 1. This maximum count in 2004 was very close to the maximum of 17 ind. in 2002, contrasting with 2003 when a much larger peak count of 73 ind. was of birds loafing on the exposed bank at Site 8 on 31st July (Plate 15). The 2003 figure appears to be linked to the chance encounter with birds on southward passage from the main colonies at Blakeney Point and Scolt Head in North Norfolk.

Seaduck were only represented by Eider and Common scoter (Plate 16). The former were encountered singly or small groups with the latter in small to medium-sized flocks (up to 70 in 2003) on occasion. The timing of occurrence suggested most of the birds encountered were non-breeding and/or early-dispersing failed breeders. The majority of seaduck using the area would be expected to occur in the autumn and winter outside the survey period.

A number of species showed also seasonal trends in keeping with migration movements. A number of waders were encountered on late northerly passage in early May (e.g. Whimbrel, Dunlin and Sanderling) with returning birds (e.g. Curlew and Common Sandpiper) from late June through to August. Guillemots were first recorded on 30th June, with small numbers of skuas from 22nd July.

Notable species recorded at sea but not at sampling stations were an adult Yellow-legged gull (*Larus michahellis*) between Sites 5 and 6 on 4th June, following the 2003 record on the river, and an adult Ring-billed gull (*Larus delawarensis*) near Site 2 in a large flock of other large gulls on 10th June. A pair of Shelduck (*Tadorna tadorna*), a species not recorded before, was noted between Site 9 and port on 7th May.

5.4 Distribution and abundance of seals and cetaceans

Small numbers of both Grey and Common seals (with a few number unidentified) were recorded at sea at 50% of sites (cf. 42% in 2003) at Scroby (Appendix VI). Far larger numbers (up to 70) of seals were recorded hauled onto the exposed sands from Sites 1, 8 & 9 during the season (Appendix VI). Seals were thus more widely distributed in 2004 compared to 2003 when the observations of haul out were limited to Site 8, whereas in 2002, these were limited to Sites 1 and 2. However, there is no real evidence that this shows a change in preference in haul out area between years, but appears to be more the result of the timing of the surveys and the route taken between survey points in relation to the state of the tide. However, there is evidence of an increasing amount of sandbank exposed (Plate 11**)**, with perhaps more choice for haul-out seals.

As in 2003, just a single Porpoise was recorded at a sampling station, this time at Site 10 (Site 5 in 2003) on 16th July. The only other records were two together between Sites 4 and 5 on 13th August with another on the same date between Sites 9 and 10. Thus, porpoises were recorded on 25% of surveys in 2004 compared to 22% in 2003 and in direct contrast with 2002 when they were seen on 67% of trips. Porpoises were not seen in the Would in 2003 or 2004 although the number of surveys was low. Still, porpoises had been seen on 40% of occasions in 2002, when a greater area including the offshore zone was covered.

5.5 Distribution and abundance of potential Little tern prey

5.5.1 Number and type of taxa

A total of 35 faunal taxa (cf. to 27 in 2003 and 24 in 2002) were captured during tows at Scroby. Of these, 29 (22 in 2003 and 20 in 2002) were considered to be potential prey of Little terns (Table 8). Those thought to be inedible included the Ctenophora (cone jellies and jellyfish) – Sea gooseberries *Pleurobranchia pileus* (Plate 17) Lion's mane jellyfish *Chrysaora hysoscella*, Moon jellyfish *Aurelia aurita* and *Rhizostoma octopus* – larger specimens of Shore crab *Carcinus maenas*, larval crabs (<1mm in length); and Razorshell *Ensis* sp.

A number of invertebrate and fish species had not been recorded previously (cf. Table 8 with 9). The invertebrates included *Callinera buergeri, Nebalia bipes, Lyianassa ceratina, Iphimedia minuta, Athanas nitescens, Dichelopandalus bonnieri* and *Liocarcinus pusillus.* Amongst the fish, only Sand smelt *Atherina presbyter* and Scaldfish *Arnoglossus laterna* had not been recorded before. As most of these species were only identified from a single or very few specimens and are therefore at low density, it appears that the recording of new species does not reflect gross changes in the prey base of Little terns. As species have been exclusively recorded in any year of the study thus far [2] there is also no evidence of any change in conditions at sea.

With far fewer sites and tows in the Would, only 14 potential prey species of 17 faunal taxa (inedible species were Sea gooseberry, Lion's mane jellyfish and Razorshell) were recorded (Table 10). This is a similar to the number recorded at Winterton alone in 2003 (12 species), when sampling was conducted throughout the season (Table 11). Although possibly a simple function of reduced sampling effort there is a notable absence of crabs, possibly reflecting differences in sea-bed conditions in the Would. The relative absence of drifting seaweeds, which may be especially abundant at Sites 11 and 12 at Scroby accounts for the relative lack of amphipods (although *Chaetogammarus marinus* was present at Winterton in 2003)

[2] Species exclusively recorded in 2002 included Whiting *Merlangius merlangus*; the isopod crustacea *Hyperia galba***,** the amphipod crustacean *Amphitoe gammeroides*; the decapod crustaceans Green Shore crab *Carcinus mamas* and Spider crab *Macropodia rostrata***;** the shrimp *Schistomysis maximus* and Green paddleworm *Eulalia bilineata* The shrimp *Acanthomysis longicornis*, the crab *Corystes cassivelaunus* and the fish Lumpsucker *Cyclopterus lumpus* were only recorded in 2003.

and the generally low density of *Idotea*, which are often associated with such material. This is turn, may indicate differences in the nature of the tidal currents in the Would. The presence of species not recorded at Scroby including the decapod shrimp *Processa canaliculata* and the fish Dab *Limanda limanda*, in 2004, despite the reduced sampling effort also points to real ecological differences between Scroby and the Would.

Table 8. Potential prey species captured, their pattern of occurrence (presence indicated by λ), and maximum density (both individuals [ind.] m^{-2} and biomass [g m^{-2}]) recorded in tows at Scroby during 2004..

Group/ Common name	Species	Maximum density		Sampling occasion							
		ind. m^{-2}	g m^{-2}	1	2	3	4	5	6	7	8
Flatworms	Tubulanidae *spp.*[*]	0.0022	0.0001		λ			λ			
Crustaceans											
a Leptostracan shrimp	*Nebalia bipes*	0.0022	0.0001					λ			
Ghost shrimp	*Schistomysis spiritus*	7.7089	0.2770	λ	λ	λ	λ	λ	λ	λ	λ
a mysid shrimp	*Siriella armata*	0.0067	0.0003					λ		λ	
a mysid shrimp	*Acanthomysis longicornis*	0.0056	0.0003								λ
a sea slater	*Idotea linearis*	0.0422	0.0014	λ	λ	λ	λ		λ	λ	λ
an amphipod	*Lyianassa ceratina*	0.0722	0.0045	λ	λ	λ					
an amphipod	*Iphimedia minuta*	0.0011	0.0001	λ							
an amphipod	*Chaetogammarus marinus*	0.0822	0.0021				λ	λ	λ	λ	λ
a shrimp	*Athanas nitescens*	0.0011	0.0001							λ	
a shrimp	*Dichelopandalus bonnieri*	0.0011	0.0001							λ	
Brown shrimp	*Crangon crangon*	0.0178	0.0183	λ		λ			λ		λ
Norway lobster	*Nephrops norvegicus*	0.0033	0.0003					λ	λ	λ	
a swimming crab	*Liocarcinus arcuatus*	0.0011	0.0001					λ		λ	
a swimming crab	*L. pusillus*	0.0011	0.0001					λ			
a swimming crab	*L. holstatus*	0.0011	0.0010			λ					λ
Molluscs											
a squid	*Allotheuthis subulata*	0.0011	0.0065	λ						λ	
Fish											
Herring family	Clupeid spp.	0.0889	0.0094	λ	λ	λ	λ	λ	λ	λ	λ
Herring	*Clupea harengus*	0.0433	0.0154	λ	λ			λ		λ	λ
Sprat	*Sprattus sprattus*	0.0467	0.0156	λ	λ	λ		λ	λ	λ	λ
Three-spined stickleback	*Gasterosteus aculeatus*	0.0022	0.0011					λ	λ	λ	
Sand smelt	*Atherina presbyter*	0.0011	0.0001								λ
Lesser pipefish	*Sygnathus rostellatus*	0.0022	0.0011	λ	λ					λ	λ
Shanny	*Lipophrys pholis*	0.0011	0.0001							λ	
Greater sand eel	*Hyperoplus lanceolatus*	0.0244	0.0114	λ	λ				λ	λ	λ
Transparent goby	*Aphia minuta*	0.0044	0.0005					λ			λ
Garfish	*Belone belone*	0.0011	0.0002							λ	
Turbot	*Scophthalmus maximus*	0.0011	0.0005							λ	
Scaldfish	*Arnoglossus laterna*	0.0011	0.0001				λ				
Sole	*Solea solea*	0.0011	0.0001			λ					
	Larval flatfish	0.0011	0.0001		λ						

[*]Some identified as *Callinera buergeri* on one occasion

Table 9. Potential prey species captured, their pattern of occurrence (presence indicated by λ), and maximum density (both individuals [ind.] m^{-2} and biomass [g m^{-2}]) recorded in tows at Scroby in 2003.

Group/ Common name	Species	Maximum density		Sampling occasion								
		ind. m^{-2}	g m^{-2}	1	2	3	4	5	6	7	8	9
Crustaceans												
Ghost shrimp	*Schistomysis spiritus*	0.91	0.01	λ				λ		λ		
a mysid shrimp	*Siriella armata*	0.008	0.001	λ		λ	λ	λ			λ	λ
a mysid shrimp	*Acanthomysis longicornis*	0.02	0.0008	λ	λ	λ						
a sea slater	*Idotea linearis*	0.01	0.0004	λ	λ	λ	λ			λ	λ	λ
an amphipod	*Chaetogammarus marinus*	0.04	0.002	λ	λ	λ			λ		λ	
Norway lobster	*Nephrops norvegicus*	0.001	0.0001					λ	λ			λ
a shrimp family	Crangonidae spp.	0.006	0.003	λ				λ			λ	λ
Masked crab	*Corystes cassivelaunus*	0.001	0.0001				λ					
a swimming crab	*Liocarcinus arcuatus*	0.001	0.0001								λ	
a swimming crab	*L. holstatus*	0.001	0.0001		λ							
Molluscs												
a squid	*Alloteuthis subulata*	0.001	0.002					λ				
Fish												
Herring family	Clupeid spp.	2.15*	0.18*	λ	λ	λ	λ	λ	λ	λ		
Herring	*Clupea harengus*	0.14	0.09					λ	λ	λ		
Sprat	*Sprattus sprattus*	0.001	0.001							λ	λ	
Shore rockling	*Gaidropsarus mediterraneus*	0.001	0.0004				λ		λ			
Three-spined stickleback	*Gasterosteus aculeatus*	0.001	0.0001				λ		λ			
Lesser pipefish	*Sygnathus rostellatus*	0.001	0.0003	λ								
Shanny	*Lipophrys pholis*	0.001	0.0002					λ				
Greater sand eel	*Hyperoplus lanceolatus*	0.002	0.001	λ	λ	λ	λ	λ				
Garfish	*Belone belone*	0.007	0.0005				λ	λ	λ			
Lumpsucker	*Cyclopterus lumpus*	0.001	0.0003							λ		
	Larval fish	0.001	0.0003		λ	λ		λ		λ		
	Larval flatfish**	0.003	0.0001	λ								

*includes both *C. harengus* and *S. sprattus*
** probably including Sole *Solea solea*

Table 10. Potential prey species captured, their pattern of occurrence (presence indicated by λ), and maximum density (both individuals [ind.] m^{-2} and biomass [g m^{-2}]) recorded in tows at all sites in the Would in 2004.

Group/ Common name	Species	Maximum density		Sampling occasion		
		ind. m^{-2}	g m^{-2}	1	2	3
Crustaceans						
Ghost shrimp	*Schistomysis spiritus*	0.0144	0.0004	λ	λ	λ
a mysid shrimp	*Siriella armata*	0.0011	0.0001			λ
a sea slater	*Idotea linearis*	0.0078	0.0012	λ	λ	λ
an amphipod	*Iphimedia minuta*	0.0011	0.0001	λ		
a shrimp	*Processa canaliculata*	0.0022	0.0067	λ		
Brown shrimp	*Crangon crangon*	0.0678	0.3517		λ	λ
Molluscs						
a squid	*Allotheuthis subulata*	0.0011	0.0031	λ		
Fish						
Herring family	Clupeid spp.	0.0089	0.0012		λ	λ
Herring	*Clupea harengus*	0.0089	0.0027	λ		λ
Sprat	*Sprattus sprattus*	0.0033	0.0013	λ		λ
Shore rockling	*Gaidropsarus mediterraneus*	0.0011	0.0006			λ
Lesser pipefish	*Sygnathus rostellatus*	0.0011	0.0001			λ
Greater sand eel	*Hyperoplus lanceolatus*	0.0022	0.0006		λ	λ
Dab	*Limanda limanda*	0.0011	0.0010			λ

Table 11. Potential prey species captured, their pattern of occurrence (presence indicated by λ), and maximum density (both individuals [ind.] m^{-2} and biomass [g m^{-2}]) recorded in tows at Winterton in 2003.

Group/ Common name	Species	Maximum density		Sampling occasion								
		ind. m^{-2}	g m^{-2}	1	2	3	4	5	6	7	8	9
Crustaceans												
Ghost shrimp	*Schistomysis spiritus*	0.006	0.0004		λ	λ		λ				
a mysid shrimp	*Siriella armata*	0.001	0.00001		λ							
a sea slater	*Idotea linearis*	0.008	0.0004		λ	λ	λ		λ	λ	λ	λ
an amphipod	*Chaetogammarus marinus*	0.22	0.0002								λ	λ
a sea spider	*Endeis spinosa*	0.001	0.000001									λ
Molluscs												
a squid	*Allotheuthis subulata*	0.001	0.005		λ							
Fish												
Herring family	Clupeid spp.	1.13	0.14	λ	λ	λ	λ	λ	λ			
Herring	*Clupea harengus*	0.004	0.002				λ		λ			
Lesser pipefish	*Sygnathus rostellatus*	0.002	0.0001									λ
Greater sand eel	*Hyperoplus lanceolatus*	0.02	0.004	λ	λ	λ	λ	λ	λ			
Transparent goby	*Aphia minuta*	0.001	0.0008						λ			
Garfish	*Belone belone*	0.001	0.0004			λ			λ			

5.5.2 Seasonal and temporal patterns of distribution and abundance

Scroby

Sea gooseberries were abundant in 2002, frequently occurring in 100's and sometimes 1000's in tows at a site. This contrasted with the situation in 2003, when potential prey for Little terns formed much the largest component of the catch. In 2004, the situation was somewhat intermediate with a relatively low number of jellyfish and apart from some notable peaks in abundance, potential prey was at relatively low density (Table 8, Appendix VII).

Consequently, there were a number of differences in the patterns of temporal distribution and abundance of the probable principal prey species in 2004 compared to 2003. In 2004, Ghost shrimp were recorded at the huge density of nearly 8 ind. m^{-2} at one site (Site 1) on one occasion (17^{th} May- Appendix VII, Table 8, Plate 18**)**, approaching 3 orders of magnitude the highest value recorded in 2003. The fact that the shrimps captured were all bright pink and a large proportion (88% from 100 specimens checked compared to 63% on the survey a week earlier) of the individuals were carrying eggs suggests a spawning aggregation, which was being exploited by a range of birds including Little tern (see 5.2.1 above). This changed the typical pattern of the concentration of all prey in the sites close to the shore (inner sites) compared to the landward (middle sites) and seaward (outer sites) edges of Scroby sands themselves, albeit based on one sampling occasion (Fig. 5 cf. Fig. 6). Thereafter, although Ghost shrimps were captured on all subsequent sampling occasions, the density declined to 'typical' values of <0.01 ind. m^{-2} (Fig. 5, Appendix VII). As well as the early season peak in abundance of potential invertebrate prey there was some evidence of a late season peak too, although this was much smaller and was chiefly comprised of *Idotea* (Plate 17) and *Chaetogammarus marinus* – Table 8, Fig. 5). Thus, 2004 was characterised by both the early season peak in *Schistomysis* also seen in 2003[3] and the late season peak in sea slaters and amphipod crustaceans seen in 2002.

In contrast to Ghost shrimps, the combined maximum density of the principal fish species Herring and Sprat (i.e. Clupeid spp.) was a fraction (less than an order of magnitude at 0.09 ind. m^{-2} – Table 8, Fig. 5, Plate 18) of that recorded in 2003 (>2 ind. m^{-2} – Table 9, Fig. 6) when they were by far the most abundant item in terms of number and also biomass (maximum of 0.18 g m^{-2}). Moreover, there was some difference in spatial distribution, with slightly more, although still very few, fish recorded at the middle sites in 2004 (Fig. 5 cf Fig. 6). Even in the preferred inner sites there was considerable inter-site variation (Fig. 4). However, unlike previous years when there was a bias to Sites 10 and 11, in 2004, Site 11 was generally poor and fish were also patchily recorded at equivalent density in Sites 9 and 12 as well as Site 10. There was also some evidence of interchange, with low values in Site 10 in mid July corresponding to a peak in density at Site 12. The difference between sites and occasions was not readily explained by water clarity, or rather lack of it, as in previous years, as there was no relationship between fish density and water clarity for the inner sites alone (r_s = -0.15, n=32, p=ns), although this was significant when all sites were included (r_s = -0.37, n=95, $p<0.001$).

[3] This may also have occurred in 2002 but sampling did not start until later

Plate 17. A catch of Clupeid fish, *Idotea* and Sea gooseberries.

Plate 18. Exceptional numbers of Ghost shrimps were captured at Site 1 in mid-May 2004.

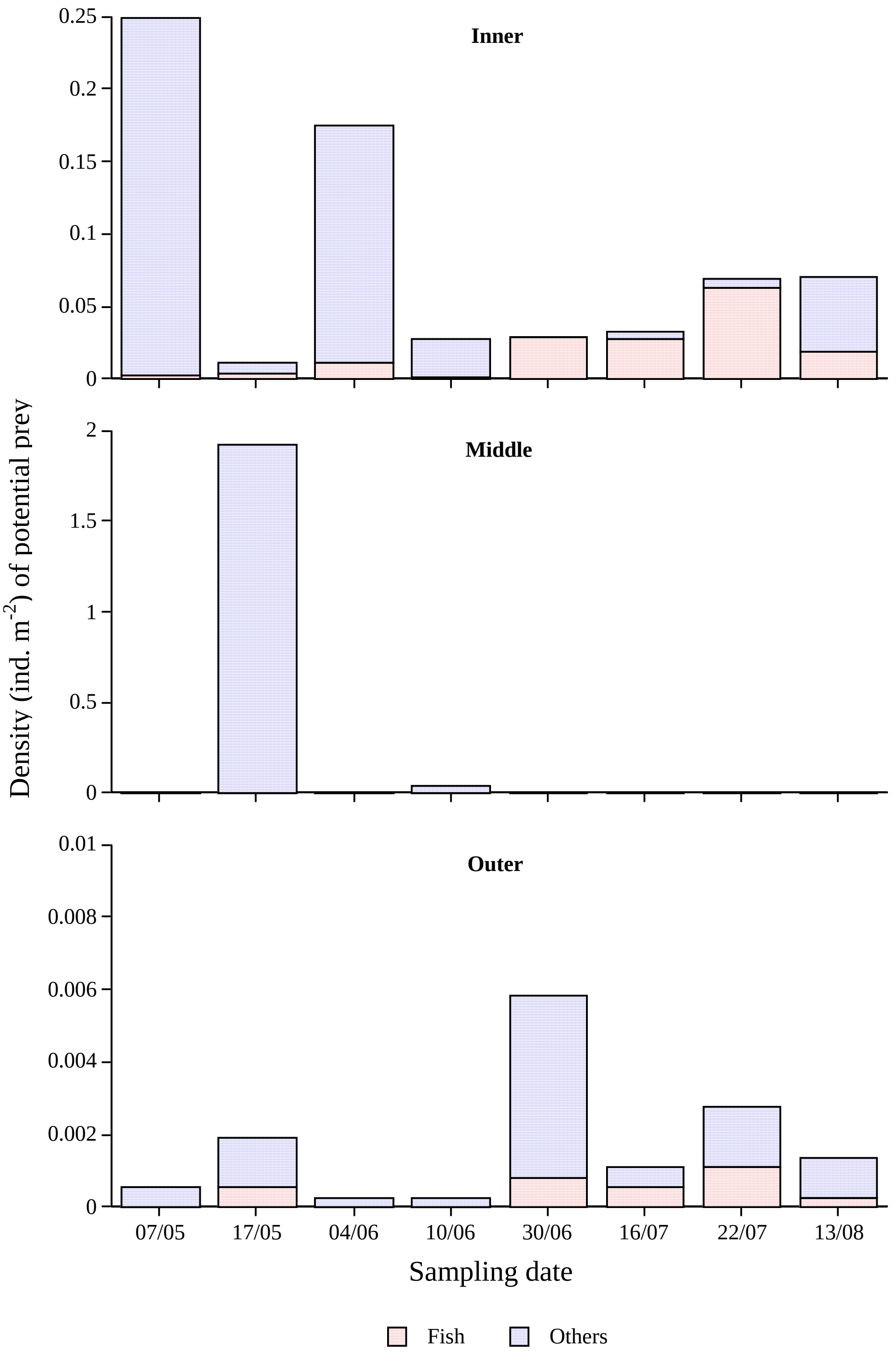

Figure 4. Mean density (ind. m^{-2}) of potential Little tern prey (both fish and invertebrates) captured in tows at the inner (9, 10, 11, & 12), middle (1, 6, 7 & 8) and outer (2, 3, 4 & 5) sampling points at Scroby on each sampling occasion in 2004.

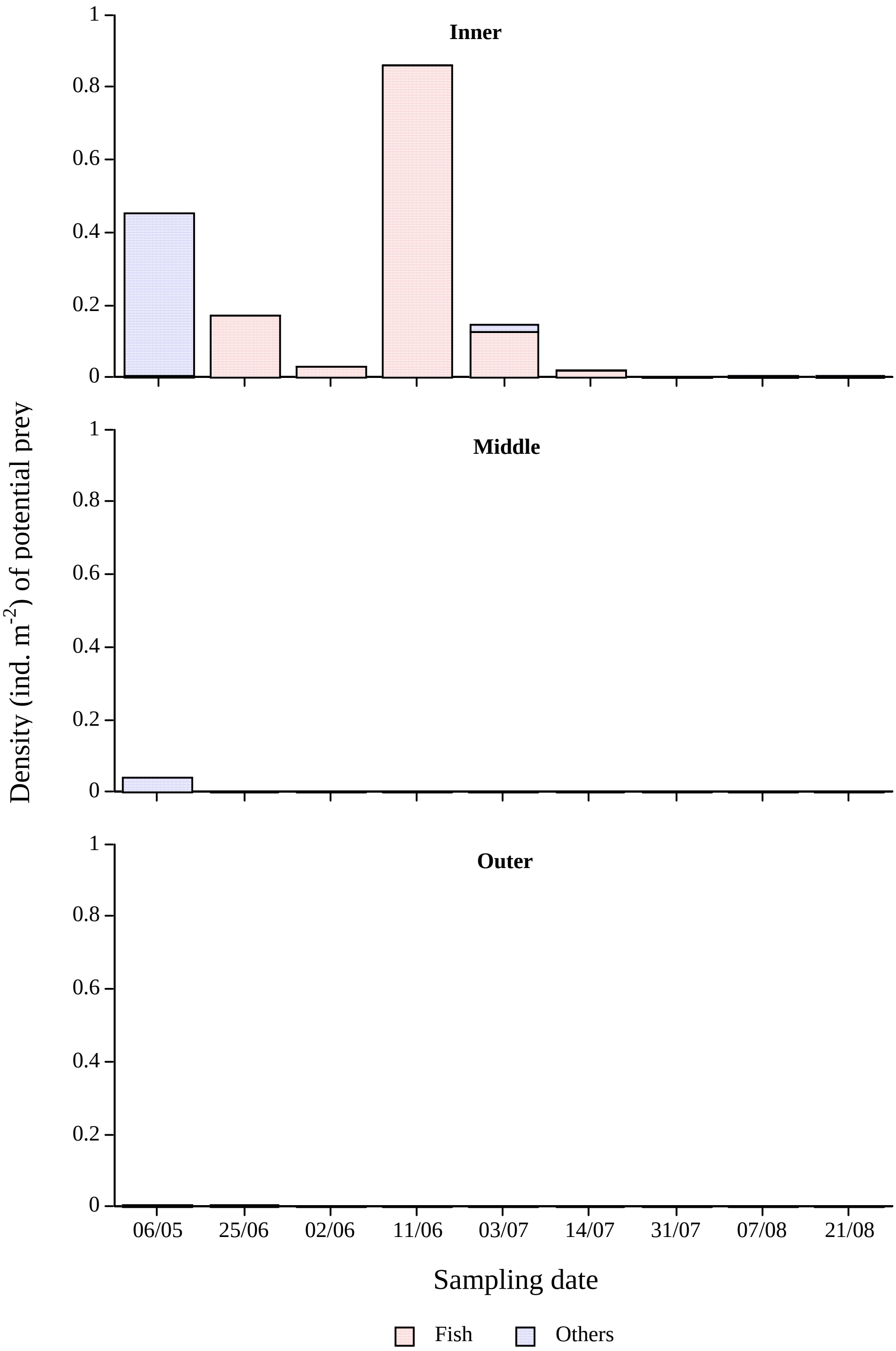

Figure 5. Mean density (ind. m^{-2}) of potential Little tern prey (both fish and invertebrates) captured in tows at the inner (9, 10, 11, & 12), middle (1, 6, 7 & 8) and outer (2, 3, 4 & 5) sampling points at Scroby on each sampling occasion in 2003.

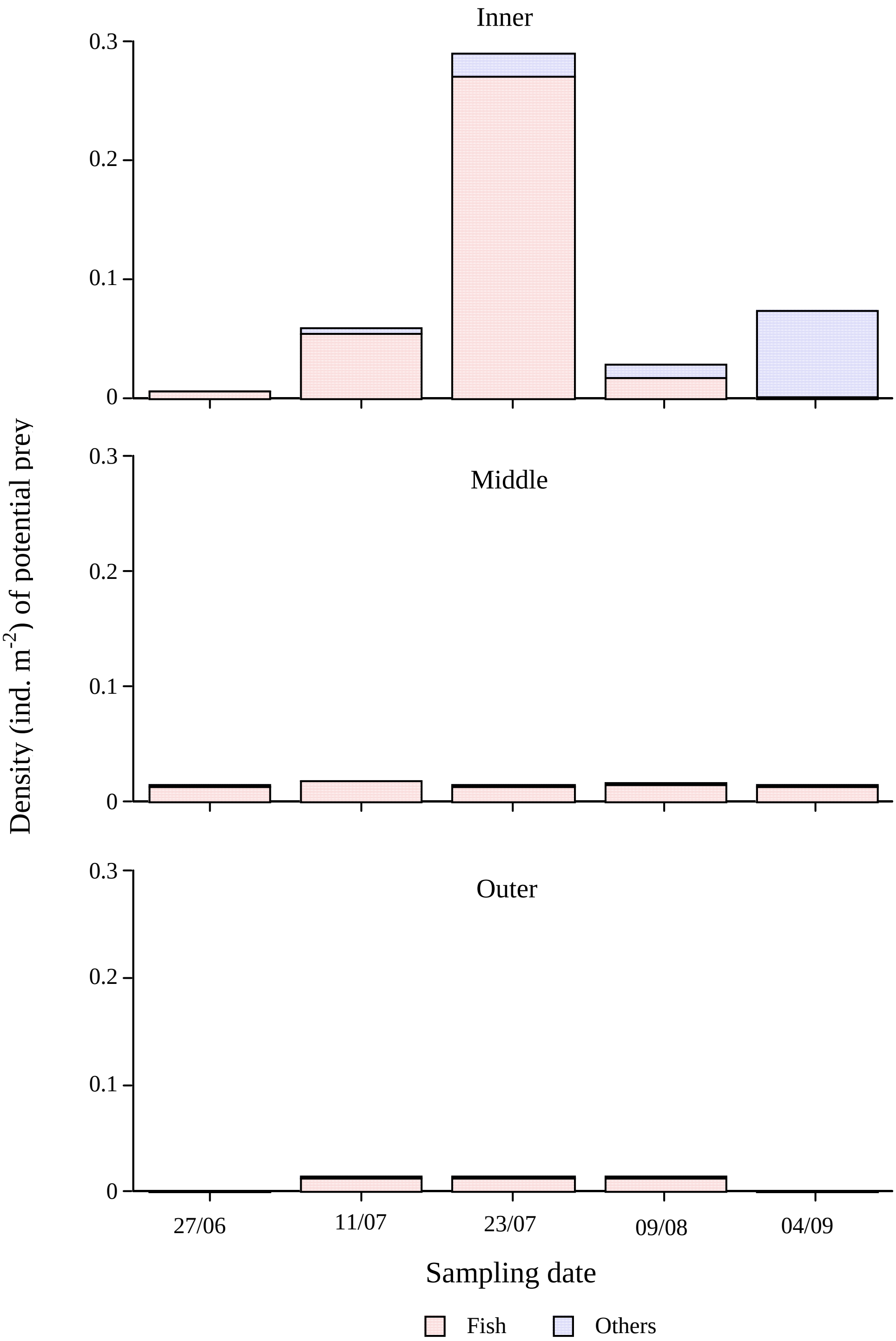

Figure 6. Mean density (ind. m^{-2}) of potential Little tern prey (both fish and invertebrates) captured in tows at the inner (9, 10, 11, & 12), middle (1, 6, 7 & 8) and outer (2, 3, 4 & 5) sampling points at Scroby on each sampling occasion in 2002.

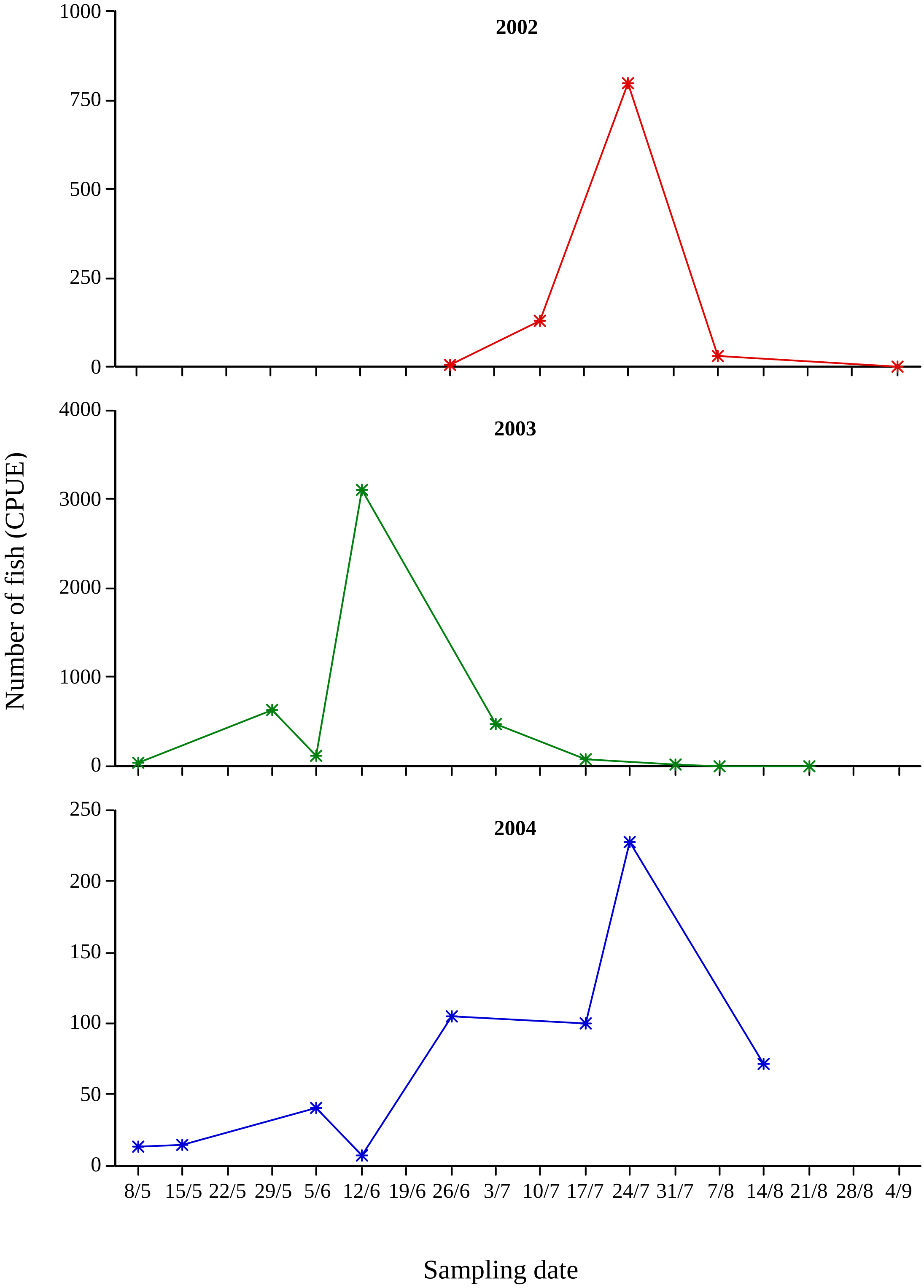

Figure 7. Seasonal pattern of abundance of Clupeid fish in the inner sites expressed as combined catch from sites 9 to 12 combined on each occasion (catch per unit effort-CPUE) from 2002 to 2004.

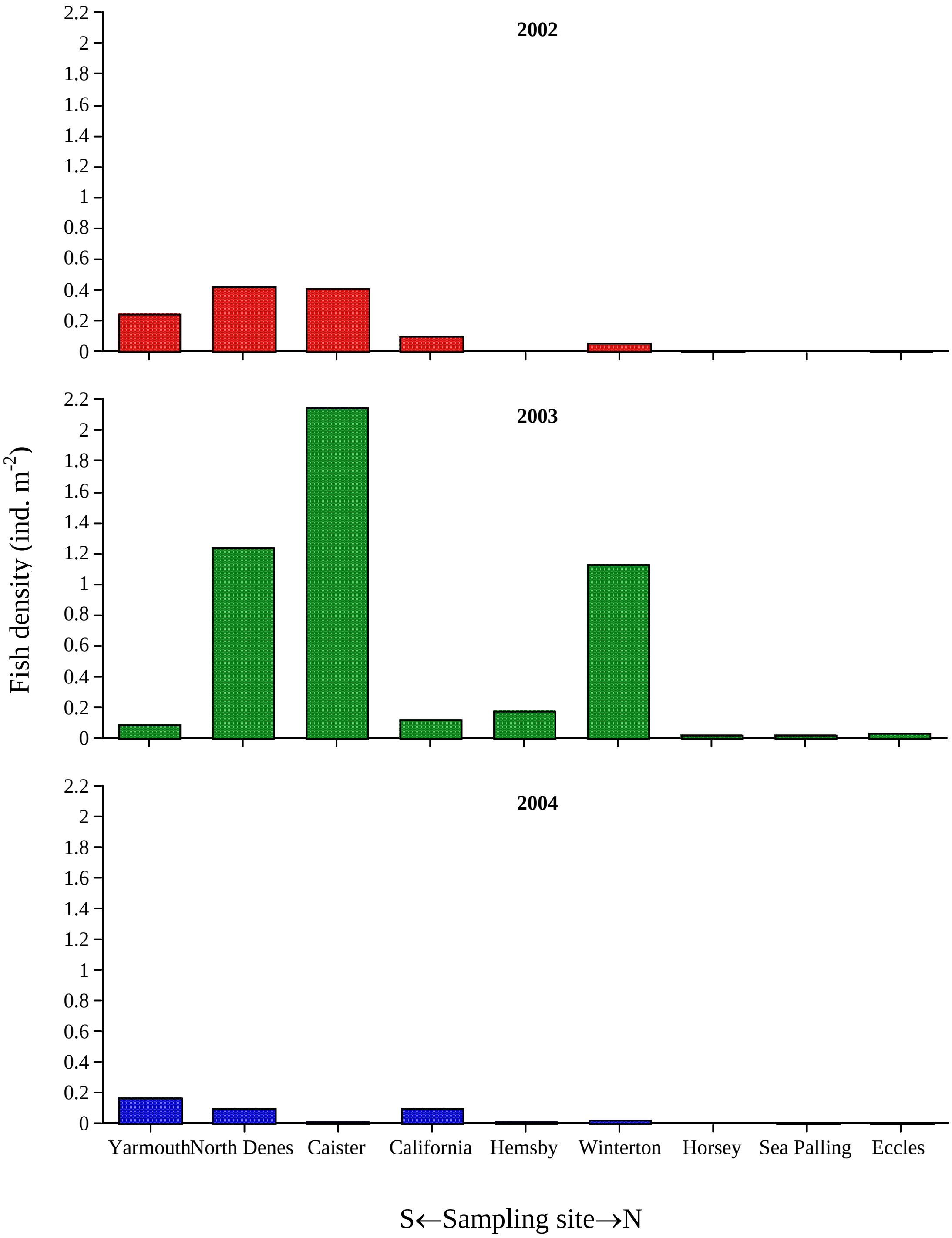

Figure 8. Maximum density (ind. m^{-2}) of fish (principally clupeids) recorded at all sampling sites along the East Norfolk coast from Yarmouth in the south to Eccles in the north, during the summer months (late April/ May to August/early September) from 2002 to 2004.

Although Clupeids were recorded on all occasions, the density of these fish increased over the season (Fig's 5 & 8). This contrasts sharply with the pattern of abundance in 2003, but bears a remarkable similarity to the pattern in 2002 (Fig. 8). In 2002 and 2004, the small peak in abundance occurred in late July, but after a short increase phase of about a month in 2002 and a protracted increase phase over some two and a half months in 2004. However, this may be partly reflective of the increased sampling effort in 2004.

In 2003, the massive peak in abundance was around seven weeks earlier than in the other years, and preceded by an extremely short increase phase. All peaks in abundance were characterised by subsequent rapid decline within two weeks to negligible levels. This gave the impression of a collapse in fish stocks, although such a pattern may not necessarily represent mortality and could also be achieved by fish simply abandoning the surface layers, or migrating from the study area.

Winterton

In further agreement with the pattern for 2002, very few fish were recorded at Winterton or any site in the Would in 2004 (Table 9), although judging from the seasonal pattern at Scroby, sampling was probably completed just before (mid-July) the potential peak was achieved (late July). Even so, the maximum density was likely to be an order of magnitude less than that recorded in 2003 and in keeping with the pattern in 2002, was lower than peak values for sites in Scroby (Fig. 9, Appendix VII).

Although sampling was more limited in the Would than in previous years, it is clear that the abundance of invertebrates was particularly low at Winterton and indeed at any site in the Would, in 2004. Combining all prey together produced a maximum density of just 0.03 ind m^{-2} at Winterton in mid July. Fish of 5 taxa constituted some 65% of this total, further outlining the scarcity of invertebrates.

5.6 Telemetry of Little terns

5.6.1 Technical issues and impact of tagging

Of the 14 tags fitted in 2004, six (43%) were never contacted, apparently not because of problems with the tag but as a result of most birds leaving the area as a result of nest failure, which, in turn, was not thought to be linked to the fitting of a tag, but part of a more general phenomenon (Table 13, Appendix VIII).

However, one tagged bird appears to have been killed by a predator, with the tag found, seemingly plucked, on the beach. This indicates the bird was taken by a raptor, the most likely candidate being a Kestrel. There is no evidence that tagging increased the chances of this bird being taken as two other adult birds were also found dead during the season. One of these had been captured and ringed (NW09891 and Y/B Left) at Winterton but was not fitted with a radio tag. The corpse was found on the beach at Caister over 10km to the south on 8th July, 13 days after being ringed with no external signs of injury and at the same weight it had been captured (51g - Allen Navarro *et al*. 2004).

A further adult bird was found at North Denes landward of the south colony at the edge of the dune on 12th July. This had a partly crushed skull indicating mammal predation, in turn suggesting the bird had been taken off the nest,
most likely at night. This coincides with the period in which a number of nests were lost, the cause of which for most was unknown although some at least were known to have subject to predation (see 5.1.1 above).

Two of the eight tags (25%) subsequently contacted after fitting suffered from a drifting signal. This compares with one of seven tags (14%) in 2003. In all cases, this created considerable confusion with the other birds and in 2004, the assumption that the tag was no longer working when it had drifted considerably into the middle of undefined 'grey' zone of the receiver dial, considerably reduced the amount of information gathered on what was an important bird nesting at North Denes (7.1 or mid-grey). This was mostly because signal drift did not occur immediately as the bird was tracked on the third day after the tag was fitted, although the signal from the tag became sporadic and it was assumed the tag was failing. In the case of the other drifting tag, the signal had changed position (from c.9.0 to just below the identifiable 'blue' range into the 'grey' undefined area (i.e. blue-grey) by the time tracking was initiated the day after the tag had been fitted.

In 2004, the maximum life of the tags ranged considerably from 2-27 days for a mean of 12 days. This was biased by the use of Ag376 batteries, which lasted over twice as long on average (range 14-27 days, mean = 18 days) than the standard Ag379 battery powered tags (range 2-12 days, mean =7.6 days). Thus, the mean life of tags was only 67% and 42% of the maximum life quoted for the Ag376 and Ag379 tags ((27 days and 18 days respectively). However, this did not specifically limit the amount of tracking time on each bird, as experiences in 2003 suggested that battery life was likely to be far below quoted possible maximum values. Whilst tracking time on bird 7.1 was undoubtedly reduced by tag drift, efforts on other birds were constrained by equipment failure (of the RIB and the receiver), birds apparently moving away from the area after nest failure, great mobility of birds after nest failure and poor weather (a series of storms and high tides were present in the area from around 6th-9th July).

Of the eight birds tagged, tracked and observed in 2004 all showed what appeared to be normal behaviour patterns (Table 13, Appendix VIII). This reinforces the experiences of 2003, when after the supply of the correct tags with thicker wire aerials, no aberrant behaviour of birds was observed (Table 14). In 2004, it is not known if the additional measure of reducing the intensity of feathers trimmed to accommodate the tag had any beneficial effect, but there was no evidence that this increased the likelihood of tags being lost.

Thus, a total of 12 birds have now been successfully fitted with back-mounted tags with no apparent adverse impacts upon behaviour. Of these, a total of 5 birds have been fitted with tags with additional ground plane aerials, although only three of these birds have subsequently been tracked. There appeared to be no effect of the ground plane over and above that of the tag and the one tagged bird (BV87138) known to have raised chicks in the study thus far had a ground plane aerial (ECON 2004).

Table 12. Summary of the fate of tags and tagged birds in 2004.

BTO ring/ colour ring	Sex	Tag frequency	Tag type	Tag fate	Behavior of bird	Fate of bird/nest/ chicks
NW09890	M	7.1 (mid-grey)	Ag376	tag drifted, re-contacted after 10 days, working for >24 <27 days	normal	nest lost on 29-30th June (day 8), possibly hatched
NV91042 Y/B Left	F	5.5	Ag379 RF+GP	tag working >5<6 days	normal	nest lost <day 20
NW09892 Y/B Left	M	13.9	Ag376	tag working >10<12 days	normal	nest failed (day 2), bird moved to North Denes
NV91076 Y/B Left	F	9.4	Ag379	tag working >6<10 days	normal	1 egg lost before tagging, other egg probably hatched, bird not contacted after chick lost (day 6)
NW09893 Y/B Left	F	7.0	Ag379	tag never contacted	not observed	nest failed within 2 days, bird not contacted
NW09895 Y/B Left	M	3.0	Ag379 GP	tag working >10<12 days	normal	nest failed by 2nd July (day 6)
NW09896	F	12.0	Ag376	tag working >16<19 days	normal	nest failed immediately (day 1), bird also at Winterton
NW09897	F	c.9.0 (blue-grey)	Ag379	tag drifted, working (>6<8 days)	normal	nest lost to predator on July 10-11th (day 10)
NV82475	F	8.2	Ag376	tag never contacted, possibly this tag found plucked off on 14th July (day 12)	not observed	nest predated by fox on July 3rd-4th (day 2), bird not contacted, predated by raptor?
NW09899	F	10.2	Ag376	tag working >12<14 days	norrmal	nest predated by fox on July 3rd-4th (day 2),
NV80731	F	0.7	Ag379 GP	tag never contacted	not observed	nest predated by fox on July 3rd-4th (day 2), bird not contacted
NW09900	F	6.4	Ag379 RF	tag failed <2 days	not observed	nest lost for unknown reason by July 18th (day 4)
NV95791	M	4.7	Ag379 RF	tag never contacted	not observed	no nest, bird controlled by whoosh net
NW09927	F	11.0	Ag379 GP	tag never contacted	not observed	no nest, bird taken by whoosh net

Table 13. Summary of the fate of tags and tagged birds in 2003.

Bird BTO ring	Sex (3brood patch)	Tag reception	Tag type	Tag fate	Behavior of bird	Fate of bird/nest/ chicks
NW09527	female? 3	10.1	back mount[1]	aerial lost, tag failed <6 days	aberrant -awkward movement -rolling on back	eggs hatched bird, partner and two chicks later disappeared, latter presumed dead
NW09528	female 3	0.4	back mount[1]	aerial lost, tag failed <4 days	aberrant -refusal to incubate -soliciting food	no eggs hatched nest failed
NV91429	female	1.7	back mount[1]	aerial lost, tag failed <4 days	some erratic -refusal to brood	eggs hatched fate of bird unknown 3 chicks may have survived
NW09530	male? 3	11.7	back mount[1]	aerial lost, tag failed <9 days	normal	nest failed bird went missing, then reappeared, likely to have re-laid
NV51914	male?	3.8 (grey)	back mount[2]	tag failed <18 days	normal	eggs hatched, fate of bird and chicks unknown
BV87138	female 3	0.9	back mount[2,3]	tag failed <18 days	normal	bird followed for 27 days before disappearing, 2 chicks likely to have fledged
NW09581	male?	13.0	back mount[2]	tag failed <18 days	normal	eggs hatched, fate of bird and chicks unknown
NW09880	female 3	2.4	tail mount	tag failed within minutes	normal	eggs hatched, fate of bird and chicks unknown
NW09881	female 3	8.1	tail mount	tag shed <8 days re-covered	normal	eggs hatched, fate of bird and chicks unknown

[1] tail mount tag with thin wire aerial
[2] modified thicker wire aerial with plastic sleeve
[3] with additional ground plane aerial

5.6.2 Activity and foraging movements of Little terns

In 2004, information was gathered from eight individuals over ten days tracking, although two of the latter were from the land only and no birds were contacted on a further two, despite considerable effort in which over 20 km of coast was covered. Thus, tracking at sea was effectively limited to just six days.

Of the eight individual birds, all but one were tracked in at least two sessions on different days (Table 15). In 2003, this was achieved for two of the five birds, with a further two tracked in different sessions on the same day. Sessions of continuous tracking varied from just 4 minutes to 250 minutes (Appendix VIII**)**, with a range of 45-307 minutes on any one bird for a mean of 163 minutes per bird, some 70% of the 236 minutes per bird achieved in 2003. However, total tracking time was 11% greater at 1320 minutes (22 hours) compared to 1188 mins (19.8 hours) in 2003. The number of fixes was also comparable, at 366 cf. 304 in 2003 and were thus taken at a similar rate (16.6 fixes hr^{-1} compared to 15.4 fixes hr^{-1}) despite the differences in tracking procedure from a large and small, fast vessel respectively (see 4.2.4 below).

Table 14. Summary statistics of radio tracking effort on individual birds in 2003 and 2004.

Year	Bird	Total track time (mins)	Number of sessions	Number of other days encountered	Total number of fixes
2003	10.1	255	2[1]	-	48
	11.7	333	2	-	66
	3.8 (grey)	121	2	-	42
	0.9	339	2	-	109
	13.0	136	1	-	17
2004	7.1 (mid-grey)	239	2	5	40
	5.5	45	2	1	12
	13.9	132	3	1	39
	9.4	217	3	2	77
	3.0	67	3[2]	2	27
	12.0	307	2	4	58
	9.0 (blue-grey)	257	3	0	105
	10.2	56	1	2	8

[1] same day [2] one very short at 4 minutes

Tagging was conducted over a similar period in both years from 21st June – 9th July in 2003 and from 25th June –14th July in 2004. However, the fate of the colonies at North Denes and Winterton in 2004 was markedly different to 2003 at Winterton, with no chicks fledged in the former year and some 447 fledged in the latter (ECON 2004). In 2004, a tiny proportion of nests hatched chicks (at Winterton possibly 3 of 150 = 2%, and 1 of 40 at North Denes = 2.5%) and many nests were lost early in the nesting cycle (see 5.1.1 and 5.1.2 above). This is clearly reflected in the activity patterns of radio-tagged birds (Fig. 10).

A. 2004

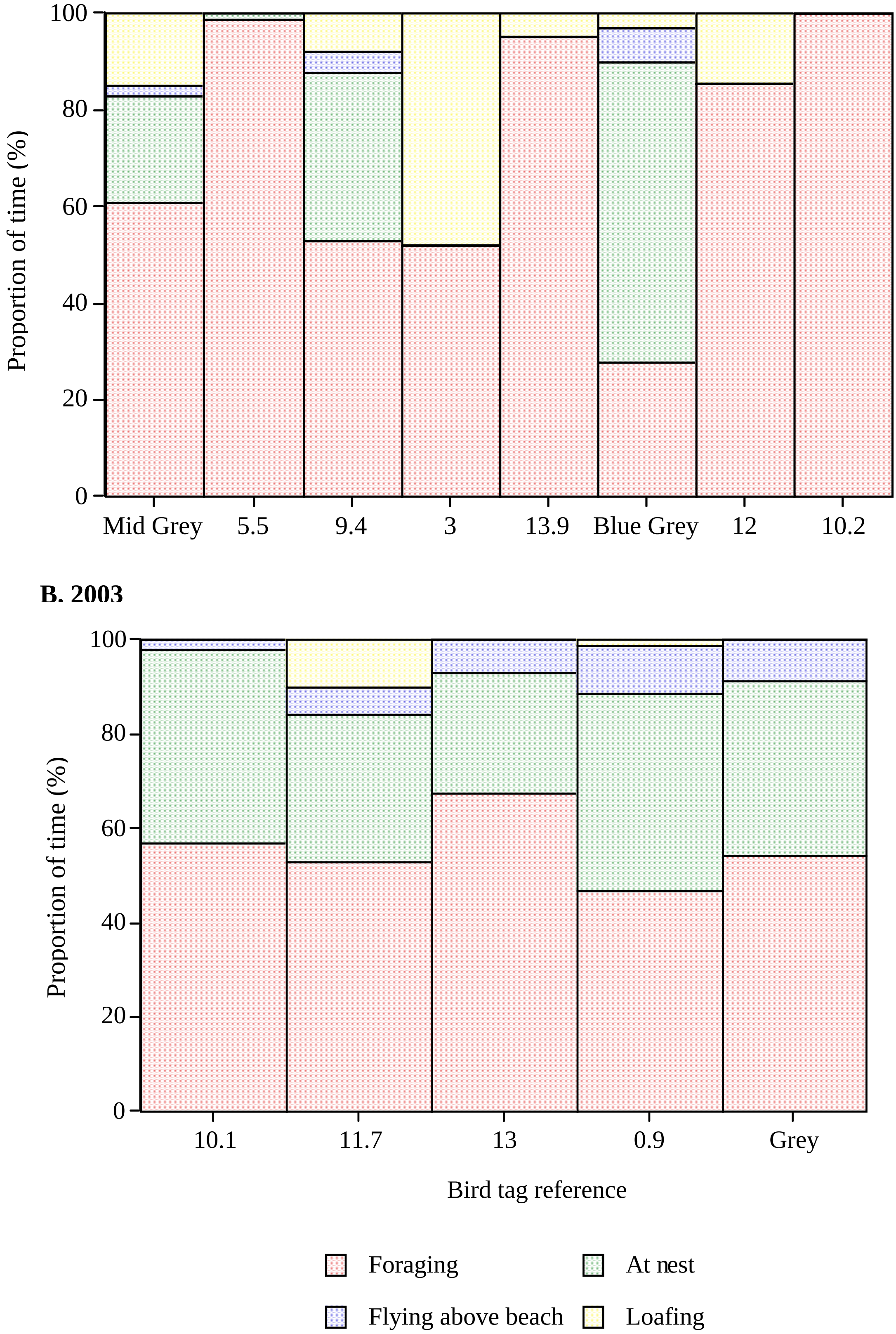

Figure 9. Proportion of time (%) tagged birds spent engaged in different activities in A. 2004 and B. 2003.

In 2003, birds varied relatively little in the proportion of time engaged in various activities and overall, 55.8 ± 3.36 % of time was spent foraging, 35.3 ± 3.04 % at nest, 6.7 ± 1.44 % flying above the beach, usually in response to disturbance by people and their dogs, and 2.2 ± 1.96 % was spent in loafing sites on the beach away from the nest, with at least some time engaged in preening. The presumed male bird, tag 11.7, was particularly prone to loafing (10% of time) and only the female tag 0.9 also engaged in such activity on one occasion, prior to eggs hatching. Loafing was therefore only undertaken by birds with eggs, although birds with eggs did not necessarily spend time loafing away from the nest.

In contrast in 2004, overall birds spent 71.8 ± 9.5 % of their time foraging, with 15.0 ± 8.2 % at nest, 1.7 ± 0.95 % flying in disturbance events and 11.6 ± 5.6% loafing. Only four birds were recorded at/near the known nest site although all eight birds had been captured at a nest. The other birds were only tracked after the nest had failed. In the case of bird 12.0, this was immediately (the following day) after tagging when it was tracked at Winterton, some 12 km from the nest. It appears that bird 5.5 was also in the process of abandonment as it spent only 1% of its time on the nest, although very little tracking time was available on this bird. Of the other birds for which more data was available, mid-grey spent a relatively low amount of time at nest (22%), although this is perhaps to be expected by male birds which incubate less than females, especially up to the 6^{th} day after a complete clutch is obtained (Cramp & Simmons 1985). This was also mirrored by reduced time at the nest being exhibited by birds in 2003 (e.g. 25.5% by bird 13.0). Female blue-grey, which was only tracked when the nest at North Denes was active (the bird disappeared when the nest was lost on day 10 -Appendix VIII), spent by far the highest time at nest (62%) when on eggs, presumably as she was being fed by the male. In contrast, female 9.4 at Winterton, which is thought to have hatched a chick, spent only 35% at nest, with the bulk of its time foraging in short bouts presumably whilst feeding the chick (Table 14).

Birds that had failed thus appeared to spend more time foraging coupled with some time loafing although this was subject to individual variation (Fig. 11). This may also be influenced by the sex of the bird, for example male bird 3.0 more or less divided its time between foraging (52.1%) and loafing (47.9%), whilst females 12.0 and 10.2 spent far more time foraging (85.8% and 100% respectively).

In 2003, even when birds were all engaged in breeding throughout the tracking period, there was considerable individual variation in the various parameters of foraging, with birds ranging in their mean number of foraging bouts hr^{-1} (1.8-5.5), mean duration of a foraging bout (4.1-31 mins), the mean distance traveled (1441-3177 m) and mean flying speed (7.3-21.8 km hr^{-1}) (Table 14). The distance from shore foraging occurred was more consistent, although the mean of the maximum distance recorded in a foraging bout in a session varied from 326-1497 m. There seemed to be scope for some of this variation to be linked to sex differences. For example, the birds that undertook by far the longest feeding bouts were the males 11.7 and 13.0. The same males also traveled the greatest distance in the process (mean of 2.5-3 km) and foraged the furthest mean distance offshore (mean >800 m). Travelling for a long time over great distance reduced the flying speeds of these two birds, which was moderate at best. The female 0.9, tended to fly faster than the other birds, traveling some distance in one session but concentrating her efforts close to shore (even the mean maximum distance was <555 m).

Table 15. Individual variation in the variables associated with foraging as revealed by radio telemetry in both 2003 and 2004. Mean (± 1SE) data from each tracking session from each bird in relation to the status of their breeding attempt are presented. Overall (all) values are also shown.

Year/ date	Bird tag ref.	Sex	Status	Feeding bouts		Distance travelled (m)	Flying speed (km hr^{-1})	Distance from shore		
				Bouts hr^{-1}	Duration (min)			Min. (m)	Max. (m)	Mean (m)
2003										
	10.1	F?	3 (day) chicks	2.35	15.20 (*6.04*)	1508 (*347*)	7.34 (*1.43*)	188 (*46*)	538 (*154*)	349 (*81*)
	11.7	M	2 eggs	1.80	19.33 (*5.33*)	2542 (951)	10.05 (*2.89*)	266 (*97*)	821 (*224*)	552 (*146*)
	13	M	2 eggs	1.32	31.00 (*16.74*)	3177 (*1365*)	9.27 (*2.89*)	189 (*81*)	1497 (*529*)	923 (*315*)
	0.9	F	3 eggs → chicks	3.72	7.43 (*1.76*)	2182 (*480*)	21.84 (*2.80*)	171 (*65*)	492 (*144*)	331 (*99*)
	Grey	M	2 eggs	5.45	6.00 (*2.02*)	1441 (*471*)	18.61 (*3.55*)	117 (*31*)	326 (*129*)	208 (*68*)
	All			2.93 *(0.75)*	15.79 *(4.53)*	2170 *(326)*	13.42 *(2.86)*	186 *(24)*	835 *(206)*	473 *(125)*
2004										
	7.1 (mid grey)	M	2 eggs → failed	1.25	30.00 *(10.08)*	2160 *(29)*	12.72 *(3.91)*	299 *(145)*	795 *(333)*	482 *(241)*
	5.5	F	2 eggs	1.14	17.5 *(4.5)*	1404 *(219)*	9.67 *(3.13)*	5 *(0)*	1005 *(166)*	385 *(25)*
	13.9	M	failed	2.77	33.3 *(22.92)*	4602 *(3473)*	9.09 *(3.56)*	68 *(15)*	975 *(484)*	496 *(239)*
	9.4	F	chick → failed	4.02	8.15 *(1.61)*	2171 *(443)*	11.73 *(1.67)*	118 *(47)*	430 *(80)*	234 *(51)*
	3.0	M	2 eggs → failed	8.00	15.00 *(4.76)*	10692 *(786)*	18.03 *(3.99)*	49 *(12)*	527 *(143)*	282 *(77)*
	12.0	F	failed	0.77	66.50 *(24.75)*	11763 *(5082)*	16.47 *(2.1)*	212 *(105)*	2421 *(600)*	1368 *(699)*
	9.0 (blue-grey)	F	eggs	3.88	10.22 *(2.85)*	2278 *(642)*	13.14 *(2.95)*	80 *(36)*	367 *(97)*	175 *(56)*
	10.2	F	failed	1.09	55.00	9764	11.64	12	1131	490
	All			2.87 *(0.86)*	29.46 *(7.58)*	5604 *(1550)*	12.81 *(1.09)*	105 *(36)*	956 *(232)*	489 *(133)*

There was also some suggestion that these foraging variables varied according to the status of the breeding attempt of the bird concerned (Table 15). For example, the nests of the far flying males documented above had only eggs when they were tracked. A change in status with hatching of chicks may have been responsible for the variation exhibited by female 0.9. With newly-hatched chicks, she reduced the duration of her foraging bouts from around 11 to 5 minutes, traveling proportionally less (2.7 km to 1.7 km) in the process.

In 2004, with birds varying in status of breeding attempt, there was even wider variation between birds for mean number of foraging bouts hr^{-1} (0.8-8.0), mean duration of a foraging bout (8.2-66.5 mins), the mean distance traveled (1404-11763 m) and mean flying speed (9.1-18.3 km hr^{-1}) (Table 14). To reinforce the impression gained in 2003, birds that changed status, in this case failed in their breeding attempt, also appeared to change various components of foraging activity, with all three birds apparently reducing the duration of foraging bouts and the distance from shore that foraging occurred, the latter being most prominent for both minimum and maximum distances.

Table 16. Individual variation in the variables associated with foraging as revealed by radio telemetry in both 2003 and 2004 for birds that changed status during their breeding attempt. Mean (± 1SE) data from pooled tracking sessions according to a particular status are shown.

Year/ date	Bird tag ref.	Sex	Status	Feeding bouts		Distance travelled (m)	Flying speed (km hr^{-1})	Distance from shore		
				Bouts hr^{-1}	Duration (min)			Min. (m)	Max. (m)	Mean (m)
2003										
	0.9	F	3 eggs	3.48	10.89 *(3.51)*	2794 *(861)*	20.53 *(5.80)*	96 *(33)*	409 *(147)*	231 *(61)*
			3, 1 day chicks	3.91	4.83 *(1.30)*	1723 *(533)*	22.82 *(2.54)*	228 *(110)*	555 *(231)*	407 *(166)*
2004										
	7.1 (mid grey)	M	2 eggs	0.88	44 *(9.54)*	1855 *(555)*	11.20 *(7.99)*	548 *(38)*	1340 *(141)*	803 *(92)*
			failed	3.45	9.00 *(3)*	2464 *(36)*	14.25 *(4.83)*	5 *(0)*	231 *(104)*	68.5 *(18.5)*
	9.4	F	chick	4.44	8.45 *(1.85)*	2126 *(486)*	11.75 *(1.6)*	123 *(55)*	457 *(82)*	246 *(56)*
			failed	2.67	6.5 *(3.5)*	2024 *(756)*	11.62 *(4.75)*	60 *(1)*	280 *(180)*	241 *(58)*
	3.0	M	2 eggs	2.32	26.00	3860	21.15	113	753	318
			failed	4.41	11.33 *(4.17)*	2277 *(849)*	16.98 *(466)*	54 *(15)*	452 *(150)*	269 *(96)*

In 2003, a further potential cause of variation in individual foraging response was tidal cycle, but only for flying speed were any significant differences revealed, birds flying faster at low water (mean around 25 km hr^{-1}) and on a flooding tide than at high water (mean around 7 km hr^{-1}). There was a trend towards shorter foraging bouts at low water and on a flooding tide, although this was not significant, with no apparent decrease in distance travelled, which was around 1.5-2.5 km irrespective of tidal state. Variation in any parameters according to tidal cycle could not be tested in 2004, with a paucity of data in slack water periods.

Despite the individual variation noted above there were significant differences between years (all observations pooled) in various quantified components of foraging (Table 16). These included the number of foraging bouts hr^{-1}, the duration of a foraging bout, the distance travelled and minimum distance from shore. In simple terms, birds foraged for twice as long in 2004 (mean±1SE = 29.46 ± 7.58 mins) compared to 2003 (mean±1SE = 15.79 ± 4.53 mins), travelling more than 2.5 fold further in the process (2004: mean±1SE = 5604 ± 1550 m: 2003: mean±1SE = 2170 ± 326 m). The reduced minimum distance from shore figures in 2004 thus appear contrary to that expected and may be influenced by data from North Denes in 2004, where birds tend to forage closer to shore (see 5.7.1 below).

Table 17. Inter-annual (2003 and 2004) variation in selected parameters of foraging activity of radio-tagged Little terns, as revealed by Mann-Whitney tests.

	N	Z	Significance (2-tailed)	p	Location of differences
Distance travelled	2003: 55 2004: 41	-2.118	0.034	*	2004>2003
Max. distance from shore	2003: 53 2004: 41	-1.129	0.259	ns[1]	-
Min. distance from shore	2003: 53 2004: 40	-2.837	0.005	**	2003>2004
Mean distance from shore	2003: 51 2004: 40	-0.704	0.482	ns[1]	-
Duration of foraging bout	2003: 54 2004: 42	-2.272	0.023	*	2004>2003
Flying speed	2003: 54 2004: 41	-0.455	0.649	ns[1]	-

ns= not significant, * = p<0.05, ** =p<0.01

These differences are borne out by the home range statistics for birds in 2003 and 2004 (Fig's 12 & 13, Table 17), with mean (± 1SE) home ranges of 4.6 ± 0.9 km^2 in 2003 and 14.22 ± 7.8 km^2 in 2004, an increase of >200%. However, the values are considerably influenced by birds mid-grey, 3.0 and 12.0, two males and a female respectively that failed at either North Denes (mid-grey and 12.0) or Winterton (3.0) and subsequently ranged over a wide area encompassing both North Denes and Winterton. Male 13.9, tagged at Winterton, was only subsequently encountered at North Denes. However, not all birds that were tracked after failure abandoned the area around the colony. For example, the female 9.4, which was tracked before and after failure at Winterton continued to be associated with the colony.

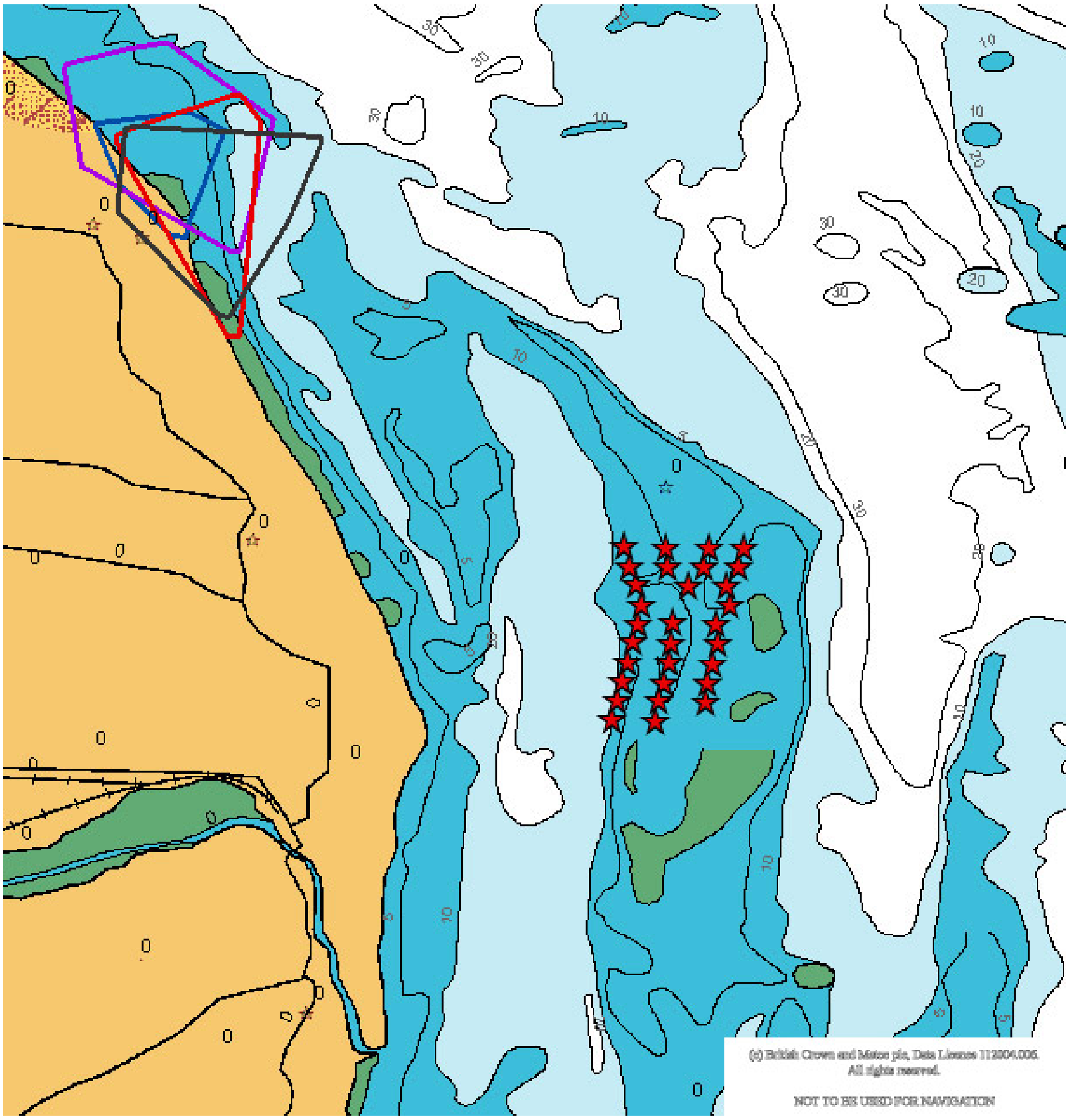

Figure 10. Maximum home range polygons for radio-tagged Little terns (key opposite) at the Winterton colony in 2003. The red stars represent the locations of the turbines installed in 2004.

	Bird
	10.1
	3.8
	11.7
	0.9

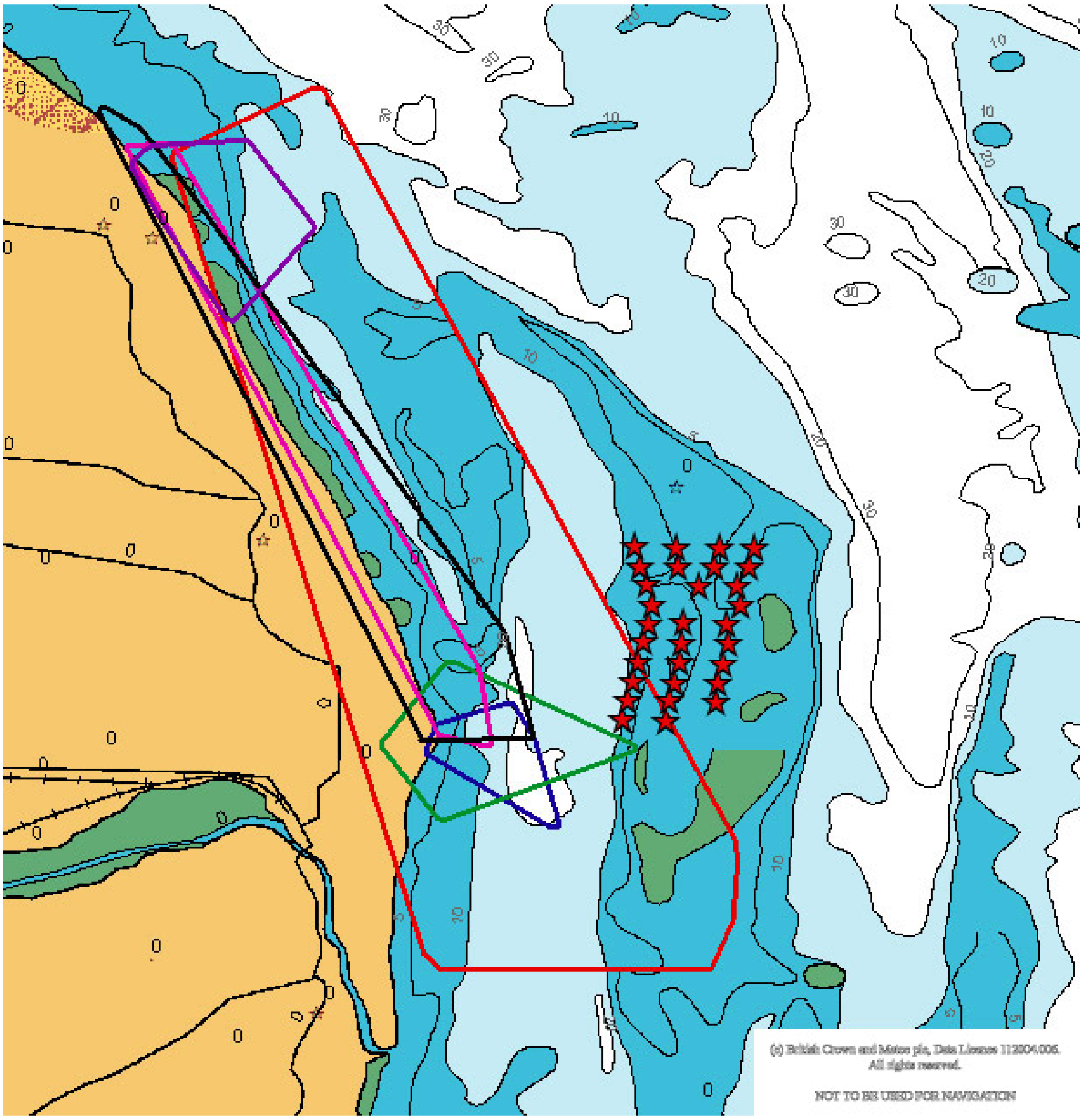

Figure 11. Maximum home range polygons for radio-tagged Little terns (key opposite) at the North Denes and Winterton colonies in 2004. The red stars represent the locations of the turbines installed in 2004.

	Bird
red	12
blue	13.9
green	blue-grey
purple	9.4
magenta	3
black	mid-grey

Wide-ranging birds were tracked for no longer than sedentary birds (means of 204 and 202 minutes respectively), and indeed, bird 3.0 was only tracked for 67 minutes in total, but was recorded at both Winterton and North Denes, illustrating its mobility. However, data was collected over a longer period for the wide-ranging birds, at 11 days, 51% more than the 7.3 days for the more sedentary birds. It seems that there was simply more chance of recording wide-ranging behaviour with a longer running data set.

Table 18. Home range statistics for radio-tagged birds in 2003 and 2004.

Year	Bird tag reference	Sex	No. of fixes	Max. area (ha)	Range span (m)	Locations from focus co-ordinates (m)		
						Mean	Med	Max
2003	11.7	M	64	627.49	4005	748	637	2041
	3.8	M	42	215.89	2268	440	334	1257
	10.1	F	47	437.17	4564	774	544	3245
	0.9	F	107	559.51	3759	668	581	2157
2004	mid-grey	M	40	1322.68	13022	3909	866	11870
	13.9	M	39	190.29	2333	635	614	1469
	9.4	F	78	426.60	3380	634	408	2409
	3	M	27	856.57	12183	6303	3972	11786
	12	F	58	5260.09	17527	4410	3588	12604
	blue-grey	F	105	481.35	2933	465	327	1542

5.7 Foraging behaviour of Little terns

5.7.1 Distance from shore

Values from the tracking sessions on individual birds showed considerable variation, with mean values of 175 to 1368 m and mean maximum values ranging from 367 to 2421 m. Clearly, foraging birds consistently flew out of the range of comfortable detection (c. 800-1000 km) of a shore-based telescope. Again, this is not to say that birds did not forage very close to shore including in the surf on occasion.

At North Denes there was significant seasonal variation in the foraging distance from shore (Table 18, Fig. 14). In something of a repeat of the pattern of 2003, birds foraged further from shore at the beginning of the study. Unlike 2003, the values did not appear to be influenced by a small number of observations at this time and were in keeping with observations of birds foraging between 3-5 km offshore on both the inner (site 1) and outer edge (sites 4 & 5) of Scroby (Fig. 4), which also corresponded to the very low prey density at the beginning of the season (Fig. 8).

Within a season, birds foraged significantly further from shore in 2004 than in both 2002 and 2003 (Table 19), with an overall mean of 460.3 m, compared to 139 m in 2003 and 38.4 m in 2002.

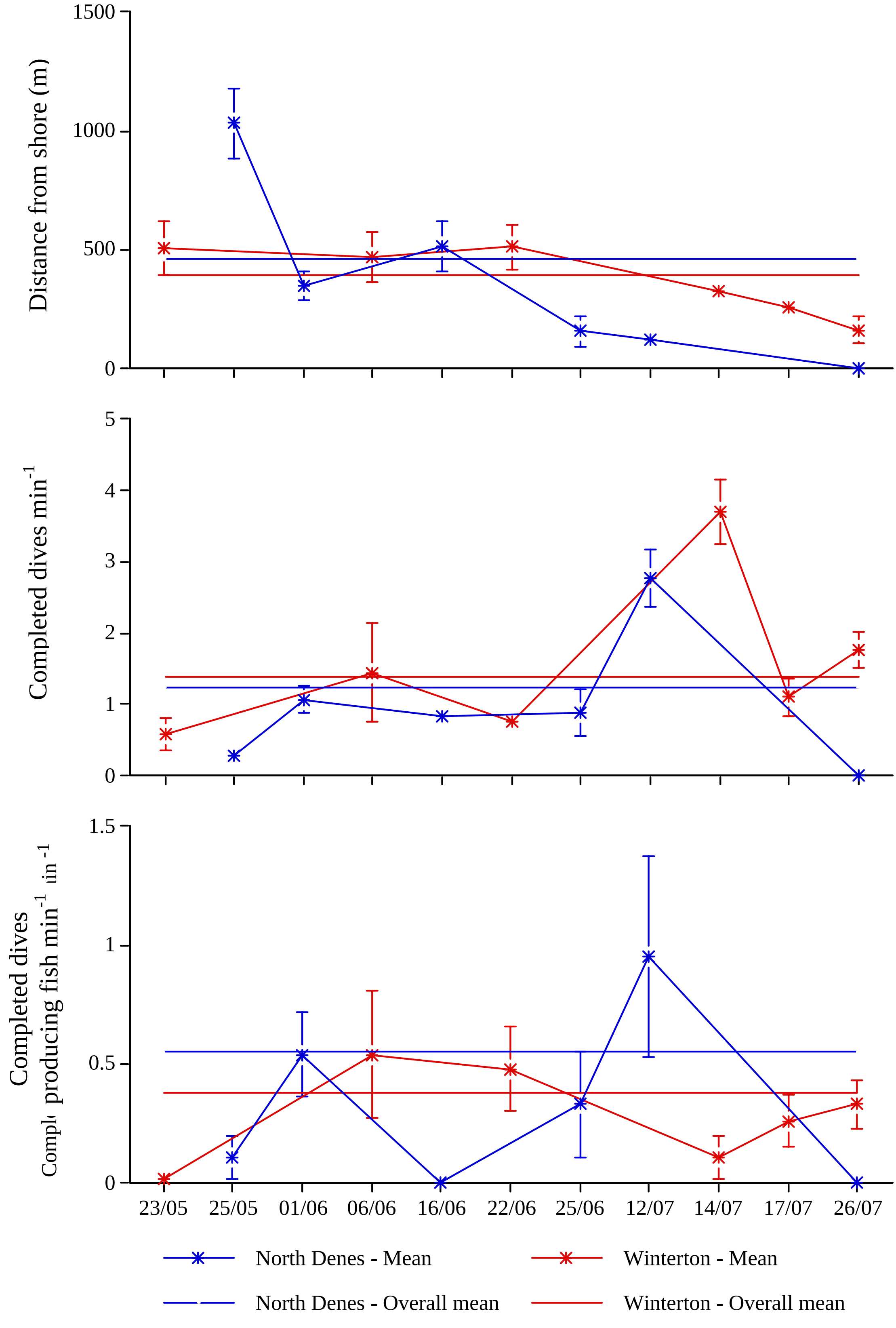

Figure 12. Mean (±1SE) foraging distance from shore, completed dives and completed dives producing fish by Little terns at the North Denes and Winterton colonies over the study period in 2004.

Although the latter two values were also significantly different from each other, the magnitude of 100 m or so may be of little meaning to a fast flying bird capable of covering this distance in around 5 seconds[4].

In contrast to North Denes, birds at Winterton foraged at similar distance from shore in all years (Table 19). In 2004, the overall mean value was 392.3 m compared to 277.2 m in 2003 and 319 m in 2002. The distance of around 300-400 m offshore corresponds to the position of an extensive and dynamic (i.e. this may shift position within, and particularly between seasons) sand bar at Winterton favoured by foraging birds. As a result of this feature, there has been no significant seasonal variation in foraging distance at Winterton over the years (Table 19). As birds at North Denes also tended to forage at around this distance in 2004, there was no difference according to site in this year unlike previous years (Fig. 15, Table 20).

Table 19. Seasonal variation in foraging distance from shore, the rate of completed dives and dives producing fish exhibited by birds at the North Denes and Winterton colonies in 2004, as revealed by Kruskal-Wallis tests.

	North Denes				Winterton			
	KW χ^2	N	P df=4	Location of differences[a]	KW χ^2	N	P df=5	Location of differences[a]
Distance from shore	40.46	75	***	1 > 2, 4, 5	9.30	82	ns	–
Completed dives. min^{-1}	36.61	84	***	5 > 1, 2, 4	28.73	89	***	4 > 1,2,3,5 6 > 3
Dives with fish. min^{-1}	11.06	60	ns	–	4.87	64	ns	–

ns=not significant ***=p<0.001 [a](post hoc p<0.05)

Table 20. Inter-annual variation (from 2002-2004) in foraging distance from shore, the rate of completed dives and dives producing fish exhibited by birds at the North Denes and Winterton colonies, as revealed by Kruskal-Wallis tests.

	North Denes				Winterton			
	KW χ^2	N	P df=2	Location of differences[a]	KW χ^2	N	P df=2	Location of differences[a]
Distance from shore	59.61	198	***	04 > 02, 03 03 > 02	1.62	275	ns	–
Completed dives. min^{-1}	23.08	221	***	02 > 03, 04	12.19	284	**	02 > 03, 04
Dives with fish. min^{-1}	25.65	179	***	04 < 02, 03	18.90	230	***	04 < 02, 03–

ns=not significant **=p<0.01 ***=p<0.001 [a](post hoc p<0.05)

[4] estimated from the maximum flying speed of 74 km hr^{-1} recorded by bird 12 during radio telemetry

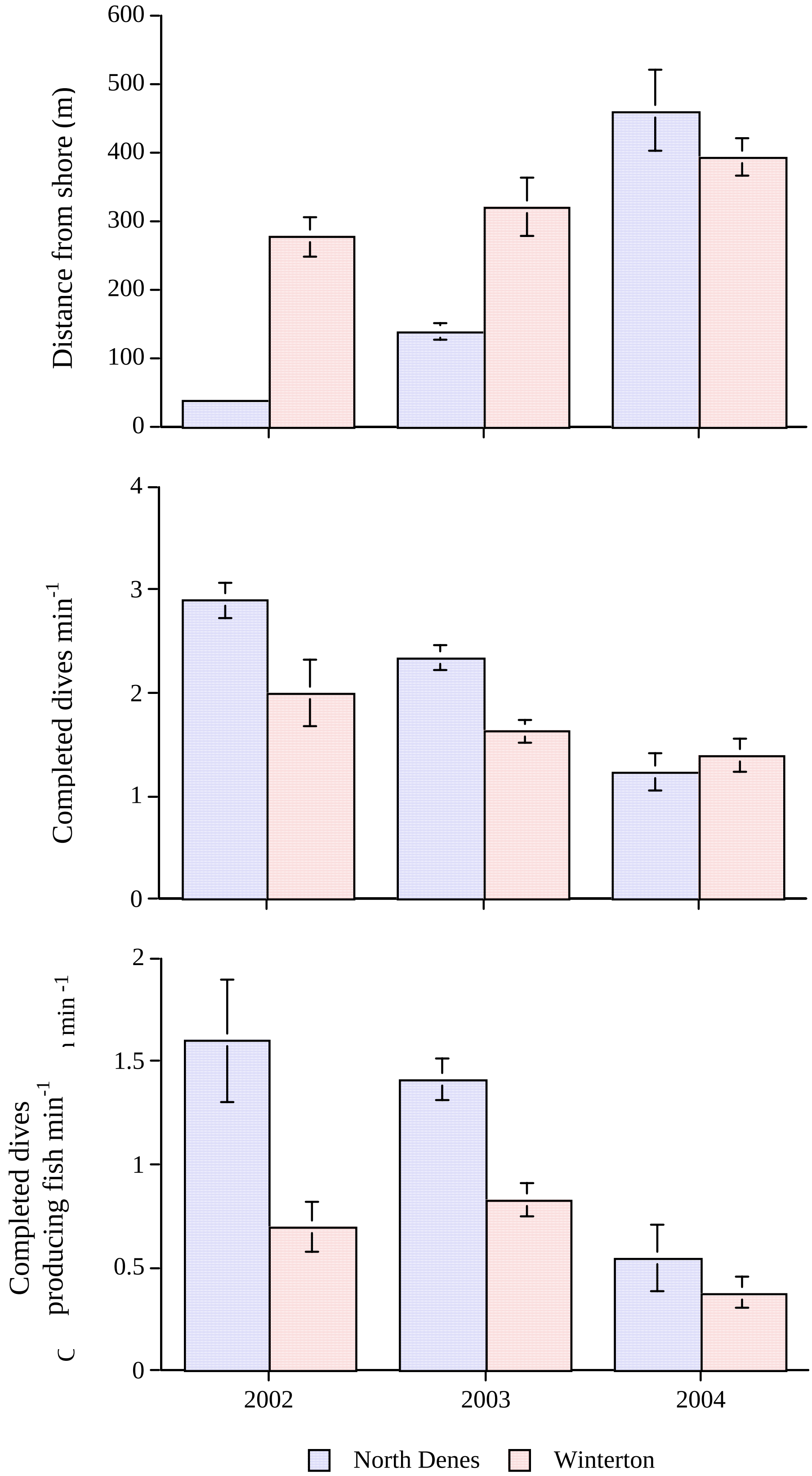

Figure 13. Inter-annual variation in foraging distance from shore, the rate of completed dives and dives producing fish exhibited by birds at the North Denes and Winterton colonies throughout the study. Mean (± 1 SE) values are shown.

Table 21. Within-year differences in foraging distance from shore, the rate of completed dives and dives producing fish between birds at the North Denes and Winterton colonies throughout the study, as revealed by Mann-Whitney U-tests.

Year	Foraging parameter	N	Z	P
2002	Distance from shore (m)	135	-8.271	***
	Completed dives min^{-1}	134	-2.125	*
	Completed dives with fish min^{-1}	134	-2.860	**
2003	Distance from shore (m)	181	-4.117	***
	Completed dives min^{-1}	170	-1.874	ns
	Completed dives with fish min^{-1}	156	-1.919	ns
2004	Distance from shore (m)	157	-0.586	ns
	Completed dives min^{-1}	173	-0.602	ns
	Completed dives with fish min^{-1}	124	-0.922	ns

ns = not significant *=p<0.05 **=p<0.01 *** = p<0.001

5.7.2 Dive and prey capture rates

The number of completed dives min^{-1} varied significantly at both North Denes and Winterton being at its peak in around mid-July (Table 18, Fig. 14) corresponding with the seasonal pattern in fish abundance (Fig. 8). This upheld the pattern seen in 2003, when dive rate was also broadly in line with fish abundance, although the peak of both was earlier in the season.

There was no significant seasonal variation in the dives producing fish min^{-1}, and apart from a rise to around 1 min^{-1} at North Denes in mid-July as expected from dive rate and fish abundance data (Table 18), it was best described as low throughout the season (means of 0.55 and 0.38 at North Denes and Winterton respectively). Indeed, the rate of dives producing fish min^{-1} was highly significantly lower than any recorded in the previous years of the study (Table 19), with this being most marked at North Denes (Fig. 15).

However, whilst the completed dives min^{-1} (means of 1.24 and 1.39 at North Denes and Winterton respectively) were significantly lower in 2004 than in 2002 at both sites, these were more or less comparable with values in 2003. There was thus some discrepancy between dive rate and fish abundance, with by far the best year for fish (Fig. 8) not producing the highest dive rate values.

As in 2003, there was no difference in dive and prey capture rates between North Denes and Winterton, suggesting prey were equally available at both sites within the two years (Fig. 9), although radically different in density between years, with abundant prey in 2003 and very few in 2004 (Fig. 8).

6. DISCUSSION

6.1 Understanding Little terns

6.1.1 The historical context of the North Denes and Winterton colonies

Little terns have been known to nest in the Horsey-Winterton area since 1919 with 20-40 pairs documented by Riviere (Taylor, 1999) and 31 nests documented in the Transactions of the Norfolk & Norwich Naturalists Society. Fifty to 60 pairs returned in 1920 but ‘the nests were robbed [of eggs] by young boys’. Thirty pairs nested on shingle swept inland of a breach of the Old Hundred stream by a severe storm in 1938. By 1967, the colony had moved towards Winterton, growing to 90 pairs by 1972, the second largest in the county behind Blakeney Point. With increasing human pressure the colony declined and by the early 1980’s <10 pairs were present, reducing to only sporadic occupation in the 1990’s. For similar reasons, a small colony between Winterton and Hemsby, which held 20 pairs in 1985, had been deserted by 1990.

Riviere noted that Little terns have been known to attempt to nest at Caister since the early 20th Century but the nests were invariably robbed by collectors (Taylor, 1999). A few pairs (up to 8 in 1955) continued to try and nest during the 1950’s, with little success. In contrast, Little terns were not known to nest at Yarmouth until World War II when human activity was restricted. A large colony was established in 1945. After the removal of the mines and barbed wire in peace-time from 1946, some birds were displaced to Scroby sands, which was then permanently exposed as an offshore island, except at times of storm and extremely high tides. A few pairs (maximum of 9) intermittently attempted to breed at Yarmouth between 1950 and 1983. On Scroby, 27 pairs were present between 1948 and 195. The island was submerged in the year of the Great Flood in 1953 but reappeared again in 1954. Breeding resumed in 1955 with up to 15 to 1963 (Taylor, 1999). Even then, success appeared to be generally limited as a result of high tides. A switch to the North beach (North Denes) occurred following the submerging of Scroby in 1965, although 15 pairs were present in 1976 when it appeared for the last time.

At North Denes, the terns enjoyed little success until 1983 and 1984 when part of the beach was fenced off to allow a sewage pipe to be laid. Successful nesting and fledging of young then occurred. It seemed clear that human disturbance was the primary factor influencing breeding success, and with fencing and proactive wardening and protection by the RSPB from 1986 onwards, North Denes rapidly became the premier nesting site for Little terns, not only in East Anglia, but also the UK. At its peak in 1991, the colony contained 277 pairs and throughout the 1990’s to 2001 regularly supported >200 pairs. Judging from the data from the Seabird 2000 surveys (a joint monitoring project between the RSPB, JNCC, Birdwatch Ireland Seabird Group and SOTEAG) (RSPB 2002), the colony supported some 11% of the Little terns in the UK in 2000. At that stage, Little terns had declined nationally by some 27% since 1985-1987 (N. Ratcliffe RSPB, *pers comm.*; RSPB 2002). This decline may well have continued, as in 2002, reports of just 1396 pairs at most larger colonies were received by the Little tern group at the RSPB (S. Schmitt *pers comm.*).

The level of success at North Denes has varied wildly over the years, with the number of young fledged per pair ranging from 0 to 1.74 (Table 22). The highest number of chicks fledged was 336 in 1998. In contrast, in 1991, despite successful egg laying, up to 96% of chicks were taken by Kestrels (Durdin, 1992). Total failure was also reported in 1996, with high tides, fox predation of at least 65 nests, followed by predation of all chicks by Kestrels (Joyce & Durdin, 1997). Although losses of eggs and chicks to periodic high tides occurs, it is predation by foxes, hedgehogs, cats and particularly Kestrels that has emerged as a key issue determining the success of the colony. This led to a programme of supplementary feeding of white mice at known Kestrel nests and the use of artificial shelters against predation for Little tern chicks. Whilst the former practice has been suspended as a result of further research questioning its efficacy (Smart & Ratcliffe, 2000), the latter continues.

Table 22. Status and production of the Little tern colony at North Denes from 1986 to 2004 whilst under RSPB protection. Data adapted from Allen Navarro *et al*. (2004).

Year	Number of pairs	Young fledged	Productivity (chicks per pair)	Cumulative productivity
1986	55	95	1.73	1.73
1987	70	96	1.37	1.53
1988	140	244	1.74	1.64
1989	180	160	0.89	1.34
1990	210	15	0.07	0.94
1991	277	12	0.04	0.67
1992	249	176	0.71	0.68
1993	168	105	0.63	0.67
1994	230	203	0.88	0.70
1995	241	126	0.52	0.68
1996	197	0	0	0.61
1997	191	142	0.74	0.62
1998	216	336	1.56	0.71
1999	200	79	0.40	0.68
2000	220	36	0.16	0.64
2001	265	103	0.39	0.62
2002	98	5	0.05	0.60
2003	10	2	0.20	0.60
2004	40	0	0	0.59
Total	**3257**	**1935**	**0.59**	
Mean	**171.4**	**101.8**	**0.64**	

In 2002, vandalism on 31st May resulted in the loss of 98 nests and led to the displacement of most birds to Winterton. Ultimately, only a small number of pairs (c. 7) managed to persist and fledge chicks (c.5) (Manderson & Mead, 2002; ECON, 2003). In 2003, low-flying helicopter patrols seemingly prevented the establishment of birds and just ten pairs ultimately nested fledging just two chicks. This was the lowest number of nesting birds since 1983 (Mavor *et al*., 2004). In 2004, despite 40 nests being put down during the season no chicks were fledged (Allen Navarro *et al*., 2004). Indeed, only one clutch of eggs is thought to have possibly hatched chicks, with all other nests lost at the egg stage (see 5.1.1 above). Predation, particularly by foxes, accounted for at least 55% of the nests and may also have contributed to the 30% lost for unknown reasons, with the remainder simply abandoned (7.5%) and lost to high tides (2.5%). Overall, it is clear that an interventionist approach focused on control of predators and human disturbance is required to maintain some modicum of success at the North Denes colony.

During this 1990's, there was an increase in the number of pairs attempting to nest at Winterton (and Bramble Hill just to the north) from 0 pairs in 1993, 2 in 1994, 6 (raising 3 young) in 1996, 14 in 1997, 16 in 1999, 45 in 2000 and 127 in 2002 (Skeate *et al*., 2004)[5]. Success was limited by high tides in 1997 and 2000, but otherwise, other causes of loss at the egg stage were important and predation and/or disturbance by people and their dogs were implicated. In 2002, at least 124 pairs (at Winterton) fledged at least 58 chicks (S. Schmitt RSPB, *pers comm*.), with this success paling into insignificance in relation to the 233 pairs and 447 young fledged in 2003. The latter was the largest production of chicks in a single colony in the UK since records began in 1969 (Mavor *et al*. 2004). Of the eighteen colonies monitored supporting a total of 851 pairs, Winterton contributed 27% of the pairs but 39% of the fledged chicks in 2003. The only other colonies producing over 100 chicks were Hamford Water in Essex (170), Kilcoole in South-East Ireland (177) and Gronant in North Wales (195), the latter also enjoying its best year ever.

Should birds fledged from Winterton survive to breed, the potential impact of this recruitment event on Little tern populations in the future is enormous, and with the longevity of Little terns, may be felt for decades. This is reinforced by the site fidelity of the birds controlled throughout this study, with all ten (four in 2002 and six in 2003) ringed as pulli at North Denes from 1988-2001. Taylor (1999) also documents another individual that was recovered at its natal site in Norfolk 17 years after ringing. These combined records buck the trend suggested by Taylor (1999), that birds move from natal sites to breed, as this was based on the control of just one particular individual produced in Norfolk that was found breeding in the East Fresian Islands Germany in several years.

6.1.2 Factors affecting colony formation

Nesting habitat

In the UK the Little tern has generally been thought of as an essentially coastal species, breeding more or less exclusively on sand and shingle or perhaps most appropriately on a combination of the two (Avery, 1990). Moreover, the focus on particular sites has perhaps led to the implication that substrate type is in some way limiting and more importantly, that this is the prime factor driving the location of colonies.

In a summary of the habitat requirements of Little tern in a publication outlining conservation status of important European species Tomialojc (1994) describes the

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[5] No data was available for 2001, although the lack of wardening suggests few, if any pairs of birds nested.

nesting habitat of Little tern as occurring '*in open areas adjacent to fresh, brackish or marine waters, preferably on islands or peninsulas either on coastal sand, shingle or shell beaches or sandy islets on larger rivers*'. Further, Catry *et al*. (2004) cite the importance of saline lagoons (salinas) as increasingly important habitat for Little terns. Whilst dense vegetation is generally avoided, birds have also been recorded using low crops such as fields of sugar beet or barley (Tomialojc, 1994) and in North America the species has been recorded nesting on extensive flat roofs of buildings (Cramp & Simmons, 1985). Indeed, artificial habitats such as gravel-topped rooftops and artificial islands have been widely and successfully used for Least tern in the USA (e.g. Krogh & Schweitzer, 1999). The use of dredged spoil has recently been recognised as a tool for the conservation of Little terns in particular areas of the UK (Charlton *et al*., 2004). It is of note that on soft (silty) dredged spoils at Horsey Island, 102 pairs of Little terns nested amongst dense vegetation (to 30 cm tall) in 2000. In 2001, the silt was recharged and no plant growth occurred and only around a dozen pairs utilised the site thereafter. The seeming preference for vegetation is thus at odds with the general statements of Tomialojc (1994). Similarly, the continued encroachment of marram grass *Ammophila arenaria* at North Denes perceived as detrimental (Wooden *et al*. 2003), has not apparently changed the focus of Little terns on the site.

From this simple review of nesting habitat it seems clear that Little tern is a relatively adaptable species in its nesting requirements and what is readily accepted at one colony may not be used at another. It thus seems likely that it would be extremely difficult to predict whether Little terns will nest at a site or not solely based on its habitat characteristics, with much apparently suitable, or at least not unsuitable, habitat being unoccupied. From this, it must be concluded that other factors are likely to be of greater importance in driving colony formation.

Human disturbance and predation

A number of factors such as human disturbance, predation or high tides are clearly important in determining the success of a colony (see 6.1.1) above. From this, there is a perception that human disturbance and predation has forced Little terns into larger and larger colonies, with birds learning from experiences in previous years and then choosing to avoid sites. This is not borne out by the pattern at North Denes, with birds nesting in successive years despite complete failure in any one year as a result of disturbance, high tides or predation of both eggs and/or chicks. In recent times at least, nesting at Winterton appears to have been in response to the failure or displacement of birds at North Denes. For example in 2002, vandalism on 31st May and the loss of many nests led to the attempt at Winterton by 14th June in 2002. In 2003, after a successful year at Winterton in 2002, birds amassed at North Denes seemingly in preparation to breed, before being displaced by low-flying helicopter patrols for a missing child, with nesting commencing on 22th May at Winterton. Even in 2004 after the most fantastic successful year in 2003, birds did not automatically set up at Winterton and the available evidence suggests that nesting was triggered by the presence of protective fencing and also perhaps by the loss of the initial nests at North Denes (28th May, 6-7th and 7-8th June).

It thus appears that North Denes and the surrounding Scroby area remains the first choice for nesting Little terns over Winterton and the Would. As argued in the previous report (ECON, 2003), this does not appear to be related to the nature of the beach, which is generally unremarkable and is even thought to be reducing in its suitability with the encroachment of marram grass (Wooden *et al*., 2003). The generally high potential for human disturbance, predation and high tides at North Denes is intuitively difficult if not impossible for a non-resident species to arrive after migration and predict to assess in advance the level of disturbance, high tides and especially predation that might occur later in the season. This is particularly true if predators switch to tern eggs or chicks, as they become available, as is the evidence for Kestrels (Smart & Ratcliffe, 2000). Birds must be expected make a choice of nest site on tangible, assessable parameters. Whilst previous experience may help determine future events, with birds remembering the outcome of previous nesting attempts it is perhaps to be expected that birds will make a fresh decision when they return from their wintering grounds. After all, as a species Little terns are adapted to an ephemeral habitat, subject to changing coastal conditions and thus exploit suitable beach areas as they become available. Little terns are seabirds which migrate around 5000 km to the coast of West Africa in the waters of Guinea-Bissau, Ivory Coast and Ghana to over-winter (Wernham *et al*., 2002) and must be considered to be highly mobile and well able to judge the quality of beaches elsewhere by sampling a wide area within a historically preferred area before committing to a site. After all, having failed at North Denes, birds quickly establish at Winterton. Further, in 1997 a bird from Zeebrugge, Belgium was also recorded at Winterton, apparently having failed at its normal site.

However, this is not to say that should predators be immediately obvious or human disturbance be rife, then birds will not use these obvious cues (as above at North Denes). It seems impossible that birds could nest at North Denes without protection and the fences tend to be erected immediately prior to first nesting. Although at Winterton protection with fences has generally not been initiated until birds have started nesting, despite the presence of people and their dogs. It therefore seems that birds may exert a strong preference for particular sites and be willing to attempt nesting at disturbed sites. Conversely, would protecting apparently suitable nesting habitat from all humans and potential predators lead to successful nesting? Whilst this clearly happened at North Denes in the past (see 6.1.1 above), the case could be made that birds wanted to nest at Nest Denes but were previously prevented by the high levels of disturbance. Thus, it seems unlikely that birds could be ‘pulled’ to convenient sites outside historically preferred areas. The key seems to be to understand why some areas are preferred.

Available food supply

So, if nesting habitat fits within a broad spectrum of suitability and if disturbance and predators are not immediately obvious, as they are unlikely to be in early season when human use of the beach is generally at a low level (Skeate *et al*., 2004) and predators are not attuned to the potential prey source, then what is the main factor driving colony formation? The obvious factor is food supply as argued by Perrow *et al*., (2004).

Little tern is adapted to foraging on small prey (maximum 9 cm and typically 3-5cm), close to the surface and does not appear particularly fussy about the type of prey being documented feeding on all manner of fish and invertebrates (Cramp &

Simmons, 1985). However, with their higher energy and protein and fat contents, fish are likely to be preferred as food, especially for chicks (Phalan, 2000). This is mirrored by the dominance of chick diet by young-of-the-year (YOY) clupeids in the first two years of this study (ECON, 2004). These fish also dominate the spectrum of available prey in the study area and are thus seen as the mainstay of Little tern reproductive success in north east Norfolk (ECON, 2004). The extravagant display of flying birds carrying fish and the presentation of fish during courtship underlines the value of fish to Little terns and both actions are suggested to act as highly visual signals to other birds and advertise the quality of the foraging area and help trigger colony formation.

Prey studies throughout this study reinforced the concept that North Denes (Site 10) and the inshore waters of Scroby in general (e.g. Site 11 at Caister), support the highest densities of fish, particularly clupeids, in the Scroby-Would area stretching to Eccles (Fig. 9). Moreover, samples taken during the pilot study upon breeding tern foraging ranges in North-West England and East Anglia (Allcorn *et al*., 2004), showed that fish density was generally low in all other sites surveyed in North Norfolk as well as at Gronant in North Wales. In addition, clupeids were absent in samples in North Norfolk and tows undertaken on the way back to dock at Gorleston indicated that the young-of-the-year (YOY) clupeids taken by Little terns were only present south of Cromer (P. Lines *pers. comm*.). This fits neatly with what is known of the spawning distribution of both Herring and Sprat (Coull *et al*., 1998).

A stock of Herring is known to spawn between November and January along the east coast of Norfolk extending into Suffolk, with the northern limit of this spawning distribution apparently extending to Great Yarmouth (Fig. 14-A). The nursery area for these fish appears to extend from Scroby in the north to the Thames estuary in the south (Fig. 14 -B). In contrast, Sprat spawn offshore in May-August in a broad swathe around the coast with the closest point to the Yarmouth area (Fig. 14-C). The nursery zone completely avoids the Wash and North and North-East Norfolk with its northern limit seemingly just to the south of Yarmouth (Fig. 14-D).

From these known distributions and judging from the small size of the individuals of both species encountered in the samples (i.e. <30 mm), prior to metamorphosis of the larvae into juveniles, there is a strong suggestion that Scroby forms a nursery ground for both these species. The suitability of Scroby in relation to the Would, may be directly related to the very different form and structure of the two systems. The North Denes colony sits alongside a deep channel (Yarmouth Road) flanked to the east by the dynamic sand bank system of Scroby Sands themselves. This creates a strong tide, which may effectively empty and flush this system twice daily. This is likely to enhance the already potentially high productivity of the large extent of shallow waters, which in turn may favour algal development and thus the zooplankton prey (principally calanoid copepods**)** of both species. In contrast, Winterton beach initially grades very slowly out to sea. However, this band of shallow water is narrow and around 1km offshore, moderate depth of 20-30m is achieved, dominated by extremely clear water, which clearly does not support dense algal populations and probably few zooplankton and thus fish. Moreover, any fish present in this zone may be unwilling to inhabit the upper layers, where they may be vulnerable to attack from the air.

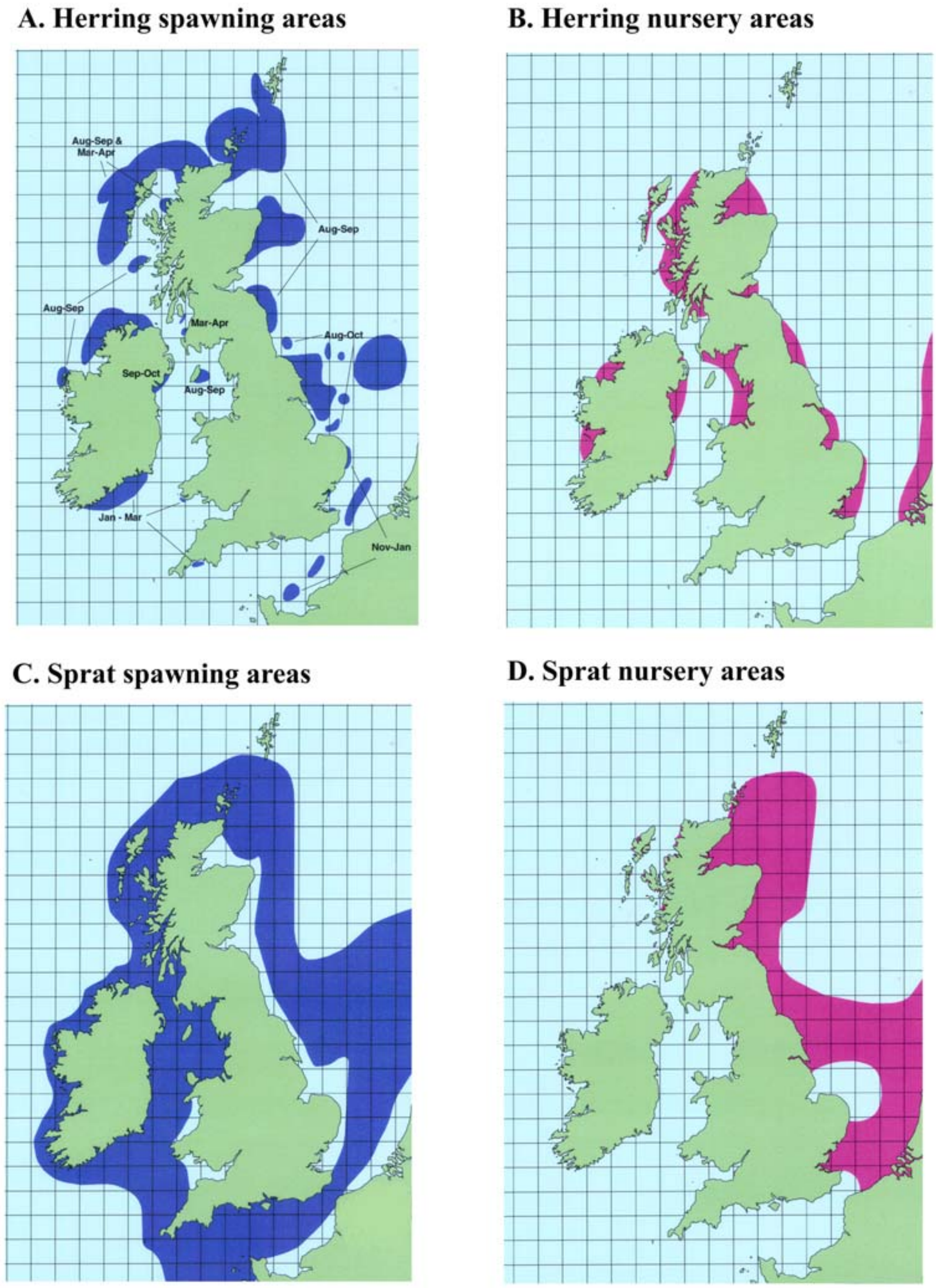

Figure 14. Known spawning (blue) and nursery (pink) areas of Herring (A & B respectively) and Sprat (C & D respectively) around the coast of Britain. Adapted from Coull *et al*. (1998).

Despite extreme inter-annual fluctuation (Fig's. 8 & 17 and see 6.1.1 & 6.1.5 below), the magnitude of the difference between years was far less at Scroby (c. 13-fold) than at Winterton (c. 400-fold), although care must be taken in interpreting the difference between 2002 and 2003 at Winterton as fish may already have declined by the time sampling had begun. Even so, there is a strong suggestion that Scroby is less likely to suffer extremes of inter-annual variation, being the optimum habitat, whilst Winterton is more transient habitat, occupied extensively only in exceptional years such as 2003 (Fig. 9). The fact that Hemsby supported a fraction of the fish found at Winterton in 2003 and other sites along the coast sampled in 2002 and 2004 also supported few fish, reinforces Winterton as the second best site behind Scroby (especially North Denes and Caister).

This makes the underlying, intuitively sensible, assumption that Little terns will select nesting grounds as close as possible to the principal foraging grounds. Although clearly capable of wide-ranging movements, small body size – being by far the smallest of the *Sterna* terns at just 60% of the size of Common tern – coupled with a rapid stiff-winged flight action and foraging technique of frequent hovering and diving, means that Little terns are likely to expend a lot of energy and have high metabolic demands. These factors coupled with relatively short wings (40% shorter than Common tern) mean that it is not apparently geared to travelling extremely long distances (>10–50 km) in search of food like larger terns. Moreover, as it is also unable to carry more than one fish at a time to chicks, and as prey are typically small, a relatively high feeding rate is likely to be required. It thus makes sense if the colony is located as close as possible to a high quality, dense food source. The patterns of movements of radio-tagged Little terns in 2003 and 2004 showed that nesting (all birds in 2003 and birds 9.4 and blue-grey in 2004) birds appear to be effectively tied to home ranges of between 2.2-6.3 km^2 (215-628 ha-Table 17), with a range span of 2.3-4.6 km. There is remarkable consistency in these figures given the differences in available prey density between years and nest site location and three is broad agreement with the general foraging distance figures of 1.5 km offshore and up to 6 km from the colony documented in Cramp & Simmons (1985). However, non-nesting/failed birds, which are no longer central-place foraging (i.e. from a nest) can clearly occupy (relatively) huge ranges, with birds in 2004 having home ranges from 1.9-53 km^2 (mean = 19 km^2) with a range span of 2.3-17.5 km (mean = 11.2 km).

Despite the fact that the maximum distance recorded traveling in a single foraging bout was 9.4 km (male bird 11.7 in 2003), the mean value for all birds in 2003 was just over 2 km, in close agreement with the values for nesting birds in 2004 (Table 14). It could be that the energetic constraints limit nesting birds to rather small foraging distances and ranges with birds having to transport prey back to a partner on the nest in the case of males or to a chick in the case of both sexes. Alternatively, it may not be the distance that is the principal limiting factor but the closely related time spent away from the nest. It may be no coincidence that the two nesting birds in 2004 showed the shortest mean duration of foraging bouts at 8-10 minutes, far shorter than the overall mean of nearly 30 minutes from all birds and close to the mean of 15 minutes for nesting birds in 2003. Long periods away from the nest with a corresponding low return rate of prey is likely to be problematic for the incubating partner, whether they are being fed by the foraging bird or if they need to feed themselves. The incubating partner may thus have to leave the eggs to forage increasing their susceptibility to predators and chilling. When chicks are present, long foraging trips means provision rate declines, perhaps below a critical threshold.

Moreover, on account of small body size, Little tern chicks are highly vulnerable to a range of predators, even moderate-sized avian ones such as Kestrels. Adult defence of chicks may thus be essential. Even if the adults themselves seem relatively ineffective against predators, especially Kestrels, some defence, even just distraction, may be better than none. Spending long periods away from the nest reduces the amount of time adults can spend being vigilant and attacking would-be predators of eggs and chicks. Also, the more Little terns that are present in the colony at any one time, the greater prospect for a predator to be driven off.

To summarise, the quality of the foraging grounds near the colony is the most likely candidate as the principal driver behind colony location, with the considerably higher, less variable availability of prey at Scroby providing the basis for North Denes to be the site of choice. Being some 12 km from Scroby, Winterton is likely to be much too far to be used as a breeding site when prey is not available locally, despite the potential advantages of better beach structure (larger and wider) and perhaps reduced human disturbance and predators. However, when prey is available, Winterton may be an excellent viable alternative and may even be preferred.

6.1.3 Timing reproductive effort

After a suitable location for the colony has been selected on the basis of the available prey resource, birds are then faced with huge seasonal variation in fish density, with populations apparently climbing to a peak before collapsing to very low levels. The situation is further complicated by the fact that the peak in fish density, which itself has varied hugely in scale (Fig.'s 8 & 15), has varied during the study, with an early peak in 2003 and a remarkably consistent (to the week) late peak in 2002[6] and 2004. An investigation of fish growth patterns and reappraisal of identification leads to the conclusion that the peaks in abundance can be contribution to the two different clupeid species. Spawning in November to January in the area (Fig. 14) Herring have reached around 35-40 mm in length by early May when the first survey is conducted (Fig. 16). By the time these fish have reached 45-50 mm by early July numbers have declined dramatically (Fig. 15). The reason for this decline is unclear but may be best explained by fish moving further offshore out of the area to continue their development. This is supported by the decline in foraging success of the birds later in the season (see 6.1.4 below). However, simple changes in behaviour of the fish through sitting lower in the water column below the sampling zone of the net or being better able to avoid the net as a result of increased size and swimming ability may also play a role.

In contrast, Sprat spawn later than Herring, probably in May (judging by the growth pattern) further offshore (Fig. 14). Larvae at <20 mm tend to appear in June (Fig.'s 15 & 16). At this stage, these fish are not capable of active swimming and must reach Scroby as a result of tidal action. Numbers of Sprat tend to reach a peak in July, perhaps as a result of continued drift of larvae into the area. The decline thereafter may be as explained for Herring, with offshore movement to continue their development perhaps the principal cause of the observed pattern.

[6] although care is required to interpret this as sampling was started later in this first year of the study

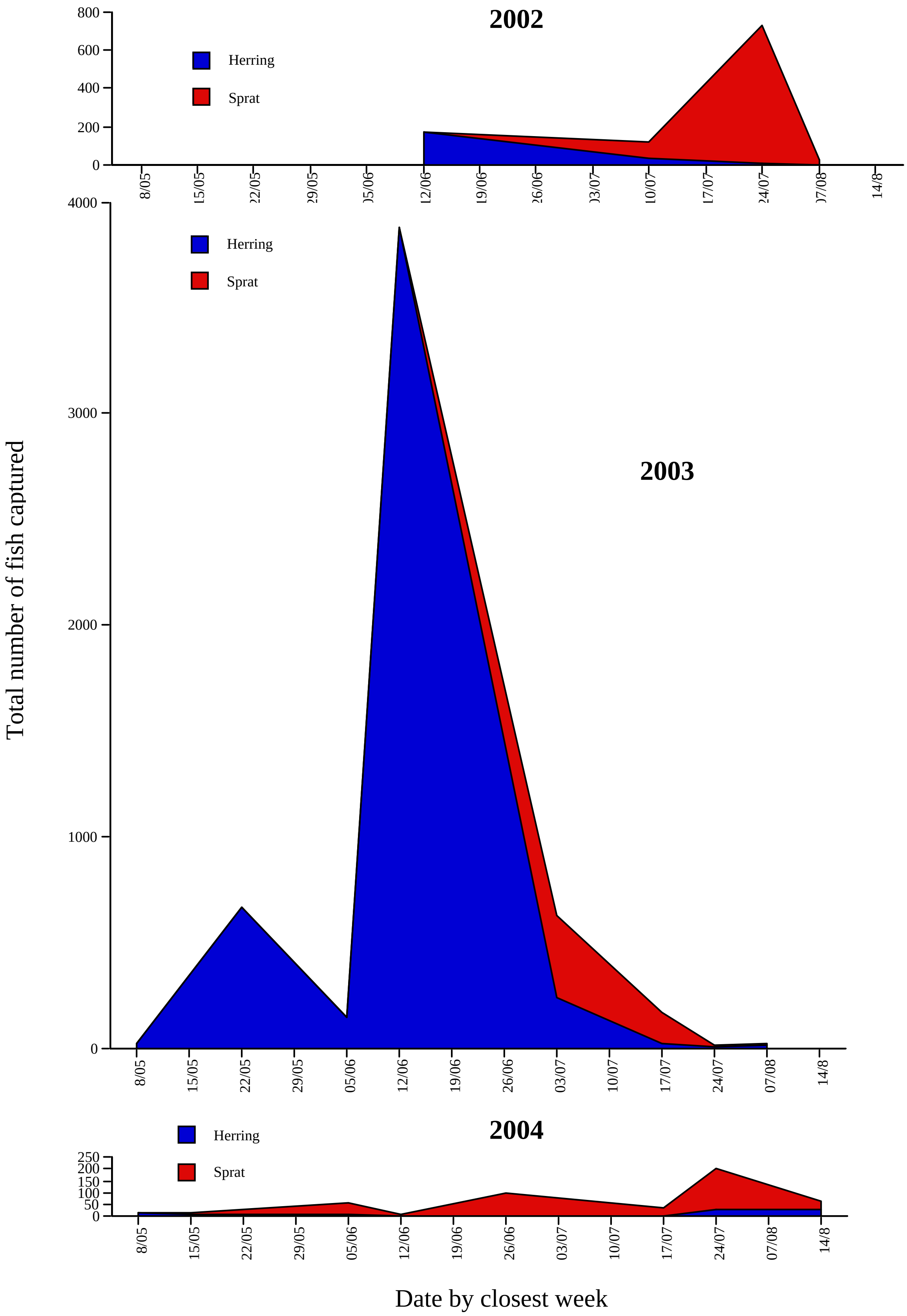

Figure 15. Inter-annual and seasonal (by closest week in which the sample was taken) abundance (all fish captured in all tows) distribution of young-of-the-year Herring and Sprat in samples from Scroby.

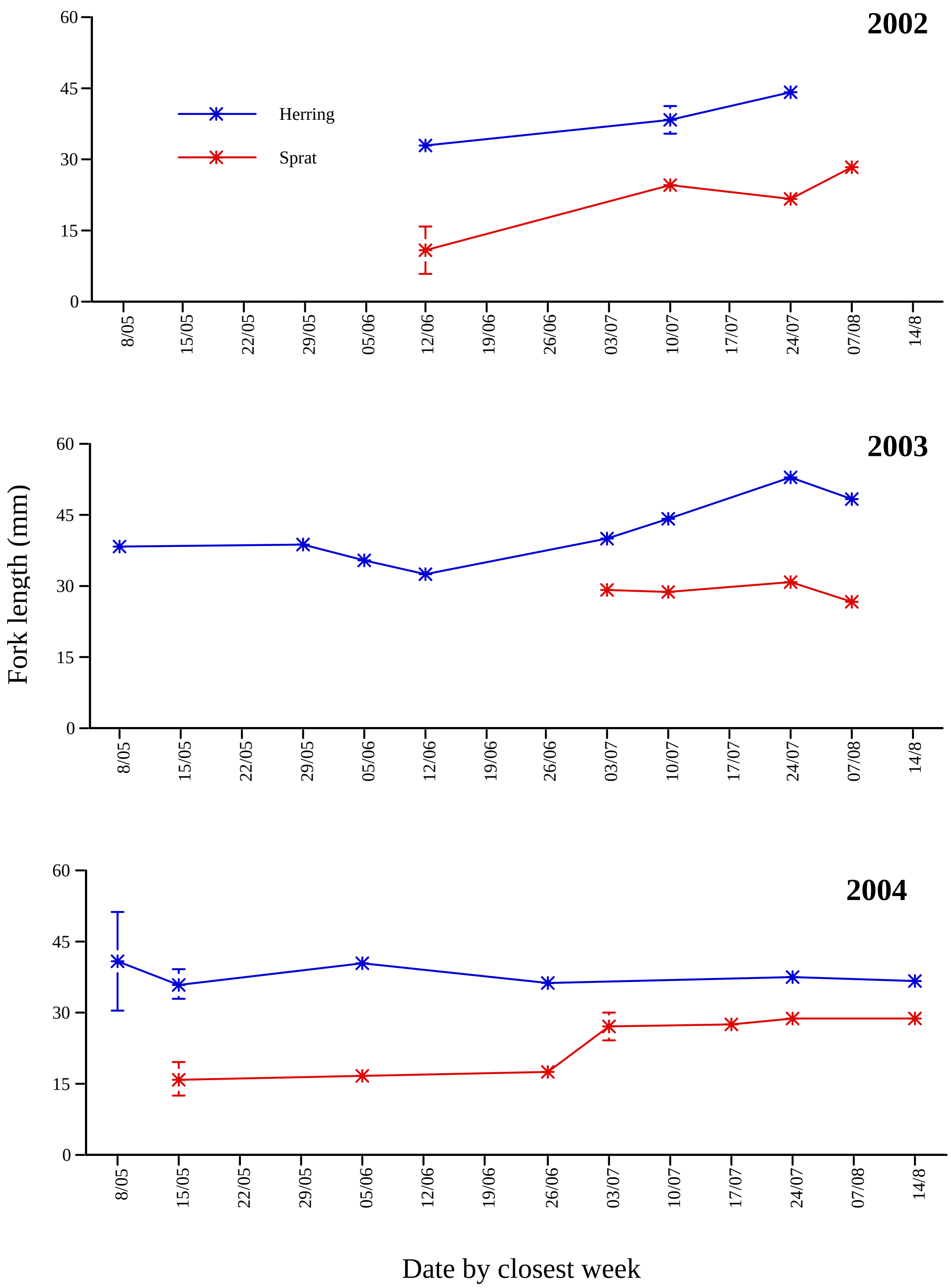

Figure 16. Inter-annual and seasonal (by closest week in which the sample was taken) growth pattern (fork length in mm) of young-of-the-year Herring and Sprat in samples from Scroby.

Little terns thus have a three-month window in which at least some fish are available to feed themselves and any chicks. Birds need to fit in a 18-22 day incubation period (Cramp & Simmons, 1985), followed by a chick fledging period of 19-20 days. Although the male has a number of mouths to feed in the early phase of incubation (itself and the female) and early hatching (itself and most of the chicks) and thus takes more of the load at this stage, chick rearing may be seen as the equivalent of each adult feeding two mouths (itself and one chick in a brood of two). However, the total biomass of food required and the demands exerted on each adult increase during the chick development period. This means the demand for prey increases and it may be critical to ensure that chicks are fledged before prey density collapses if birds are to avoid a metabolic knife-edge of finding enough food for all.

Thus, if birds fail in their first attempt as a result of predation or a high tide, they are at risk of trying to raise chicks in a period of reduced fish density. This has particular consequences if they also change site. The chances are that the best site for fish was selected in the first place and the new site may have even fewer fish. This means that if birds are going to fail or even abandon a site, they will intuitively have a better chance of ultimately raising chicks if this happens early, giving them time to attempt to re-nest and raise chicks whilst food can still be found. In the current study, this may have been the key to the success at Winterton in 2003. Abandoning North Denes and nesting before the end of May meant that birds were fledgling chicks by early July, as prey density rapidly declined in that year.

At North Denes, birds have become remarkably synchronised over the years, usually having established nests with eggs by mid to late May. Following incubation, chicks have usually hatched by the first or second week of June. The typical chick fledging period of 19-20 days thus coincides exactly with the observed peak in young-of-the-year Herring. In 2004, with very few Herring, the peak nesting period was as late as early July (see 5.1.1 and 5.1.2 above). On one hand it may be that re-nesting birds inevitably tend to coincide with the late, reduced food supply offered by Sprat, or alternatively it may be that at least some birds in 2004 deliberately delayed breeding in an attempt to coincide with the peak occurrence of Sprat. Synchronisation between breeding and prey abundance may be achieved by birds continually sampling the food supply with the size of prey (perhaps amongst other cues) indicating the species of fish.

6.1.4 Factors influencing foraging success

Successful foraging is the product of a relatively complex process involving searching for, locating and capturing prey. A wide range of factors may play a role on each stage of this process resulting in large differences in success. Such factors are likely to follow a hierarchy of importance, with those influencing subtle differences in efficiency likely to be some way down the list. For species such as Little terns, which appear to be extremely efficient, that is, they hardly seem to miss prey once it has been encountered, foraging success is likely to closely mirror prey abundance or more specifically availability, which varies between seasons, within a season and within a day.

As to be expected the huge variation in fish abundance between years and between sites (from 13 to 400 fold at North Denes and Winterton respectively) is broadly in line with what would be predicted. For example, the rate of attacks (dives) resulting in fish capture at either site was significantly lower in 2004 than in any other year. Moreover, the rate of dives producing fish was significantly higher at North Denes compared to Winterton in 2002 when prey were more abundant at the former, rather than in 2003 and 2004 when prey density was broadly equally high and low respectively.

There are clear energetic advantages in foraging as close to shore as possible, to search for prey for a short a time as possible and to maximise the number of successful dives, particularly when capturing important prey i.e. fish. In 2002, with greater availability of prey at North Denes compared to birds foraged significantly closer to the shore which coupled with a higher capture success, led to a significantly higher capture rate. The number of dives of 2-3 per minute was towards the lower end of the range of 1-7.3 for the species (Cramp & Simmons, 1985), which may have been a function of the relative ease with which terns catch prey in the area. In 2003, again in accordance with a general increase in prey availability and particularly at Winterton relative to North Denes, although birds still foraged significantly closer to shore at North Denes, there was no detectable difference in dive and fish capture rate between the two sites.

Data from radio-tagged birds in 2003 and 2004 closely agrees with that expected in relation to the general lack of fish, particularly Herring, in 2004. Although partly confused by the fact that most birds were not associated with nests in 2004, birds foraged for significantly longer time periods (c. 2-fold) and travelled significantly further (c. 2.5 fold). Despite most birds being relieved from nest duties they seemed to have to spend more time foraging; an average of 72% compared to 56% in 2003, perhaps simply to meet metabolic demands.

Despite general close agreement between prey abundance and foraging success there are a number of anomalies. For example, the rate of completed attacks does not follow the same inter-annual pattern as the rate of dives producing fish as the highest overall dive rates were not achieved in the year of most abundant fish. This may be testament to the fact that birds may achieve high dive rates simply by switching to other, less profitable prey such as invertebrates. Such prey may be routinely exploited by adult birds, although data from 2003 and 2002 shows that chicks, perhaps apart from very young individuals are rarely presented with such items (ECON, 2004). There are also occasions when invertebrate prey is likely to be particularly important for adults when fish prey are at low abundance at the beginning and end of the season. This is supported by the observations in 2004 when a large number of Little terns (150) were observed feeding on Ghost shrimps some distance offshore. Moreover, the peak in use of Scroby sands themselves at the beginning and end of the season may be linked to the availability of invertebrates, as fish are rarely encountered in these habitats in samples[7]. Recently fledged chicks, which have yet to learn the skills required to catch fish efficiently, may also forage on invertebrates to supplement any fish provided by their parents.

As the rate of completed attacks may be influenced by birds feeding on invertebrates it is strange that this expression of foraging success had tended (certainly in 2003 and 20040 to follow the massive seasonal variation in fish abundance, which overlays and

[7] although this may also be limited by the difficulty in sampling very shallow water

may mask patterns associated with inter-annual variation. Moreover, the rate of dives producing fish does not necessarily track fish abundance. For example, the virtual collapse of fish populations from the beginning of July in the peak Herring year of 2003 did not have quite the predicted effect on foraging success. Although dive rate and fish capture declined at North Denes, it was less variable at Winterton and even increased at the end of the season. In this case, birds were attempting to provision chicks and were seemingly able to compensate for the decline in prey abundance by what may be described as simply working harder. This may include increasing flying speed and traveling greater distances (see above), whilst resting less.

Finally, daily cycles of tide may influence foraging success and obscure general patterns by changing the typical response of the bird. As outlined, some compensation by the bird is to be expected. In 2003, radio-tagged birds flew faster at low tide. This may simply have resulted from birds being more focused on commuting to a favoured area. Sandbanks exposed offshore and also along the shore further down the coast at low tide were thought to be likely targets. Such a pattern of foraging in a particular area according to tide has been shown for Kittiwakes *Rissa tridactyla* (Irons, 1998). Tidal cycle has predictable effects on fish abundance and consequently on the foraging success of their bird predators, including terns. For example, Brenninkmeijer *et al*. (2002) working in the tidal waters of Guinea-Bissau in West Africa showed there was little foraging activity amongst Little, Sandwich and Royal terns *Sterna maxima* at high tide, with food intake rate around 2-fold higher during receding and low tides as during an incoming tide. Moreover, for Little and Sandwich terns, food intake rate was lower in the most turbid waters.

Turbidity is partly a function of tidal cycle – with shallow moving waters likely to have a greater concentration of suspended materials than still waters – as well as wind direction and strength. In the current study, there was a clear relationship between greater turbidity and increased fish catches, which is attributed to fish moving closer to the surface to feed amongst the plankton. Greater turbidity affords greater protection against aerial attack and hence, in the study Brenninkmeijer *et al*. (2002), the foraging intake of birds was reduced. Ironically, for Little terns, this offered greater foraging opportunity and birds aggregated in turbid waters accordingly. It seems no coincidence that the sites with the highest fish densities, sites 10 and 11 (North Denes and Caister respectively), tend to be the most turbid and are located adjacent to, and within foraging range of the North Denes colony. Contrary to turbidity reducing the opportunity for foraging it is argued that it may be an essential prerequisite for Little terns, as it brings their small fish prey closer to the surface where they can be reached by this shallow diving small species. It is anticipated that the inter-relationships between tidal cycle, wind and wave action and turbidity will be a profitable area for future research.

6.1.5 Factors influencing breeding success

The presence of a dense, high quality food supply close by is intuitively an essential prerequisite for successful breeding, although a number of other factors notably disturbance and predation may have great impact. At a national level, the latter in particular been the focus of attention as being responsible for breeding success or failure in Little terns. For example, the RSPB (2002) attribute the long-term chronic decline in Little tern populations to a decrease in productivity, which is argued to be ultimately linked to increase fox predation through an increase in population and range, particularly in East Anglia and eastern Scotland. This is despite what is known for other seabird populations, with a strong correlation of food supply as indicated by the much publicised wholesale failure of breeding seabirds in the UK in 2004 as a result of the collapse in Lesser sandeel *Ammodytes marinus* stocks (JNCC 2004).

Certainly, from historical information (see 6.1 above) there seems little doubt that without limitation of disturbance of nesting terns by humans and their dogs, by means of fencing and wardening, few Little terns would ever be successful in North East Norfolk. Furthermore, particularly at North Denes, there is evidence that egg predation by foxes and hedgehogs is a serious issue and 24 hour protection with regular patrols and the use of electric fences is required to limit the impact of these predators. It is of note that the same level of protection was not required at Winterton, despite it being fringed by a far more extensive dune system likely to contain greater numbers of these predators. However, in the case of foxes at least, it is known that routine and intensive control is routinely undertaken by the estate owners and this may ultimately have a beneficial impact upon Little tern egg and chick production.

On a local scale, predation by Kestrels has also clearly been a major limiting factor of success at North Denes, with Kestrels taking virtually all i.e. several hundred, chicks in some years (see 6.1 above). There is evidence that the extent of Kestrel predation is linked to local populations of small mammals. In poor years for mammals, Kestrels are likely to switch to, and concentrate on Little tern chicks, particularly early in the season when the availability of chicks is at its peak (Smart & Ratcliffe, 2000). However, even when the population of chicks was small in 2003, the loss of at least one near-fledged chick to a Kestrel had a marked impact, reducing the population productivity by 33%. An advantage of high fish prey availability at North Denes may be that adults have time to spend on other activities, particularly defence of eggs and chicks against numerous people and predators, especially Kestrels. Unfortunately, Little terns appear unable to offer effective defence against Kestrels in contrast to larger gulls. Little terns may be more adapted to the latter as they have shared similar habitats over the millennia. In contrast, Kestrels may offer a more recent threat as tern colonies became larger and more fixed and Kestrels learnt to exploit the potential food resource.

At Winterton in 2003, although Kestrels were seen frequently over the colony, particularly at the end of season, there was no evidence of predation. It may be that the extensive dune system offers an adequate supply of small mammals or that the colony is too far from the nearest Kestrel breeding site to offer a viable food source for kestrel chicks. In contrast to Kestrels, a pair of Sparrowhawks frequently attacked the colony and almost certainly took at least some chicks. How many were lost to predation cannot be estimated although an idea of the total losses can be gleaned from estimates of the numbers of chicks alive from ringing returns and subsequent counts of fledglings. For example, with 66 recaptures on the second occasion and 16 on the third; using the Petersen mark-recapture method, the chick population was estimated as 541 following the first set of recaptures on 5th July and 672 on the 12th July using the total number of chicks ringed to date. The apparent increase was probably caused by the small number of birds (35) captured on the final date compared to the second (162), decreasing the confidence in the estimate. Moreover, the population was no longer ‘closed’ by the final date as chicks had begun to fledge. Using only the first estimate in relation to the total fledgling count of 447 suggests that at least 83% of chicks alive at the beginning of July survived to fledge. It thus seems that predation was relatively unimportant and certainly nothing like that seen at North Denes in recent years.

The complete collapse of the colony at Winterton at 2004, tragic though it was, allows an evaluation of the relative impact of the very low fish stocks in 2004, principally the virtual absence of Herring, with other factors such as disturbance and predation.

As outlined above, it is unclear if birds selected Winterton as a first choice over North Denes. Single nests were recorded at North Denes and Winterton at virtually the same time, with the former being lost to a predator and the latter abandoned, most likely as a result of human disturbance. Subsequent nests at North Denes were also lost to foxes in the period 6-8th June. This occurred at the same time as massive disturbance at North Denes, albeit >1 km away from the colony in the form of 'Pop Beach', an event attracting tens of thousands of visitors. With protection at Winterton limiting human disturbance, the number of nests escalated rapidly with 150 present on 14th/15th June. By the next survey, just 10-12 days later, 57% of these nests had been lost, with the bulk of these immediately to the north of the roped-off track through the colony allowing access to the beach. The aggregated distribution of the nests lost is strongly suggestive of a disturbance event rather than birds simply abandoning their nests, which would be expected to be an individual decision spread throughout the colony. The fact that nest loss was concentrated around the path through the colony suggests a human link. However, there is also some evidence of predation. Skeate *et al*. (2004) re-found 13 inactive nests in this area that had been part of a individual monitoring programme. Of these, there was no visible sign of eggs in 10 (77%), although broken eggshell was found at one (8%) and single half-buried eggs were found at a further two (15%). Also, a visit to a cluster of three nests one of which one was still occupied by the partner of radio-tagged bird 3.0, revealed the other two nests were inactive and all eggs (two in each) had gone, with fox/dog prints around one of them. A visit to the nest of bird 9.4 revealed only 1 egg where there had previously been two. Although it is plausible that this had hatched (radio-tagging strongly suggested at least one chick was present a few days later) it is of note that a nearby nest, which had also previously contained two eggs had gone and was also surrounded by fox/dog prints.

There is thus a strong indication that the contents of at least some of the nests were predated, although it is not known how many nests were subject to predation, whether the presence of the predator(s) caused abandonment of non-predated nests or that the contents of previously abandoned nests were taken. Indeed, large gulls flying over the beach would be expected to quickly remove any abandoned eggs. Moreover, if a fox were involved it would be expected to take a large number of nests, unless it was interrupted, in which case it would be highly likely to return (see 5.1.1 above). On balance, although a fox cannot be ruled out it appears that the large-scale disturbance event followed by some limited predation of eggs including elsewhere in the colony was most likely perpetrated by a dog(s).

After this event, some re-settlement of birds apparently occurred in the southward end of the colony and the protective fence was extended as a result. However, this was only temporary respite as a further precipitous decline in the number of active nests was then observed, with only around 40 nests present on the 29th June, with just a handful by the 1st week of July (Allen Navarro *et al*., 2004) and none on the 16th July

(Skeate *et al*., 2004). Again, whilst further disturbance/predation cannot be ruled out, there is a total lack of any supportive observations. Rather, mass abandonment of nests seems more likely. Clearly, birds had not or could not entirely commit to the breeding attempt, with a mean clutch size from 56 monitored nests of just 1.81 eggs, i.e. nearly 0.5 egg per clutch lower than the national standard of 2.3 - Cramp & Simmons, 1985) with only one containing a maximum clutch of three eggs. Birds captured at the nest in 2004 were marginally lighter (3.3%) than in 2003 (mean ±1SE = 53.8 ± 0.8g cf. 55.6 ± 5.1g) reinforcing the suggestion that body resources for egg-laying were at a premium in 2004.

Birds also appeared to be spending relatively little time at the nest. Of the three radio-tagged birds with active nests just two days after tagging[8] occupancy of the nests was more sporadic than it might be, with only 9.4 'focussed' on the nest probably as this bird appears to have subsequently hatched a chick. Over the three hours of observations until dusk, male bird 3.0 did not visit the nest at all although its partner did, and the nest of female 5.5 and its partner was only sporadically occupied by both birds, before being left untended for at least two hours as dusk fell.

Specific foraging observations at Winterton in this period in June indicate that birds were travelling large distances from the colony to forage. Of the 53 birds followed, 34 (64%) were lost at a range of 700-1500 m heading out to sea. Of those, 56% (19) were lost heading south towards the wind farm at Scroby. These observations support the more general trends in foraging, such as i) the significantly lower fish capture rates in 2004 (see 6.1.4), ii) birds in 2004 doubling the length of foraging bouts, flying over twice as far in the process and iii) radio-tagged birds in 2004 extending foraging time to a mean of 72% compared to 56% for birds in 2003. In relation to the latter there was a hint of sex differences in foraging time after failure, with the females 12.0 and 10.2 spending virtually all their time foraging (85.8% and 100% respectively). It is plausible this was a result of them attempting to regain condition after their breeding attempt. In general, radio-tagged birds that failed ranged widely, occupying huge ranges (mean of 25 km^2) compared to the mean of 4.4 km^2 occupied by nesting birds, remarkably similar to the mean of 4.5 km^2 occupied by nesting birds in 2003. Wide ranging is likely to be a direct response to a generally low prey supply and the need to be flexible to exploit patchy resources wherever they become available.

It thus seems that the ultimate factor causing many birds in the Winterton colony to lay few eggs and subsequently abandon them in 2004 was the lack of prey, especially Herring. Birds appear to have been on a metabolic knife-edge of maintaining body condition whilst attempting to breed. However, proximate factors such as disturbance and predation may also have been of importance. For instance, some chicks were hatched at Winterton and it is extremely unlikely that these chicks were abandoned. Judging from the activity of bird 9.4, it appears at least some prey was being captured and being fed to the chick. Once a large number of birds had abandoned, the immediate pressure on a deprived food supply may have been relieved (although birds including radio-tagged individuals, clearly continued to forage in the area) and there conceivably may have been enough prey for at least some pairs to fledge a chick or two. The fact that most nests appeared to hatch chicks at Eccles reinforces this suggestion. At Eccles, predation by a Kestrel was thought to be a particularly important factor in chick mortality with one observation of three chicks taken within

[8] the nest of birds 7.0 and 13.9 having been lost with only the latter ever subsequently contacted

30 minutes (Bowman, 2005). At Winterton, the attentions of a large female Kestrel, was implicated in the demise of most of the Ringed plover chicks hatched, resulting in no chicks being fledged (Skeate *et al.*, 2004), and is thought likely that this also accounted for at least some of the few Little tern chicks hatched.

Once displaced from Winterton it is possible that some Little terns attempted to re-nest at North Denes and Eccles, although data from the latter site is limited (see 5.1.3 above). The timing of nesting of birds at North Denes, with a peak in nests put down in early July, was in line with the occurrence of Sprat in the waters around Scroby (see 6.1.3 above). Predation by foxes in particular continued, but it is unclear if this was ultimately responsible for the lack of chicks hatching and fledging in this second attempt. A more interesting question is that if there had been no predation, despite the relative lack of prey, could at least some chicks have been produced?

It is of note that the abundance of Sprat late into the season at North Denes was of similar perhaps greater, magnitude than the abundance of Herring as they declined in 2003. At this time, an enormous number of chicks were present on the beach and the sharp decline in the abundance of prey at the beginning of July appeared to have serious consequences for their survival. However, there was no evidence of any decline in provisioning rate to chicks, this being maintained at around three items per chick per hour during the season. In fact, a similar value has been maintained throughout the study, irrespective of site and fish density. The provisioning rate in this study is at the lower end of the range documented in the general literature of Cramp & Simmons (1985), although the quality of the YOY fish prey may compensate. Cramp & Simmons (1985) also document that feed rate typically increases with age, with young chicks of 1-5 days old fed at 2.7 chick hr^{-1}, 6-10 day chicks at 4.1 chick hr^{-1}, 11-15 day chicks at 9.0 chick hr^{-1} and 16-20 day chicks (i.e. immediately prior to fledging fed at 10.4 chick hr^{-1}; although there is no indication of the type of prey fed to chicks. It thus seems that in this study birds were able to maintain provisioning rate, although it may have been preferable to increase it with the increased demands of progressively larger chicks. There is a clear benefit in maximising provisioning rate to chicks as faster growth may allow faster development with chicks fledging and leaving the beach earlier (15-17 rather than 19-20 days is known) thereby reducing exposure to predators.

In 2003, in order to at least maintain provisioning rate in the face of reduced prey density it seems likely that the adult terns travelled further to reach an exploitable stock. Unless birds fly faster to compensate for travel time, longer foraging trips have the disadvantage of leaving chicks exposed to predators for longer periods, especially in the later stages of chick development when both parents appear to be providing prey. There is limited evidence that birds were indeed travelling further in this period, as observations on birds at sea during surveys for the DTi (Allcorn *et al*., 2004.) in early July recorded Little terns carrying prey back to the colony from at least 5km to the south (i.e. towards Scroby). Radio contact with a known reliable fisherman, suggested many Little terns were foraging over Caister Shoal some 8km away.

Clearly, the birds were able to bear such costs and still successfully raise chicks achieving the incredibly high productivity of 1.92 in the process, higher than anything yet seen at North Denes (Table 18). This is considerably higher than the productivity of 0.5 $pair^{-1}$ achieved in 2002. Whilst at first glance the overall provisioning rate appears little different, at 2.6 compared to 2.99 in 2003, this is per chick and for each chick this would equate to 10 feeds per day. Thus, for the typical brood of two chicks to fledging, adults were supplying 20 additional fish per day. With a fish density some 2 orders of magnitude lower in 2002 it is perhaps remarkable they were able to raise chicks at all and may be seen as even greater testament to their foraging ability and adaptability.

From this discussion, it seems that late-nesting Little terns had the potential to raise at least some chicks from North Denes, if they had not been subject to the attentions of nest predators. Certainly, the level of protection at North Denes declined during the season, with only relatively few nests at any one time and the general perception that birds were being unsuccessful. Wardening staff became increasing employed on other duties (Allen Navarro *et al*., 2004). However, if all measures (e.g. electric fencing, 24 hour protection and the lethal control of predators) had been implemented, perhaps 2004 would not be remembered as the worst year on record (with 1996) for Little terns at North Denes.

6.2 The impact of the Scroby wind farm

6.2.1 The scenarios of impact

Any assessment of the impact of the wind farm on Scroby sands upon the North East Norfolk population of Little terns, the most important population of this endangered bird in the UK, effectively depends on whether Scroby forms an important component of the habitat exploited by the birds and their prey resource.

The initial studies in 1995 (Ecosurveys Ltd., 1995) and 1999 (Econet Ltd., 1999) showed that birds did indeed at least on occasion, use the southern part of Scroby. For this reason, the location of the proposed wind farm was displaced to the north more or less due east of the colony. The scope for the use of the entire area occupied by Scroby to around 5 km offshore (i.e. well beyond the 1.5 km suggested as the maximum distance Little terns would forage offshore, although birds were thought to travel up to 6km from the colony when foraging - Cramp & Simmons, 1985) has now been confirmed by the combination of surveys, observations and radio-telemetry during the current study prior to and during construction. Moreover, this study has shown that the foraging range and distances covered in a single bout (up to 25 km) enabled by a flying speed of up to 74 km hr^{-1}, are far greater than thought, bringing Scroby within easy reach of birds from North Denes and even possibly from Winterton.

The evaluation of the actual *importance* of Scroby as a foraging ground compared to waters closer inshore is still being undertaken and will form a crucial part of assessing the collision risk of birds with turbines (see below). At present, it is thought that Scroby may be used under particular phases of the tidal cycle and particularly in relation to water clarity inshore. As this increases, perhaps in high or low water slack periods, prompting fish to drop deeper in the water column birds may have to travel further, perhaps to shallower water, where any fish may remain in diving range of foraging birds. The shallow banks of Scroby may be ideal, thereby making Scroby an important supplementary component of the foraging range of birds from North Denes which may even be part of the colony site-selection process of the birds (see 6.1.2 above).

As documented in the previous reports (ECON, 2003, 2004), Scroby sands may be an integral part of the system that ultimately supplies a wealth of YOY clupeids to the breeding terns at North Denes and perhaps also to Winterton, underpinning the success of the SPA. Thus irrespective of whether birds actually use Scroby sands themselves as a foraging ground, Scroby may be of critical importance to The North East Norfolk population of Little terns.

Whilst impact of the wind farm upon Little terns may be *positive* or *neutral* as well as *negative*, positive impact is thought to be limited to the creation of alternative foraging grounds around the turbines as a result of changes in geomorphological conditions offering alternative habitat for prey species.

In contrast, obvious possible negative impacts upon Little terns include:

- Direct mortality of birds striking turbines;
- Disturbance of birds, with displacement from important foraging areas around the turbines i.e. habitat loss;
- Changes in the nature of the prey resource as a result of changes in geomorphological conditions promoted by the turbines.

To the latter it is also necessary to add that changes in the nature of the prey resource could also conceivably result from the displacement of prey from the turbines either during installation – as a result of noise, vibration, re-suspension of fine particles and even release of natural and artificial chemicals (pollution) – or during operation (e.g. noise and vibration).

All of these may have effects on individual birds, which compound to impact on the entire colony, thereby ultimately reducing its success.

Of the potential effects, direct mortality can only be measured once the turbines have been built. Whilst results from previous studies (see Percival, 2000) suggest this is likely to be insignificant this still needs to be quantified. To date, collision risk has been estimated through a mathematical model developed by Scottish Natural Heritage (2000). However, concern has been expressed over the value of this model and English Nature have recently let a contract in which the model is to be thoroughly evaluated which will lead to the development of a more appropriate model where this is necessary. Moreover, estimation of collision risk depends on a thorough knowledge of the encounter rate of birds with turbines, which itself is a function of the use of the birds of not only the wind farm but also of the space occupied by the turbines. Estimation of encounter rate has rarely been adequately achieved and the continued use of radio telemetry, quantifying how much time Little birds use the wind farm coupled with further data on the flight heights of birds (both when foraging and commuting) offers a specific means of providing such data.

Direct disturbance of birds by the turbines seems unlikely given that there are no other similar cases for a range of bird species (Percival, 2000). But, given the lack of data on coastal turbines and a limited, but growing (see 6.1 above) understanding of Little tern ecology, a disturbance effect cannot be ruled out.

ECON (2003) suggested it was perhaps more likely that the installation of turbines will change the nature of the area and its suitability for foraging terns. The presence of 30 large structures anchored to the bed was thought likely to have at least a local effect, with possible repercussions for the prey base of Little terns. However, any effects may be positive as well as negative. For example, fish may concentrate around the structures, as they do around reefs and wrecks.

Overall, there are many scenarios of potential impact, both positive and negative, with individual to population effects. ECON (2003) considered what would be the worst-case scenario and analysed this in broad theoretical terms, with particular reference to whether mitigation was plausible. A worst-case scenario of an impact of the proposed wind farm was offered in that all birds would be displaced from North Denes. Even if this occurred, Little terns may simply move further along the coast to Winterton and successfully breed and fledge chicks; as was clearly demonstrated during both 2002 and 2003, with terrific fledging success in the latter year. However, successfully raising chicks at Winterton may be something of an exception rather than the rule and ultimate success of a site may only be judged after several years, the yardstick being a productivity of at least 0.65 chicks $pair^{-1}$ $year^{-1}$ over the lifetime of the birds (Biggins *et al*., 2000).

The ultimate factor controlling breeding success at Winterton, indeed at any colony is argued to depend on the prey resource at sea. Should this be maintained at the level experienced in 2003 then continued success is likely. If not and birds are displaced from North Denes by the turbines, increasing the prey resource at Winterton through for example, provision of additional fish habitat, may be considered as mitigation.

6.2.2 The potential impact of installation

It was not possible to monitor the short-term impact of the installation of turbine monopiles beginning in late October (21^{st}) and continuing to the beginning of January (6^{th})**,** directly on Little terns simply as they are not in the UK at this time, wintering off the west coast of Africa mainly in the waters of Guinea-Bissau (Wernham *et al*., 2002**)**. Moreover, there was no license requirement to monitor the *indirect* effects of construction on the prey resource or conditions potentially affecting the prey resource. Any longer-term impact was to be determined through comparison of data from the summer of 2004 following construction with pre-construction data gathered in the summers of 2002 and 2003.

Monitoring during the summer of 2004 revealed what appeared to be several outstanding features of the abundance and distribution of Little terns interlinked with their prey resource. Young-of-the-year Herring failed to recruit in any numbers, with disastrous consequences for breeding Little terns, which suffered their worst year, along with 1996, since the formation of the colony in 1983. In what appeared to be a quest for alternative prey, Little terns were observed in large numbers several km offshore feeding on Ghost shrimp early in the season as well as being consistently present on the outer edge of Scroby beyond the wind farm in locations they had never been seen before. A subsidiary sand bar, which had formed through the wind farm may have been part of the attracting for foraging Little terns. The key question is was either the construction of the wind farm or the subsequent presence of the wind farm likely to be responsible for these exceptional events or were these simply coincidental? Clearly, it is extremely difficult to judge just how exceptional the events observed in 2004 were without a longer specific data set and to begin with, it is useful to place the failure of Herring recruitment and Little terns in the area into as wide a context as possible. In other words, to establish whether the events were local or part of a wider phenomenon in the North Sea. If local, there must then be a viable mechanism through which the wind farm could account for the observed patterns.

Recent seabird failures in the North Sea

There is increasing evidence of the large-scale ecological effects of global climatic fluctuations, particularly in the oceans, with the El Niño-Southern Oscillation and the North Atlantic Oscillation (NAO) amongst the best understood (Stenseth *et al*., 2002). Changes in sea surface temperature and wind conditions can dramatically influence the availability of nutrients and phytoplankton production, which knock-on to the temporal and spatial abundance distribution of zooplankton and cascade through the food web with effects on zooplantivorous fish and ultimately their predators including large fish, seabirds and marine mammals such as seals and Killer Whales *Orcinus orca*. Small pelagic zooplanktivorous fish such as the clupeids including Sardine *Sardina pilchardus*, Anchovy *Engraulis* spp. and Herrings *Clupea* spp., which are closer to the signal from the lower trophic levels are thus highly sensitive to environmental fluctuations (see Stenseth *et al*., 2002).

In the North Sea, there is increasing evidence of regime shift associated with the NAO. Reid *et al*. (2001) document that after 1988 onwards the pressure difference between Iceland and the Azores increased to highest levels this century enhancing the northerly advection of warmer waters leading to increased absolute and seasonal extent of phytoplankton abundance and thus increased zooplankton abundance. Movement of water north coupled with an increased food supply led to a massive increase in the western stock of Horse mackerel *Trachurus trachurus*, which was subsequently exploited by the pelagic fishery. Although Horse mackerel have benefited as a result of changes in the NAO, there are inevitably differences between different taxa, and the increased possibility of mismatch between predators and prey will disfavour some species. For example, zooplankton peaking earlier in the season with warmer temperatures may occur too early for particular species of larval fish.

In 2004, there was much media interest in the impact of possible influences of climate change mediated through the NAO upon seabirds (e.g http://www.birdlife.net/news/features/2005/01/north_sea_seabirds.html, http://www.climateark.org/articles/reader.asp?linkid=33959). In February 2004 wrecks of dead Fulmars hit the coasts of France, Belgium, Germany, and the Netherlands as well as the UK. Amongst the female biased (90%) samples, post-mortem revealed starvation was the main cause of death. The effect continued into the breeding season with the lowest season on record for Fulmars in south-east Scotland, unprecedented breeding failure of Guillemots on Fair Isle in Shetland with generally poor success of Kittwake on the British North Sea Coast (e.g. Bempton Cliffs in Yorkshire - Pitches 2004a). Decline in the stock of Lesser sand-eel upon which many species of seabirds depend was attributed as the major cause of widespread breeding failure in the Northern Isles of Britain (JNCC 2004). Increased water temperatures as a result of the changes in the NAO are thought to have changed plankton/sandeel dynamics with the overall effect of reducing sandeel abundance (JNCC 2004).

However, it is important to point out that the effect has been so dramatic as a result of the concentration of so many seabirds in a few colonies such as those in the Northern Isles of Orkney and Shetland, and the birds' relative dependance on a single species in those locations. To illustrate, the breeding success of Kittwake in North-east Scotland was improved in 2004, the production of Guillemot chicks on Skomer and of Fulmar chicks in North-west Scotland were also at rather typical values. Even at the worst affected colonies Atlantic puffin *Fratercula arctica* did not experience the same low breeding success as other sand-eel feeders. JNCC (2004) speculated that was a result of a more catholic diet and the relative immunity of their chicks to predation by skuas and gulls as a result of nesting in burrows. With a lack of easy targets from which to rob sand-eels, Great skua *Catharctica skua* in particular turned its attention to chicks and even adults of other seabirds, as well as roadside carrion (Heubeck & Shaw, 2004) although this did not ultimately not buffer the impact upon its extremely poor breeding success. Elsewhere, other seabirds were heavily influenced by other climatic variation with many Shags *Phalacrocorax aristotelis* and Puffins in eastern Scotland killed by heavy rain and onshore gales, which also affected terns in North East England (JNCC 2004). In more detail, a 1 000 dead chicks were found amongst the 2 000 breeding pairs of Sandwich terns on the Farne islands, after half the previous June's total rainfall fell in just two days http://www.birdlife.net/news/features/2005/01/north_sea_seabirds.html.
So much water fell that inundation of Puffin burrows led to a 65% loss of chicks (Pitches, 2004b).

Overall then, whilst seabird success was disastrously low in many parts of the North Sea in 2004, this was the result of a number of factors. Failure in the Northern Isles especially was mostly linked to a lack of sandeels, which in turn appears to be linked to changes in plankton dynamics, which ultimately disfavour sandeels. The effect was made acute by the local dependence of many bird species upon this particular prey species. Elsewhere, whilst feeding on other prey the same bird species fared much better. Whilst impacts on birds in 2004 were part of wider phenomenon associated with climatic fluctuation mediated through the NAO, not all species of fish and bird will be affected in the same way and will depend, in part on the ability of both fish and birds to adapt breeding cycles and choice of prey.

The fate of Little terns in 2004

As outlined by Schmitt (2005), in keeping with other species, Little tern colonies suffered a range of fates in 2004, which ultimately led to a relatively poor breeding season with around 0.41 chicks per year, less than half of that experienced in 2003, although this was heavily influenced by the Winterton and Gronant (North Wales) colonies where virtually two chicks per pair fledged in 2003. Gronant maintained high productivity in 2004 and other sites such as Coll in Scotland fledged 1.26 chicks per pair, with Hodbarrow in North-West England fledging a record number of chicks. Kilcoole in south-east Ireland was the most successful site overall with 189 chicks fledged.

Overall, poor weather and particularly gales in June were cited as most important with predation depressing productivity. For example at Scolt Head, North Norfolk, the 90-

95 pairs fledged no young after egg predation by Common gull and Oystercatcher and especially cold and windy weather in mid-June, which killed at least 15 broods along with 250 broods of Common tern, 1000 broods of Sandwich tern and 100's of Black-headed gulls (Lawton, 2005). Similar problems were encountered at Holkham (Harold 2005) and Blakeney (Wood, 2005) with egg-collectors also taking the contents of up to 10 nests at the latter site. Only in North-east Norfolk at North Denes/Winterton/ Eccles was food shortage raised as an issue (Smart, 2005) although at Scolt Head, Lawton (2005) thought that '*food during the early part of the season appeared scarce, with birds feeding exclusively on small sandeels, there appearing to be a complete absence of whitebait* [i.e. Clupeids] *offshore until July*'. The timing of this increase is indicative of the presence of Sprat (see 6.1.3 above).

Just a few miles away in Suffolk, fortunes were considerably better with 15 pairs at Minsmere raised 15 chicks, the first since the late 1990's (Howe, 2005) and the colony at Languard/Felixstowe Ferry was also successful (Iden, 2005). In Essex, at Hamford Water, a productivity of around 1 chick per pair was also achieved and '*food seemed more plentiful than in other years*' (Woodrow, 2005).

It seems clear that the shortage of prey for Little terns in North-east Norfolk was very much a local phenomenon, tied in to the dependence of Little terns on the recruitment of Herring in this area (see 6.1.2 & 6.1.3 above). Moreover, the complete failure of birds at the egg stage through abandonment as a result of a lack of food is unprecedented in the life of the colony at North Denes since monitoring began in 1986.

The failure of Herring recruitment in 2004

Following the collapse of the largely autumn-spawning Herring stock in the North Sea in the 1960s and 1976 as a result of the combined effects of overfishing of adults and immature fish on their nursery grounds poor survival of young fish followed by poor recruitment (Scottish Natural Heritage 2004, Fisheries Research Services 2004). A ban on fishing from 1977 to 1983 allowed stocks to recover. Exploitation levels are now strictly controlled by the International Council for the Exploration of the Sea (ICES). Herring stocks are considered to be within safe biological limits in terms of spawning stock biomass and fishing mortality. The spawning stock has increased from relatively low levels in the mid 1990's to the highest levels since prior to the collapse of stocks 1965, as a result of a succession of strong recruitment events and management measures to reduce exploitation. The 1998 and 2000 year classes were very strong, but despite the increase in spawning stock biomass, recruitment in 2002 and 2003 were the lowest since the early 1980s (ICES 2004). No specific attempt has been made to explain the reduced recruitment in the early part of this century, although slower maturation of the strong year classes of 1998 and 2000, which constitute the bulk of the spawning stock may have had some influence. Moreover, spawning stock biomass *per se* may not be the best predictor of the number of young fish recruited as mortality of eggs or larvae may over-ride the number of eggs laid (Axenrot & Hansson, 2003). It should also be noted that the index of recruitment produced is for the entire North Sea and ICES (2004) show that the bulk of this fluctuation occurs within the dense populations off the coast of Scotland and North-east England. The lower numbers of recruits off the coast of eastern England were more stable from 2001-2003. No figures are yet available for 2004.

There is thus no specific available information on stocks in the East of England and particularly around Scroby, apart from the samples taken during this study, and these do not accord particularly well with general figures. Whilst low recruitment of herring was reported for Herring in the North Sea as a whole in 2003, it was clearly spectacularly good around Scroby, with unprecedented success for the Little terns. The inter-dependence between seabirds and their prey has been demonstrated many times. For example, the study of Særte *et al*. (2002) demonstrated that the number of Puffin chicks fledging in some Norwegian colonies was so closely correlated with the recruitment strength of Herring that this could even be used to predict the year-class strength of Herring. The fact that the Little terns at Scroby suffered an unprecedented failure through abandoning their nests is therefore strongly suggestive of an unprecedented event in the recruitement dynamics of their main prey species, Herring.

Dramatic inter-annual fluctuation of YOY is a common phenomenon amongst many fish species, which may be of great consequence for the long-term fluctuations in the species' stock size (Pitcher & Hart, 1982). A wide range of factors may determine recruitment success. These may operate in a chronological sequence from the size of the spawning stock, the number of eggs per female, egg survival and larval survival. Predation may be important in determining the size of the spawning stock or egg or larval survival. Alternatively, food supply may be critical in determining larval survival. It has also been demonstrated that adequate feeding is essential during the critical phase of changeover from internal (yolk-sac) to external nutrition and starvation for even short periods can result in a point of 'no return'.

In the opposite of the examples cited above for sand-eels, which is effectively a 'cold-water' species, as a general theme, an increase in spring temperatures is likely to increase algal abundance resulting in enhanced populations of zooplankton. In the case of Herring and other clupeids, which are specialist copepod zooplankton predators, higher temperatures as a result of the NOA may be expected to increase Herring recruitment strength, rather than decrease it. This assumes no mismatches between the availability of food and the emergence of the larvae (see above). This is certainly the case with spring-spawning Herring in the Barents Sea, where recruitment strength of YOY and ultimately the size of the spawning stock produced was positively correlated with the average temperature of the Kola section of the Barents sea in the winter months (Toresen & Østvedt, 2000).

Alternatively, if early seasonal temperatures are low, this may ultimately result in a poor food supply for copepods, in turn the main resource of YOY Herring. Recent data on the NAO suggest that after a succession of positive values, a slight negative value was recorded over the winter of 2003/2004 (http://www.cru.uea.ac.uk/~timo/projpages/nao_update.htm**)**. Although the strength of the relationship between the NAO and Herring recruitment is not recorded in the UK, it is relatively strong in the Baltic (Axenrot & Hansson, 2003). Part of the relationship is thought to be caused by the interaction between jellyfish especially *Aurelia aurita* and Herring larvae, with jellyfish acting as both predators and competitors (C. Lynam. A. Brierley, M. Heath & S. Hay Fisheries Research Services Aberdeen *unpubl. data*). Cooler waters favour *Aurelia* partly as its main predator the larger jellyfish *Cyanea capillata* prefers warmer ones. The fact that the NAO index is only slightly negative suggests any influence on herring recruitment would be slight at best. Moreover, such a radical shift in the food web would be expected to lead to changes in the abundance and distribution of all manner of organisms. However, there is no evidence for this and in particular, the abundance of Sprat was of similar magnitude to other years and indeed may even have been more abundant and persistent in 2004 than in 2003 (Fig. 18). Whilst it is possible that through spawning later Sprat avoided any bottleneck restricting the survival of Herring, this seems unlikely given the temporal overlap between the two species.

Moreover, if herring had suffered through food limitation this would be expected to show if differences in growth rate between years. There is a tendency for the rate of growth of the few Herring present to be relatively low in 2004 although this occurs later in the season and there is no evidence to suggest that the early growth of herring was effected as the fish appeared in samples at their ‘normal’ length of around 40 mm at the beginning of the sampling season. Overall the similar growth pattern in all years of both Herring and Sprat suggests food supply has not limited Herring growth and survival to the extent of causing recruitment failure.

Thus, it seems more likely that the cause of the failure to recruit lies in some parameter of the spawning stock or egg survival. Whilst the spawning stock in the North Sea as a whole is at it highest levels for the last 40 years and fishing mortality is currently at its lowest for the last 20 years and within safe biological limits (Fisheries Research Services, 2004) this is not to say that a local effect is not possible. Possible candidates for wholesale loss of eggs include the removal of adults through commercial fishing either before or after fish reach their spawning grounds and direct disturbance of spawning grounds. Unfortunately, no information is available to make serious comment on the former at the present time, although there was some observation by local people of trawling apparently for Sprat/Herring by a large Dutch or Danish vessel in the winter of 2003/2004 in the Lowestoft area (*pers. comm*.).

In relation to disturbance of spawning grounds, Herring are known to spawn in the area between November and January, which coincides exactly with the period of piling (Coull *et al*., 1998) Whilst there is no indication that Scroby sands themselves are the location of the spawning grounds as coarser substrate such as gravels are preferred, there is some anecdotal evidence that some such substrate may occur in the deeper channel of the Yarmouth Road and near Britannia Pier.

Herring and other related fish are known to be particularly sensitive to underwater noise with the potential for damage to internal organs and the swim-bladder (Nedwall & Howell, 2004). As a result of the sensitivity of fish to noise, Coull *et al*. (1998) produced maps of seismic sensitivity. Primarily as a result of the potential for an impact upon spawning Herring, the area around Scroby is outlined as being sensitive in the months of November and December (and January) compared to October and February (Fig. 17). Coull *et al*. (1998) do not consider which part of the stock is most sensitive or what the effects on particular parts of the stock may be.

However, there has been some assessment of the potential behavioural and physical effects of pile driving noise on a range of fish species. For example, Engell-Sørensen & Holm Skyt (2001) working at Rødsand, Denmark concluded that avoidance reactions are likely to occur up to 30 m from the source, especially for species with swim bladders. Measured noise levels were thought capable of harming the hearing ability of clupeids such as Herring and Sprat, but that this may regenerate over time.

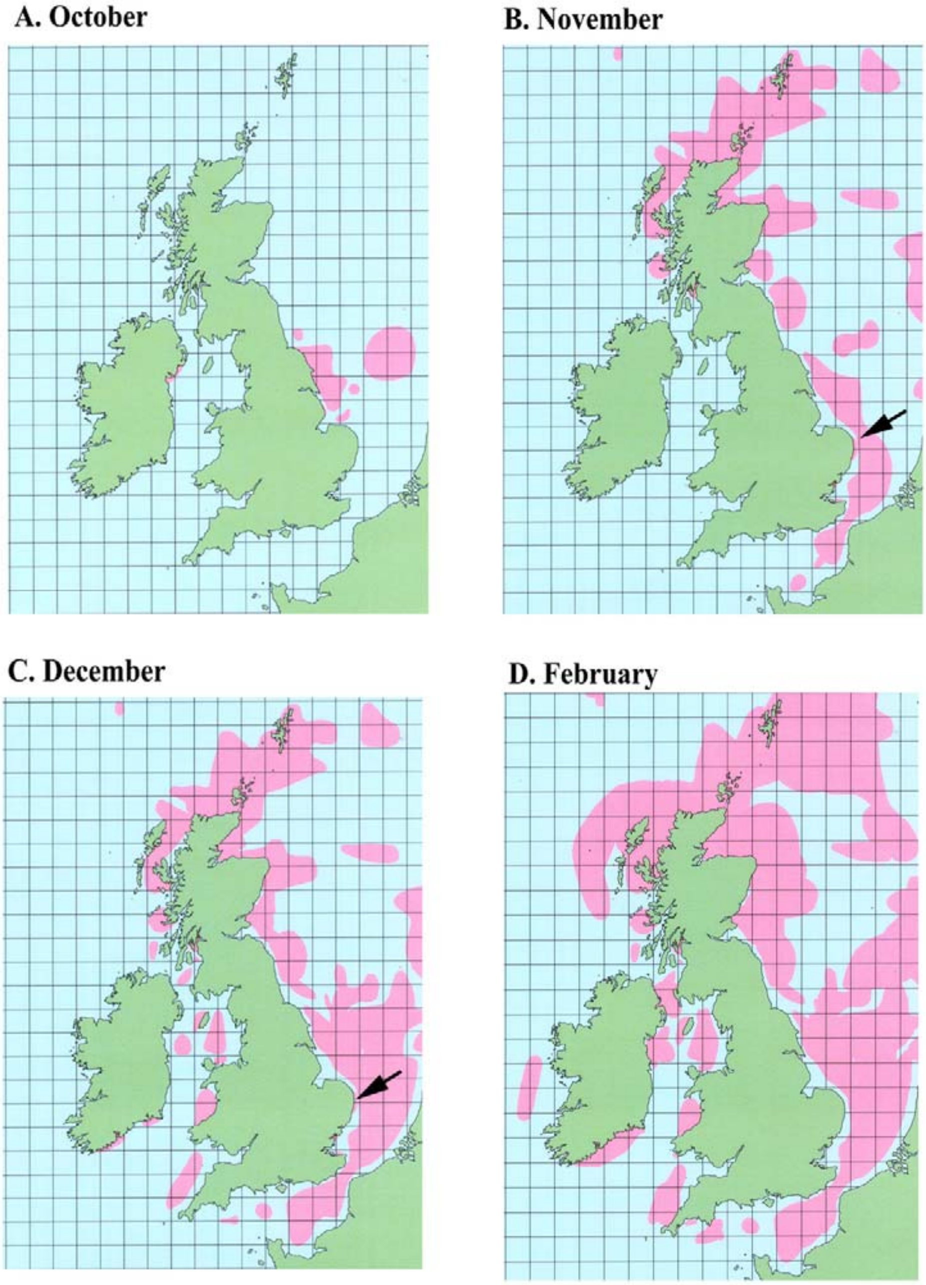

Figure 17. Distribution of areas of seismic sensitivity (pink) in A. October, B. November, C. December (as January) and D. February around the coast of Britain. Arrows indicate the extension of the sensitive area into the inshore waters around Great Yarmouth in November-December as a result of inshore spawning Herring. Adapted from Coull *et al*. (1998).

Further studies have shown much more severe reactions than mere avoidance and minor physiological damage at the sort of Sound Pressure Level (SPL) of between 192-261 dB levels generated during pile driving (Nedwall & Howell, 2004).
For example, in a study on the impacts of pile driving on Pacific Salmon in northern California, caged salmon were placed at various distances from pile driving being undertaken for a major road crossing. At a sound level of 261 dB, fish within 10-12 m of the pile driving died immediately, whilst fish up to 1000m from the pile suffered such injuries that they were likely to die shortly after pile driving (Caltrans 2001).

Nedwall & Howell (2004) suggested that the frequency of the sound plays an important role in the magnitude of the response. Herring and Cod *Gadus morhua* did not respond to sounds played back from a trawler at frequencies of 20-60 Hz, but avoided the noise at frequencies of 60-300 Hz and 300-3000 Hz (Engås *et al*., 1995). Piling noise spectra peaks at approximately 250 Hz, where fish such as Cod and Salmon are known to have their greatest hearing and it could be surmised that this is similar for Herring.

If anything it appears that the sort of noise experienced during pile driving at Scroby, which could be heard about 20 km away through air at Berney Marshes (M. Smart RSPB *pers comm*.), would be likely to generate avoidance at much greater distance than that suggested by by Engell-Sørensen & Holm Skyt (2001). Values of 100's if not 1000's of metres, more in keeping with the 15 km influence of effect upon the abundance and general activity of Harbour porpoises during pile driving at Horns Reef, Denmark (Tougaard, *et al.*, 2003) seem more likely.

From this it seems plausible that adult Herring would have been displaced from the waters around Scroby if they do indeed spawn around there. A reduction in the numbers of spawning fish may then have lead to a reduction in the number of YOY. Even if adult Herring successfully spawned at Scroby perhaps in periods without acoustic disturbance, as larvae usually hatch within about three weeks although this is temperature dependent (http://www.gma.org/herring/biology/life_cycle), all larvae born in the waters around Scroby are likely to have been subject to the full impact of acoustic disturbance. As larval fish are neither capable of swimming against the tide and thus avoiding any disturbance or potentially damaging impact if the tide exposes them to such risk, and are also the most sensitive to physiological effects, it seems highly likely that the bulk of larvae born in Scroby in this period are likely to have been damaged if not killed outright, with obvious consequences for the number of YOY recruits. Thus, the only means of compensating for losses of larvae at Scroby would be drift movement of Herring larvae into the area from other stocks in much the same way as seems to occur for Sprat (see 6.1.3 above).

To summarise, whilst it should be stressed that only circumstantial evidence is available and no information is available on likely mortality of adult fish through commercial fishing, the best current explanation for the lack of YOY Herring in 2004 is the negative short-term impact of piling, with scaring of adults away from the area and/or mortality of young larvae.

Changes in the distribution of Little terns at Scroby

Increased use of Scroby Sands by Little terns was recorded in 2004, with the largest number of birds yet encountered at a site recorded in the southern part of Scroby in early season. Moreover, birds were recorded on several occasions on the outer edge of Scroby near the wind farm, where they had never been recorded before.

Observations of birds leaving the beaches at both North Denes and Winterton to forage reinforced the evidence from radio-tagged individuals that foraging Little terns frequently used Scroby Sands to forage in 2004. This coincided with observed changes in the nature of Scroby in 2004 especially the formation of a subsidiary sand bar through the wind farm. But is this subsidiary sand bar linked to the installation of the turbines or simply part of ongoing dynamic changes in the system that are not related to the turbines?

In Annex J of the Environmental Statement for the site Halcrow & Partners (1996) - state that '*the effect of piles on currents will be primarily to obstruct the flow. From this point of view, the effect of piles may be to have a very small stabilizing effect on the sandbank*.' The later LIC Engineering report (1999) in Annex P also states that '*placing a windfarm on the Scroby Sands will increase the flow resistance on the 'Sand' which will lead to an accretion of sand, i.e. an increase in height. The increase in height will theoretically be very small (of the order of 1 cm) compared to the natural variations of ±3 metres over the last 150 years*.' The displacement of the sand bar system was also predicted to '*be small (of the order of 10 m) compared with the extent of the banks (1.5 km – 2 km wide and 10-12 km long)*'. However, the report also stresses the roughness of this calculation, and states that this figure may in fact be anywhere between 1 m and 30 m. Accretion may also result in part from the presence of scour protection material. Although it is specifically designed to mix with the sand to create a gradual transition from the natural seabed, its inevitable re-distribution was identified as being likely to lead to increased stability of the seabed in the immediate vicinity of the pile foundation (LIC Engineering, 1999).

Overall, a lack of existing data at the time of the proposal means that only low confidence could be attached to the predictions (Halcrow & Partners 1996). Indeed this partly relates to a more general lack of understanding of the dynamics of offshore sandbanks, and how they are formed in the first place (Walkden 2005). As yet, there is no model that integrates sandbank dynamics, hydrodynamics, bathymetry and sediment transport, which Walkden argues is required for accurate prediction of offshore sandbank behaviour. Therefore observation and validation of theoretical calculations from early models is a highly important stage in the development of the industry as a whole, especially since the offshore bank system at Scroby is known to be particularly complex (Halcrow & Partners, 1996). Consequently, the bulk of scientific literature relating to the potential impacts of offshore wind farms on the morphology of sandbank systems emphasizes the need for future research (see COWRIE website: http://www.thecrownestate.co.uk). Although models may be used to assess whether a development is likely to have a significant impact, such an assessment cannot be viewed as conclusive since the offshore wind industry is young and Scroby Sands represents something of a pioneering venture.

In the case of the subsidiary sand bar there seems little evidence one way or another whether its formation is linked to the turbines or is simply part of natural variation. This may only be undertaken as the post-construction monitoring proceeds.

Whatever the cause, additional shallow waters around Scroby may have offered birds additional foraging grounds, perhaps especially for invertebrates. The use of such areas by birds remains unquantified and it is not known for example if birds use these areas at certain states of the tide or if birds were attracted in 2004 as prey resources were especially low closer to the beach, the typical focus of foraging activity.
The expansion of foraging habitat, especially in years of low prey availability may prove to be a *positive* impact of the wind farm, although this may be tempered by the attraction of birds and thus at greater risk of collision with turbines. The continued use of radio telemetry, developed for use on Little terns for the first time in the UK during this study, is seen as a key tool in the assessment of this risk during any post construction monitoring. Combined with further data gathering on the flight height of Little terns, the relative amount of time spent at risk may be determined.

7. CONCLUSIONS & RECOMMENDATIONS

The ultimate, primary aim of this study was to assess the impact of the proposed wind farm upon Little terns. Monitoring in 2002 and 2003 was to form a baseline against which future change relative to the presence of the wind farm could be evaluated. This included any impact following piling from late October to early January 2003 and during turbine construction itself until August 2004. Post-construction impacts may be evaluated in monitoring conducted in 2005 and 2006.

In studies thus far an attempt has been made to extend monitoring to include Winterton cSAC (candidate Special Area of Conservation), a traditional breeding site located some 12km to the north but included in the Great Yarmouth North Denes SPA for Little terns, which had only been sporadically used in recent times. Further sampling in other areas to the north (e.g. Eccles) occupied by what has become known as the North East Norfolk population of Little terns had also been attempted.

This strategy has been justified as unfortunately, in all years of the study thus far Little terns have not bred in numbers at North Denes, being displaced to Winterton largely as a result of disturbance and predation. This has severely hampered establishment of baseline conditions. However, at Winterton moderate success was recorded in 2002 when a minimum of 124 pairs raised a minimum of 43 chicks. In 2003 however, success was spectacular with 233 pairs fledging 447 chicks. This is a greater total and productivity per pair (1.92) than ever achieved at North Denes and indeed is the largest number of chicks fledged from a single colony since records began in 1969. With the chance of return of these birds to the area, as evidenced by the recapture of previously ringed birds (all 10 were from North Denes) during the radio tagging exercise, it is possible the impact of this recruitment event may be positively felt for years, even decades to come. Any impact may begin to be felt in 2005 when fledglings from 2003 return for the first time to breed.

Monitoring undertaken has significantly advanced the understanding of the foraging and breeding ecology of Little tern. This was seen as being of critical importance in allowing a thorough understanding of likely impacts of the wind farm.

In accordance with the known distribution of spawning and nursery areas of Herring and Sprat, Scroby appears to be by far the most important nursery area for clupeids along the stretch of coast sampled (including into North Norfolk). What are thought to be locally born Herring appear in the first samples in May at about 30mm in length. Peak numbers of Herring are recorded in June, before numbers rapidly decline, perhaps as these fish move further offshore. Little tern breeding is thought to be closely tied in with the seasonal pattern of Herring, with chick development occurring in the peak phase, with fledging prior to the decline in fish density. Abundant herring are therefore thought to be critical to success. In contrast, Sprat spawn offshore and larvae appear to be transported into the area through residual drift. Sprats appear in samples at about 15 mm in May/June, reaching a smaller peak of abundance than Herring by late July before again disappearing almost completely from samples in August. Late or re-nesting terns, particularly if these have moved colony may rely on this later peak in Sprat although they may still experience difficulty in finding enough food for chicks.

The presence of a unrivalled food supply was thus thought to be the main reason North Denes is the site of choice for breeding Little terns in North-East Norfolk, with Winterton the next most suitable, possibly on account of its developing sand banks some 300 m offshore. Scroby is also more predictable in that the fish populations show far less inter-annual fluctuation than at Winterton. Fish densities may reach 2 individuals per m^{-2} with the best sites immediately adjacent to the North Denes colony and Caister. This is almost certainly because these sites tend to have more turbid water, which is thought to bring the fish closer to the surface and within reach of the terns. Little terns as well as fish are thus significantly associated with more turbid water.

When fish prey is abundant, birds forage significantly closer to shore and enjoy a significantly higher rate of dives producing fish. There is a suggestion that in good years at North Denes prey are so readily caught to mean adults may spend time near the nest and chicks as an aid to their defence. Chick provisioning rate may be readily maintained, even accounting for seasonal decline in prey towards the end of the season. The lowest rate of dives producing fish at both Winterton and North Denes were recorded in 2004 (just 30% of the best values) in accordance with a virtual failure of recruitment of young-of-the-year Herring.

Whilst breeding performance is frequently modified by disturbance and predation, a good food supply is an essential prerequisite. All the evidence suggests that for the first time this was lacking.

In 2004, 150 nests were laid at Winterton compared to 40 at North Denes. The bulk of the nests at North Denes were put down extremely late in the season (early July), which coincided with the seasonal peak in Sprat numbers rather than the typical period of late May, which ties in with the earlier peak of Herring. At Winterton, egg counts showed a mean of just 1.81 per clutch nearly 0.5 egg per clutch lower than average, indicating resources were limiting for birds. A disturbance event most likely perpetrated by humans and their dogs also occurred at Winterton, although the great majority of birds abandoned their nests after this event. It is suggested this was caused by the acute shortage of prey bringing metabolic constraints into operation.

Radio telemetry showed that birds in 2004 travelled over twice as far in foraging bouts lasting twice as long compared to 2003, with the maximum distance traveled in a single foraging bout, a staggering 25 km. Radio-tagged birds spent an average of 72% of their time foraging compared to 56% in 2003 even when they had chicks to feed. When nesting, birds appear to be tied to home ranges of around 4 km^2. In 2004, after failure, some birds ranged widely within average ranges of 25 km^2 incorporating the entire stretch of coast between North Denes and Winterton, seemingly in an attempt to exploit any available food supply.

With mass abandonment at Winterton, just 2% of the nests are believed to have hatched chicks. The few that did hatch may then have been consumed by Kestrels as was the case at Eccles. Birds fared no better at North Denes with just 2.5% of nests thought to have hatched chicks, Although foxes were the most significant cause of egg loss, it is debateable if any chicks would have fledged even if they had survived to hatch. No chicks fledged, making this the worst year on record (with 1996 when Kestrel predation decimated chick numbers) at North Denes.

Mass abandonment as a result of a lack of resources had not been documented at the colonies at North Denes and Winterton since the inception of colony protection at the former in 1986. With the strong inter-relationship between Little tern productivity and Herring recruitment, this also indicated an exceptional event in Herring recruitment in the area. This is notwithstanding that inter-annual variation in recruitment of YOY fish including clupeids is a known phenomenon and is to be expected. Unfortunately, detailed analysis of the factors responsible for the failure of Herring to recruit was constrained by a lack of anything but rather general data and only a speculative analysis of possible explanations could be conducted.

Factors with potential influence were thought to include the mortality of older Herring in the area perhaps through commercial fishing reducing the local spawning stock – although in national terms this is as high as it has been in the last 40 years – as well as the interaction between recruitment and temperature and food supply – although negative effects on other parts of the food web would also have been expected. Recent research on the impact of underwater noise from pile driving on fish with both avoidance and mortality, indicates the potential for a short-term impact of the piling of the turbines at Scroby conducted from November-December 2003, which coincides with the documented critical spawning and initial development period for Herring in the area. Sprat recruitment may have been unaffected as larvae are spawned later in spring reputedly outside the area before they drift into the area on the tide. Clearly, only a longer data set specific to the area will enable a better judgment of the events of 2004.

Perhaps as a result of the lack of fish prey, increased use of Scroby Sands themselves was recorded in 2004, with the largest number of birds yet encountered in a survey at a site recorded in the southern part of Scroby in early season whilst feeding on Ghost shrimp. In surveys, birds were recorded on several occasions on the outer edge of Scroby near the wind farm, where they had never been recorded before. These patterns were reinforced by the ranging behaviour of radio-tagged birds, two of which were recorded around the Sands. Foraging observations showed that even birds nesting at Winterton may attempt to use the waters around Scroby. These observations reinforce the strategic importance of North Denes for Little terns. Even in the absence of a large or successful colony a large number of birds are likely to utilise North Denes and the water of Scroby at some point in the season.

Changes in the nature of Scroby, particularly the emergence of a subsidiary sand bar through the wind farm may have increased the available foraging area and/or its quality to Little terns, although this may be balanced by the potential of increased risk as birds fly through the wind farm. The continued use of radio telemetry, developed for use on Little terns for the first time in the UK during this study, is seen as a key tool in the assessment of this risk during any post construction monitoring. Combined with further data gathering on the flight height of Little terns, the relative amount of time spent at risk may be determined.

The use of radio telemetry within a continued monitoring programme in 2005 and 2006 is thus essential to assess post construction impacts. In theory, any further type of negative impact may be mitigated at least in part, 'in kind', including at alternative sites e.g. Winterton or even Caister where birds also used to nest, perhaps with the intention of drawing birds away from the wind farm area. Provision of fish habitat and proactive wardening/protection schemes are thought likely to be most profitable. In relation to the latter the RSPB/EN are committed to using all means as their disposal to promote the success of colonies at either Winterton and North Denes in 2005, enhanced by the prospect of a large breeding population with the potential of chicks fledged from Winterton in 2003 for the first time.

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