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Scroby Sands Ornithological Monitoring

Assessing the impacts of the Scroby Sands Offshore Wind Farm upon Little Tern *Sternula albifrons*: summary of monitoring programme 2002-2006

August 2008

EXECUTIVE SUMMARY

Background information

Over the period October 2003 to August 2004 E.ON UK (formerly PowerGen) Renewables Offshore Wind Ltd. constructed an offshore wind farm (OWF) comprised of 30 high capacity turbines beginning approximately 2km offshore of North Denes in Great Yarmouth, Norfolk, on part of Scroby Sands, an extensive and dynamic sand bar system running broadly parallel to the coast for approximately 5km.

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 *Sternula albifrons* in the UK, protected and managed by the Royal Society for the Protection of Birds (RSPB) on behalf on Great Yarmouth Borough Council. Little Terns are an endangered species 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, ~11% of the UK total, around 3.5% of the North & Western European population and 0.6% of the entire European population (inclusive of the poorly defined but large populations in Russia and Turkey).

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. But, such is the importance of the site and its species that Department for Environment, Food and Rural Affairs (DEFRA), after discussion with English Nature (now Natural England –NE) instructed that monitoring of Little Terns be undertaken to validate these conclusions. Suitable methodologies were developed after further consultation with the Royal Society for the Protection of Birds (RSPB).

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.

It must, however, be stressed that in relatively short-term studies of this type in which interactions are likely to be complex between the birds, their prey and predators, stochastic factors such as climate and disturbance it is extremely unlikely that cause and effect in relation to the impact of a development such as an OWF can be unambiguously determined. A carefully reasoned approach was therefore adopted to establish the *most likely* cause of observed patterns. Given the conservation importance of the species and the site the precautionary principle was applied throughout.

Methodology

Reversing the pattern of the previous 20 years, Little Terns did not breed in numbers at North Denes in the period 2002-2004 inclusive, hampering the establishment of baseline conditions towards the assessment of the impact of the wind farm. Consequently, an attempt was made to extend monitoring to also include Winterton cSAC (candidate Special Area of Conservation), a traditional breeding site located some 12km to the north included in the Great Yarmouth North Denes SPA for Little Terns, which had only been sporadically used in recent times (over the last 20 years) (Figure A). Further sampling in other areas to the north as far as Eccles (>20km from North Denes), occupied by what may be termed the North East Norfolk population of Little Terns was also attempted.

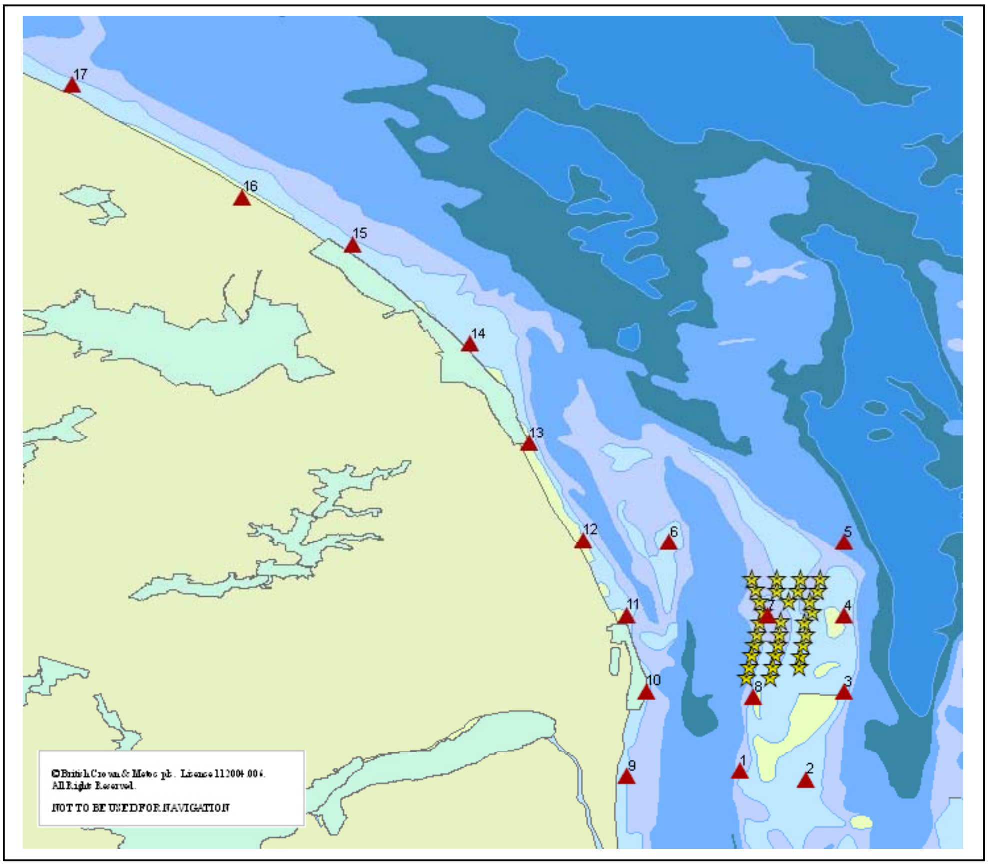

Figure A. Map of the twelve sampling sites at Scroby (1-12) including the North Denes colony (10) and additional sampling sites (13-16) in the Would including Winterton (14) as far north as Eccles (17). Locations of the 30 turbines in the Scroby Sands wind farm is indicated by yellow stars.

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 comprised of collision risk modelling after an understanding of use of the wind farm had been gained.

In all years monitoring was conducted throughout the breeding season (May/June-August) of Little Terns, with the following recorded approximately every one to three 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.

The number of sampling stations was maintained at *n*=12 at Scroby on all occasions covering all areas to ~6km from the colony at North Denes. After 2002, offshore sampling was restricted to inshore waters only at Winterton and other sites in the Would.

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 was towed 553km during the course of the study sampling 57.3ha^2. A total of 23,016 ind. of 46 potential prey species, including 18 fish species were captured. Of these, young-of-the-year (YoY) clupeid fish – Herring *Clupea harengus* and Sprat *Sprattus sprattus* – the crustacean Sea Slater *Idotea linearis* and the Ghost shrimp *Schistomysis spiritus* were by far the most numerous.

A total of 5,001 Little Terns were observed during surveys along with 9,565 other birds of 47 species and six unidentified taxa. Despite the number of registrations of Little Terns it was deemed unlikely that the methodology could adequately describe the relative use of the OWF in particular and from 2003-2006 inclusive, radio telemetry of individual Little Terns was undertaken for the first time in the UK under license. A total of 51 birds were tagged at both North Denes and Winterton where active colonies were of sufficint size, with useful data gathered on 37 individuals. Short battery life (mean ~12 days) of the small tags (~1g) was a key limitation of data collection. Nevertheless, a total of 145 hours of tracking foraging birds at sea yielded 3,217 location fixes, which proved invaluable to provide an estimate of the use of the area occupied by the OWF by Little Terns, which was a key component of collision risk modelling.

During colony studies, 915 birds were observed leaving the colonies to forage for a total of 40.3 hours of actual foraging time. During chick provisioning, a total 108 broods of chicks were observed over 227.4 hours in which 1,022 provisions were made. Assessment of the general development of the colonies including timing and pattern of breeding attempts, number of chicks hatched and fledged and causes of any failures at any particular stage (e.g. losses of nests to high tides and eggs or chicks to predators) and overall measures of success of the colony (peak nest numbers and chicks fledged), was achieved through close liaison with RSPB and NE wardens at North Denes and Winterton respectively.

Key findings

In 2002, the North Denes colony of 98 nests was destroyed by a single act of vandalism, although a small number of pairs (~7) managed to persist and fledge chicks (~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 both 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. Potential switching between the two sites by what is effectively the same population of birds, reinforced that judgement of overall trends in relation to the construction and operation of the OWF were best conducted at the scale of the SPA as well as at the scale of the single colony at North Denes.

Little Terns returned to Winterton in 2004, putting down 150 nests, although all failed mostly as a result of unprecedented abandonment at the egg stage. At North Denes a total of 40 nests were initiated over the course of a very late protracted season but no chicks fledged. Overall, the complete failure of the SPA remains without precedent (Figure B).

A similar pattern was observed in 2005, with the loss of 83 nests at Winterton again mostly through abandonment. In this year, the majority of the North-East Norfolk population attempted to breed at North Denes for the first time in the study, with a peak of 221 active nests. Although >400 Little Terns chicks hatched, a single pair of Kestrels nesting and raising five chicks at the Racecourse, were thought to have predated virtually all of them. Just 11 Little Tern chicks fledged.

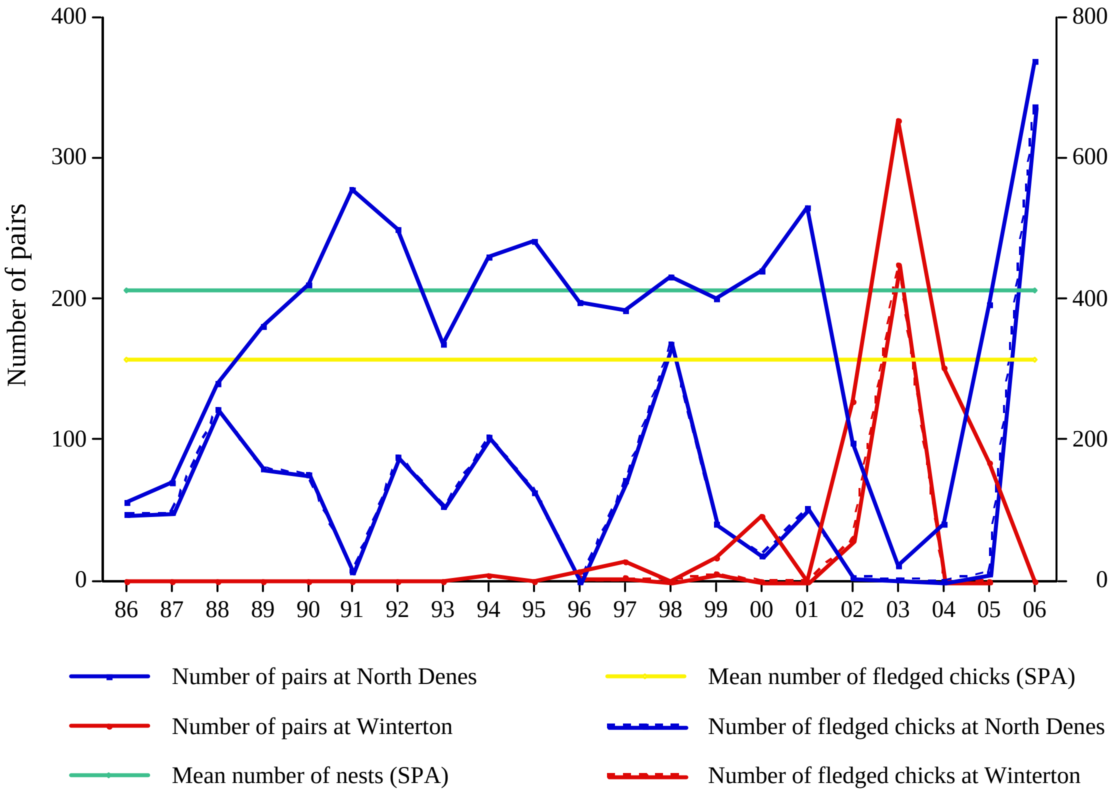

Figure B. Number of pairs of Little Terns and fledged chicks at both North Denes and Winterton since the beginning of colony protection in 1986. Mean number of pairs and fledged chicks from the SPA as a whole is also shown. Note that only in 2004 does a total failure of the SPA occur in terms of fledged chicks, although this is very close to zero in 1991 and 1996. Compiled from RSPB data.

Decimation of the colony led to a resumption supplementary feeding (at the nest with white mice and day-old chicks) of Kestrels by the RSPB in 2006 marking the initiation of a six-year programme alternating 'feeding' with 'no feeding'. Kestrel visits to the colony declined dramatically, few Little Tern chicks were predated and a record number fledged (673 ind.)[1].

However, detailed analysis of the prey at sea and foraging patterns of the birds clearly showed that a successful season had occurred despite a continued prey shortage beginning in 2004. Chick provision observations showed that YoY clupeids were overwhelmingly the most important prey item and thus the mainstay of colony success or failure. In addition, the timing of egg laying at North Denes in mid to late May suggests that, historically, Little Tern breeding is closely tied in with the seasonal pattern of Herring. What are thought to be locally born Herring (from eggs laid in November/December) typically appeared in the first samples in May at about 30mm in length, with peak numbers were recorded in June, before numbers rapidly declined perhaps as these fish moved further offshore (Figure C). Chick development thus typically coincides with the peak phase, with fledging prior to the decline in fish density.

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[1] Whilst this remains the official figure, this is determined by a single experienced individual and is considerably higher than predicted by the detailed monitoring of number of nests and mean clutch size undertaken by the wardens and the average number of chicks in broods observed in this study.

In contrast, Sprat spawn offshore and larvae appear to be transported into the area through residual drift. Sprat appeared in samples at about 20 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. A much earlier peak in YoY Sprat abundance, more akin to the typical pattern for Herring promoting more 'normal' timing and synchrony of reproduction perhaps aided the success of the North Denes colony in 2006.

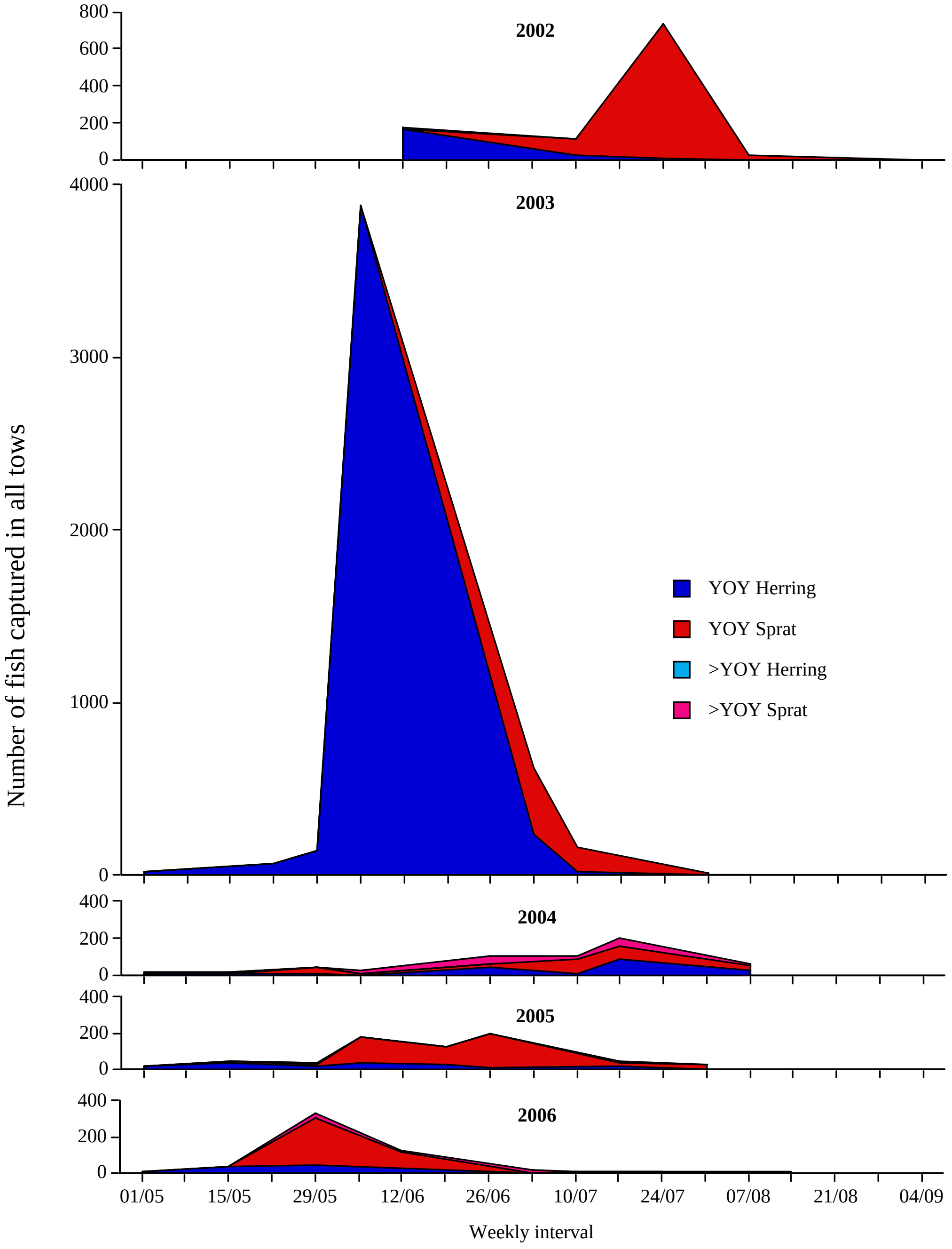

Figure C. Inter-annual (2002 to 2006 inclusive) and seasonal (by closest week in which the sample was taken) abundance (catch-per-unit effort of fish captured in all tows) of young-of-the-year (YoY) and older (>YoY, generally 1+) Herring and Sprat at Scroby. Note the lack of samples in May/early June 2002 in the peak Herring season.

During the period of occurrence, fish were 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 – North Denes seems to be the location of choice. This also accords with the known distribution of spawning and nursery areas of Herring and Sprat suggesting the area around Scroby Sands is by far the most important nursery area for clupeids along the stretch of coast sampled. Within Scroby, concentrations of fish at North Denes and Caister almost certainly result from the tendency of these sites 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.

Whilst YoY Herring were significantly more abundant prior to construction in 2003[2] compared to all years during and after construction, there was no detectable difference in the numbers of Sprat. In accordance with the virtual failure of recruitment of YoY Herring, birds foraged significantly further from shore at North Denes with a significantly lower rate of attacks producing fish during and after construction in 2004-2006 than before construction in 2002 and 2003 (Figure D). Little Terns at both North Denes and Winterton responded to a depleted prey supply by laying a reduced clutch size (0.5 egg less than average). It is speculated that the shortage of prey was so severe at Winterton in 2004 and 2005 to mean metabolic constraints came into operation and nesting birds were forced to abandon their nests. Mass abandonment for this reason appears to be unprecedented in the history of Little Terns in the SPA.

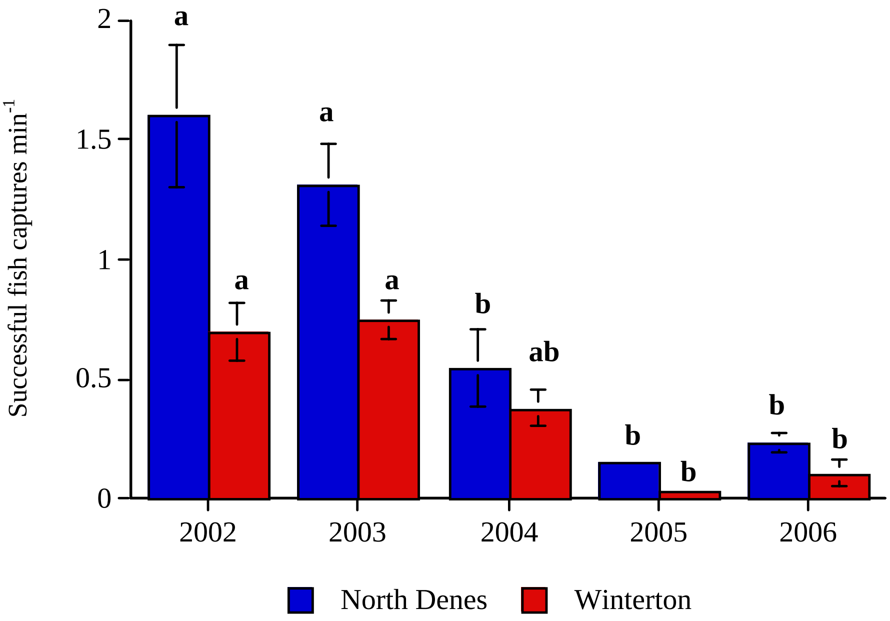

Figure D. Inter-annual variation (mean ± 1 SE) of the rate of completed foraging attempts resulting in successful fish captures at the North Denes and Winterton colonies from 2002 to 2006 inclusive. Significant differences within colonies are denoted by different letters.

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[2] The initiation of sampling later in the season in 2002 after the potential peak in Herring means that statistical tests could only be applied to data from 2003 onwards, although the similarity in attack and fish capture rates of foraging birds suggests fish were also abundant in 2002.

Detailed information from radio telemetry showed that Little Terns had maximum foraging ranges of ~1200-1600 ha in 2005 and 2006 over twice that recorded in 2003[3] at around 500-600 ha with even 85% kernel ranges reaching 900ha in 2006 compared to <300ha in 2003. Birds appeared to compensate for increased foraging range without allocating any more time to foraging (43-55% in different years), by undertaking fewer bouts per hour (<1.9 compared to 2.4-3.9), but increasing flying speed to ~30 km hr^{-1} compared to a median of 10-13 km hr^{-1} in 2003 and 2004. Birds thus extended the distance from shore reaching median values of ~1300-1650m in 2005 and 2006 compared to 400-500m in earlier years.

Boat-based surveys suggested a similar pattern with 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, there was a significant increase in the number of birds recorded at Site 4, to the seaward side of the wind farm after construction as no Little Terns had been recorded here prior to construction in 2002 and 2003. Although the change in use of Site 7 in the wind farm was not significant, up to 39 ind. were recorded in 2006 compared to a maximum of 2 ind. in 2004 the only other year in which birds had been recorded.

The key achievement of the compensatory behaviour of adults involving increased ranging behaviour and faster flight times to more distant foraging grounds (by ‘working harder’) was a significantly increased provisioning rate to chicks by 2006 (with median values were some 2-3 times higher in 2006 compared to any other year), underpinning the success of the colony. In order to achieve this it seems likely that other behavioural mechanisms also had to be involved, such as simultaneous foraging by both adults, leaving the chicks undefended in the colony. Data that may support this theory awaits analysis, but if this proves to be the case, this is likely to only be possible in years where predation risk to chicks is low. It remains plausible that the supplementary feeding of Kestrels in 2006 effectively freed both adult Little Terns to forage and overcome a depleted prey supply.

Potential impacts of the OWF

Although the phenomenon of inter-annual variation in recruitment of YoY clupeids, particularly according to the North Atlantic Oscillation (NAO) is well known, virtual failure of Herring from 2004 to 2006 was thought to be exceptional, if only because of the unprecedented failure of Little terns, which appear to depend on Herring recruitment. Without specific data, analysis of possible explanations of the lack of YoY could only be circumstantial. However, comparison of local recruitment trends with those published for the wider North Sea revealed a considerable mismatch (e.g. Herring failed in the wider North Sea in 2003 whilst recruitment was spectacularly good st Scroby), implying the local stock could be subject to its own set of vagaries.

Discussion of the possible factors responsible for the failure of Herring recruitment suggested the potential for a short-term impact of the piling of the turbines at Scroby conducted from November-December 2003, coincident with the documented spawning and initial development period for Herring in the area could not be discounted, especially given recent research on the impact of underwater noise from pile driving on fish showing the considerable avoidance, injury and mortality at surprisingly large distances from the source of the noise.

But, the continued lack of recruitment of YoY Herring in 2005 and 2006 could not be explained by an impact of construction activity in the winter of 2003/04 unless it was the adult spawning stock of the area that was severely impacted. If this was indeed the case, the capture of large mature Herring in early 2008 may indicate recovery of the stock and the prospect of resumed recruitment of YoY Herring.

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[3] Small sample size prevented analysis between sites although there was no suggestion this was likely to be different and thus all data by year uses pooled data from birds at either the North Denes or Winterton colonies.

Clearly, even if there was a negative indirect impact of construction of the wind farm upon the prey resource of Little Terns, the birds were generally able to compensate for the effects of a reduced prey supply through a series of behavioural mechanisms apart from perhaps in 2004 when prey was at a particular low level. Any negative impact of construction thus appeared to be short-lived.

The formation of a subsidiary sand bar within the wind farm appeared to be responsible for an increasing use of the wind farm area by Little Terns from 0% in 2004 to 2% of time by 2006 (Figure E). Whether the change in habitat was linked to the installation of the turbines and thus a true positive indirect impact or was simply coincident remains unknown. Whatever the case, there was no evidence for one of the main perceived impacts of a wind farm, that of avoidance leading to displacement as usage of the wind farm area increased in the operational phase. But, this potentially *positive* impact of Little Terns to the wind farm was tempered by an increase in their risk of collision, which was further exacerbated by an increasing number of breeding birds at North Denes by 2006.

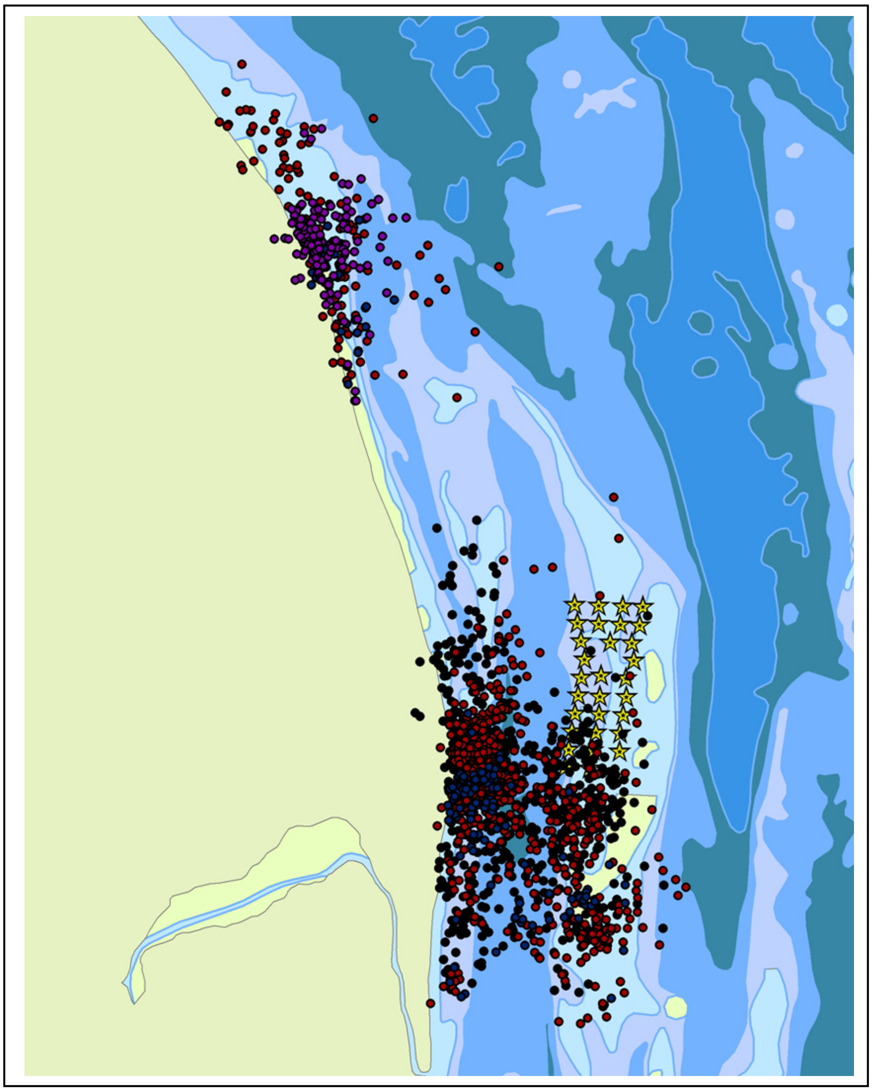

Figure E. Foraging fixes (*n* = 2049) of all radio-tagged Little Terns from each year at both North Denes (ND) and Winterton (W): 2003 (W - purple), 2004 (W & ND - blue), 2005 (W & ND - red) and 2006 (ND - black). The location of turbines is indicated by yellow stars.

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Despite the relatively low use of the wind farm area and the tendency of Little Terns to fly below turbine height, such was the number of passages through the wind farm area during the period of colony occupancy by Little Terns that collision risk modelling predicted that 27 adults and 7 juveniles may be killed per annum at an estimated avoidance rate of 98%. Matrix analysis illustrated that this could have population-scale effects of *major* significance from a local-regional scale to a national scale and *moderate* (and thus still undesirable) significance up to an international scale, particularly when considering the impact on likely background mortality.

Conclusions & Recommendations

The described in-depth single-species study in relation to an offshore wind farm is without precedent in the UK. It is suggested to have more than achieved its FEPA license requirements. Moreover, the monitoring undertaken has significantly advanced understanding of the foraging and breeding ecology of Little Terns at their most important breeding colony in the UK, which is also of international importance. The information gained may prove invaluable to the species' future conservation.

Notwithstanding this positive role of the study there is concern over the potential continued impact of the OWF, and recommendations focus on further studies to verify the *theoretical* risk of collision in particular, the nature of the prey supply available to the birds and the means of possible mitigation should this be required, as well as the possible relative impact of other developments in the area.
Of primary importance is the need to determine whether collision is indeed likely to occur to the level predicted and its impact on a population-scale. This may be undertaken in two complementary ways:

- Actual monitoring of the rate of collision – which will require development of novel techniques such as capture of collision victims at selected turbines with net structures, adaptation of video cameras, TADS or radar, or extended visual monitoring from fixed structures.
- A form of Population Viability Analysis (PVA) to determine thresholds of 'acceptable' mortality levels below which population-scale effects are unlikely.

Should measured and predicted levels of mortality prove to be unacceptable, this should trigger mitigation measures. The most obvious of these is shutdown of turbines most obviously during colony occupation (May to August), although this may be effective only during especially vulnerable periods if these can be established (perhaps later in the chick development period as fish density declines).

An alternative approach to 'compensate' for collision victims could be even more intense proactive wardening/ protection to ensure maxiumum productivity from the colonies, although further production of chicks cannot compensate for loss of breeding adults on a one to one basis, but needs to account for the mortality of juveniles until they breed. Further alternative solutions include the creation of suitable nesting and foraging habitat at alternative sites such as Winterton or even Caister where birds also used to nest, perhaps with the intention of drawing birds away from the wind farm area. The establishment of a small colony at Eccles where birds are thought to forage around the offshore reefs illustrates the potential for this idea.

It must also be highlighted that should Herring recruit in coming years as effectively as they did in the early years of this study (e.g. 2003 and possibly also 2002) prior to construction, Little Terns are unlikely to have to routinely range as far as the wind farm area, or if so, may simply concentrate on Scroby Sands themselves. In this case, the risk of collision will inevitably decline.

With the cessation of monitoring in 2006, nothing is known of the subsequent recruitment of YoY Hering in the area, save that adult Herring may have spawned successfully in the winter of 2007/08. More information on spawning grounds, the impact of local small-scale drift fisheries on adults and perhaps the factors promoting larval recruitment could lead to protection of important sites and reduction of fishing through no-take zones/seasons.

Finally, a major new development, the Outer Harbour, has been initiated over the last two seasons. At ~3km away this is well within the foraging range of the birds from the colony. As there appears to be no requirement for monitoring of any prospective link to the Great Yarmouth North Denes SPA and its Little Terns, their prey and habitat conditions, it will remain difficult to attribute any future detrimental changes in the suitability of the nesting and foraging habitat of the North Denes colony and thus the success of the SPA, to the Outer Harbour, the OWF or to natural variation. It may therefore be prudent to maintain a ‘watching brief’ in the form of a resumption of some aspects of monitoring undertaken in this study. Such monitoring may also provide a measure of the value of any mitigation measures adopted.

Draft 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 (*Sternula 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) on behalf of Great Yarmouth Borough Council (GYBC).

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.

Such is the importance of the site that after discussion with English Nature (EN) (now Natural England - NE) and RSPB, the Department for Environment, Food and Rural Affairs (DEFRA), 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, which is the subject of previous annual reports (ECON 2003, 2004, 2005, 2006). Monitoring was to be divided into four areas of work:

- 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;
- 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;
- Prey studies i.e. spatial and temporal distribution of the prey resource available to birds at sea.
- Bird strike studies (i.e. determining the risk of Little Terns colliding with turbines).

Whilst the first three areas were undertaken throughout the entire monitoring period, bird collision risk could only be determined during the breeding seasons after construction (2005 and 2006). This is because in the year of construction in 2004, the turbines were only brought on line after the end of the breeding season, when the birds quickly disperse away from the area. Thus, in 2004 the turbines were not in full operation whilst Little Terns were present.

In all years of the study, breeding colony studies and (at least) foraging behaviour at sea was also conducted at Winterton, some 12 km north along the coast, which forms part of the SPA. In all years of the study birds with the exception of 2006, Little Terns attempted to nest at Winterton, most often in response to displacement from North Denes for one reason or another. This additional work within the SPA was undertaken to further understanding of the foraging ecology of Little Terns and the factors affecting reproductive success. Knowledge of such factors prior to the inception of this project was 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.

This document represents the final report on all monitoring conducted from 2002 to 2006 inclusive, providing information on the data gathered in 2006 for the first time and building on the dataset documented in previous reports (ECON 2003, 2004, 2005, 2006). To the best of the authors' knowledge, the study represents one of the most in-depth studies of a single species in relation to a wind farm yet conducted. Alongside the recently completed studies at Horns Rev and Nysted in Denmark (Petersen *et al*. 2006), the study contributes considerably to the science of assessing the impact of offshore wind farms upon seabirds.

Although no detailed specific information was gathered on the impacts of Scroby Sands wind farm on other bird species, the fact all species were identified during surveys meant that the *potential* for impact on other seabird species could also be raised during the study, which was of relevance to other wind farm sites, particularly in the nearby Round 2 Strategic Area of the Greater Wash.

2. BACKGROUND INFORMATION

2.1 Historical context & status of the Great Yarmouth North Denes SPA

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. In 1920, 50 to 60 pairs returned 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. Occupation was only sporadic in the 1990's. For similar reasons, a small colony between Winterton and Hemsby that had held 20 pairs in 1985 had been deserted by 1990.

Riviere also 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 eight in 1955) continued to try and nest during the 1950's, with little success. Little Terns were not known to nest at Yarmouth until World War II when human activity was restricted, with a large colony becoming established in 1945. After the removal of the mines and barbed wire in peace-time from 1946 onwards, 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 nine) intermittently attempted to breed at Yarmouth between 1950 and 1983. On Scroby, 27 pairs were present between 1948 and 1951. 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 pairs 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 submersion of Scroby Sands 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. Human disturbance was thus seen as 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 and Joint Nature Conservation Committee [JNCC] amongst others) (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 1,396 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 hugely over the years, with the number of young fledged per pair ranging from 0 to 1.74 (Table 1). Up until the beginning of the study period in 2002, 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 *Falco tinnunculus* (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 supplementary feeding was suspended as a result of further research questioning its efficacy (Smart & Ratcliffe 2000) (until 2006 – see 5.1.1 below), the use of chick shelters continues as a standard pratice.

Table 1. Status and production of the Little Tern colony at North Denes from 1986 to 2006 whilst under RSPB protection. Data adapted from Allen Navarro *et al*. (2006).

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
2005	196	11	0.06	0.56
Total	**3453**	**1946**		**0.56**
Mean ± 1SE	**172.7 ± 17.5**	**97.3 ± 20.8**		

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)[4]. 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.

ECON (2004) suggested that if the chicks fledged from Winterton in 2003 survived to breed[5] the potential impact of this recruitment event on Little Tern populations in the future could be enormous, and with the longevity of Little Terns, may be felt for decades. This was reinforced by the site fidelity of the birds controlled (captured having been ringed previously) throughout this study, with all fourteen (four in 2003, six in 2004 and four in 2005) 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, that 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.

With some suggestion that the loss of the first few nests to predators discouraged the formation of a large colony at North Denes in 2004, Little Terns re-established in numbers at Winterton. A peak count of 150 nests was obtained by 15th June 2004. After some evidence of a minor disturbance/predation event causing the loss of around 37 nests, the unprecedented mass abandonment of nests then occurred. This was thought to be due to the lack of a suitable prey supply (ECON 2005, Perrow *et al*. 2006). Circumstantial evidence linked the recruitment failure of young-of-the-year herring *Clupea harengus*, the principal food supply of nesting birds in the area, to construction activity; principally the noise and vibration generated during pile-driving (during location of turbine bases) in the spawning season of the local herring stock (ECON 2005, Perrow *et al*. 2006).

An impact of construction activity in the winter of 2003/04 could not explain the lack of recruitment of Herring in 2005 unless the adult spawning stock of the area was severely impacted, reducing the chances of recruitment over several years until the stock recovered. Whatever the

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[4] No data available for 2001, although the lack of wardening suggests little, if any, nesting.

[5] These were due to return for the first time as 2nd summer birds in 2005 after spending the whole of their 1st winter and the following summer in the wintering grounds off West Africa.

explanation for the lack of Herring, the result at Winterton was the same with a repeat of the abandonment of nests (83 nests lost) observed in 2004. Nonetheless, late nesting birds at North Denes had a high level of clutch survival (74%) and >400 Little Tern chicks hatched. In a further repeat of previous events, this time comparable with 1996, systematic predation by the Racecourse pair of Kestrels then occurred, as they successfully raised their own brood of five chicks. It was estimated they predated 455 Little Tern chicks and just 11 are thought to have fledged (Smart *et al*. 2005). It was unclear how many chicks would have survived without the attentions of these predators, and thus whether the effects of a depleted prey supply could be compensated by the increased endeavours (time spet foraging and distances travelled) of Little Tern parents.

The breeding season of 2006 offered the potential for a test of relative impact of prey supply and predation as the RSPB embarked on a six-year study of the effects of the efficacy of diversionary feeding (Allen-Navarro 2006). The intention was to alternate feeding/no feeding at Kestrel nests in successive years, with 2006 being the first year where supplementary food (white mice) would be offered at the nest of the Racecourse Kestrel pair (at least), assuming Little Terns nested at North Denes and hatched chicks.

The need for management to promote Little Tern productivity is emphasised by the fact that a reduction in productivity is thought to be driving the long-term decline of Little Terns in Britain (and Ireland) (Ratcliffe 2004). The most transparent cause of reduced production at colonies is predation, especially by Red Fox Vulpes vulpes and birds of prey although a lack of long-term data on causes means that there may be other underlying causes. Matching colony location with a suitable food supply appears to be a key theme (Perrow *et al*. 2004), as indicated by the continued concentration of birds at fewer but larger colonies (Ratcliffe 2004). These larger colonies also tend to have higer productivity, which may indicate a better prey supply or alternatively suggest these may be better defended against predators. A simple population model developed by Ratcliffe (2004) suggested that a productivity of 0.67 chicks pr yr^{-1} was required to maintain the population. Even at North Denes the largest and one of the most successful colonies in the UK, cumulative productivity of the colony has been below this value since 1999 (Table 1).

2.2 Potential impacts of the Scroby Sands offshore wind farm

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

Potential negative impacts include:

- Direct strikes of birds with turbines;
- Direct displacement (through avoidance) of birds from important foraging grounds (i.e. habitat loss);
- Indirect effects through 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.

The results of the monitoring in 2004 suggested a further negative impact was plausible:

- Changes in the productivity of important foraging grounds as a result of impacts of construction/operational activity upon the distribution or abundance of important prey species.

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 through both direct action and 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, although investment of resources (especially financial) in proactive protection especially against predators and human disturbance over and above that already achieved by the RSPB, was also thought to offer a valuable 'in-kind' solution.

It has also been stressed that not all impacts may be negative. 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.

Positive impacts 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 prey resource for Little Terns. Fish find structures particularly attractive and the species richness as well as the abundance and distribution of fish could conceivably change to the benefit of Little Terns. Changes in local habitat conditions may occur with the presence of the turbines, with any change in patterns of erosion and deposition potentially influencing the size and shape of the sand bar(s) and thus the area of shallow water supporting fishes. Even if not changing the actual abundance of fish, their availability to Little Terns may change for the better.

2.3 Development of impact assessment methods for seabirds

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. Initially, the bulk of generation (60-70%) was hoped to come from turbines sited offshore (DTI 1999). In keeping with the fact that the 2010 target is now likely to have a considerable shortfall, there are fears that offshore wind will also falter without additional Government support (http://bwea.com/media/news/060404.html), although with support, offshore wind could power 6% of the UK's energy needs by 2015. It has also become clear that there are a number of limitations ranging from raw materials, lack of supply chains, suitable vessels for installation and the planning process.

In reation to the latter, the first round (Round 1) 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), 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). The monitoring using both aerial (plane) and boat-based surveys in 2003 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.

This recommendation was effectively incorporated within the aerial survey programme of the three Strategic Areas for Round 2 developments – Thames, Greater Wash and North-West – begun in 2004 and completed in 2006 (DTI 2006, BERR 2007). Aerial surveys provide a 'broad-brush' scale to the evaluation of important areas of birds. As Scroby Sands is fully covered by the survey block GW6, the recent publication of these aerial surveys enables the value of Scroby Sands for a range of bird species not well covered by the specific monitoring programme for Little terns, to be broadly assessed.

A requirement for increased survey effort has also led to the concurrent development of appropriate and cost-effective 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 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. A series of recommendations as to how surveys from either platform are best conducted is presented in the final report (Camphuysen *et al*. 2004) posted on the crown estate web site (http://www.thecrownestate.co.uk).

The preferred size of vessels for standard boat-based surveys is >20 m length offering an eye height of at least 5 m. The latter is particularly important to detect birds on the water such as auks and is less important in the detection of flying birds. The focus of the study upon Little terns, a ubiquitously flying species, the shallow waters of much of Scroby Sands precluding the use of large vessels and the need for consistency meant that the initial use of smaller vessels prior to the publication of COWRIE recommendations was continued. In fact, the methods developed were based on a broadly standard approach, with a transect of 300 m set either side of the boat (see 4.1.2 below).

Typically, calculation of absolute density of flying birds relies on a series of 'snapshots' along the transect as otherwise the density of flying birds, which are typically traveling far faster than the survey platform, tends to be overestimated. Unfortunately, it was not possible to conduct a meaningful series of snapshots with very short transects (1 km) at sampling stations at Scroby, and thus any calculation of the absolute density of flying birds may be subject to error. As a result and in a similar to many other studies (e.g. Allcorn *et al*. 2004) the numbers of birds of different species are most appropriately judged as a relative density estimate or catch-per-unit effort (CPUE).

Other methods have been developed to assess bird distribution and abundance in relation to wind farms. This has ranged from static and virtually continuous observation to overcome large temporal variation in use of sites by birds (e.g. on migration) such as in Kalmar Sound, where a small offshore lighthouse was used (Petersson 2005), to the specific development of radar (Desholm & Kahlert 2005) and even thermal imaging systems (i.e. the thermal animal detection system or TADS – see Desholm *et al*. 2006), to gather data on the behavioural response of birds to turbines by both day and night. At Scroby Sands, radio-telemetry was adopted to track individual bird movements in relation to the wind farm (see 4.3 below).

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 – 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 (labelled 1-12) is shown in Fig. 1 and Table 2.

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 2, Fig. 1), were sampled. The Hemsby site was easily sampled with little time cost on course to Winterton and provided sample coverage of the entire 15km 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 (Fig. 1, Table 2).

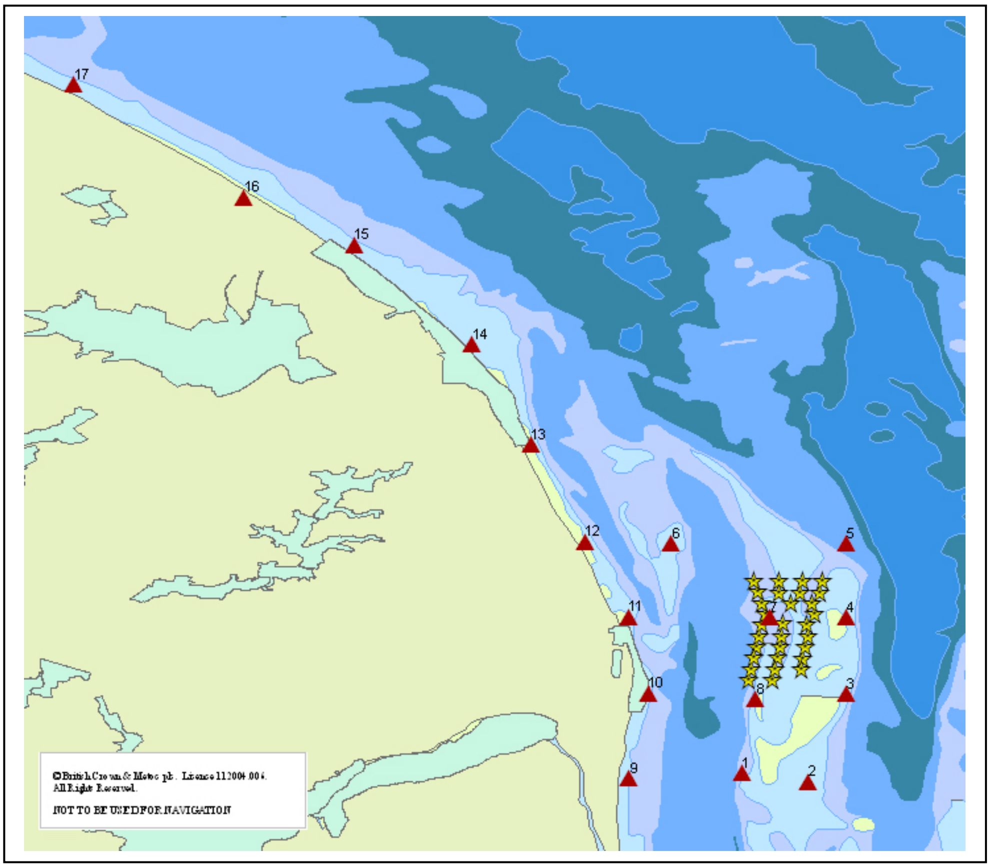

Figure 1. Map of the twelve sampling sites at Scroby (1-12) and additional sampling sites (13-16) in the Would including Winterton (14) as far north as Eccles (17). The location of the 30 turbines in the Scroby Sands wind farm is indicated by yellow stars.

Table 2. Latitude and longitude of survey sites in the entire study area including Scroby and the Would. Sites are listed from inshore to offshore from each shore identification point.

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

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

In 2003, time and resource 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. Similarly, in 2005, sampling as far north to Winterton was constrained to two occasions, once in early June and once in early July (see 4.1.1 below), coinciding with the prospective peaks in abundance of fish (see 5.5.2 below). Sites north of Winterton were sampled only on the latter occasion.

3.2 Timing of the study

In 2006, the study commenced on 2nd May the same date as in 2005 and within a few days of the start date in 2003 (6th May) and 2004 (7th May). The last visit for any purpose was undertaken on 16th August comparable to 2004 (13th August), but a week later than 2005 (4th August) and nearly a earlier than in 2003 (21st August). Some difference in dates is as a result of the timing of events in the colony, with early failure in 2005 leading to the early southward migration of the vast majority of Little Terns from the study area. In 2006, slightly fewer visits were undertaken (27) covering the various aspects of the project than the average (32) were undertaken (cf 40 in 2005, 35 in 2004, 37 in 2003 and 23 in 2002) with longer sessions covering several aspects (e.g. foraging observations and chicks provisioning). The timing of individual visits and their purpose is documented in the methods for each aspect of work outlined below. The frequency of field visits varied from daily during intensive periods, especially involving radio telemetry (see 4.2 below), to a maximum of 10 (14 in 2004) days at the beginning of the study period before birds had started nesting.

3.3 Details of vessels and personnel

Offshore work was conducted from the chartered ‘Sea Venture’ a registered 10m workboat operating from Gorleston in 2002, 2003, 2005 and 2006, skippered by Paul Lines (PL) of Enviroserve Ltd. a company specialising in supplying craft and meeting the needs of personnel on offshore developments, especially wind farms. The similar Girl Kayla under the same skipper was used in 2004 with similar required technical features (e.g. Digital Global Positioning by Satellite [dGPS] system, accurate depth sounder and net hauler) and appropriate safety equipment and procedures.

Prey studies at sea were undertaken by Dr Martin Perrow (MRP) and Eleanor Skeate (ERS) of ECON and PL, with MRP conducting all bird counts. Radio telemetry at sea was undertaken by MRP assisted by ERS and PL. Colony studies were undertaken by MRP and ERS.

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. 119954 (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 by the ringing team led by the Reverend Arthur Bowles of Great Yarmouth (see 4.3.2 below).

4. METHODS

4.1 Surveys of birds at sea

4.1.1 Number & timing of surveys

At Scroby, eight surveys incorporating bird counts and sampling of prey available to Little Terns, were undertaken over one day at intervals between 4-18 days (mean = 12 days) (cf. 6-22 days for a mean of 14 days in 2005)[6] (Table 3). The distribution of surveys at Scroby was similar to 2003 and 2004.

Time constraints (with resources directed at telemetry in particular –see 4.3 below) meant surveys of all sites as far north as Winterton (i.e. sites 1-14 – see 3.1. above) could only be undertaken in early June and July (Table 3) (1-17– see 3.1. above) with sites as far north as Eccles only covered on the latter occasion. The supplementary surveys was designed to allow a least a gross comparison between prey densities available to birds Winterton and the smaller subsidiary colony at Eccles to be evaluated in comparison to North Denes as in previous years.

In 2005, in a similar fashion to previous years surveys were generally begun between 07.00 and 09.00hrs (apart from one occasion when the survey was begun at 16.30hrs) 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.

Table 3. Calendar of bird counts and prey studies in all years.

Year	**Site**	**Relative timing of visit**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
2002	Scroby				12+13/06	26/06	10/07	26/07	07/8	05/09
	Winterton					27/06	11/07	23/07	09/08	04/09
	Eccles					27/06	11/07	23/07	09/08	04/09
2003	Scroby	06/05	26/05*	02/06	11/06	03/07	14/07	31/07	07/08	21/08
	Winterton	12/06	21/06	25/06	01/07	07/07*	15/07	28/07	07/08	21/08
	Eccles				12/06					
2004	Scroby	07/05	17/05	04/06	10/06	30/06	16/07	22/07	13/08	
	Winterton		17/05		10/06		16/07			
	Eccles		17/05		10/06					
2005	Scroby	02/05	20/05	30/05	04/06	22/06	02/07	21/07	04/08	
	Winterton				04/06		02/07			
	Eccles						02/07			
2006	Scroby	02/05	19/05	01/06	14/06	06/07	16/07	27/07	16/08	
	Winterton					06/07	17/07*			
	Eccles									

* Prey studies only

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[6] Simultaneous counts of birds could not be undertaken on 30th May as a result of observer illness and thus the next sampling date was brought forward to 4th June to compensate.

4.1.2 Survey technique

The same methodology has been employed throughout the study period (2002-2005). Namely, at each survey station on each occasion, all birds were recorded by eye supplemented by the use of high-resolution Leica binoculars (8 x 40 in 2002 and 10+15 x 40 from 2003), particularly to confirm species identity. As well as being identified to species wherever possible, birds were aged and assigned to one of several age categories (0 - juvenile, 1 year - including birds showing both 1st winter and 1st summer plumage, 2 year, 3 year etc. to 6 – adult). Birds were also assigned to one of five flight height categories (on surface, and in flight with A –<1 m, B–1-20m, C–20-120m D–>120m above sea surface). This was for the purposes of calculation of strike risk with birds between 20-120m within the zone swept by the turbine rotors.

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 vessel to cover 360^0. Counts were conducted from the vessel as it travelled along a 1km transect (divided into two 500 m sections - see 4.2.2 below) whilst trawling for prey. Using the relationship between platform and eye height of the observer, it was estimated that a distance of 300m from the observer could be readily and routinely seen, corresponding to the standard distance used for strip-transect counts of seabirds at sea (follow links to COWRIE http://www.crownestate.co.uk). This is further than the 200m estimated during previous surveys (Ecosurveys Ltd. 1995, Econet Ltd. 1999), but this value was arbitrarily derived and 300m was considered to be a more realistic value. Thus, direct comparison of the numbers of birds seen in counts in all years was possible.

The methodology used produces a count, which is most appropriately thought of as an *index of abundance* and thus *an index of bird use.* In order to put these numbers into context of other studies, it was also desirable to calculate the density (D) of birds from the area of sea sampled. Whilst traveling at 3.5 knots over a 10-minute count period, the boat was effectively sampling a 1,000m long by 2 x 300m wide strip transect.

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, such an estimation of density is very crude and should be treated with extreme caution as a ‘ball-park’ figure for gross comparison with other studies. This is partly because most of the birds sampled within transect were not resident, but simply flying through. This comprised all the terns recorded as well as the majority of other species, with the exception of most auks and some gulls. Consequently, all the birds recorded are unlikely to occur at the same time within transect, thereby overestimating density. This is despite attempts to record particular individuals/groups only once. The *snapshot* technique in which birds are recorded almost instantaneously at intervals during the sampling period is the preferred method of estimating density of flying birds (see 2.2 above). As this had not been undertaken in the initial surveys, coupled with the lack of scope to apply this technique in short transects (i.e. providing <3 snapshots per transect), no attempt was made to incorporate this into the methodology.

4.1.3 Foraging behaviour & location of Little Terns

As in 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, flight height (see 4.1.2 above), and behaviour, especially when foraging, of any Little Terns seen at sea, including away from sampling stations, was routinely recorded. Observations also extended to actively foraging terns of any species.

For the first time in the study, rather than recording an approximate location, an attempt was made to record the actual location of any Little Terns when first encountered. For this, the GPS position of the vessel was recorded, with the bearing (within 10^o using a hand-held compass) and an estimate of distance (within 10m when < 100m, within 50m when <300m within 100m when >300m) of the bird(s) from the vessel. This data was to be added to records of non-tagged birds encountered during radio telemetry, in order to further understanding of spatial and temporal use of the study area by Little Terns.

4.2 Surveys of the prey resource at sea

4.2.1 Development of a suitable methodology

As in 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, flight height (see 4.1.2 above), and behaviour, especially when foraging, of any Little Terns seen at sea, including away from sampling stations, was routinely recorded. Observations also extended to actively foraging terns of any species.

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In order to calibrate the larval tow net against the modified Riley net used throughout 2002, both nets were towed simultaneously (Plate 2) 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 (9 mm and 3 mm 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

$$y = 1.197\,x + 0.1113 \qquad R^2 = 0.78 \qquad p < 0.001 \qquad \text{(eq. 2)}$$

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

Plate 1. Deploying the Riley net from the Sea Venture in 2002.

Plate 2. Larval tow net (foreground) and Riley net in action in 2003.

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

For fish

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

For invertebrates

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

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

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

4.2.2 Sampling methodology at sea

Sampling the prey resource available to Little Terns was conducted in the same manner as previously described (ECON 2003, 2004, 2005). 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 1 km at each station, with the net sampling 1000m x 0.92m = $920m^2$ 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, 2003 and 2005, 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). Once on board the net was inverted and a careful search for retained animals undertaken. All Ctenophora (comb jellies and jellyfish) and any other large and inedible fauna (e.g. large crabs) were identified and counted before being 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).

4.2.3 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).

The clupeids, herring and Sprat are notoriously difficult to separate as juveniles and following discussion with CEFAS this not being attempted in 2002, with fish simply described under the generic term of ‘clupeid’ (‘whitebait’ in fishing parlance). However, greater familiarity with the two species led to identification of individuals >30mm whenever possible using several criteria including counts of the number of fin rays, relative position of the ventral and pelvic fins, nature of the ventral keel and its serrations, and body shape and colour in the following manner:

- Anal fin ray count: 16-17 rays = Herring, 19-20 rays = Sprat, 18 rays =either species.
- Pectoral fin ray count: 16 rays = Sprat, with 17 rays = either species.

- Pelvic fin ray count: 9-10 rays = Herring, 7 rays = Sprat, 8 rays = either species.
- Dorsal fin ray count: 20 rays = Herring, 16 = Sprat, 17-19 = either species.
- Relative position of dorsal to pelvic fins: dorsal in front of line of pelvics = Herring, behind = Sprat, level = either species. With some of the smaller fish in the 30-40mm range, this is not an entirely reliable characteristic as the fins have only just developed and their relative positions may not yet have stabilised.
- Ventral keel: strongly developed with strong serrations = Sprat, with weak keel and serrations = Herring.
- Body colour and shape: with larger juveniles Herring may be clearly darker blue on upper surfaces with a more domed head shape, whilst Sprat are more of a green silver colour and a flatter head profile.

In all instances a final identification was made based on a combination of the features described above. Unfortunately, it proved impossible to separate between the larvae of Herring *Clupea harengus* and Sprat *Sprattus sprattus* when fish were very small (<30mm) as at this size as identification features, such as rays, ventral spines, the relative position of dorsal and pelvic fins, and differences in colour and head shape have not yet fully developed. Length frequency distribution was thus used to differentiate between larval Herring and Sprat with what were assumed to be young-of-the-year (YoY) sprat consistently entering samples at a smaller fork length than YoY Herring as a result of their later spawning cycle: spring/summer compared to late autumn/winter for Herring. During 2005 for example, YoY Herring ranged from 31-43 mm in survey 1, with Sprat being considerably smaller at 8-25 mm even by survey 3. By the end of the season YoY Herring ranged from 37-62 mm by survey 7 with Sprat just 17-38 mm by survey 8 (Fig. 2). In other years when the length frequency distributions were inconclusive over a particular size range, the ratio of identified fish within that size range was applied.

Lengths were adjusted following attempts to quantify the change in length and weight of preserved specimens and to allow the ‘fresh’ biomass, and thus the biomass available to Little Terns, to be better estimated. In 2003, 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. In 2006, a further attempt was made to estimate the change in length specifically with a sample of fresh larval (from 17-61 mm) clupeids not differentiating between Herring and Sprat. Individual fish were then preserved in the standard way and re-measured several days later. Log_{10} transformation of data illustrated length decreased in a constant manner.

$$y = 0.9325x + 0.1556 \quad R^2 = 0.959 \quad p < 0.0001 \quad \text{(eq.5)}$$

Weight of the preserved specimens in both 2003 and 2006 also 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*=135)

$$y = 0.8785x + 0.1825 \quad R^2 = 0.9674 \quad p < 0.0001 \quad \text{(eq.6)}$$

For *Idotea* (*n*=63)

$$y = 1.0202x + 0.0175 \quad R^2 = 0.849 \quad p < 0.0001 \quad \text{(eq.7)}$$

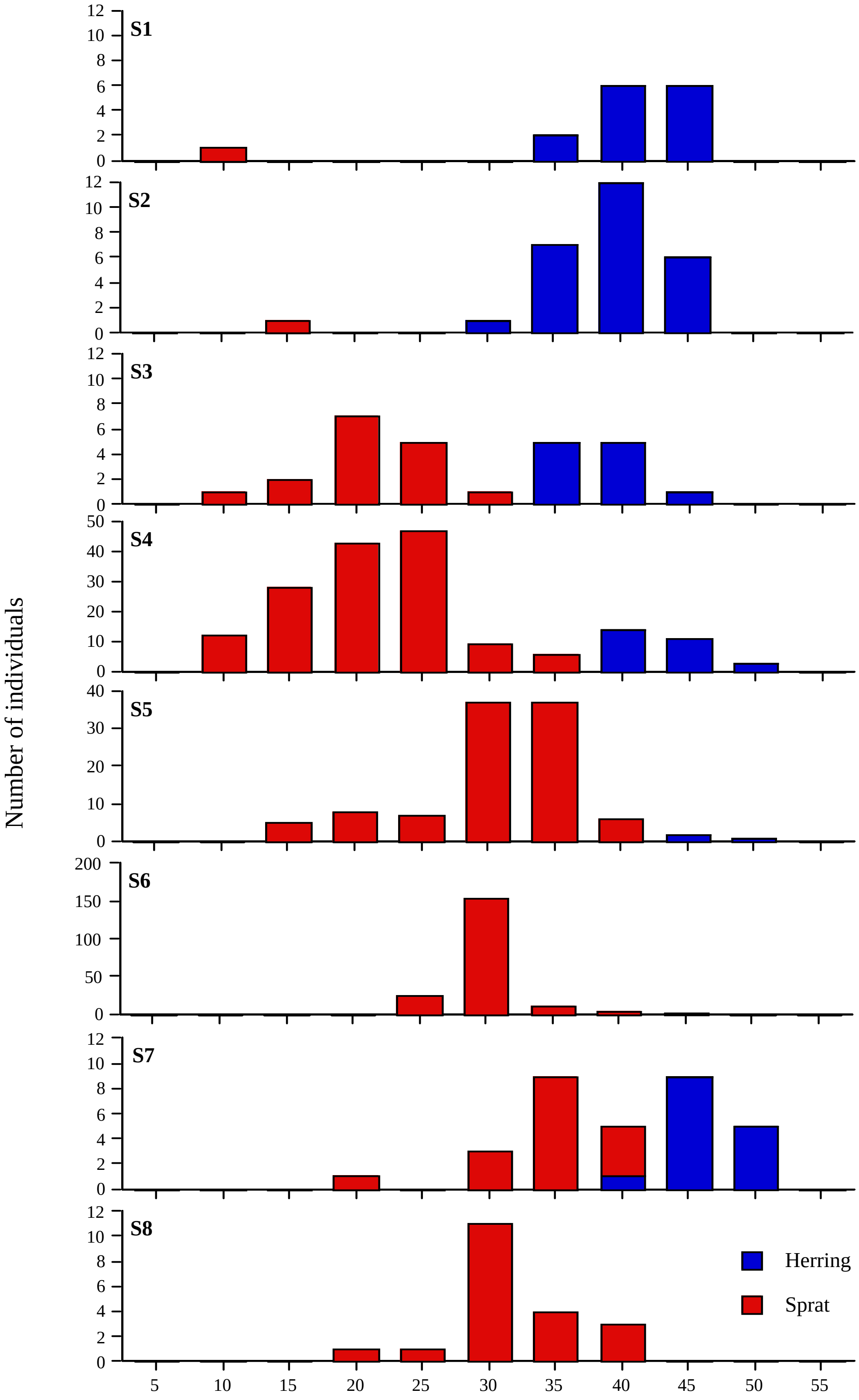

Figure 2. Polymodality in the length frequency distribution of clupeid fish throughout the 2005 season (sample occasions S 1-8). The different modes are thought to result from the different growth regimes of YoY Herring and Sprat stemming from their different reproductive cycles. Identification of specimens >35mm was also confirmed from morphological characters.

For shrimps (*n*=21)

$y = 0.9908 x + 0.0567$ $R^2 = 0.995$ $p < 0.0001$ (eq.8)

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)

$y = 2.438 x – 4.8812$ $R^2 = 0.623$ $p < 0.0001$ (eq.9)

For *Idotea* (*n*=272)

$y = 2.8041 x – 5.0184$ $R^2 = 0.924$ $p < 0.0001$ (eq.10)

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

$y = 5.1392 x – 7.2648$ $R^2 = 0.695$ $p < 0.0001$ (eq.11)

The true fresh biomass of individual preserved specimens taken in any year 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.

4.2.4 Analysis of tow net sample data

The highly temporally and spatially patchy tow net data failed normality tests (Kolmogorov-Smirnov) even after transformation ($\log_{10}$+1), and thus non-parametric Friedman tests were used to explore inter-annual differences in abundance and biomass of both fish and invertebrate prey for Little terns using MINITAB v14. This was achieved by pooling all catches from all twelve sampling stations (24 tows) as catch-per-unit-effort (CPUE) and then using the sampling occasion as a repeat measure to account for seasonal variation in catches.

The lateness of sampling in 2002 coupled with the use of a different net that was later modified (and calibrated), meant that analysis using all eight sampling occasions (a ninth sample in 2003 being excluded) incorporating the entire period of colony occupancy by Little Terns, could only be conducted from 2003 onwards (Table 3). An alternative analysis was also conducted using only fish data from the initial nesting and chick development period up until typical fledging period in early July (occasions 1-5) as this was likely to be the critical period determining success or failure. Only fish were analysed as the dominant component of chick diet (see 5.8.1 below).

A third analysis using both numerical fish and invertebrate data (biomass was not measured adequately in 2002) from all years over the entire sampling period to August (sampling occasions 4-8 inclusive) generally incorporating late peaks of Sprat (ECON 2006)[7] was also conducted. Where there were significant differences in any variable between years from any analysis, a visual comparison of ranks was performed to show the likely location of differences.

Simple exploration of the relationship between fish density (pooled from the two tows at each site) and water clarity (Appendix II) was undertaken using the Spearman rank correlation coefficient using all sites on all occasions (*n*=96) and the inner sites (*n*=32) within each year. The relationship between fish density and the number of Little Terns recorded at a site was also explored in a similar manner.

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[7] apart from the exceptionally early Sprat peak in 2006 – see Figure 7

4.3 Radio telemetry of Little Terns

4.3.1 Adaptive experiences of tags & tagging

The capture of adult Little Terns at the nest, fitting them with radio tags and tracking them at sea was without precedent in the UK before it was undertaken as part of this study from 2003 onwards. Undertaking such procedures on a protected declining species was only justified by the importance of the need to fully assess the impact of the presence of the Scroby Sands wind farm.

Any changes upon the distribution of foraging birds and perhaps ultimately risk of collision as a result the presence of the turbines could only be assessed if there was a negligible impact of tagging upon the behaviour of the birds. This necessitated continuous careful evaluation of any perceived impacts, likely causes and assessment and subsequent modification of techniques.

During the first attempt at tagging in 2003, tags were attached using both back-mounted (Warnock & Warnock 1993, www.biotrack.co.uk) and tail mounted (www.biotrack.co.uk) techniques at the request of the British Trust for Ornithology (BTO) the licensing authority. Despite the latter being a standard method that had reputedly been used successfully on the similar-sized Whiskered Tern *Chlidonias hybrida* (Biotrack *pers comm*.), this was abandoned as being completely unsuitable for Little Terns after a trial on two birds (Perrow *et al*. 2006). It proved difficult to fit a tag to the limited extent of central tail feathers and of the two tags fitted, one ceased to operate within a few minutes and was not subsequently contacted and the other was found shed with tail feathers attached within a few days of fitting. It seems likely that the failed tag met the same fate.

The first three birds fitted with back-mounted tags exhibited abnormal behaviour patterns similar to those documented by Massey *et al*. (1988) working on the very closely related Least tern *Sterna antillarum* (ECON 2003, Perrow *et al*. 2006). There was no evidence that handling itself was responsible as all birds initially behaved normally (ECON 2004), and was thought to stem from the fact that the aerials snapped at the base of the tag within 6 days of attachment (Appendix III). Replacement of the 20cm wire aerial with a thicker (~0.75 mm) multi-strand wire with a plastic sleeve over the first 5 cm of its 15 cm length on all unused tags eliminated this problem and this design was used subsequently on all tags fitted.

Tag performance was identified as of particular importance in limiting data collection (Perrow *et al*. 2006). For example, three of the 13 tags fitted (23%) for which useful data were collected in 2003 and 2004 year suffered from a drifting signal. This created confusion with other birds and in 2004 considerably reduced the amount of information gathered on one of the few birds nesting at North Denes. The phenomenon of drifting tags may be related to rapid temperature changes experienced as the bird dives and immerses, with possible absorption of salt water by the tag sealant (Plastidip) over time (J. French *pers comm*.). Unfortunately, no combative measures were available.

However, steps were taken to improve the poor tag life experienced in 2003 by trialling a larger Ag376 battery in five of the 14 tags fitted in 2004. The weight of the tag was kept to a maximum of 1.1 g (1.8% of body weight) by only using the larger battery with a standard and not additional ground plane aerial. The remaining nine tags used standard Ag379 batteries, five of which had standard aerials and four had both standard and ground plane aerials.

There was no detectable difference in the clarity or distance of reception of tags with additional ground plane aerials. However, Ag376 batteries lasted over twice as long on average than the Ag379 (means of 18.0 and 7.6 days respectively), although the respective mean life was still only 67% and 42% of the maximum quoted values.

It seems that the field conditions encountered by the tags will invariably reduce maximum tag life derived under optimal conditions, although a few tags achieved longevity close to the maximum value (e.g. one Ag379 tag was known to work for 27 days cf. the maximum of 28 days).

All tags fitted in both 2005 and 2006 therefore contained Ag379 batteries with only standard aerials. To also combat the potential for high tag failure rate, as much data gathering as possible was undertaken immediately after the tags had been fitted. An attempt was therefore made to fit tags to nesting terns in sequential batches of up 5 tags to cover the entire period of incubation and chick development (at least 40 days in the life of each breeding attempt).

4.3.2 Capture of adults

Adult Little Terns were captured at the nest at both the North Denes and Winterton colonies through the use of a 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.

According to the plan, 1-5 birds were captured on up to four separate occasions at the principal colony (Winterton in 2003 and North Denes from 2004-2006) and one occasion at the subsidiary colony, from mid-June up to the second week of July (Appendices III & IV). Days were carefully selected to provide optimum weather conditions, being warn with still or light winds and no rain. Attempts were typically conducted either early morning or late afternoon when other disturbance from visitors was at a premium. Plans to attempt capture birds were abandoned in advance on the basis of the local weather forecast or on the advice of staff on site and on two occasions at North Denes initial an attempt to capture birds were abandoned after a few minutes as a result of inclement weather conditions: freshening winds in which birds were unwilling to settle.

On each capture attempt at either North Denes or Winterton, specific nests were targeted. At North Denes the exact location and history of the selected nest was known to RSPB staff protecting the colony. Only nests with apparently complete clutches preferably that were known to have undergone at least half the incubation period of around 20 days, were selected**.** This was to further reduce the already perceived low risk of any birds abandoning their nest as a result of handling.

Cage traps were placed over two or three targeted nests containing eggs, with the ringers retiring to the dunes or strand line in the case of North Denes some 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 (Plate 3), 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 make the capture. Birds generally flushed into the larger chamber where it could be captured by reaching in through a further hinged door in the roof (Plate 4). On a few occasions, the bird 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.

During the study, a total of 56 individual birds (57 captures) were captured, with 51 of these fitted with tags (Plate 5). Details of the biometrics of the birds fitted with tags (as well as the characteristics and response of the tags and the birds) are supplied in Appendix IV. Five birds were surplus to requirements as a result of all traps catching simultaneously and the other (NW09880 on its right leg and a yellow colour ring on its left leg) that was fitted with a tail-mounted tag (that failed within a few minutes - ECON 2004, 2005, Appendices III & IV) at Winterton in 2003, was retrapped at Winterton in 2005. This was not re-tagged.

In total, eighteen (32%) birds (including the retrapped adult above) captured were controlled, meaning they had previously been captured (Table 4). Fifteen (83%) of these were ringed as pulli (chicks) at North Denes, with one ringed as a pulli from Winterton and one from Landguard, Suffolk (probably as a pulli). These birds already had standard metal BTO rings on the right leg. Otherwise, birds were ringed with a metal ring on the right leg supplemented by a colour ring on the left leg according to the year and location of capture (Table 4, Plate 5). As a result of the lack of resources to always purchase two sets of different colours to differentiate between the two sites, too few colour rings being available (2006) and a faulty batch of rings which were easily detached and appeared to have been made too large (2005), only 33 adults (59% of those that could have carried them) could be colour-ringed. This supplemented the colour ringing of pulli using the same colour according to year and site and on the right leg during the standard chick ringing scheme, which has been undertaken whenever possible since 2001 (Allen-Navarro 2006).

Table 4. Details of colour ringing of both adults and pulli Little Terns during and prior to the study.

Year	Site	Colour & location	Number of adults colour (and metal) ringed	Number of retraps	Colour & location	Number of chicks colour (and metal) ringed
2001	North Denes				O right	160 (380)
2002	North Denes				SB/O right	6 (6)
2003	Winterton	Y left	9 (6)	4	Y right	309 (309)
2004	Winterton	Y/B left	8 (12)	6	Y/B right	
2005	North Denes	O/W left	5 (8)	3	O/W right	30 (36)
	Winterton	G/Y left	4 (4)	1	G/Y right	
2006	North Denes	B/O left	7 (8)	5	B/O right	220 (336)

Y=yellow, B=black, O=orange, W=white, G=green, SB= sky blue,
with '/' indicating position above and below i.e. Y/B means yellow over (above) black

Plate 3. Little Tern settled on eggs within the cage trap.

Plate 4. A successful capture of a Little Tern by the Reverend Arthur Bowles.

Plate 5. A radio-tagged and colour-ringed (2003 at Winterton) adult Little Tern.

Plate 6. Taking measurements from an adult Little Tern.

After ringing, a number of measurements were taken (Plate 6). An attempt was made to sex each bird on the basis of morphological features, although it should be noted that with no absolute irrefutable measure of sex, sexing a bird was only tentatively undertaken. However, based on previous experience including the subsequent observation of the behaviour of tagged birds suggest the most reliable sex-related characteristic is the length of the outer tail feathers with those on males being longer than those on females with little overlap (Table 5, Perrow *et al.* 2006). Males also tend to have longer wings and bills and weight more, but all these measurements overlap (Table 5). Similar data on the same nominate race *albifrons* in North-West Europe are presented in Cramp & Simmons (1985). On this basis, of the 56 individual birds captured, 55 were assigned a sex, with 24 (44%) thought to be male and 31 (56%) thought to be female (Appendix IV).

Table 5. Sex-related variation in selected biometrics of captured Little Terns.

Biometric (unit)	**Statistic**	**Sex**	
		Male	**Female**
Wing length (mm)	mean ± 1SE	180.2 ± 0.7	176.8 ± 0.7
	range	174.0-192.0	170.0-187.0
	n	24	33
Tail fork difference (mm)	mean ± 1SE	41.0 ± 1.9	28.8 ± 0.8
	range	35.1-49.0	17-36.2
	n	24	30
Bill length mm)	mean ± 1SE	31.3 ± 0.3	30.0 ± 0.3
	range	28.5-34.1	27.4-32.5
	n	24	30
Weight (g)	mean ± 1SE	55.2 ± 0.6	53.9 ± 0.6
	range	51-60	49-60
	n	24	33

4.3.3 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.

Attachment of back-mounted tags was similar to that recommended by Warnock & Warnock (1993) for use on small wading birds. Prior to fitting, the position of the tag complete with its muslin backing material was tested on the back of the bird. After careful observation of the first three birds and to reduce the risk of aberrant behaviours (see 4.3.1 above), only very light trimming of the underlying feathers was undertaken in order to preserve their insulating properties. This was at risk of enhancing the chances of the tag being shed prematurely, but given the over-riding importance of bird welfare and the fact that tags appeared to be retained longer than the life of the battery meant this was more than acceptable. Cyanoacrylate Superglue was then applied to the backing material and the tag pressed on (Plate 7). The site of attachment was 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 just sat quietly before flying off. Virtually all birds were seen to shake in the air before flying towards the sea, where they were thought likely to bathe.

A notable exception to this pattern was female NV51860 captured late in the study on 23rd June 2006. After release, this bird flopped to the ground within a few metres before jumping around awkwardly whilst flicking its wings. It then went on to obviously recover and walk normally before flying off. The three other birds tagged after this on that day behaved normally. However, a second bird, female NV95985 captured on 28th June exhibited similar but less extreme behaviour. A chance spillage of glue and subsequent contact of activator on the skin of one of the ringers caused a burning sensation and it was speculated that this may have caused the reaction of the two birds. A further explanation offered was the release of fumes upon activation exacerbated by the fact that both birds were handled within the confines of the portakabin at North Denes. Alternatively, both reactions may simply have been more sensitive for whatever reason to being handled and went into mild shock. Whatever the case, the use of activator was suspended thereafter, and the remaining five birds tagged behaved normally. As a general precaution for further tagging studies, where there is sufficient air temperature to mean the superglue sets rapidly naturally, it is recommended that activator is not used.

From 2002-2004, after confirmation that the tag was still working and whether or not its position on the receiver dial had remained unchanged or had ‘drifted’, the birds were left to acclimatise for at least 24 hours before any telemetry was attempted. However, with no evidence that this influenced the nature of the data gathered, in 2005, telemetry was undertaken on two birds at North Denes within hours of tagging, with single fixes obtained on a further three birds on the same date (11th July) (Appendix III). A similar procedure was therefore adopted in 2006.

4.3.4 Telemetry at sea

In all years, staff onshore carried telemetry equipment to confirm any tags fitted were still working and birds were behaving normally. Otherwise, all telemetry was conducted at sea. In 2003 at Winterton, this was conducted from the 10m work-boat *Sea Venture*. The limited speed of the vessel (~6 knots) meant that relatively few fixes could be taken from birds that proved to be capable of ranging widely and very rapidly. From 2004 onwards telemetry was conducted from aboard a rigid-hulled inflatable boat (RIB) capable of high speed (>30 knots hr^{-1}) (Plate 6). Three similar but different RIBS were chartered, with the sole use of the *Alpha 1*, a 6.3m Humber Offshore Ocean Pro fitted with a 200hp outboard engine and capable of reaching speeds of up to 40 knots (Plate 8), in both 2005 and 2006.

With knowledge of the limitation of tag performance (see 4.3.1 above), from 2004 onwards as much tracking as possible was undertaken following tag attachment, and without the limitations of poor weather and with reduced technical failure of the vessel, receiver, aerial and tags, a progressively larger data set was gathered (see 5.8.1 below). This was also enhanced by the use of a third person in both 2005 and 2006 to record boat position relative to each fix on a bird as the information was relayed by a receiver/aerial operator tracking the bird. This enabled the RIB skipper to concentrate entirely on keeping as the vessel as close as possible to the target bird.

The range of the tags at sea was confirmed at a maximum of 1 km by moving away from a bird on a nest of known position on a number of occasions at both the North Denes and Winterton colonies. This is notwithstanding interference and a fluctuating signal in some positions at both colonies, which were subsequently avoided, and the relative position (i.e. over dune ridges or behind rocks and other structures) and orientation of the bird to the aerial and receiver.

In all years, tracking sessions lasting between 3-7.5 hours (excluding travel time) were undertaken in the period between 07.30 to 19.30hrs. Tidal state was though likely to be randomly distributed throughout the data set and no attempt was made to partition data according to different tidal states.

Plate 7. Details of the back-mounted radio tag and aerial attached to a Little Tern.

Plate 8. The rigid-hulled inflatable boat (RIB) and crew used to track Little Terns in 2005 and 2006.

At the start of each session, each tag was checked for a signal. Where none was received from a particular tag, a number of attempts were made over the course of the day to locate it. When following a bird, location fixes were recorded as frequently as possible. In 2003 and 2004, fixes were collected at a minimum of two-minute intervals. In 2005, with a third person involved in data collection, the minimum interval was reduced to a minimum of every 15-20 seconds during foraging. At an average flight speed of 12.8 km h^{-1} (Perrow *et al*. 2006), a bird would have travelled 53 m between fixes, but at maximum flight speed (73.7 km h^{-1}) could have moved 306 m between fixes. A shorter time interval of recording thus improved the resolution of the location data. The actual location of the bird was derived from the known position of the vessel fixed by dGPS along a bearing of maximum signal strength coupled with an estimate of distance (m) along that bearing as derived from the perceived signal strength relative to the maximum value of 1 km at full volume and gain.

In 2003 and 2004, 'near visual' fixes in which the signal was received from amongst a number of foraging birds, were obtained on 27 occasions (4.5% of fixes). These 'near visual' fixes were supported by actual sightings of a tagged bird on 18 occasions (3% of all fixes). In 2005, despite a greater number of 'near visual' (*n*=53) and visual (*n*=54) fixes, this was outweighed by the greater number of fixes (see 5.6.2 below), and the proportions were thus very similar (both 4%) to previous years. The proportion of near visual (*n*=23) and visual (*n*=129) fixes increased to 14% in 2006 with several bouts in which the bird was quickly encountered and subsequently followed by eye after getting close enough (<50m) required to initially see the tag.

Visual observation confirmed that signals comprised of intermittent 'pips' and 'squeaks' produced by most of the tags occurred when the bird was diving. On the 522 occasions this occurred in all years combined (17.2% of all fixes), the bird was classed as feeding.

Where the bird moved out of range a course thought likely to intercept the bird was taken. Where this was unsuccessful, further searches were made until the bird was either re-located or declared lost, whereupon a search for another tagged bird was initiated. In 2004 and 2005 when a greater number of birds failed and subsequently ranged more widely (see below), the search for birds began at North Denes before moving on to Winterton, and in 2004, extended to Horsey and even Eccles (20 km away). On a few occasions in 2004 and 2005, additional searches of other sites were also undertaken on foot after a journey to the site by car.

4.3.5 Analysis of telemetry data

Bird locations were calculated from the vessel coordinates and the bearing and estimated distance of the bird from the boat. In 2003 and 2004, the vessel's dGPS plotter was used to derive bird location, whereas in 2005 and 2006 a specially designed spreadsheet (developed by Luuk Folkerts of Ecofys BV) was used. The latter converts WGS84 co-ordinates to two-dimensional British National Grid (BNG) and uses angle and distance from the boat position to derive the position of the bird. Conversion back into WGS84 is then undertaken before plotting in a Geographic information System (ArcGIS v.9.2). Home range analysis was undertaken using Ranges 6 v1 2202 (www.anatrack.com), which requires coordinates in BNG. Following analysis, all home range graphics were exported to ArcGIS v9.2 shapefiles and displayed over a digitised version of the Admiralty Chart for Norfolk (SeaZone Solutions Limited Licence No. 112004.006).

Since much of the data was gathered from continuous tracking sessions, the fixes could not be assumed to be statistically independent, in that the location of one fix was likely to have been influenced by, or autocorrelated with, that of the previous fix. Data can be corrected for autocorrelation by calculating a sampling interval that gives a low spatio-temporal dependence and eliminating excess fixes (Swihart & Slade 1985). However, in order to quantify the likely degree of autocorrelation associated with the data, the time to independence (TTI) of bird 1.8

(tracked 2006) was calculated in Ranges v1.2. This bird was selected as the best-tracked example, being tracked continuously for > 3 hours on all four days that it was encountered, with 328 foraging fixes (399 overall) representing a relatively large subset (15%) of the entire dataset. The TTI was found to be 7 minutes.

Whilst this highlighted the potential influence of autocorrelation within the dataset, the removal of autocorrelated fixes was considered undesirable in view of the disadvantages highlighted by other studies, namely significant underestimation of range size and rates of movement (Rooney *et al*. 1998, de Solla *et al*. 1999). Including potentially autocorrelated fixes was considered the best option in the circumstances on the basis that the unpredictable temporal and spatial patchiness in prey distribution already compounds accurate home range estimation, and thus any home ranges calculated are likely to be underestimates of the ‘real’ home range.

The flight speed of Little Terns, which regularly fly at speeds of over 50km per hour provides a further argument for the inclusion of all fixes. At such a speed Little Terns may travel over 400m in just 30 seconds. Assuming a mean range span of 4.3km for birds with active nests up until 2005 (ECON 2006), at a mean fix rate of 0.58 fixes per minute (calculated from the whole dataset) a bird may readily travel >33% of its range span between fixes. Therefore, if the location of a bird at Time 2 is very close to its location two minutes ago at Time 1, its location is not necessarily a function of its position at Time 1, but may instead be a function of another variable, such as prey availability: de Solla *et al*. (1999) having previously highlighting the association of autocorrelated fixes with important resources. Since the prey of Little Terns occurs in shoals, which are only available to the birds when they are in the top 30 cm of the water column, clusters of fixes are potentially important indicators of core feeding areas.

The potential influence of particular events or tracking days on the home range calculations of individual birds was recognised, although no attempt could be made to incorporate confounding influences. As the basis of much of the comparison was between years, which in turn was linked to the abundance of fish there was no evidence to suggest that confounding variables were anything other than randomly distributed through the data set. Nevertheless, whether the birds were linked to an active nest or had failed for whatever reason was incorporated within analysis as a likely significant variable influencing home range size and related parameters. As a result of failure any bird is effectively freed from the confines of central-place foraging from a nest and its dependents (the other adult and its eggs and chicks) and had the potential to range more widely, including fluxing between colonies perhaps looking for an opportunity to re-nest.

Consequently, the status of the nest attempt by each bird was continually verified using available means (visits to the colony by the researchers, daily patrols of the RSPB wardening staff and the behaviour of the bird during telemetry). From the resulting chronology of tagged birds (Appendix III) birds from active nests were differentiated from failed birds and analysed separately. Data for birds that failed during the monitoring period was also partitioned between active and failed periods and used accordingly (see below). The number and proportion of birds from active nests varied from 100% in 2003 and 2006 to 71% in 2005 and a low of 50% in 2004[8], when widespread failure occurred (see 5.1.1 below).

A range of different analyses was used to describe the foraging range of tracked birds. At this point, the nature of the data and the analyses used requires clarification. Since investigation of the foraging behaviour of the birds at sea and their use of the offshore area were the priorities of the telemetry study, all the analyses carried out on the telemetry data relate to *foraging* behaviour, and therefore *foraging* ranges, as distinct from the home ranges which would encompass fixes taken when the bird was not foraging, e.g. when it was on the nest or loafing on the beach. Those

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[8] These figures relate to the nest status at the time telemetry data was gathered and not ultimate success of the nesting attempt.

fixes that did not relate to active foraging were removed prior to analysis targeted towards answering questions about offshore foraging behaviour.

Minimum Convex Polygon (MCP) analysis, carried out using Ranges 6, provided a maximum measure of foraging range for individual birds. A Minimum Convex Polygon (100% MCP) is a polygon derived from the outlying location fixes for any given tracked bird. Other parameters, namely the range span, and the mean, median and maximum distances from the nest site[9] were also calculated. A minimum of 30 fixes is required for this analysis and tracked birds with fewer fixes at sea than this (n=1 in 2003, n=4 in 2004, n=3 in 2005 and n=2 in 2006) were therefore excluded (Kenward 2001). When a bird was tracked when its nest was active and when a nesting attempt had failed, it was either classified as either one or the other (i.e. actively nesting or failed), based on when the majority of the data was gathered. Other data relating to the less well-monitored period was then discarded to avoid the potentially confounding influence of nest status on home range size. Tracking was undertaken on just three birds with an active nest that subsequently failed: 9.0 in 2004, and 4.7 and 10.0 in 2005. The former of these was only tracked when the nest was active, and was never encountered after its nest was predated. Of the 2005 birds, 4.7 failed instantly but later re-nested, although only 8 fixes relate to the re-nest, which were therefore excluded from home range estimation. The nest of 10.0 failed early in the life of the tag and thus the majority of the tracking was carried out after the nesting attempt had failed.

Foraging range estimated from MCPs was further refined by incremental area analysis, based on the principle that the range size increases as the number of location fixes is increased until an asymptote is reached (Fig. 3). To determine this value, the mean proportion of total home range was calculated for all birds and plotted every five fixes. The asymptote was then calculated using the standard exponential curve equation ($y = a + b * (1-e^{-cx})$), where y is the uncorrected home range area (as calculated in Ranges), a is the intercept, b is the asymptote, c is the slope of the line, and x is the number of fixes (Gilbert *et al*. 2005). Since it is not possible to solve this equation when y = 100% and $a + b$ is less than 100, a value of 95% was adopted. The number of fixes required to calculate 95% of home range for active birds was calculated to be 180 (Appendix V). Only 1 bird (1.8 in 2006) had >180 fixes and the home ranges of all the remaining birds were therefore corrected using a re-arrangement of the standard exponential curve equation given above, applying a gradient generated from two plots of the proportion of fixes versus mean home range size, one for actively nesting birds (a=96.18, b=0, c=0.0251) and the other for failed birds (a= 109.56, b=0, c=0.0291) (Appendix V) in order to account for potential differences in home range size according to nest status. Kruskal-Wallis tests were then used to determine whether there were any inter-annual or sex related differences in corrected home range sizes.

Though once the standard method of home range calculation 100% MCPs, have recently been criticised on the grounds that they attach too much importance to outliers, which define the shape and size of the polygon. Whilst the outliers and the MCP was considered of interest in its own right with regards to this dataset, the amount of tracking on each bird (mean of 79 foraging fixes per bird) made incremental area analysis of MCPs problematic. As originally highlighted by Gautestad & Mysterud (1995), the longer an animal is tracked then the greater the probability of it dispersing to a new area, or undertaking a longer than normal movement. Plots of individual curves by bird show that this phenomenon of the foraging range levelling off only to increase again as more fixes are gathered occurred in a relatively high proportion (50% in 2003, 100% in 2004, 67% in 2005 and 71% in 2006[10]) of birds (see ECON 2006, Perrow *et al*. 2006). As a result, all birds (all except 1.8 in 2006) required home range correction (see above), but also led to the prospect of high foraging range estimates incorporating areas little used by the birds.

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[9] As described above, all non-foraging fixes were removed, although the nest site was entered into Ranges as a focal location for the purpose of this analysis.

[10] individual birds where this occurs were 3.8 and 10.1 in 2003; 9.0, 12, 13.9 and 7.1 in 2004; 10.0, 3.1, 0.3, 8.8, 6.4, 8.1, 5.5 and 2.6 in 2005; 1.8, 7.6, 8.6, 1.1, and 6.8 in 2006

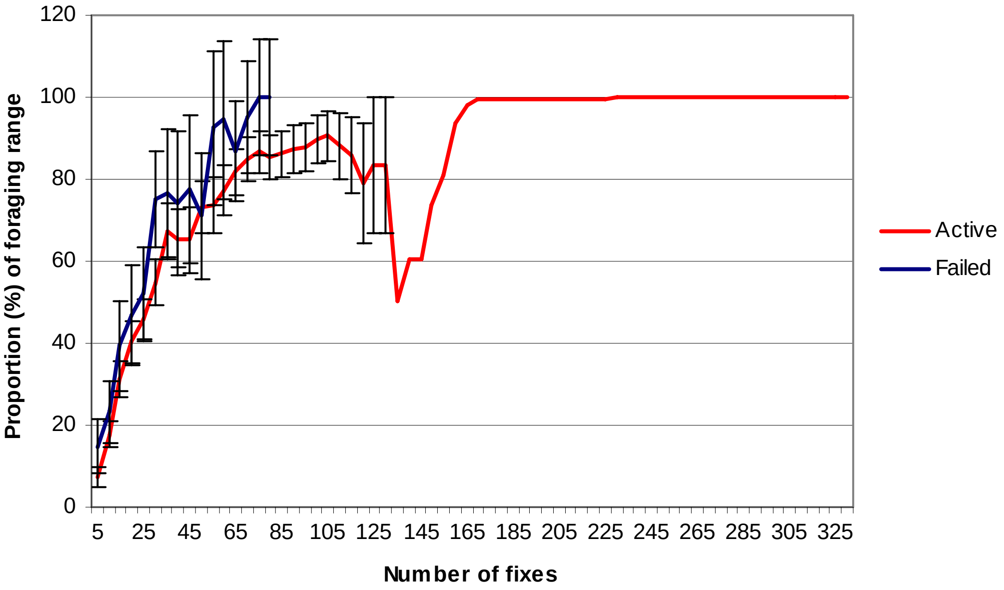

Figure 3. Relationship between the number of fixes (in increments of five fixes, total *n*= 2125) and the mean (±1 SE) proportion (%) of the total estimated foraging range for active (*n*=20) and failed (*n*=7) Little Terns (with >30 fixes at sea) tagged from 2003-2006 inclusive. For active birds, the anomaly at around 125 fixes is caused by the sole contribution of the best-tracked bird (1.8 in 2006) at this point and thereafter.

Therefore the use of alternative locational analyses, namely ellipses, density contouring and kernel contouring, all based on location density estimators that would thus exclude outliers, were investigated with the aim of reducing the influence of occasional longer distance movements and providing more meaningful estimates of foraging range areas. This approach also facilitated the investigation of other influences (namely inter-annual variation, variation between sites, variation according to nest status, and differences between males and females) that might otherwise have been masked.

Of the available techniques, ellipses assume a normal distribution around the arithmetic centre of the ellipse, which in this instance would have resulted in a large proportion of the foraging range on the beach where the birds cannot actually forage. Kernel contours and other forms of density contouring on the other hand are better able to reflect the shape of home ranges by allowing for clumping in the data. For example, Don & Rennolls (1983) developed a multinuclear model in which circular estimates of density distribution and biological attraction points were combined to estimate contours. Kernel analysis is a form of density contouring that is more convenient than harmonic mean estimators for example as the outputs are not so heavily dependent on grid size and tracking resolution, which would be problematic when dealing with the relatively large variation in tracking resolution associated with the dataset (e.g. sometimes the bird was seen and could be estimated to within a metre, whereas at other times it could be up to a km away, with distance estimation reliant on the subjective interpretation of signal strength).

Kernel contours use a bivarate normal estimator, which reduces the dependence on grid size and tracking resolution, and instead the most influential parameter is the choice of smoothing parameter, also referred to as the bandwidth or window width. Seaman & Powell (1996) suggested that the reference smoothing parameter, the standard deviation of the rescaled *x* and *y* coordinates divided by the sixth root of the number of locations, might lead to the overestimate of range area when locations have a strongly multimodal distribution, and suggest that a smaller *h* value might be used based on least squares cross validation (LSCV) of the mean integrated square error. LSCV provides an objective way to find an appropriate value of *h*.

LSCV was carried out in Ranges 6 for each bird, using the [LSCV Inflection] default starting with a multiplier of 1.51 and working downwards in steps of 0.02 to 0.09. When an inflection is reached then the programme stops (the *h* value). However, in some instances when the resolution is large relative to the range span, the LSCV process fails. This was the case with all 2003 birds (0.9, 3, 10.1 and 11.7), as well as bird 3 in 2005 and bird 0 in 2006. Therefore a median value of all successful LSCV estimates was taken, in this instance 0.35, and applied to the whole dataset on the basis that it was the most representative value available for the species (in accordance with the guidance presented in the Ranges 6 help files).

Incremental area analysis was then carried out on all birds based on the calculation of a 99% kernel contour calculated using the median *h* value of 0.35, assuming fixed kernels and a default matrix of 40 cells. Incremental area analysis was then carried out according to the principles described above for MCPs, although the process was carried out in Ranges, where the location and area are calculated with each increasing fix. The mean proportion of the foraging range calculated was plotted against the number of fixes to derive an asymptote, which was again calculated using the standard curve equation given above. Since a = 86, it was not possible to solve the equation for values of y >86, so y (the proportion of foraging range) was taken to be 85%. Using these values, the asymptote was calculated to be 113 fixes. Foraging range estimates for birds with more than 113 fixes (namely 5.6, 8.1 and 12.8 in 2005 and 8.6 and 1.8 in 2006) were thus considered to be an adequate representation of foraging range, whilst all other birds were corrected. As with MCPs, corrected foraging ranges were calculated using a re-arrangement of the standard exponential curve equation, applying a gradient generated from two plots of the proportion of fixes versus mean foraging range size, one for actively nesting birds and the other for failed birds (Appendix V) in order to account for potential differences in home range size according to nest status. Again, Kruskal-Wallis tests were then used to determine whether there were any inter-annual or sex-related differences in corrected home range size.

Inter-annual differences in core foraging range were also examined visually by pooling all birds by year and creating a kernel for the colony in each year. Although 99% kernel contours were used for incremental area analysis, the nature of the correction process and equation meant that only 85% of the final foraging range could be generated. Thus 85% kernels were chosen as the most meaningful measurement in this instance, both because the data is comparable with the individual kernels, but it also provides a more meaningful estimation of *core* foraging range. The use of a pooled dataset also meant that actively nesting birds with <30 foraging fixes that were excluded from the other home range analyses could be included (namely bird 13 in 2003, active records from bird 3 in 2004, birds 1.9 and 7.4 in 2005 and bird 4.2 in 2006). However, all failed birds were excluded on the grounds of potential differences in foraging ranges according to nest status. Therefore, both failed birds (7.1, 10.2, 5.5, 12 and 13.9 in 2004; 3.8, 6.4, and 8.8 in 2005; and 12.9 in 2006) and fixes from birds once they had failed (9.0 and 3 in 2004; 4.7 and 10.0 in 2005) were excluded from the dataset. The outputs of the 85% kernel contour analysis were maps, to give a visual presentation of the differences in core foraging area used by the whole colony between years, and an actual area (in hectares) used in each year.

It is also acknowledged that kernel analysis has some important limitations. Overlay of original fixes with output shapefiles showed that the contours where the bird is most likely to be encountered inevitably excluded a large number of fishing fixes in relatively distant locations, with the greatest probability of encounter occurring in the immediate area around the colony. Whilst this probably does represent the real-life distribution of the bird, the relative probability of the encountering the bird *actively fishing* inshore versus known hot-spots further offshore, to which it had presumably specifically chosen to travel, was considered a factor worthy of further investigation. Whilst birds may often be encountered around the colony, it was considered that this could simply be a function of the nest location and may not relate directly to foraging activity offshore. Indeed offshore foraging locations were considered likely to represent important areas probably used when prey was not abundant inshore.

As a consequence, cluster analysis, a technique that enables the identification of clusters within a mononuclear range, was also used to investigate inter-annual differences in the abundance and distribution of these fishing areas. Cluster analysis has the advantage that, unlike MCPs, it uses nearest neighbour distances rather than outliers to derive polygons around clusters of points. Isolation of fishing fixes from the main database was considered the most appropriate data to use in cluster analysis, as only fishing fixes could provide a potential measure of the location, abundance and variation within actual fishing areas. Since only two birds, 0 and 1.8 in 2006, had >30 fishing fixes, analysis by bird was not possible, so again data (in this instance fishing fixes only) from all actively nesting birds was pooled by year in the manner described above for the 85% kernels. A value of 85% was applied to all years to facilitate inter-annual comparisons after objective coring indicated values varying from 60% to 100% (100% representing a situation where the clusters are fused). As well as outputting an area for each cluster, and a number of clusters per year, the analysis also results in the calculation of a Patchiness Index, ranging from 0 (very highly patchy) to 1 (not patchy at all), also providing a general comparison between years. This was expressed visually as a map representing key fishing clusters.

Further individual-based outputs of the telemetry data were: 1) % time spent in different activities – at nest, foraging, loafing and flying above the beach typically as a result of disturbance of varying sorts; 2) number and duration of foraging bouts per hour; 3) total estimated distance travelled in a foraging bout – also converted to flying speed (km hr^{-1}); and 4) minimum, maximum and mean distance (m) of fixes from shore.

These data were pooled in different ways. For example, only birds with >50 minutes tracking time were used in the comparison of time spent in different activities, partitioned by individual bird using pooled data from however many tracking sessions were available. Iner-annual differences were explored with birds with active nests (n=27) only, with a further overall comparison between active and failed (n=8) birds. Two birds, 4.7 and 10.0 in 2005, had sufficient data as both active and failed birds.

For the other parameters, a mean value for each bird (as the replicate) in each year was generated from all individual data. An inter-annual comparison for birds with active nests including birds that later failed (birds 3.0 in 2004 and 10.0 in 2005) or re-nested (bird 4.7 in 2005) was undertaken, which had between 1-26 foraging bouts was undertaken (n=5, 3, 10 and 9 from 2003-2006 inclusive).

As there was no evidence for any site (H=2.07, North Denes n=15, Winterton n=5, df=1, p=0.15) or sex-related (H=0.32, female=11, male=9, df=1, p=0.57) differences in the size of foraging range as expressed by kernel analysis, it was assumed that neither would be an important determinant of other foraging parameters and no specific attempt was made to control for these aspects and data was pooled for sexes and sites.

Similarly, no specific attempt was made to utilise or exhaustively compare data from the small number of failed birds (n=8 in total), which were assumed to utilise what would be a flexible foraging range not bound by central-place foraging from a nest (see 5.6.4) and were this also thought likely to utilise their time in a different way (see 5.6.3).

4.4 Bird collision risk

Predicting the risk of collision of birds with turbines has become a vitally important tool in assessing the likely impact of any wind farm. This is theoretically straightforward given key parameters of the placement, dimension and operation of the wind turbines and the movements, abundance and behaviour of the birds. As a result, Band (2000) developed a specific model for Scottish Natural Heritage (SNH) that was then quickly adopted by the British Wind Energy Association (BWEA) as a standard assessment tool (Percival *et al*. 1999). Over concerns of the validity of the model, Chamberlain *et al*. (2005) under contract to English Nature (now NE) concluded the model was theoretically sound and its use has continued.

The model basically calculates number of birds likely to be killed in a wind farm in a specified period of time (typically annually) in two broad steps:

- Step 1. Calculation of the number of birds flying through ‘virtual’ rotors of the wind farm prior to being built. Two sources of information are required including the survey results and the layout of the wind farm and the size and operation of the turbines.
- Step 2. Calculation of the probability that a bird will actually fly through a rotor after the wind farm has been built and then is hit by a rotor blade. This step is also a product of two factors: a) the chance that a bird actually flying through a rotor is hit by a blade (the collision risk factor) and b) the behaviour of the birds responding (or not) to the presence of the turbine (1- avoidance rate).

In relation to Step 1, Band *et al*. (2007) outline the means of applying the model in different scenarios including whether movements of birds are likely to be predictable or less predictable. In either case, these scenarios typically apply to the onshore situation where an effort is made to cover the whole site using a number of vantage points (VP’s) overlooking the site. From the data and survey effort, the number of birds flying through the wind farm (direct flight) or the volume of airspace used by birds (occupied airspace) can be calculated relatively straightforwardly. In boat-based surveys offshore, the entire site cannot be seen from the survey platform and surveys typically aim to calculate density of birds. In this case, the density can be assumed to be constant across the wind farm site and with knowledge of the length of passage across the site and speed of the bird, a passage rate can still be calculated. This method developed by Luuk Folkerts at Ecofys (in the Netherlands) has now been applied to a number of Round 2 wind farm sites in the Greater Wash (see SCIRA Offshore Energy Limited 2006, Centrica Energy 2007).

At Scroby Sands, boat-based surveys did not use a snapshot methodology and thus could not be readily applied to a density-based approach. Nonetheless, boat-based surveys did provide supportive data for the approach adopted, which utilised the radio telemetry data from 2003-2006 in a manner more akin to an onshore scenario. It is important to note that the modelling approach simply provides a guide to how many birds *may* be killed by collision with turbines. In the case of North Denes relative assessment between years depending on the number of birds present within the colony was seen to be useful. No attempt to verify the predictions made for 2004 to 2006 when turbines were actually in operation through direct observation or search for carcasses was made, as this was beyond the scope of the study (see Appendix I).

The telemetry data gathered on Little Terns was adapted for use and applied to the illustrated example of Hen Harrier *Circus cyaneus* by Band *et al*. (2007), in a series of steps. First, in each year of tracking separately, all location fixes for each tracked bird (both active and failed birds, as all are potentially at risk from collision) were plotted and the number of fixes in the wind farm relative to fixes in the wider area was determined. Assuming a similar rate of taking fixes in different parts of the area covered by birds over the tracking period time, the number of fixes within the wind farm to total fixes describes the proportion of time the bird spends in the wind farm. This is assumed not to be sensitive to any differences in rate of fixes in different years. However, there is a possibility that with a low fix rate and low occupancy of the wind farm, fixes within the wind farm would be missed. To incorporate this possibility and to generally be precautionary because very few fixes were actually recorded from within the wind farm (32 in total), for the occasions where a bird was very likely to have travelled through the wind farm as a result of fixes on one side and then the other within a short time interval, a location fix was also assigned to within the wind farm in a *post-hoc* manner. An example of the route taken by a tracked bird in a single foraging bout is shown in Fig. 4. For each year data from all birds was pooled to give an overall tracking time, and an overall time spend by birds in the wind farm. This was used to generate a percentage of time spent in the wind farm by all birds. This was 0% in 2004, 0.9% in 2005, 2.05% in 2006 and 1.29% overall (2003 was not included since in this year only birds from Winterton were tracked).

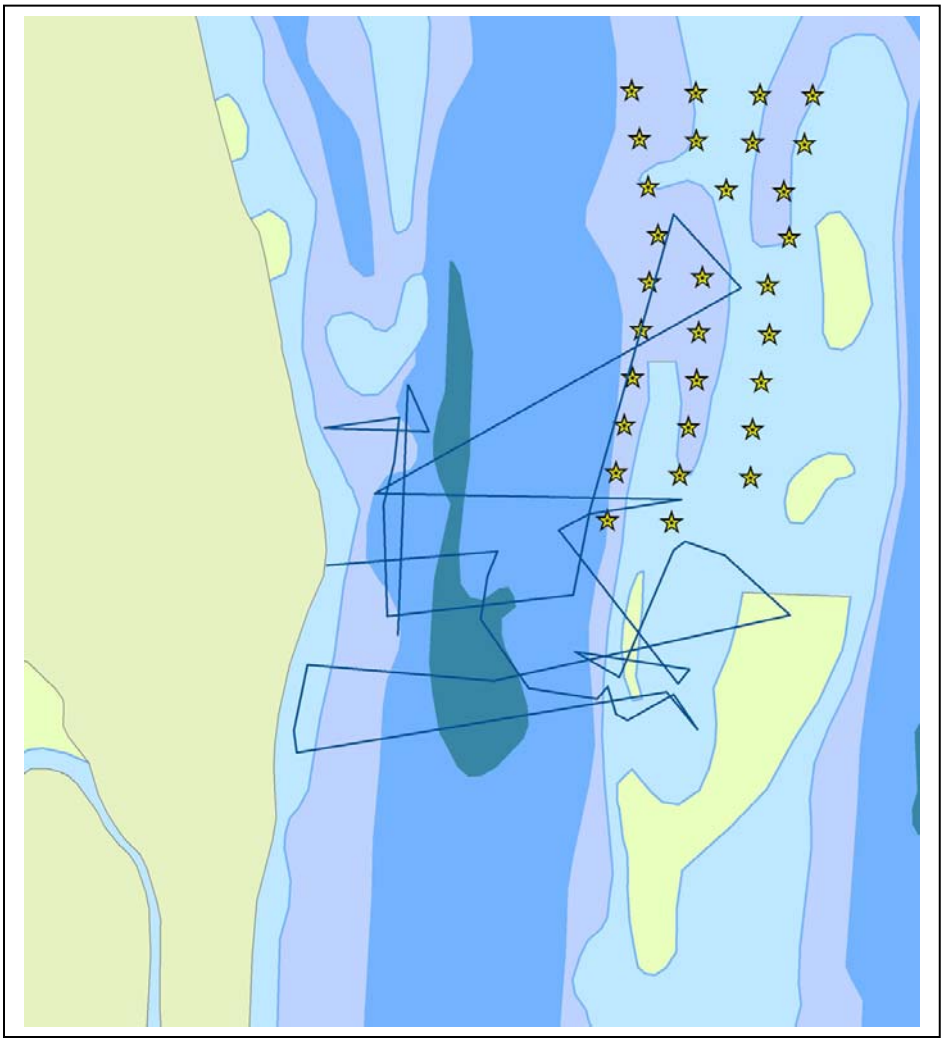

Figure 4. Example of the route taken by a tracked bird (1.8 in 2006) in a single foraging bout incorporating fixes within the Scroby Sands wind farm.

The proportion of time that Little Terns spent within the potential strike zone at ~20 m or more above sea surface was determined from records from foraging observations gathered in 2005 and 2006 (see 4.5.2 below). During each foraging bout whether complete (i.e. the bird was followed for the entire duration of the bout to and from the colony) or incomplete, any height category occupied by the birds was recorded. Without a definitive time spent in each height category if this changed during the bout, an equal proportion of time within that bout was ascribed to each height category recorded. A total of 419 foraging bouts yielded 1041 minutes of observation time in which birds spent 26% of time at < 1m above sea surface (typically traveling), 67% between 1-20 m which incorporates the typical foraging height of Little Terns (Cramp & Simmons 1985) and 7% at > 20m. With no basis for suggesting this was likely to be different between years, the value of 7% was applied to all years and thus the proportion of time spent at risk height within the wind farm could be calculated based on proportion of time birds spent foraging, which was calculated from telemetry data by year as 61% in 2004, 52% in 2005 and 46% in 2006.

The next step was to apply the time spent at risk height in the wind farm for the ‘average’ bird (assuming no difference between tracked and non-tracked birds) to an estimate of occupancy of the wind farm by all the birds in the colony. The time spent at the colony varies slightly between years. Whilst birds begin to arrive from wintering grounds in mid-April, the total numbers of birds in the area may not become obvious until nesting begins some time after mid-May. However, it is likely that virtually all birds have actually returned to the area by May 1st and this was taken at the inception of the breeding period. Whilst there is some variation in the main fledging date and a tendency for birds to depart the area earlier when nesting has been successful, bird numbers typically reduce markedly by mid-August (ECON 2006), coinciding with when the RSPB terminate their Little Tern warden contracts on August 15th. On average, birds were judged to occupy the nesting colony and surrounds for 107 days.

Whilst there is some variation in the main fledging date and a tendency for birds to depart the area earlier when nesting has been successful, bird numbers typically reduce markedly by mid-August (ECON 2006), coinciding with when the RSPB terminate their Little Tern warden contracts on August 15th. On average, birds were judged to occupy the nesting colony and surrounds for 107 days.

Little Terns are thought to only actively forage by day (Davies 1981) in a similar manner to other tern species (e.g. Sandwich Tern – Stienen 2006). Consequently, a total of 1176 daylight hours were utilised by Little Terns in the breeding season. Telemetry showed that birds spent different proportions of time foraging at sea in different years (range of means of 61% in 2004, 52% in 2005 and 46% in 2006), which may be linked to the abundance of prey. The potential difference between males and females could not be determined and thus a mean proportion was applied from all birds in the relevant year. Thus, in 2004 each bird spent 721.7 hours at sea in the breeding season compared to 606.9 in 2005, 542.1 in 2006 (height data was not gathered in 2003 and 2004).

Scaling by the number of birds in the colony based on the maximum number of breeding pairs recorded by the RSPB (n=10 in 2003, n=40 in 2004, n=196 in 2005 and n=396 in 2006) multiplied by two, suggests = 57,737 birds at sea hours in 2004, 237,918 in 2005 and 429,372 in 2006 showing huge variation. Multiplying by the occupancy of the wind farm in different years and by occupancy by risk height thus gives 0, 150 and 601 hours in 2004 to 2006 respectively.

This information was then used to estimate the number of passes Little Terns made through the rotors per year to complete Step 1 of the modelling process. This in turn relied on information on the relative volume of the area swept by rotors (Vr) compared to the volume of the wind farm (Vw). The latter was derived from a polygon around the extremities of the wind farm allowing for the blade length of turbines from bases (3.82 km^2) multiplied by the diameter of the rotors (80 m) = 305,600,000 m^3. The volume of the area swept by rotors is derived from:

$$30 \text{ (the number of wind turbines) } * \pi R^2 * (d+L) \qquad \text{(eq. 11)}$$

where R is the rotor radius (40 m), d = the maximum depth of the rotor blade from front to back (2m) and L is the length of a Little Tern (0.24m) (Cramp & Simmons 1985).

The area swept by rotors of 337,784 m^3 was thus 0.1 % of the wind farm area. The bird occupancy of the rotor area (*b*) is thus multiplied by Vr/Vw = 0 bird seconds in 2004, 596 bird seconds in 2005 and 2,392 bird seconds in 2006. At an average flight speed (*v*) of 7.05 ms^{-1} derived from telemetry using the minimum distance traveled between fixes for all foraging bouts in all years (*n*=219), the time (*t*) for a bird to make a complete transit through a rotor is:

$$t = \mathrm{d} + \mathrm{L}\ / v \qquad \text{(eq. 12)}$$

The number of *adult* Little Tern transits through rotors per annum is therefore b/t = 0 in 2004, 1,877 in 2005 and 7,528 in 2006. However, in some years a large number of fledged chicks swell the population. Whilst recently fledged birds do not appear to stray far from the colony, with the adults mainly feeding them on the beach, after a few days juveniles begin to attempt to feed themselves in inshore areas as well as traveling with their parents to all parts of their prospective home range. At this stage, these inexperienced juveniles may thus be at risk from collision.

With no information on the potential use of the wind farm site by these juveniles, as a precautionary approach it only be assumed this is equivalent to that of adults (i.e. 0% in 2004, 0.9% in 2005 and 2.1% in 2006). As juveniles tend to accompany adults closely, the same flight height and speed were also assumed. The major difference was the period in which juveniles may be present before departing for winter quarters with their parents. Whilst this varies to some extent between years, fledged chicks tend to appear around the first week of July (e.g. July 7th at Winterton in 2003 – Wooden *et al*. 2003 and July 9th at North Denes in 2006 - Allen Navarro *et al*. 2006), building to a peak by the end of July, when maximum fledging counts are generally conducted. To be precautionary, 30 days potential occupancy (i.e. from 16th July to 15th August inclusive) was assumed for the 5, 2, 11 and 673 chicks fledged from North Denes from 2002, 2003 and 2006 (there being none in 2005) (Allen Navarro 2006). Taking these values through the calculations above suggests the number of transits through rotors per annum was thus 0 for 2004, 33 for 2005 and 1,795 for 2006.

In practice, Step 2, the mechanistic calculation of the probability that a bird flying through a rotor is actually hit by a rotor blade forms the heart of the SNH-model, taking a large proportion of the calculation effort. The spreadsheet associated with SNH guidance (http://www.snh.org.uk/strategy/renewable/sr-we00a1.asp) was used to make the necessary calculations. Turbine parameters were as specified for Vesta V-80 (pitch was assumed to be 20, rotor diameter – 80m, rotation period – 3.5 seconds and maximum chord 3.52) with Little tern parameters including length and flight speed specified above. The outcome of this modelling step is a collision risk factor that lies somewhere between 5% and 20%, depending on the bird species and turbine type. The variation in the collision risk factor is quite small compared to the uncertainty in the other factors in the expression. This illustrates that the final outcome is relatively insensitive to much of the detail within the model itself. In fact, the factor of 1-avoidance rate is particularly influential, and SNH generally suggest that a precautionary avoidance rate of 95% is used, although most birds will typically show much higher avoidance rates than this in the order of 98-99% (Percival 2000, Petersen *et al*. 2006).

4.5 Breeding colony studies

4.5.1 Colony development

Close liaison was maintained with RSPB staff, notably Mark Smart the Little Tern Project Manager, lead Little Tern warden Kat Allen Navarro (from 2004 onwards) and the various 2 or 3 seasonal wardens in any year, as well as John White of EN (employed from 2003 onwards) with specific responsibility for Winterton.

RSPB staff and their volunteers closely monitor the North Denes colony, the intensity of which has increased in recent years which now involves virtually daily counts of nests and monitoring of their individual progress (Allen Navarro 2006). John White also undertakes regular nest counts at Winterton, as does Neil Bowman at the smaller subsidiary colony at Eccles, which became established in 2003. Any specific information of direct relevance to this project gathered was immediately made available with all information for each breeding season subsequently appearing in annual RSPB reports (Manderson & Mead 2002, Wooden *et al*. 2003, Allen Navarro *et al*. 2004, Smart *et al*. 2005, Allen Navarro *et al*. 2006).

There was thus no requirement to attempt to count nests during observations of foraging birds and chicks at either North Denes or Winterton. However, supplementary information on the development of the colony was gathered during observation periods.

4.5.2 Foraging ecology

With a possible risk of disturbance to a Schedule 1 species during breeding colony studies of foraging behaviour and especially chick provisioning, MRP held a Schedule 1 license issued by NE, in each year of study (see 3.3. above).

Throughout the breeding season from mid May to early August in each year of study, between 6-8 visits to undertake foraging observations were undertaken, with the exception of 2002, when as a result of the late start of the contract only four surveys could be conducted. Fewer visits could be undertaken at Winterton as a result of resource constraints, although 5 visits were still typically undertaken. The exception was 2006, when after the initial single visit with very low use by birds, and subsequent complete lack of nesting, foraging observations were abandoned. The mean interval between surveys was similar between years, ranging from 11 to 17 days, with exceptional peak values in any one-year being 5-29 days (Table 6). After 2002, the distribution of surveys within each breeding season was very similar.

Table 6. Calendar of foraging observations of Little Terns at the North Denes and Winterton colonies from 2002-2006 inclusive.

Year	Site	Relative timing and date of visit							
		1	2	3	4	5	6	7	8
2002	North Denes				18/06		16/07	29/07	12/08
	Winterton				25/06	05/07	19/07	29/07	12/08
2003	North Denes	15/05	26/05		19/06	04/07	18/07		01/08
	Winterton			06/06	10/06	26/06		24/07	01/08
2004	North Denes		25/05	01/06	16/06	25/06	12/07	26/07	
	Winterton		23/05	06/06	22/06		14/07 17/07	26/07 27/07	
2005	North Denes	12/05	26/05	05/06	16/06	22/06	07/07	20/07	31/07
	Winterton	12/05	26/05	07/06	16/06		07/07		
2006	North Denes	15/05	26/05	06/06	20/06	30/06	05/07	23/07	10/08
	Winterton	15/05							

Observations of foraging birds were made over all states of tide during daylight hours at a variety of times from 10.45hrs until 20.00hrs in sessions lasting 1.25-5hrs. The aim on each visit was to follow at least 20 birds, although both this and the duration of observations were constrained by the number of birds present and foraging. Thus, in practice, the number of foraging events on each occasion varied somewhat. For example, in 2005, between 5-27 foraging events were recorded at North Denes, with 9-21 at Winterton per visit, for season totals of 140 and 74 foraging events respectively. Total observation time on each visit thus also varied, e.g. from 12 to 100 minutes (mean [±1SE] = 58.8 ± 10.8 mins) at North Denes and 21 to 55 minutes (mean [±1SE] = 37.4 ± 7.14 mins) at Winterton in 2005. A similar range of values was recorded in all years. Overall, a total of 560 birds were observed at North Denes (mean [±1SE] = 112 ± 25.2), with 355 (mean [±1SE] = 71 ± 16.6) at Winterton, supplying a total observation time of Little Terns engaged in foraging activity for 24.2 and 16.1 hours at North Denes and Winterton respectively. However, all foraging parameters could not be derived from all observations, particularly as a proportion (mean of 58% at North Denes and 60% at Winterton) of birds were ultimately lost from view and could not be followed for an entire bout.

On each occasion, observations were initiated by scanning for birds leaving the colony or beach frontage and heading out to sea which is typically the precursor to foraging activity. This was undertaken either by eye or with the use of binoculars before transfer to a high quality telescope (Kowa TSN4) with 80mm objective lens with either a 20x or 20-60x magnification eyepiece. On occasion, observations were also conducted with high quality binoculars (Leica 10x42 Geovid with laser rangefinder) where two observers were simultaneously gathering data on different birds.

If no birds were visible, patrols over a limited area of beach (up to 1km) were undertaken, which continued until birds were located. However, after more than about 20 minutes without observations, a bird already at sea and perhaps even foraging was selected for observation. Any bird was continuously 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). A different bird was then followed. However, in some years at some sites (e.g. North Denes in 2002 and 2004 and Winterton 2005) with very few nesting birds, a bird returning to the beach, perhaps feeding a partner or chick visible to the observer could be kept in sight and observations then continued with the same individual.

For each timed (seconds) foraging bout, the following data were recorded:

- 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 attacks;
- Total number of foraging attempts;
- Number of completed attacks (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 (aided by the use of rangefinder binoculars and use of markers such as buoys at known distance);
- Outcome of observation i.e. bird lost from view or activity of bird following foraging such as return to beach or present prey to waiting chick or partner.

Data were gathered in the 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. An aborted hover simply meant the bird stopped hovering and moved on, whereas an aborted dive involved the bird pulling out of a dive prior to immersion. In both cases, birds typically resumed searching immediately.

Foraging Little Terns utilise specific flight patterns and actions. In brief, this involves birds patrolling relatively low over the sea (typically 3-8m above the surface – Cramp & Simmons 1985) adopting a head-down attitude (Plate 9). Upon locating prey, the bird typically hovers rapidly for a few seconds before an attempt is made to capture the prey item in a variety of ways (see below). Hovering is generally conducted into the wind and where this is strong the bird may fly very slowly and hovering becomes hard to distinguish as a distinctly separate action and appears more as a stalling motion with the wings held aloft above the head ('sailing') prior to diving or dropping to the surface.

Although influenced by weather conditions, the mode of attack seems to primarily depend on the prey type and its position in the water column. The characteristic, rapid plunge-dive, undertaken more or less 90° to the surface, with wings held in swept back 'dart' style appears to be mostly directed at rapidly swimming fish further below the surface. Upon emerging from the water after a dive a bird shakes vigorously in flight as it deals with any prey captured. However, where the speed of a dive could take the bird past potential prey very close to the surface, swooping to splash upon the surface ('surface splash') often occurs at a moderate (c. 45°) angle. This technique appears to be particularly directed at invertebrates on the surface (Plate 10). Sudden swooping without diving to pick prey off the surface ('surface pick') in the manner of marsh terns (*Chlidonias* spp.) was also noted, again apparently concentrating upon small invertebrates but also used to snatch fish with the bird hardly getting wet in the process.

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 and identified 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'. 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. Especially in these circumstances fish were readily separated in 'clupeid' or 'sand eel' from the very different length to width dimensions of these different taxa.

At greater distance (>300 m) 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 outcome of the attack was classed as 'unknown' and the data not used for anything other than for calculation of attack (dive) rate.

For successful dives, as a result of the high confidence in assignation of fish as prey it was effectively assumed that if dives were classed as successful but the prey was unidentified, this was something other than a fish. Nonetheless it is recognised that calculation of the rate of dives resulting in the capture of fish per minute (dive fish^{-1} min^{-1}) seen to be an important foraging parameter, may have been conservative, although there was no evidence that this varied between years. Moreover, it is plausible that some attacks actually 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, 2005).

Previous reports (ECON 2003, 2004, 2005) have examined seasonal patterns of various parameters of foraging within each colony using simple non-parametric analyses (Kruskal-Wallis tests). Whilst some differences are apparent in some years, these are not generally consistent and no further attempt was made to explore seasonal variation within the full data set. Instead, as outlined above, analysis focused on inter-annual and site differences using all pooled data from any particular combination of site and year.

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

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

Parameters selected to represent important aspects of the foraging ecology of Little Terns and determined within each bout were the distance from shore (m) (where more than one value was noted a mean was calculated) completed attacks min^{-1}, attacks producing fish^{-1} min^{-1} for any and every bout, and time (min) of completed bouts.

It was assumed that all birds observed had the prospect of foraging (i.e. they would take prey as it became available) even if they did not make even a single attempt to capture prey whilst being observed and were effectively in transit to a foraging ground. Moreover, for any one bout the maximum value of any estimated distances from shore foraging was used. For birds that were ultimately lost from view, the distance at which this occurred was estimated wherever possible (or assigned a value of 1,000 m where this had been omitted) and included as a minimum estimate of foraging distance from shore. The duration of completed bouts was used as a minimum (as there was bias to birds maintained within view) estimate of the time taken to either capture a suitable prey item for a partner or chick or to satisfy the needs of the individual bird.

Data consistently failed normality tests (Kolmogorov-Smirnov) even after appropriate transformation ($\log_{10}$+1), and thus separate non-parametric tests (Kruskal-Wallis) were used to explore inter-annual differences in the selected parameters at both North Denes and Winterton using MINITAB 14. Where there were significant differences, *post-hoc* comparisons were performed to show the location of the difference. Mann-Whitney U-tests were then used to determine if there were any differences between the sites in each year, apart from 2006 where the general absence of Little Terns at Winterton apart from a small number in early season (providing n=5) prior to nesting, precluded testing.

4.5.3 Chick provisioning ecology

Although Little Terns attempted was made to nest at both North Denes and Winterton in all years, with the exception of Winterton in 2006, observations of chick provisioning behaviour were not always possible, as a result of a low success of chick hatching at some sites in some years. Of these 2004 was particularly poor with no chicks observed to hatch from 40 nests at North Denes, with only four known to hatch from the 150 nests (count in ECON 2005) at Winterton (Allen Navarro *et al*. 2004) (see 5.1.1 below**)** with at least another suspected to have been hatched by a radio-tagged bird (female 9.4) (ECON 2005). During foraging observations whilst a bird returning to the beach was seen to present prey to one of these chicks, these had disappeared within 1-2 days and no specific observations could be made. A low hatching rate at Winterton in 2004 was principally caused by mass abandonment of eggs. A similar event occurred in 2005, with the small number of chicks hatching being predated by a Kestrel and Carrion Crows *Corvus corone* (John White *pers comm*.), again before observations could be made.

Observations were therefore restricted to 2002, 2003, 2005 and 2006 at North Denes and 2002 and 2003 at Winterton. Observations were typically undertaken every 1-2 weeks, with the aim of an extended observation period being to account for any variation in chick provisioning rate according to age/size, which has been noted by several authors (Cramp & Simmons 1985, Phalan 2000). However, the location of any differences varies between studies and seems to be dependent on a number of factors other than chick age/size, such as prey availability.

In practice, the frequency of visits was further partly determined by the sychronicity of the nesting attempt and the persistence of chicks in the face of predation and other factors (e.g. high tides). For example, despite a late season at North Denes in 2005 when chick observation were first made on 30th June, very few chicks remained by 20th July, a small number having fledged and the majority having been predated by kestrels (see 5.1.1 below) (Table 7). Conversely, in 2006, a record number of nests, extended hatching period of chicks and low chick predation rate as a result of diversionary feeding of Kestrels, ultimately allowed observations to be extended into August with six visits completed, rather than the usual three to five.

Table 7. Calendar of Little Tern chick provisioning observations at the North Denes and Winterton colonies from 2002-2006 inclusive.

Year	Site	Relative timing and date of visit							
		1	2	3	4	5	6	7	8
2002	North Denes			01/07		16/07		29/07	12/08
	Winterton			02/07	05/07	15/07		29/07	12/08
2003	North Denes	19/06		04/07		18/07			
	Winterton	20/06 21/06	26/06 28/06 29/06 30/06	02/07 04/07	07/07 08/07 10/07 11/07	13/07 16/07 17/07	21/07 24/07 25/07	28/07 31/07	05/08 06/08
2005	North Denes		30/06		07/07	14/07	20/07		
2006	North Denes		30/06		05/07	13/07	23/07	27/07	10/08

At the beginning of the observation period at either site, 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 all noted as documented above (4.5.2). Continuous observations on any family unit (nest or brood) of chicks were conducted from a minimum of 45mins to over 3 hrs in the period 11.00-19.00hrs. Trial observations showed that observation periods of <45 mins were likely to lead to bias in calculation of provisioning rate as chicks tended to be fed in intensive ‘bursts’ by both parents.

The number of chicks in each brood (not always immediately apparent – see below), approximate age and timing (using a stopwatch) and nature of particular events and features was then recorded. The latter included:

- When either adult left and returned to the nest/brood;
- The identity of the prey (i.e. species of fish or invertebrate where possible, or unknown) and its size relative to bill length;
- The fate of the prey (i.e. eaten by chick, eaten by adult or removed by adult) brought to the nest/brood.

With two observers observations were conducted on up to five broods simultaneously, with the potential for multiple observations decreasing as chicks aged. When very young, chicks are brooded for lengthy periods by either adult. At this stage chicks tend to stay together, but become more independent from each other with age, such that it becomes more difficult to assign chicks to the same family or brood with absolute certainty.

Chicks are capable of wandering from the ‘nest’ within a few days of hatching, and indeed, may be actively encouraged by the adults to do so in the face of disturbance. Such behaviour was frequently observed at Winterton in 2002 and 2003, but this was rarely observed at North Denes in 2005 and 2006. This may have been because of the high risk of chicks wandering outside their limited ‘home range, being attacked by adults from other ‘nests’.

Moreover, in the face of frequent attacks by Kestrels in 2005, larger more mobile chicks tended to take refuge in the Marram *Ammophila arenaria* and Sand Couch *Elytrigia juncea* at the landward edge of the colony and were frequently out of sight of the observers. These only tended to break cover and call loudly to be fed upon the return of a provisioning adult to the nest site or where the chick was last fed. Disturbance, particularly by humans and their dogs tends to lead to mass displacement of chicks from their ‘home’ area either to the dunes or towards the sea depending on the position of the intruder. When chicks could be followed, no feeding was observed in this period and the fact that the chick(s) was temporarily out of sight was therefore unlikely to lead to bias in recording until chicks returned to their original location. On some occasions, the chick(s) did not return or there was uncertainty over their identity. In such cases, the observation period was terminated at the time the chick(s) was first lost and a further brood selected for observation.

Large chicks capable of flight (which may occur at 14 days but more generally at 16 days onwards) tended to abandon their home area and could only be retained in view for a limited time (as little as five minutes). As soon as a juvenile was lost, observations switched to a bird of similar age and development in order to construct a 'composite' of juvenile provisioning, with the chances of actual feeding effectively being random within each observational period.

In total, 108 broods were monitored over the course of the study equating to a a mean of 12.5 broods (including a single composite of fledged juveniles in 2006) were monitored per year (all years except 2004) at North Denes, with a mean of 30 broods (including a single composite of fledged juveniles in 2003) monitored at Winterton in 2002 and 2003. The data set from Winterton 2003 was boosted considerably by the observations of UEA student Rob Howe on 18 occasions from 25th June to 5th August, which were made available to this study (Howe 2003). Total observation time was 118.33 hours at North Denes and 109.03 hours at Winterton, with mean observation time per brood in each year ranging from 108-151 minutes and 90-145 minutes respectively. The primary output of observations was a provisioning rate (feeds hour^{-1}) for each brood and 'an average individual chick' in each brood on each occasion.

Data failed normality tests (Kolmogorov-Smirnov) even after appropriate transformation ($\log_{10}$+1) and thus separate non-parametric Kruskal-Wallis tests were used to explore differences in provisioning rate according to year following separate tests to investigate the effects of both chick age and site upon provisioning rate. The former was undertaken after partitioning the sample of confidently aged chicks (n=56) recorded by a single observer (thereby excluding records by Howe 2003) into four approximate categories: 0-4 days (n=18), 5-8 days (n=19), 9-12 days (n=5) and >12 days (n=14) but not capable of flight. The exploration of potential differences between sites using Mann-Whitney U-tests was restricted to 2002 and 2003 when chicks were present at both colonies.

5. RESULTS

5.1 Colony development

5.1.1 North Denes

Little Terns tend to arrive back in the UK from their winter quarters in the second half of April, often being noted at Breydon Water and North Norfolk virtually simultaneously from the 15th onwards i.e. 15th in 2003, 17th in 2002, 21st in 2006 and 22nd in 2004 and 2005 (NNNS 2003, 2004, 2005, 2006, 2007, Allen Navarro *et al*. 2004, Smart *et al*. 2005).

Over the next few weeks as the colony forms numbers observed at North Denes beach fluctuate, with the highest numbers of birds typically observed on the beach at high tide. For example, 70 were observed on 11th May in 2004, with up to 300 on 19th May in 2005 (Smart *et al*. 2005) (Plate 11). The numbers observed may or may not directly reflect the number of birds in the area, as evidenced by records from surveys at sea in 2004, when 55 were recorded on 7th May, with this increasing to 164 by the 17th May (ECON 2005), exceeding high tide counts. In 2005, whilst good numbers of Little Terns were seen at sea in May with 80 on 2nd May, 112 on 20th May and an estimated 175 on the 30th May, these never reached the level of beach counts.

Plate 11. Little Terns aggregating on the beach at North Denes at high tide.

Plate 12. A pair of Little Terns preparing to mate.
The male bird (right) is carrying a clupeid fish as a mating gift.

In line with what is traditionally thought to be the beginning of the nesting period, the fences (an outer rope fence with an inner electric fence) around the colony were erected from 12th-16th May in 2001-2006 (Allen Navarro 2006), with a focus just to the south of Snickham's Point. In keeping with what had become standard practice, from 2001-2005 the colony was divided into a 'north' and 'south' colony, with public access through the centre to the information hut. The hut was changed to a port-a-kabin (with solar panels and accompanying portable toilet) from 2003 onwards, with better facilities to receive visitors.

In 2006, as a result of visitor pressure, particularly at the seaward edge of the colony and dune encroachment from the landward edge, fencing was extended to the sea limiting access to people walking along the sea front and the central access point was abandoned accompanied by a shift in the position of the port-a-kabin to the northerly end of the fenced area. The increase in the intensity in management was further reflected in the employ of more contract wardens (increase to four rather than three), greater facilities for the public (availability of telescopes and binoculars to watch the birds and guided walks). The contract wardens are supported by a variable number of volunteers (mean of 26 and peak of 39 in 2005), although only the former take the responsibility of 24-hour wardening, initiated once a threshold number of nests is reached. With more wardens, greater investment in monitoring has been possible, with daily nest counts from 2004 onwards (compared to just four occasions in 2001- Allen Navarro 2006), as well as monitoring of a sample of individual nests to better determine hatching success nest outcome. In 2006, 16 remote temperature loggers were placed in nests (25 in total) to indicate duration and frequency of incubation.

During May birds engage in courting flights, courtship feeding and mating (Plate 12) with the first nests traditionally laid in mid-May immediately after the colony is fenced. For example, in 2002, 13 nests were already in place on 17th May five days after the fences were installed. However, Allen Navarro (2006) notes that there is an increasing trend towards later nesting. In 2003, the first nest was not discovered until May 28th – as it became clear the colony was already in the process of being abandoned (Wooden *et al*. 2003) – 25th May in 2004 (Allen Navarro *et al.* 2004 and 31st May in 2005 (Smart *et al.* 2005).

In the latter report, the authors noted that many other Little Tern colonies elsewhere in Britain were late to start. The presence of the first nest by May 21st in 2006 promised to reverse the trend, but in fact the peak in nest counts was not achieved until 20th June. With no nests at Winterton in 2006 there is no evidence that this situation was influenced by re-nesting birds, as happens in other years. For example, a peak of 196 nests on 28th June 2005 coincided with the failure of nests at both Winterton and Eccles, whereas in 2004, a low peak of just 17 incubating birds was not reached until early July. That is unless these had come from colonies further afield in North Norfolk, elsewhere in the UK or even the Continent. The presence of a dye-marked bird at Winterton in 1997 that was had initially attempted at Zeebrugge, Belgium in that year illustrates the potential for rapid transfer between colonies within a nesting season.

In a summary of events at the colony over the five period from 2001-2006, incorporating this study and the construction and initial operation of the wind farm, Allen Navarro (2006) describes 2001 as the only season that could be described as 'typical' for the colony, with normal development, an average numbers of nests (265) and an average number of chicks fledged (102). The 2002 season was exceptional as a result of the unprecedented vandalism of the colony on 31st May with fences ripped up and thrown into the colony, with the loss of 98 nests, which with little re-nesting as a result of displacement to Winterton (see below) ultimately led to a poor season. The subsequent investigation by the police and the wildlife crime unit of the RSPB was inconclusive.

In 2003, during the first three weeks of May, a police helicopter undertook low patrols of the beach and surrounds in a search for a missing child. This created a major disturbance in the area and as it caused the Common Terns to temporarily desert (for a period of weeks) their breeding platforms in Breydon Water was also thought to be responsible for Little Terns not fully settling at North Denes, For example, up until the peak count of 80 birds on May 21st, birds would arrive in small groups from the north at around 08.00 hrs remain until about 16.00, whereafter they would leave in small groups until all had gone by about 17.00 hrs (Wooden *et al*. 2003).

The 2004 season was exceptional in that not a single chick is thought to have hatched, which was unprecedented in the life of the colony since RSPB began managing it in 1986. The events from 2002-2004 were generally conceived as failure of the colony and given its international importance were clearly unacceptable. The RSPB and its financial and institutional partners (NE, GYBC and E.ON) responded with further investment of time and resources.

Mean clutch size had not been recorded systematically until recently (2005 and 2006). In both these years, mean clutch size was far lower than the value of 2.05-2.45 documented in the literature (Cramp & Simmons 1985) at 1.89 and 1.6 eggs in 2005 and 2006 respectively. Contrary to the expected pattern in 2005, Smart *et al*. (2005) recorded a lower mean clutch size of 1.71 eggs in earlier nests (hatched by 7th June) compared to 2.03 eggs per nest in later nests (still being incubated between 7th-9th June). Despite the lack of recording, there is limited evidence of higher clutch size in earlier years as even the number of chicks fledged per pair (e.g. 1.56 as recently as 1998 with several values to 1.74 in the late 1980s – Allen Navarro 2006) produced similar values, although these should be far lower as losses of eggs and chicks inevitably occur. (This is notwithstanding the anomaly between clutch size and number of chicks fledged in 2006 – see below). Only at Winterton in 2003 in recent years did a productivity of 1.92 chicks per pair suggest a mean clutch size in keeping with the general literature.

Moreover, in 2005, incubation periods were longer than typical with a mean of 23.9 days (range=19-29 days, *n*=29) compared to the 21.5 days (range 18-22 days) recorded by Cramp & Simmons (1985). A virtually identical pattern was recorded in 2006, with a mean of 23.71 days (range=17-28 days, *n*=24). Remote logging of temperature in the nest in 2006 revealed considerable variation in temperature as a result of relatively long periods without incubation including at night with dips to what was likely to be ambient temperature at 15-20° from the >30° provided by the incubating bird. This introduces the prospect of extended incubation time in relation to time spent at the nest which may also be a function of time spent foraging in relation to food supply as well as the frequency of disturbance, although the latter is often of very short duration.

Systematic information on the outcome of nests is also available from 2004 onwards. This varied markedly between years, with only 2.5% of the 40 nests laid at the colony hatching chicks in 2004 (Allen Navarro *et al*. 2004), compared to 74% of the sample of 94 nests monitored in 2005 (Smart *et al*. 2005) and 73% of the 65 nests monitored in 2006 (Allen Navarro *et al*. 2006). The key difference between 2004 and 2005 and 2006 was the high losses to fox predation (at least 45% of all nests) in 2004 corresponding to a lack of 24-hour wardening and night patrols using two million candlepower lamps. In 2005 and 2006, intense wardening reduced fox predation to just 5% (*n*=5) and 3% (*n*=2) respectively, which is a similar level to that recorded for other species such as Hedgehogs *Erinaceus europaeus* (1% of monitored nests in 2006, and at three nests not included in the monitored sample in 2005).

In 2006, predation was less important that nest desertion (i.e. egg(s) still present) in 6% of cases. Disturbance and poor weather are thought to be causes of desertion, although the case of one egg being incubated for 42 days before finally being abandoned also indicates infertility may also be involved (Allen Navarro *et al*. 2006). Predation by adult birds may also result in nest desertion, with one of the three birds recovered dead in 2005 likely to have been killed by a cat *Felis catus*. A range of factors are thus likely to contribute to the loss of the 14% (2005) and 16% (2006) of nests lost in 2005 and 2006. Losses of nests to high tides that may be important at other colonies are generally unimportant at North Denes, with the only significant event in recent years being the loss of ~10 nests on 22nd July 2005. The events of 1996 when an estimated 84 nests were lost to high tides appear not to have an equal either before or since (Joyce & Durdin 1997).

Whilst ground predators may be effectively controlled through the use of electric fencing and 24-hour wardening, the same cannot be said for flying predators. Kestrels have been an omnipresent threat for some time at the colony, which led to the first attempt at supplementary feeding of Kestrels with white mice in 1992 (Smart & Ratcliffe 2000). The effect of this proved inconclusive and so further management in the form of chick shelters was attempted. Comparing the results of production in 1997 to 1996 when at least 41 chicks were taken (causing the loss of all 45 remaining nests which had already suffered from fox predation and high tides) Thomas & Atkins (1998) suggested a drainpipe design of chick shelter had considerable potential. However, Kestrels again proved to a major problem in 1999 and a further attempt to determine the effect of diversionary feeding was undertaken in 2000 by Smart & Ratcliffe (2000) with the conclusion that this feeding could not explain the annual or seasonal variation in predation of Little Tern chicks by Kestrels, principally because the latter were observed to take 461 Little Tern chicks (Biggins *et al*. 2000). An even greater total of 526 chicks were recorded predated in 2001 (Allen Navarro 2006). Kestrels even had an impact in 2003 when the number of chicks was small, with the loss of just one near-fledged chick reducing colony productivity by 33% (ECON 2004).

No chicks were available to be taken in 2004, but Kestrel predation was again evident in 2005. A pair nesting at the Great Yarmouth Racecourse <1km from the colony, was responsible for all known mortality of Little Tern chicks, with at least 143 observed taken in a total of 284 visits to the colony. The male bird was responsible for the bulk of predation (the female only conclusively identified as responsible for 3% of chick predation), although even the fledged juvenile kestrels (five) also attempted to take Little Tern chicks (Plate 13). Kestrel attacks were also recorded during telemetry studies (*n*=8) and chick feeding studies (*n*=11), typically resulting in all adult birds being flushed from the beach, with birds mobbing the attacking Kestrel *en masse* including at some distance from the colony (Plates 14 & 15). Only a low proportion of attacks were thought to be seen by the wardens based some distance away in the port-a-kabin and using information from the number of nests, clutch size, hatching success and the number of chicks fledged (*n*=11), it was estimated that Kestrels predated 455 chicks, effectively decimating the colony (Allen Navarro 2006).

Whilst a number of potential avian predators (e.g. gulls, crows etc) are recorded around the colony, there appears to be no records of these taking eggs or chicks. For example, adult and sub-adult Mediterranean Gulls (Plate 16) frequently attend the colony, which in the latter part of July 2005 were also joined by at least four newly fledged birds of unknown origin (ECON 2006). Whilst more than capable of taking eggs and small chicks none of these birds were seen to do so, although this may be simply be a reflection of the vigorous response of Little terns to all medium and large-sized gulls (Plate 17).

5.1.2 Winterton

The use of the Winterton area by breeding Little Terns underwent a revival in the period of this study. Following the presence of a peak of 90 pairs in the 1970s, this declined to <10 pairs in the 1980s and sporadic occupation in the early 1990s. Numbers of pairs began to increase again in the late 1990s and by 2000, 45 pairs attempted to nest at Winterton itself (16 pairs) as well as further north in the Bramble Hill area (29 pairs) (Skeate *et al*. 2004).

There was a general view that formation of the colony at Winterton often represented overspill of especially re-nesting birds from North Denes, and this was largely confirmed in 2002, when after the vandalism event and loss of 98 nests at North Denes, 124 nests ultimately established at Winterton (ECON 2003).

Plate 13. Fledged juvenile Kestrel from the 'Racecourse pair' attending the colony.

Plates 14. & 15. **Typical pattern of attack by a male Kestrel on the colony, with the attacking bird being mobbed by numerous adult Little Terns to no avail; a Little Tern chick being visible in the talons of the Kestrel (lower plate).**

Plate 16. Mediterranean Gull in 'winter' plumage.
Note the leg ring suggesting the bird is of Dutch origin.

Plate 17. Little Tern attacking a sub-adult Mediterranean Gull in active defence of the colony.

Nonetheless, Chris Lake the EN warden had already fenced an area prior to the breakdown of the North Denes, which contained 17 nests by 4th June illustrating that at least some pairs had selected Winterton as a first choice breeding site.

Allen Navarro (2006) suggests that where both colonies are utilised, nesting may commence earlier at Winterton than at North Denes. This was certainly the case in 2003, when the first nests were recorded by May 22nd some six days prior to the belated attempt at North Denes (see above). In 2004 however, nesting appears to have been triggered by the erection of protective fencing by the warden John White and the loss of initial nests established at North Denes on 28th May and during the first week of June (ECON 2005). Further, in 2005, the first nests were recorded on 31st May at both colonies, bucking the trend suggested by Allen Navarro (2006). Whatever the case, colony build-up may be startlingly rapid. In 2004, at least 150 nests were present by 14th June less than two weeks after colony inception. Similarly in 2005, within a week of the first nests, 74 were present on the 6th June although this peaked at 83 nests by the 13th June. No birds attempted to nest at Winterton in 2006 seemingly representing the end of the period of renaissance.

The factors influencing the outcome of hatching appear to be different at both colonies. High tides tend to have a greater effect at Winterton, particularly in the lower-lying more northerly area. In 2002, some 48 nests were lost on 27th/28th June compared to just six lost at North Denes although only a few nests were actually present at the latter at this time. Similarly, around 30 nests were lost on June 19th/20th in 2003. Also in contrast to North Denes, predation of nests by foxes and other ground predators appears to be very limited, which is fortunate given that protection of the colony was initially restricted to rope fences. The lack of foxes is thought to be the result of intense control by gamekeepers on the estates in the surrounding countryside (Rick Southwood NE *pers comm.*). Even after the introduction of an electric fence to support the rope fence and the division of the colony into a north and a south section, with a walkway for pedestrians in between, humans and their dogs and even ATV and 4x4 vehicles may be frequently recorded breaching colony defences (Wooden *et al.* 2003).

In 2004, a disturbance event prior to 24-26th June led to the loss of 37 nests between groynes 50-61. A monitored sample (*n*=13) showed that at least some (15%) of nests still contained eggs that had simply been abandoned (ECON 2005). Some re-nesting in more southerly areas of the colony then occurred. However, disturbance alone could not account for the general decline from 150 to 65 nests in this period and the further precipitous decline in nests that led to only a handful being present by 1st July. The unprecedented abandonment of so many nests as a result of lack of suitable prey was offered as the best explanation, although many birds continued to linger in the area into July (ECON 2005).

These events were repeated in 2005, with a decline from 83 nests to 52 by 27th June and just 9 by 5th July. Mass departure of nesting birds was apparent in late June. This was reflected by the four birds radio-tagged at the nest on 22nd June, with only one seemingly still attached to a nest by the 27th June. Two of the four birds were then subsequently recorded at North Denes >12km away, with one bird actually followed as it flew to North Denes.

It seems that the rapid loss of nests was caused by a combination of factors with a background of low food availability, which may have led some birds to even abandon their nests as was also observed in 2004, coupled with predation of eggs and hatching chicks by Carrion crows *Corvus corone* (with these working in pairs to flush adults off the nest) and predation of chicks by Kestrels. A small number of nests did persist until 21st July, when the high tide inundated much of the colony, pulling down half the fence line and leaving only 3 pairs. A few days later, all nests were abandoned and no young had fledged (ECON 2006).

Whilst the events in 2005 illustrated that predation of chicks may occur, as with egg predation this again seems generally less important than at North Denes. This is illustrated by the fact that only one kill was documented at the colony in 2003 when 447 chicks fledged and this was by a Sparrowhawk *Accipiter nisus*. The fact that a pair of Sparrowhawks were seen to launch at least four attacks from 17.45 to 19.42 hrs on 24th July alone, suggests more chicks than this were lost. A Herring Gull may also have taken one on the same day (ECON 2004). Whilst Kestrel activity was noted as being high towards the end of the season, the attentions of Little Terns caused the falcon to circle away on each occasion. Unlike at North Denes, it may be that the extensive dune system at Winterton offers alternative small mammal prey and if the observed birds are not part of a breeding pair with the demands of hungry chicks, there is little incentive to run the gauntlet of defending Little Terns.

5.1.3 Eccles

Nine offshore reefs from Eccles in the north to Waxham in the south were installed in 1997. Little Terns began to prospect the area behind the northernmost reef with the largest and most undisturbed area of beach in 1998. Two pairs were seen nest scraping in 1999 and a pair with two recently fledged chicks was observed in 2000, although nesting was not actually confirmed until 2002 (Skeate *et al*. 2004). Eleven pairs then nested with 12 chicks fledged. Local naturalist Neil Bowman protected the nesting birds by demarking the area with ropes and poles donated by EN. Whilst this offered no protection against (even) ground predators, it did have the desired effect of limiting human disturbance in what is a popular area for tourists and local dog-walkers.

In line with the spectacular season at Winterton in 2003 (see 5.1.2 above) the number of pairs increased to 37 in 2003 with 58 chicks fledged. As at Winterton, prey appeared to be abundant to the ‘warden’ (Neil Bowman *pers comm*.). In 2004, Skeate *et al*. (2004) recorded Little Terns from 12th May onwards. On 26th May, several pairs of birds amongst the 34 recorded were involved in nest prospecting and scraping behaviour, which led to 27 nests by 14th June. This early nesting illustrates that Eccles was as attractive a site as Winterton at least to some birds. Moreover, numbers gradually increased, 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*.). Active nests with eggs were still present by 27th July several weeks after chicks would had generally fledged in other years (see 5.1.1 & 5.1.2 above). A similar pattern of re-nesting was observed at North Denes (see 5.1.1 above).

Re-nesting implies that the food supply was adequate, and certainly better than at Winterton at this time where a poor prey base was thought to be responsible for abandonment of eggs (see 5.1.2 above). The reefs potentially offer a different habitat for a greater diversity of fish and invertebrates than the open sea interspersed by sandbars at Winterton. With an adequate prey base and a lack of egg predators, most nests were thought to hatch chicks, the obvious exceptions being two nests thought to have been lost as a result of the incubating adult being taken by a Kestrel. What was thought to be the same bird then systematically predated the remaining chicks in a manner only seen at North Denes (Neil Bowman *pers comm*.). Ultimately, no chicks survived to fledge.

Events at the Eccles colony are documented in detail by Neil Bowman, in the *Little Terns in Britain & Ireland in 2005* newsletter (Schmitt 2006). As at Winterton, the first Little Terns did not arrive until the last few days in April. No nests were recorded until 4th June, some days after the main colonies building up with a total of 36 attempts. A violent electric storm on 20th June appears to have a dramatic impact on the colony as 19 nests had disappeared immediately after. The cause of this loss appears to have been predation by Carrion Crows and Magpies *Pica pica*, seemingly utilising the disturbance during the storm to their advantage. Predation of eggs by these birds then persisted with Little Terns abandoning the colony on 26th June, coincident with similar events at Winterton. As documented above, there was no immediately apparent shortage of prey.

In relation to corvid predation, it is of note that Neil Bowman had not seen a Magpie on the beach at Eccles before and suggested this was a result of the decline in persecution of these birds on surrounding estates. Skeate *et al*. (2004) indepedently recorded a rapid increase in corvids (Carrion Crow, Magpie, Rook *Corvus frugilegus* and Jackdaw *Corvus monedula*) on the beach between Eccles and Winterton, and thought this had a negative impact on the nesting success of Ringed Plovers. Further, they thought that the increase in corvids was directly linked to a rapid increase in human visitors and their rubbish, which is readily exploited by these scavengers.

As at Winterton, no birds nested at Eccles in 2006, although 2-3 pairs regularly displayed over the colony during the season (Bowman 2007). Clearly, virtually all birds in the area opted to nest at North Denes, representing something of a return to the baseline established during the late 1980s through to 2001.

5.2 Distribution & abundance of Little Terns

5.2.1 North Denes & Scroby

The presence, size and nature of the development of a colony at North Denes will inevitably affect the number of Little Terns present at Scroby and the distribution of the individuals during the season. Thus, in both 2002 and 2003 when few birds nested at North Denes (5.1.1 above) the peak count of birds combined on one date at all sites at Scroby was relatively low, being 57 in 2002 and just 25 in 2003 (Fig. 5). From 2004-2006 much larger numbers of Little Terns were encountered in surveys, consistent with the attempted use of North Denes as the main colony, whether this was ultimately successful or not.

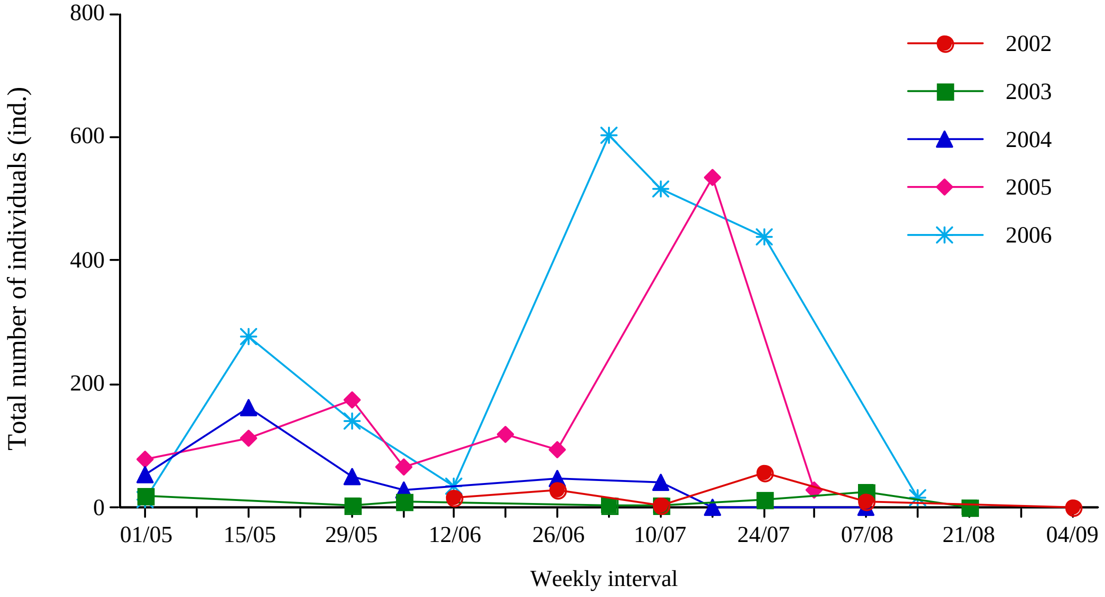

Figure 5. Seasonal trends in the number of Little Terns recorded in Scroby surveys (at all sites combined on each occasion) in all years of the study (2002 to 2006).

A build-up in numbers during May into early June accords to initial colony development (Fig. 5). In some years, such as 2004, peak numbers of Little Terns were recorded at this time (164 in mid-May - ECON 2005). A similar build-up in numbers was noted in 2006, with 278 in mid-May, and in 2005, 175 birds were present by 30th May. Counts then tended to decline, presumably as birds became involved in nesting activity with at least one bird associated with a nest.

In 2005 and 2006 the establishment of large numbers of nests (nearly 200 in 2005 and a peak of 369 in 2006) - representing a return to more typical numbers recorded from 1989 to 2001 (see Table 1) - intuitively suggested many birds were likely to be recorded on surveys. In 2005, despite the failure of the colony to fledge chicks (as a result of kestrel predation –5.1.1 above) the number of terns continued to increase throughout the breeding season culminating in 536 on 21st July (the day of the high tide that affected the both the North Denes and Winterton colonies – see 5.1.1 & 5.1.2 above). This would represent virtually the whole of the Little Tern population of North East Norfolk incorporating North Denes, Winterton and the Eccles colonies. It is also a possibility that failed breeders from elsewhere (e.g. North Norfolk, Humberside or even Scotland) were also represented. Data from the RSPB wardens who checked 806 Little Terns for rings between 17th June and 24th July, suggests at some birds were 'stopping-over' in the North Denes area on southward migration as five colour ringed birds (sky blue) from Cleveland were recorded amongst the 77 colour ringed birds from different years at North Denes/Winterton (Smart *et al*. 2005). A further 212 birds were metal ringed (probably mainly from North Denes where 2162 have been ringed since 1995) leaving the bulk of birds (512 ind. - 63.5%) with no rings. The small number of birds (28 ind.) two weeks later on 4th August tends to reinforce the suggestion that birds were aggregating at North Denes before undertaking southward migration. Similar behaviour has previously been noted at Breydon Water a few kilometres inland of Great Yarmouth (Taylor 1999).

In 2006, with the successful fledging of a huge number of chicks (673 ind.), numbers recorded in surveys remained extremely high throughout July with counts of 604, 515 and 440 on 6th, 16th and 27th respectively. Unlike 2005, there was no obvious suggestion of accumulation of birds from other colonies, although the extraordinary count of fledglings, higher than that predicted from clutch size and nest counts (Allen Navarro *et al*. 2006) suggests this was possible. Mass exodus of all birds had occurred by early August.

With an active colony present throughout the breeding season, there is clear potential for aggregation of birds around the colony itself and for this to dominate the season's counts from boat surveys. This was indeed the case in 2005 and 2006, with 71% and 80% respectively of all Little Terns were recorded at Site 10 immediately adjacent to the colony (Fig. 6). This contrasts sharply with just 15% at Site 10 in 2004, when just 40 nests were laid during the season (Table 1) and by far the largest count of birds at any site on any occasion (157 ind.) was at Site 1 in the southern part of Scroby in mid May. This unusual gathering of foraging Little Terns, Common terns and assorted gull species was caused by the availability of what appeared to be a spawning aggregation of Ghost shrimp *Schistomysis spriritus* (ECON 2005).

Site 2 also accumulated a reasonable proportion (26%) of the small number of Little Terns present in 2003, which reinforces the impression of a bias of distribution of birds from the colony along a south-east axis to the southern end of Scroby Sands, which tends to form the largest area exposed at low tide (Plate 18). This area was raised as being of importance to foraging Little Terns in the initial surveys in 1995 (Ecosurveys Ltd. 1995) and 1999 (Econet Ltd. 1999), which ultimately led to the proposed wind farm being re-positioned to the north in its current location.

Bias towards particular sites was also shown in 2002 and 2003 when birds were only recorded at 6 (50%) and 5 (42%) sites respectively. However, with greater number of birds from 2004 onwards, birds were generally recorded at all (100%) sites, the only exception being 2005 with 92% of sites (the only exception being Site 7 in the wind farm itself). More birds were recorded at both Sites 5 and 4 from 2004 onwards with peak counts of 18 ind. at Site 4 in 2004 and 33 ind. at Site 5 in 2005 (Fig. 6). No Little Terns had been recorded at Sites 4 or 5 prior to construction in 2002 and 2003. This represents a significant change in use (expressed as proportion of birds to account for a general increase in numbers of birds at North Denes in later years) in Site 4 (Kruskal-Wallis, *n*=38, df =4, H=17.02, p=0.002) but not Site 5 (Kruskal-Wallis, *n*=38, df =4, H=5.96, p=0.202).

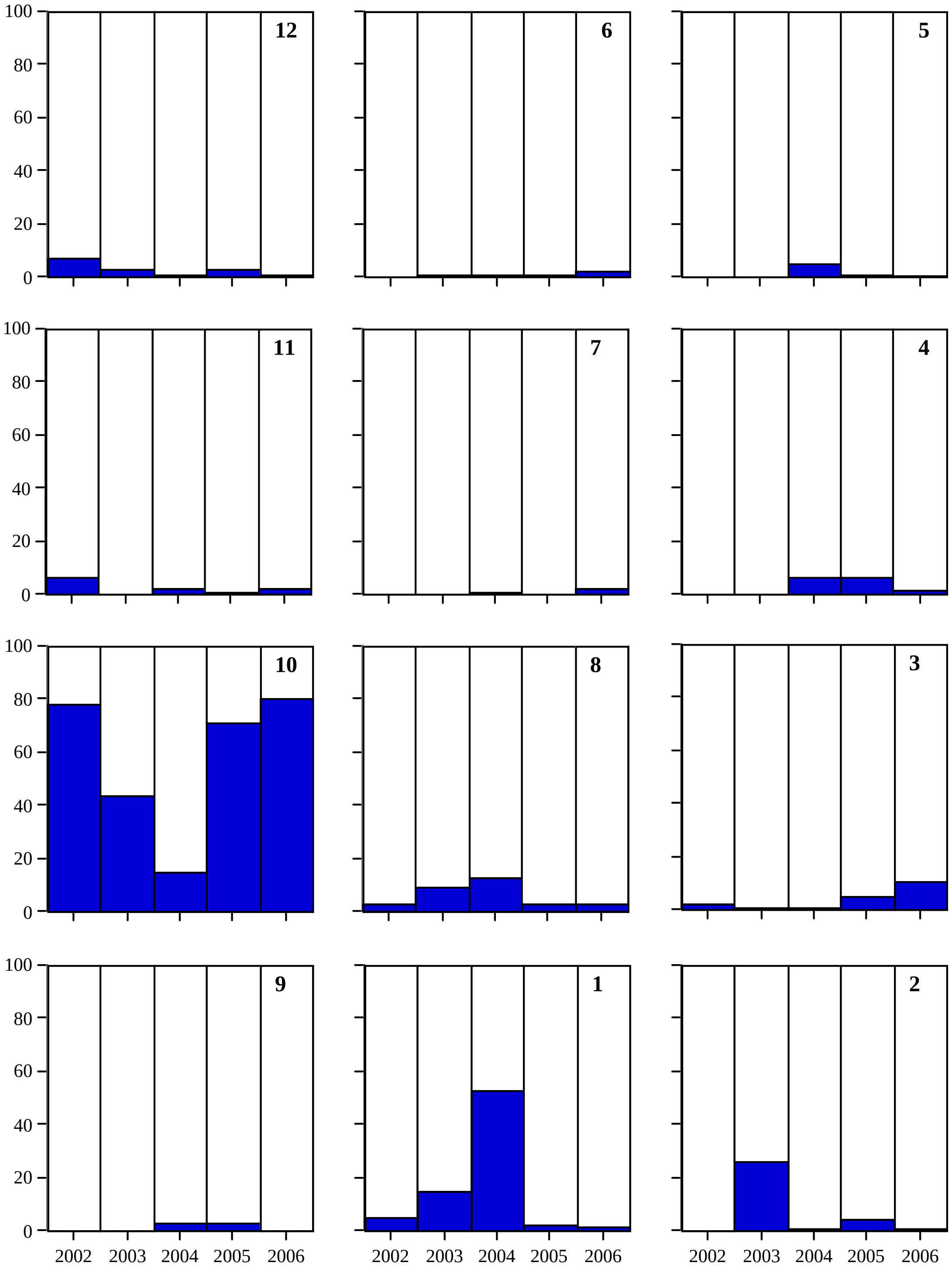

Figure 6. Proportion (%) of Little Terns at each site (pooled for all sampling occasions *n*=6-8) at Scroby from 2002 to 2006. Sites are orientated on the page as they occur in space i.e. from south (bottom) to north (top) and west (left) to east (right).

Although post-hoc comparison did not detect the location of the difference this appears to be focused on 2005 (i.e. post construction) with a median use of 5% (cf 0 in other years). To access site 4 directly from the colony implies Little Terns fly through the wind farm. However, the use of Site 7 wholly contained within the wind farm did not change significantly ((Kruskal-Wallis, *n*=38, df =4, H=2.83, p=0.587) although up to 39 ind. were present in 2006, compared to a maximum of 2 in 2004 the only other year in which birds had been recorded.

Use of sites in and around the wind farm coincided with the expansion of the sand bank through the wind farm site (Plate 19). However, there was also general increased usage of the seaward (eastern) edge of Scroby by Little Terns after construction, as reflected by the significantly greater proportion of birds at Site 3 (Kruskal-Wallis, *n*=38, df =4, H=9.46, p=0.05, with 2005 the outstanding median value at 3%, with 1.7% in 2006. In fact, up to 201 birds were present at Site 3 in 2006, compared to a maximum of 44 birds in 2005 and just 1 ind. (2004 & 2003) or 2 ind. (2002) in other years.

In some years, the distribution of Little Terns seemed to be partly explained by the distribution of their fish prey, as numbers of terns at a site was significantly positively correlated with fish density (Table 8). The latter was, in turn, significantly negatively correlated with water clarity (see 5.5.2 below). As a consequence, Little Tern numbers were also significantly negatively correlated with water clarity in all years (Table 8) and on the strength of the relationships appeared to be a consistently better general descriptor of Little Tern distribution than fish,

However, there is likely to be bias in these inter-related relationships as their strength is influenced by the tendency of the waters in the middle and outer sites to be rather transparent (Appendix II), where birds were more rarely recorded (see above) and fish hardly ever occurred in samples (see Fig. 7). Moreover, it is not clear whether with the virtual absence of fish is caused by high water clarity or is simply reflective of a preference for more inshore waters close to the beach. Thus, if correlations are performed using data for birds, fish and water clarity from the inner sites only, the relationships tend to be weakened and no longer significant.

Table 8. Spearman rank correlation coefficients (rs, +/-) and their significance[1] from correlations between numbers of Little Terns, fish density (ind. m^{-2}) and water clarity (m) using all sites/occasions (*n*=96[2]) and the inshore sites only (*n*=32) from 2003 to 2006 inclusive.

Variable	Year	Sites	Fish density	Water clarity	Significance
Number of Little Terns	**2003**	All	+0.22*	-0.28	**
		Inshore	+0.27	-0.10	ns
	2004	All	-0.03	-0.36	***
		Inshore	-0.08	-0.28	ns
	2005	All	+0.31**	-0.25	*
		Inshore	+0.05*	+0.93	ns
	2006	All	+ 0.173	-0.297	**
		Inshore	+0.039	0.007	ns

Notes: [1]*= p<0.05, ** p<0.01 and *** p<0.001), [2] *n*=95 in 2004 and 2006

5.2.2 Winterton & the Would

Gross numbers of Little terns recorded at sea at any of the five (Hemsby, Winterton, Horsey, Sea Palling and Eccles) sites in the Would of the inevitably broadly reflect the occupancy of the colonies at Winterton and to a lesser extent, Eccles. Thus, in 2003 as the successful colony developed at Winterton the number of birds recorded in surveys at sea rose steadily from 54 ind. in June to 125 ind. in early July, 148 on 28th July coinciding with juveniles foraging for

**Plate 18. Overview of the Scroby Sands and the wind farm in autumn 2004.
Aerial photograph taken on 6th October 2004 by Air Images Ltd. during a seal survey.**

**Plate 19. The subsidiary sand bar forming through the wind farm.
Aerial photograph taken on 6th July 2004 by Air Images Ltd. during a seal survey.**

Few bird and prey surveys could be undertaken in the Would from 2004 onwards. Nonetheless, numbers of Little Terns tended to be lower than may be expected from occupancy of the colonies, apart from the complete lack of birds at any site in 2006 consistent with the lack of nesting at Winterton. To illustrate the lack of consistent foraging in the inshore waters around the colonies, in 2004, both in mid May and early June when surveys were conducted all along the coast from Yarmouth to Eccles, very few Little Terns (<7 ind.) were recorded in surveys when up to 300 birds (from 150 nests - ECON 2005) were present at Winterton for part of the season and up to 100 birds were recorded at Eccles by the warden (ECON 2005). Only by 16th July long after the colony had been abandoned were a large number of Little Terns recorded (153 ind.), perhaps suggesting failed birds from elsewhere as well as Winterton iteself. Similarly, in 2005, counts of >6 ind. Little Terns were only recorded at Winterton. In early June a relatively small number of Little Terns (n=24) was recorded at sea/flying despite the presence of nearly three times as many nests by this time (see 5.1.2 above). A relatively large number of birds (n=121) was again recorded after the failure of the colony in early July which again may also have included failed birds from Eccles and even further afield (e.g. North Norfolk) as well as Winterton. At Eccles, no birds were recorded in either early June or July, with surveys occurring in the period immediately before the first of the 36 nests had appeared and after the last had failed (see 5.1.3 above).

5.3 Distribution & abundance of other birds

5.3.1 Scroby

A total of 43 other [than Little Tern] species with six unidentified taxa were recorded at Scroby in counts during the study period from 2002-2006 (Table 9, Appendix VI). The species recorded included three species of tern (including Little Tern), seven species of gull and twelve species of waders amongst a mixture of true seabirds, migrating shorebirds and other species more typically associated with terrestrial habitats. The latter included seemingly unlikely species such as Kestrel, Woodpigeon *Calumba palumbus* and Chiffchaff *Phylloscopus collybita* (Table 9).

Aerial species including Swift, Swallow, House Martin and Sand Martin were all represented, with Swift and Sand Martin frequently encountered. A breeding colony of the latter is present in the soft cliffs at California, although this may have declined after 2002 as only small numbers of birds were encountered in the latter years. Fulmars also breed in the soft cliffs of this area and small numbers of these birds (<5 ind.) were frequently encountered in inshore waters adjacent to the colony, although they have never yet been recorded at other inshore sites (ECON 2003, 2004, 2005, Appendix VI) in contrast with the frequent presence of odd individuals of this highly mobile species at all sites further offshore.

The location of Scroby Sands near to the coast and the internationally important Breydon Water SPA, and with the Broads SPA nearby, means that a range of coastal and wetland species as well as migrating landbirds were always likely to be recorded. This is despite the fact that surveys were limited to the summer months outside the main spring and autumn migration periods. More species would certainly be added if surveys had also been conducted in these periods.

This is also illustrated by the fact that a number of other species have been recorded at sea but not at sampling stations. These included an adult Ring-billed Gull *Larus delawarensis* near Site 2 in a large flock of other large gulls on 10th June 2004 and a pair of Shelduck *Tadorna tadorna* between Site 9 and port on 7th May 2004. Unsurprisingly then, new species continued to be recorded throughout the study and in 2006, Mallard *Anas platyrhynchus*, Red-throated Diver *Gavia stellata* and Black-throated Diver *Gavia arctica* were recorded for the first time at sampling stations, although divers had been seen by the observers in the area before.

Table 9. Maximum number of individuals of each bird species recorded at Scroby in a survey (12 sampling sites) in each year of the study from 2002 to 2006 inclusive.

Species		Year				
Common name	**Scientific name**	**2002**	**2003**	**2004**	**2005**	**2006**
Mallard	*Anas platyrhynchos*					3
Common Scoter	*Melanitta nigra*	14	70	3	7	11
Red-Throated Diver	*Gavia stellata*					1
Black-Throated Diver	*Gavia arctica*					1
Great Crested Grebe	*Podiceps cristatus*	1				
Northern Fulmar	*Fulmarus glacialis*	4	9	11	8	9
Northern Gannet	*Morus bassanus*	3	4	68	20	7
Cormorant	*Phalacrocorax carbo*	15	5	9	3	7
Shag	*P. aristotelis*	1				
Kestrel	*Falco tinnunculus*			1	1	1
Oystercatcher	*Haematopus ostralegus*	2	4	6	4	2
Ringed Plover	*Charadrius hiaticula*	1	1			2
Grey Plover	*Pluvialis squatarola*		1			
Knot	*Calidris canutus*				1	
Sanderling	*Calidris alba*				3	
Unidentified large sandpiper	Calidrid sp.		1	1	2	
Dunlin	*Calidris alpina*		1	6	75	3
Black-tailed Godwit	*Limosa limosa*	4				
Whimbrel	*Numenius phaeopus*			3	2	
Curlew	*Numenius arquata*			2	9	2
Redshank	*Tringa totanus*			1	2	
Common Sandpiper	*Actitis hypoleucos*		5	2		
Turnstone	*Arenaria interpres*	3		1		1
Unidentified wader						30
Unidentified skua	*Stercorarius* sp.	1				1
Arctic Skua	*Stercorarius parasiticus*	2	3	3	3	
Mediterranean Gull	*Larus melanocephalus*	3	4	1	8	10
Little Gull	*L. minutus*	1				5
Black-headed Gull	*L. ridibundus*	72	33	20	20	56
Common Gull	*L. canus*	5	6	3	12	8
Lesser Black-backed Gull	*L. fuscus*	346	55	56	71	46
Yellow-Legged Gull	*L. michahellis*					1
Herring Gull	*L. argentatus*	166	114	224	188	118
Great Black-backed Gull	*L. marinus*	8	5	15	15	23
Kittiwake	*Rissa tridactyla*	7	4	21	52	2
Unidentified gull	*Larus/Rissa* sp.			20	55	46
Unidentified large gull	*Larus* sp.					134
Sandwich Tern	*Sterna sandvicensis*	38	98	62	59	73
Common Tern	*S. hirundo*	55	59	122	87	46
Little Tern	*Sternula albifrons*	57	20	164	536	604
Unidentified tern	*Sterna* sp.		1	100	46	120
Guillemot	*Uria aalge*	26	5	7	9	33
Razorbill	*Alca torda*				2	1
Feral (Racing) pigeon	*Columba livia*			6	5	18
Woodpigeon	*C. palumbus*			1		1
Swift	*Apus apus*	6	2	35	12	1
Sand Martin	*Riparia riparia*	19	5	4	8	1
Barn Swallow	*Hirundo rustica*		2	3	2	3
House Martin	*Delichon urbica*				2	
Chiffchaff	*Phylloscopus collybita*		1			

The irregular occurrence of many species and the replacement of one with another meant that after the first two years the number of species stayed virtually constant (26 in 2002, 27 in 2003, 32 in 2004 and 33 in 2005, 31 in 2006). In general, most species (70%) were relatively uncommon, with peak counts in any year of <20 ind. This included eleven species that were only recorded in a single study year. A few species – Common Scoter, Gannet, Dunlin and Black-headed Gull and Guillemot – generally occurred in low numbers with one exceptional season or even event (Table 9).

All of these species are of seasonal occurrence or are encountered on passage through the area. For example, Guillemots are known to be relatively common in the winter outside the survey period but also occur from late June with adults and adult/chick combinations probably originating from the nearest colony in North Yorkshire. Birds appear to move relatively rapidly through the area and the larger numbers in 2002 appears to be a largely chance encounter.

Similarly, whilst non-breeding Scoters may be seen as singletons or more typically as small groups during the summer, 70 ind. were seen in one flock at Site 2 on 14th July 2003. The timing of occurrence suggests these birds were early-dispersing failed breeders. Indeed, like Guillemots, the majority of seaduck using the area would be expected to occur in the autumn and winter outside the survey period.

The peak in Black-headed Gulls was caused by the aggregation of 69 ind. on/around the beach near Britannia Pier on 23rd July 2002 after dispersal of young birds from colonies around the coast and inland from the Broads. A similar situation occurred with Kittiwake with 81% of the peak count of birds on 21st July 2005 occurring at Site 7. On this occasion birds on passage appear to have been driven onshore by strong winds. Similarly, strong winds in a known period of dispersal of birds from breeding colonies far to the north appears to have been responsible for exceptional Gannet numbers on 30th June 2004, although rather than occurring in one flock these were encountered in smaller groups of birds in all offshore sites (2 to 5 ind.).

Overall, just five species – Little Tern, Common Tern, Sandwich Tern, Herring Gull and Lesser Black-backed Gull (see Plates 20-23 respectively) – stand out as being particularly numerous, with peak counts of >50 individuals in 75% or more of survey years (Table 9). All of these species, apart Sandwich Terns breed locally in the Yarmouth area, with Little Terns on North Denes beach, Common terns on platforms in Breydon Water and both gull species on roofs of mainly industrial units around the port of Great Yarmouth/Gorleston. Sandwich Tern formerly bred in the area, on Scroby Sands themselves when these were routinely above mean high water. In the period of constant occupancy from 1947 to 1965 peaks of 450 pairs were achieved in 1948 and 1952, although only in four years were many young fledged. Breeding then occurred sporadically until 1976 with 2 pairs in 1972, 60 in 1975, and 200 in 1976, after which the bank remained permanently below mean high water.

As local breeders, Common Terns (Plate 20) and Herring (Plate 22) and Lesser Black-backed Gulls (Plate 23) were more or less ubiquitous in their distribution and abundance and could be encountered anywhere at any time although the terns especially varied considerably in numbers between sites and between occasions. For example, in 2004, 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 ind. at all other sites), in keeping with its relative proximity to their breeding colony at Breydon Water.

Considerable variation in the peak numbers of gulls between years was thought to be the result of the chance occurrence of aggregations. These were noted with birds either roosting on Scroby at low water, flying to or from this roost (probably from or to a the known roost at Breydon Water), associating with fishing vessels or as a result of the dispersal of juveniles of both Herring and Lesser Black-backed Gulls (Plate 23) from the breeding colonies in July.

Plate 20. Common Terns from the breeding colony on platforms in Breydon Water were frequently encountered in surveys of Scroby throughout the summer.

Plate 21. Numbers of Sandwich Terns at Scroby reached a peak in late summer suggesting post-breeding dispersal from colonies, most likely those in North Norfolk.

Plate 22. Herring Gulls were ubiquitous in their distribution at Scroby Sands.

Plate 23. Juvenile Lesser-blacked (and Herring) Gulls were a common sight at Scroby from July as they fledge from rooftop colonies in Yarmouth/Gorleston.

In contrast to the other species, peak numbers of Sandwich Terns were highly seasonal, most likely relating to the chance encounter of birds on southward passage at the end of the breeding season from the main colonies at Blakeney Point and Scolt Head in North Norfolk and perhaps even further north. Thus, peak numbers tended to occur from the middle to the end of July (31st in 2003, 16th in 2004 and 2006 and 21st in 2005). In 2004, 73 ind. were observed loafing on the exposed bank at Site 8 on 31st July, a phenomenon that was also frequently observed from the RIB during telemetry of Little Terns (Plate 21). The only exception to a peak at the end of their breeding season was in 2002 when the lower peak (38 ind. at all sites-Table 9) was on June 12th, perhaps representing passage of late breeding birds known to occur in North Norfolk (M. Rooney NE *pers comm*.).

5.3.2 The Would

A similar number of species (34 excluding Little Terns) have been recorded in the Would including Winterton over the study period despite the much reduced survey effort (both number of sites and sampling occasions) particularly in the latter years of the study compared to Scroby (i.e. from 40 km of transect covered in 2002, to 21 km in 2003, 12 km in 2004, 7 km in 2005 and just 2 km in 2006 compared to 72-108 km at Scroby). Only with minimal sampling effort in 2005 and 2006 did this lead to small number of species being recorded (12 and 6 species respectively), although only in the latter were maximum counts of the more common species notably reduced (Appendix VI).

As at Scroby a similar range of seabirds, passage migrants and terrestrial species was recorded (Appendix VI). These included further unusual species such as Marsh Harrier *Circus aeruginosus* and Carrion Crow *Corvus corone* as well as waterfowl such as Wigeon *Anas penelope* and true seaduck in the form of Eider *Somateria mollissima* supplementing the more typical Common Scoter.

However, the numbers and the patterns of occurrence of some species also point to some ecological differences. Most notably, of the five common species at Scroby only Little Tern breeds in the Would; at Winterton and at Eccles. Maximum numbers of Little Terns recorded around the breeding sites in both areas have fluctuated considerably, partly linked to breeding success (see 5.1.1, 5.1.2, 5.2.1 & 5.2.2 above). For example in 2003, the maximum count at Winterton where they bred successfully was far higher (>12-fold) than recorded at any site at Scroby. However, even in years where there was no successful breeding (e.g. 2004 & 2005), counts in excess of 100 ind. were recorded at Winterton with the aggregation of failed breeders, particularly later in the season.

With the absence of nearby breeding colonies, the maximum numbers of Herring and Lesser Black-backed Gulls and Common Terns occurring at a sampling station are typically low compared to those recorded at Scroby (e.g. Lesser Black-backed Gull <14%, Herring Gull <51%, and Common Tern <25%). Being largely a passage migrant Sandwich Tern may be encountered in numbers at any site along the coast and in 2004 the maximum count at a site in the Would was >2-fold greater than any recorded at Scroby.

5.4 Distribution & abundance of seals and cetaceans

5.4.1 Seals

Pooling the results from all surveys within each survey season showed that Grey *Haliochoerus grypus*, Harbour *Phoca vitulina* and unidentified seals were relatively well distributed across Scroby Sands, occurring at either 5 (42%) or 6 (50%) of sites in 2002, 2003, 2004 and 2006. The exception was 2005, when seals were only recorded at 2 sites (17%), with just a single Harbour Seal recorded at sea rather than hauled out (Appendix VII).

In all years the great majority of seal sightings generally related to animals hauled out on the exposed sandbanks, which can only be readily seen from some sampling stations (typically 1, 2 and 8) and then more easily around low water. The maximum number of animals recorded in a survey fluctuated somewhat from lows of 55 ind. (2005) and 56 ind. (2002) to 76 ind. (2003), 118 ind. (2004) and a high of 169 ind. in 2006. The difficulty of routinely separating the two species even when hauled out at distance from a moving vessel with relatively low eye height meant that species trends were not well recorded and thus may have confounded results. Thus, it is not surprising that the pattern suggested did not generally correspond to that revealed by aerial surveys which showed an overall increase in Grey Seals with a distinct drop in Harbour Seal numbers in 2004 coinciding with construction, before partial recovery in 2005 and 2006 (ECON 2008 b). The overall pattern of the mean number of seals showed no significant variation, although mean values dranged from 96 ind. to 141 ind. with lower values in 2003 and 2004.

Differences in haul-out pattern between years may have contributed to a lack of agreement between the two datasets as much of the sandbank could not be seen during boat-based surveys and therefore counts at particular sites heavily biased the results. It is of note that in two of the three years of lower counts, seals were only recorded from a single site (Site 2 in 2005 and Site 8 in 2003). In most other years seals were recorded at at least two haul-outs, including stations 1 & 2 in 2002 and 2006 and stations 1 and 8 in 2004 (ECON 2005).

Overall it is highly doubtful that the counts of seals reflected real changes in population trends or even preference in haul-out area, with variation due to the timing of the surveys and the route taken between survey points in relation to the state of the tide. Boat-based surveys, designed to record Little Terns and their prey thus provide little more than anecdotal information on the abundance and distribution of seals at Scroby Sands.

5.4.2 Harbour Porpoise

In contrast to seals, there is a hint that surveys indicate real change in the abundance of Harbour Porpoise *Phocoena phocoena* in the area, despite the limited frequency of surveys and the relative rarity of sightings. For example, the frequency of occurrence of records during surveys (from all areas and not solely sampling sites) declined from 67% of surveys in 2002, to 22% in 2003 and 25% in 2004 and 2005 (including a record of a mother and calf on 2nd May) to just 13% (i.e. one) in 2006.

Notably, this trend is not reflected by numbers recorded at actual sampling sites with a smattering of records across the years (1 at Site 5 on 2nd June 2003, 1 at Site 10 on 16th July 2004, 1 at Site 5 on 2nd July 2005 and 2 at Site 4 on 1st June 2006), apart from 2002, when animals were most frequently seen. Encountering a Porpoise was therefore a chance affair considering the small length of transect surveyed relative to their likely low density. Alternatively, during the extensive telemetry of Little Terns covering large amounts of sea over many hours, Porpoises could still be described as fairly common. For example, in 2005 a singleton logging at the surface as well as a group feeding were all recorded on 17th June, with two together on 24th June, and two separate animals on 15th July.

The overall trend at Scroby was mirrored by surveys in the Would with no observations at all after 2002 when Porpoises had been seen on 40% of occasions. However, no firm conclusions can be drawn from this observation as the number of surveys and thus the length of transect diminished considerably in the latter years of the study and only in 2002 did this include a much greater area whilst covering the offshore zone.

5.5 Distribution & abundance of potential Little Tern prey

5.5.1 Number & type of taxa

Scroby

A total of 54 different faunal taxa[11] were captured during tows at Scroby over a total of 468 km^{-1} sampling 472,320 m^{-2} (47.2 ha^2) during the study (Appendices X & XI). This was

comprised of 22, 23, 34, 24 and 23 taxa from 2002 to 2006 respectively. Between 82-88% of taxa in any year (83% in total) were considered to be potential prey for Little Terns. Those thought to be inedible included the Ctenophora (comb jellies and jellyfish) – Sea Gooseberries *Pleurobranchia pileus* (Plate 22) Lion's Mane Jellyfish *Chrysaora hysoscella*, Moon Jellyfish *Aurelia aurita* and *Rhizostoma octopus* – the barnacle *Semibalanus balanoides*, Hermit Crab, large specimens of Shore Crab *Carcinus maenas*, larval crabs (<1mm in length); and Razorshell *Ensis/Solen* spp.

Faunal richness appears to have been particularly high in 2004, with a number of species not recorded before or subsequently, including *Callinera buergeri, Nebalia bipes, Lyianassa ceratina, Iphimedia minuta, Athanas nitescens, Dichelopandalus bonnieri, Liocarcinus arcuatus* and *L. pusillus* and Scaldfish *Arnoglossus laterna* (Appendix VIII). A number of technical factors may have influenced this trend, including reduced sampling effort in 2002 (with 6 sampling occasions), the use of a smaller meshed tow net from 2003 onwards (see 4.2.1 above) and the greater experience of both sorting samples in the field and laboratory.
However, it was expected for this to also be reflected in a higher number of recorded species in 2005 and 2006.

It is of also of note that invertebrate numbers and biomass were at their highest in 2004 (see below) potentially as a result of the lack of predation and competition from fish, which were at their lowest (see below). However, if fish abundance was an important factor then faunal richness may also have been expected to be lower in 2003, with large numbers of fish potentially limiting small invertebrates in the sea but also masking the presence of small invertebrates in the net.

The lack of consistency for any other explanation, coupled with the magnitude of the difference (43% greater than any other year) suggest that high faunal diversity in 2004 is both real and reflective of ecological change, perhaps linked to climatic factors. Certainly, 2004 was noted for poor weather conditions and high winds (see ECON 2005), which may have led to greater mixing of the water column bringing a greater range of species to the surface layers.

The Would

Fewer sites and sampling occasions (particularly in the latter years of the study) and thus tow length (total of 85 km sampled) and area sampled (101,400 m^{-2} or 10.14 ha^2) in the Would was reflected in fewer potential prey species (21) and faunal taxa (27)[12] (Appendices X & XII). However, it is of note that no more taxa were recorded in 2002 (12 taxa) when the intensity of sampling was much greater (60,000 m^{-2} sampled) compared to 2003 (17 taxa in 19,320 m^{-2}), 2004 (15 taxa in 11,040 m^{-2}) and 2005 (13 taxa in 6,440 m^{-2}).

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[11] To avoid potential duplication of records, unidentified groups (e.g. larval crab) were omitted, but only where other species in the group were identified. These figures also assume that both Herring and Sprat that were not specifically identified in 2002 were actually both represented amongst the general group 'Clupeid sp.', as they have been in all other years.

[12] inedible species were jellyfish and comb jellies, Sea Gooseberries, barnacles and Razorshell

A possible explanation for this is that in 2002, half the sampling effort was undertaken offshore where few faunal taxa were captured. Furthermore, the fact that similar numbers of taxa were recorded with minimal sampling effort in inshore waters only in the latter years not only illustrates the importance of the inshore zone for fauna but also that only a few species may be relatively common and thus readily sampled.

Overall the number of faunal taxa was higher than expected in proportional terms compared to Scroby: with 50% of the taxa in 18 % of the tow length and 22% of the area sampled. Indeed, several species yet to be recorded at Scroby were recorded in the Would including the prawn *Processa canaliculata* and the fish Whiting *Merlangius merlangus* and Lesser Weever *Echiichthys vipera*.

The potential for real ecological differences between Scroby and the Would is also indicated by the notable absence of crabs in the latter (Appendices X & XII). This possibly reflects differences in sea-bed conditions particularly beyond the inshore zone. Sampling further offshore in 2002 also revealed the presence of extremely clear waters (in which the net was often visible to a depth of >5 m) with a lack of tide-borne suspended material and seaweeds. This relative absence of drifting seaweeds, which in contrast may be especially abundant at Sites 11 and 12 at Scroby, partly accounts for the relative infrequency of invertebrates (although *Chaetogammarus marinus* was numerous on occasion at Winterton in 2003), which are also often associated with such material (see 5.5.2 below). *Idotea* was the only species that was relatively frequently recorded (Appendix VIII).

5.5.2 Seasonal & temporal patterns of distribution & abundance

Invertebrates

The ubiquitous Sea Gooseberries (Plate 24) were particularly abundant at Scroby in 2002, frequently occurring in 100's and sometimes 1000's of individuals in tows at a site, conferring a maximum density of >500 ind. 100 m^{-2} (Appendix VIII). This contrasted with 2003, when potential prey for Little Terns, particularly Clupeid fish formed an equal component of the catch (ECON 2004 and see *Fish* below). Like fish and jellyfish, Sea Gooseberries are an important predator of smaller invertebrates (shrimps and the like often being visible within their gut through their transparent bodies) and may determine the abundance of at least some of the invertebrates falling prey to Little Terns.

The abundance of potential invertebrate prey available to Little Terns also tends to vary both temporally and spatially in accordance with the life histories of particular species. Ghost Shrimp is generally by far the most numerous (both in terms of number and biomass) species overall at Scroby (Tables 13 & 14), but tends to be much more abundant in early season, disappearing from samples later in the summer (although it did persist at both Scroby and Winterton throughout the season in 2004 – Appendices X & XI). In 2004, Ghost Shrimp were recorded at the huge density of nearly 800 ind. 100 m^{-2} (7.7 ind. m^{-2}) at one site (Site 1) on one occasion (17th May - Appendix VIII, Plate 25) considerably more (at least 8-fold) than the highest value recorded in any other year, although early season peaks were also noted. (Fig. 7). 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 Terns (ECON 2005). The concentration of Ghost Shrimp at Site 1 albeit based on one sampling occasion changed the typical pattern of the concentration of invertebrates in the sites close to the shore (inner sites) compared to the landward (middle sites) and seaward (outer sites) edges of Scroby Sands themselves (Fig. 7).

Plate 24. A catch of Sea Gooseberries, Sea Slaters and clupeid fish.

Plate 25. Exceptional numbers of Ghost Shrimps were captured at Site 1 in mid-May 2004.

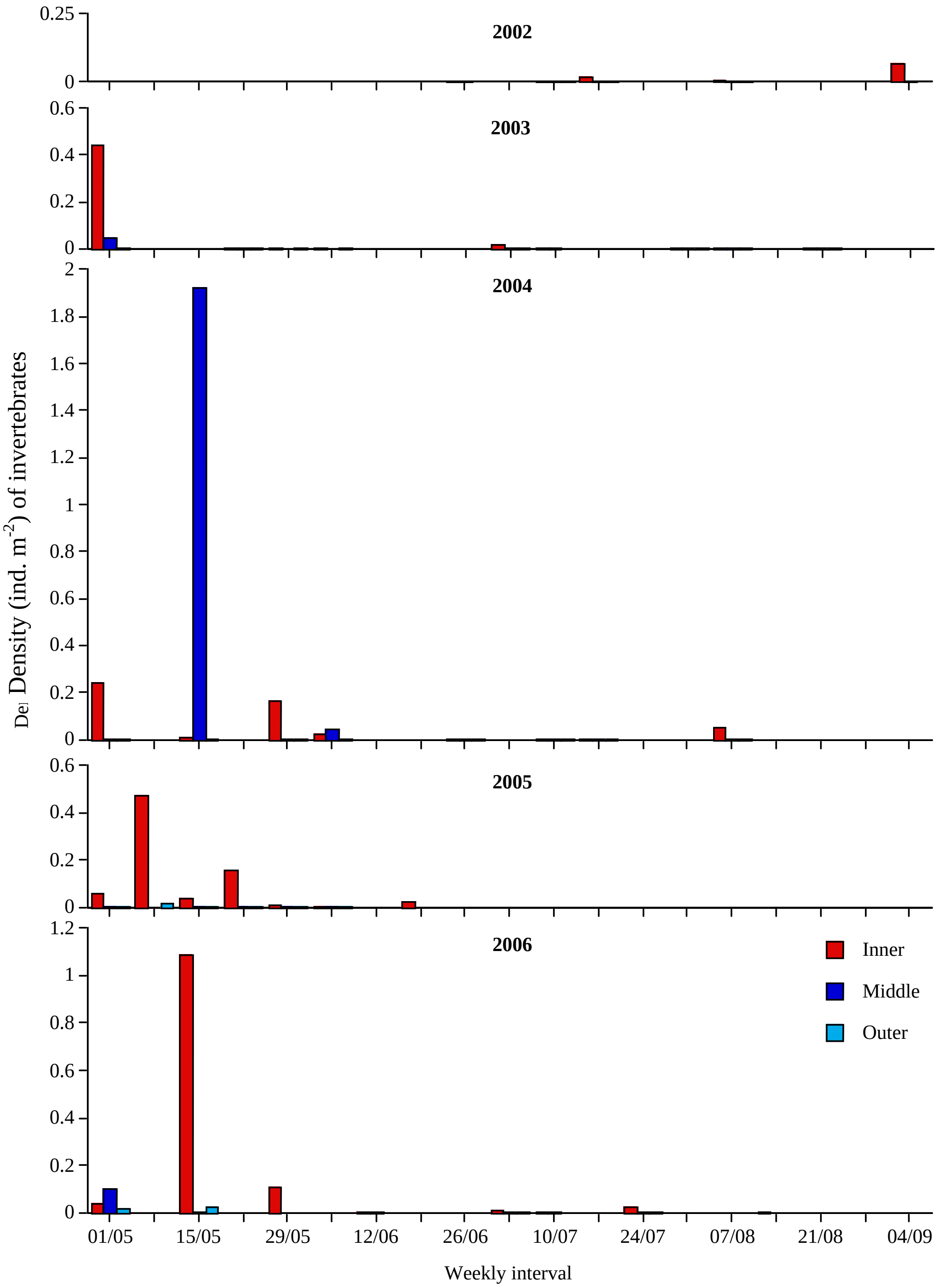

Figure 7. Mean density (ind. m^{-2}) of invertebrates suitable as prey for Little Terns, captured in combined tows at the inner (9, 10, 11, & 12), middle (1, 6, 7 & 8) and outer (2, 3, 4 & 5) sampling sites at Scroby as partitioned by the week of sampling, from 2002 to 2006 inclusive.

Invertebrates that assumed more importance later in the season with the decline of Ghost Shrimps included the Sea Slater *Idotea linearis* (Plate 24) and amphipod crustacea such as *Chaetogammarus marinus*. The latter in particular tended to be associated with floating materials such as detached seaweeds, which in turn tend to be associated with inshore waters. The relatively large size of *Idotea* (to 40mm) means that it may form a proportionally larger part of the biomass than smaller species and may be a more important prey item for Little Terns (Appendix VIII). However, it still tends to achieve far lower maximum biomass values than Ghost Shrimps at peak, which may even exceed the biomass values achieved by small, typically young-of-the-year (YoY) fish (Appendix VIII). Numerical density of late season amphipods and *Idotea* also never rivals that of Ghost Shrimp, leading to a typical decline in invertebrate abundance later in the season (Figure 7).

Despite seasonal variation in peaks of different taxa, the density of potential invertebrate prey for Little Terns was significantly different between years using all occasions from 2003-2006 inclusive (Freidman test S = 10.2, *n*=8, df=3, p=0.02). Judging from the estimated medians, 2004 was the outstanding year (median of 204.4 cf. 56.4, 41.6 and 26.6 from 2003, 2005 and 2006 respectively), coincident with a low abundance of fish (see *Fish* below). Although biomass of invertebrates exhibited a similar trend this was not significant (Freidman test S = 7.01, *n*=8, df=3, p=0.07). There was also no significant difference using only later season data (occasions 4-8) from all years (Freidman test S = 7.52, *n*=5, df=4, p=0.11), presumably as this did not incorporate peaks of Ghost Shrimp.

In the Would, Sea Gooseberries achieved similar maximum densities to those recorded at Scroby with 400-500 ind. 100 m^{-2} in some years (Appendix VIII). However, high densities were recorded in both 2002 and 2005 with lower numbers in 2003 and 2004. The temporal pattern was thus different to Scroby with high density in 2002 only and moderate density in 2003. The pattern for what are considered edible invertebrates was also different, with low numbers of Ghost Shrimp recorded throughout, although this may have been in part caused by few samples in early season when *S. spiritus* appears to breed (see above). The most numerous invertebrate was *C. marinus*, although this was only relatively numerous in 2003 and even then, although peak densities were high for this species (22 ind. 100 m^{-2}), only conferred a low density of edible invertebrates just a fraction (34-fold lower) of that achieved at Scroby.

In contrast, the peak biomass value of invertebrates recorded in the Would (35.2 g 100 m^{-2}) was directly comparable to that at Scroby (27.7 g 100 m^{-2}), also in 2004, albeit caused by the largely chance capture of several large individuals of Brown Shrimp *Crangon crangon* on one occasion at Winterton on a low tide on the inshore sandbank (Table 16). Otherwise, the benthic *Crangon* was relatively infrequently captured in both samples at Scroby and the Would and generally at very low density and biomass

Fish

Although 18 species of fish have been recorded in tow samples at Scroby (with a further two species, Whiting and Lesser Weever recorded in the Would- see 5.5.1 above), the Clupeid spp., YoY Herring and Sprat (Plate 24) were by far the most frequently recorded (Appendix VIII) and abundant both in terms of number and biomass (Appendices VII & IX). Clupeids were also the dominant fish species recorded in the Would by both number and biomass (Appendix X).

At Scroby, there was considerable variation in the abundance of clupeids and thus fish in general between years, with 2003 outstanding (maximum >2 ind. m^{-2}) and both 2004 and 2005 particularly poor (maxima of 0.09 and 0.07 ind. m^{-2} respectively) with 2006 little better (0.15 ind. m^{-2}) and 2002 being somewhat intermediate (maxima of 0.4 ind. m^{-2}). The relative standing of the latter is difficult to interpret with the lack of early season samples and there is a suggestion from a decreasing trend that this is likely have been much higher early in the season (Fig. 8).

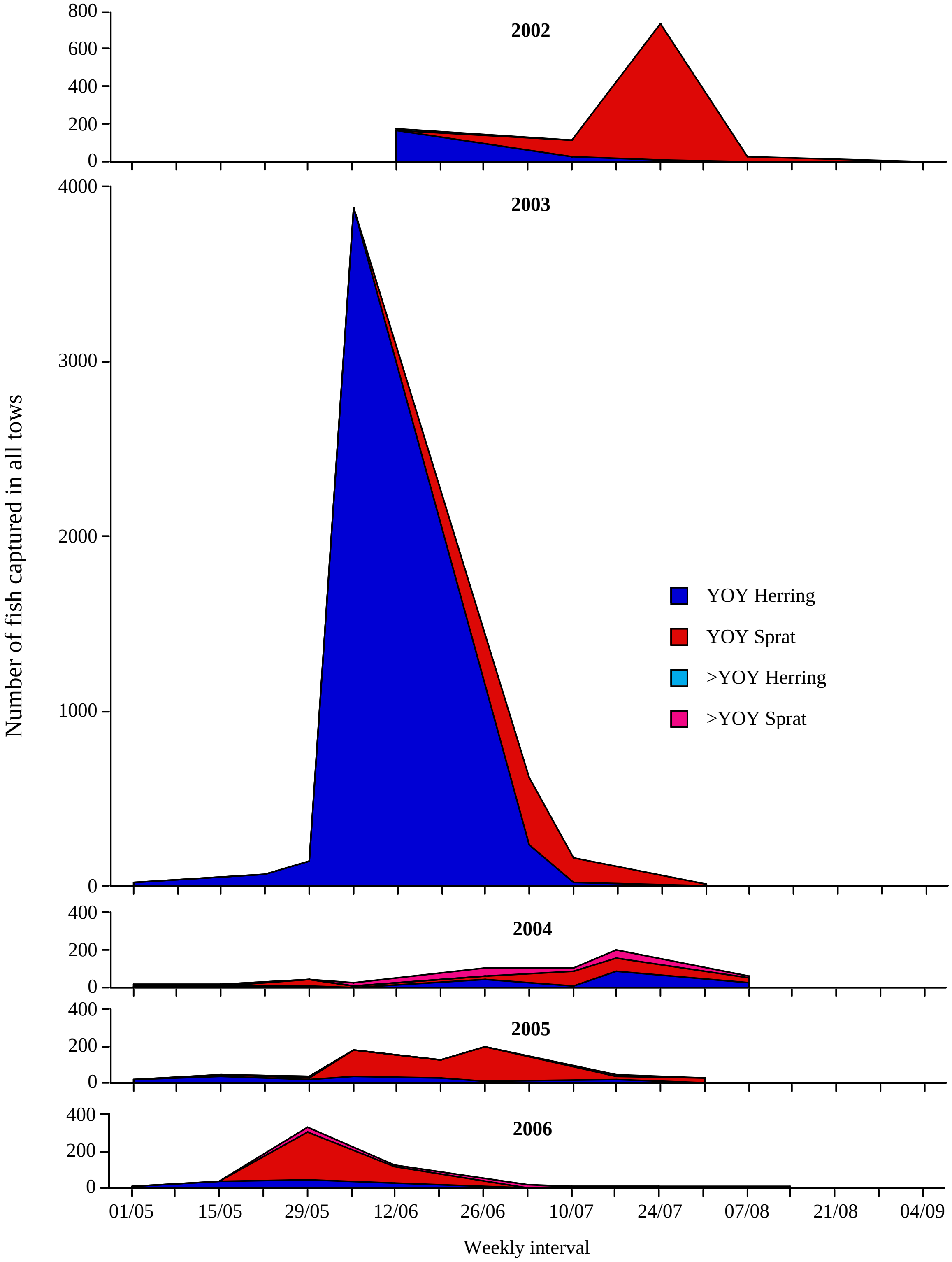

Figure 8. Inter-annual (2002 to 2006 inclusive) and seasonal (by closest week in which the sample was taken) abundance (catch-per-unit effort of fish captured in all tows) of young-of-the-year (YoY) and older (>YoY, generally 1+) Herring and Sprat at Scroby.

There was no statistically significant difference in the numerical abundance of fish between all years (2002-2006 inclusive) using later season (4-8) samples (Freidman test S = 8.64, *n*=5, df=4, p=0.07) or with all sampling occasions (1-8) excluding 2002 (Freidman test S = 6.30, *n*=8, df=3, p=0.10) although there is evidence of a trend in the dataset. Consequently, using only early season data (occasions 1-5) coinciding with courtship and incubation when peaks in fish abundance are often more apparent, there is a significant inter-annual difference in numerical abundance (Freidman test S = 8.28, *n*=5, df=3, p=0.04). As 2003 has by far the highest estimated median (435.3) compared to all other years 41.8 in 2004, 61.0 in 2005 and 21.0 in 2006), the significant difference appears to lie between 2003 and all other years.

There is however no significant difference in biomass (Friedman test S = 3.96, *n*=5, df=3, p=0.27). With little indication of reduced growth of YoY Herring in 2003 compared to the other years (Fig. 9), it appears the small contribution of larger and thus heavier (1+ fish) in catches in 2004 and 2006 especially, was sufficient to mean biomass estimates were not significantly different between years. Of the two species, Sprat appeared to be the more important and both number (Freidman test S = 13.97, *n*=5, df=4, p=0.03) and biomass (Freidman test S = 12.80, *n*=5, df=4, p=0.01) of these 1+ fish showed significant differences between years (2002-2006) using late season samples (occasions 4-8). Highest median values for both measures were achieved in 2004 (for number: 13.0 compared to <1.6 for all others; and for biomass: 1.17 compared to <0.08 for all other values) showing this was the exceptional year.

Nonetheless, as the numbers of 1+ fish were very small, the principal cause of the inter-annual and seasonal variation in the abundance of clupeids was the recruitment strength of YoY Herring, which where abundant in 2003 and dominated catches particularly earlier in the season (Fig. 8). From 2004 onwards, however, YoY Herring were conspicuous by their virtual absence. Such is the difference between years that whichever part of the dataset is tested then the inter-annual differences are statistically significant: 2002-2006 inclusive using later season (4-8) samples (S=11.30, *n*=5, df=4, p<0.05); all sampling occasions (1-8) excluding 2002 (S=11.19, *n*=8, df=3, p=0.01); and early season (1-5) samples from 2003-2006 only (S=10.84, *n*=5, df=3, p=0.01). In all cases, the estimated medians for 2003 are far higher illustrating that this is the outstanding year (e.g. for 1-5, the median for 2003 is 236.3 compared to 17.8, 19.5 and 8.5 for 2004-2006 respectively).

Herring first appeared in catches at around 35-40mm and displayed variable growth patterns to reach a maximum of around 60mm by the end of the season (Fig. 9). Even in 2003, which appeared to be an excellent year for recruitment, the numbers of Herring declined rapidly by late June. What were thought to be Sprat entered samples at much smaller size as YoY than Herring at a mean fork length of ~20mm (Fig. 9), with individuals as small as 7mm. Up until 2004, there was a tendency for Sprat to increase in abundance towards the end of the season in July, thereby mostly replacing Herring but at a much lower level than that achieved by the latter species in some years (Fig. 8). However, the peak in Sprat was earlier in 2005 and then even earlier in 2006, effectively appearing by late May, when Herring would be expected to be numerically dominant. Nonetheless, there were no significant differences in the numbers of YoY Sprat between years irrespective of whether this focused on later season (occasions 4-8) samples from 2002-2006 inclusive (S=5.39, *n*=5, df=4, p=0.25), all samples throughout the year (occasions 1-8) dataset from 2003-2006 inclusive (S=5.56, *n*=8, df=3, p=0.14) or on early season (occasions 1-5) samples from 2003-2006 alone (S=2.60, *n*=5, df=3, p=0.46).

Despite inter-annual and seasonal variation clupeid fish always tended to be concentrated in the more inshore (inner) sites (Fig. 10), although the relative importance of these varied. In 2002 and 2003 there was a bias to Sites 10 and 11. However, 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. Sites 9 and 11 produced higher densities in 2006 (Fig. 11).

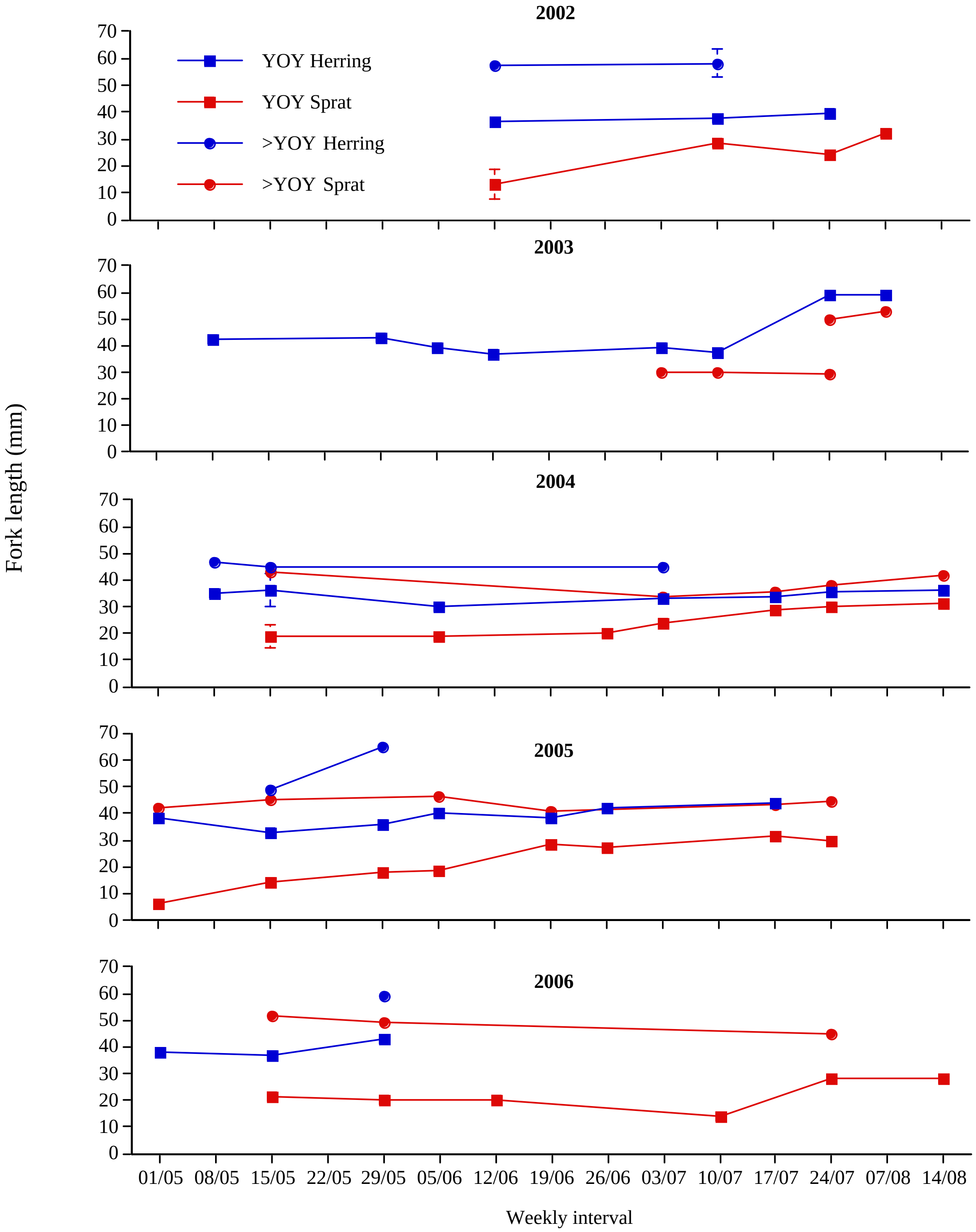

Figure 9. Inter-annual (2002 to 2006 inclusive) and seasonal (by closest week in which the sample was taken) growth pattern (mean ± 1SE fork length in mm) of both young-of-the-year (YoY) and older (>YoY, generally 1+ Herring and Sprat in samples from Scroby.

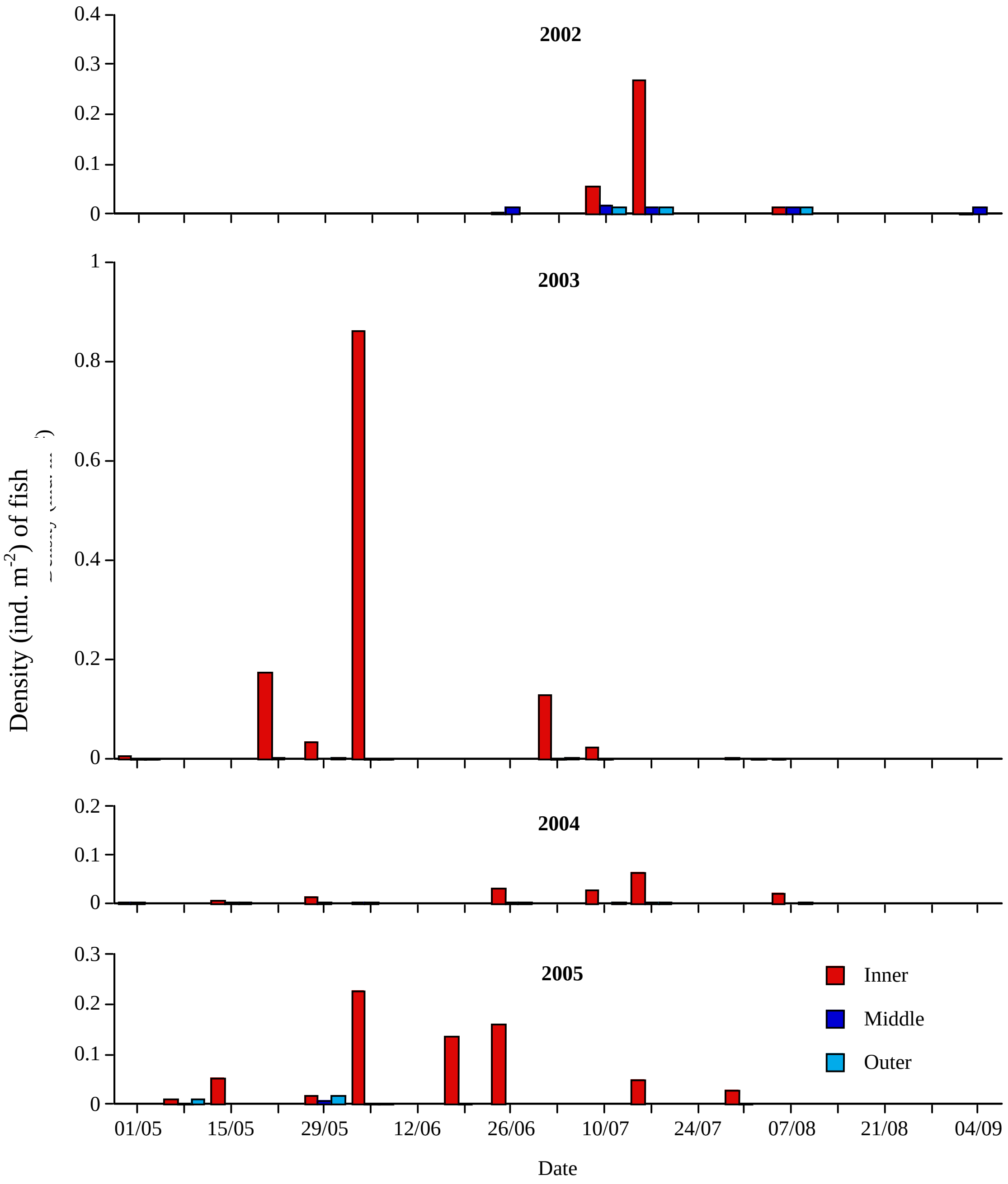

Figure 10. Mean density (ind. m^{-2}) of fish captured in combined tows at the inner (9, 10, 11, & 12), middle (1, 6, 7 & 8) and outer (2, 3, 4 & 5) sampling sites at Scroby as partitioned by the week of sampling, from 2002 to 2006 inclusive.

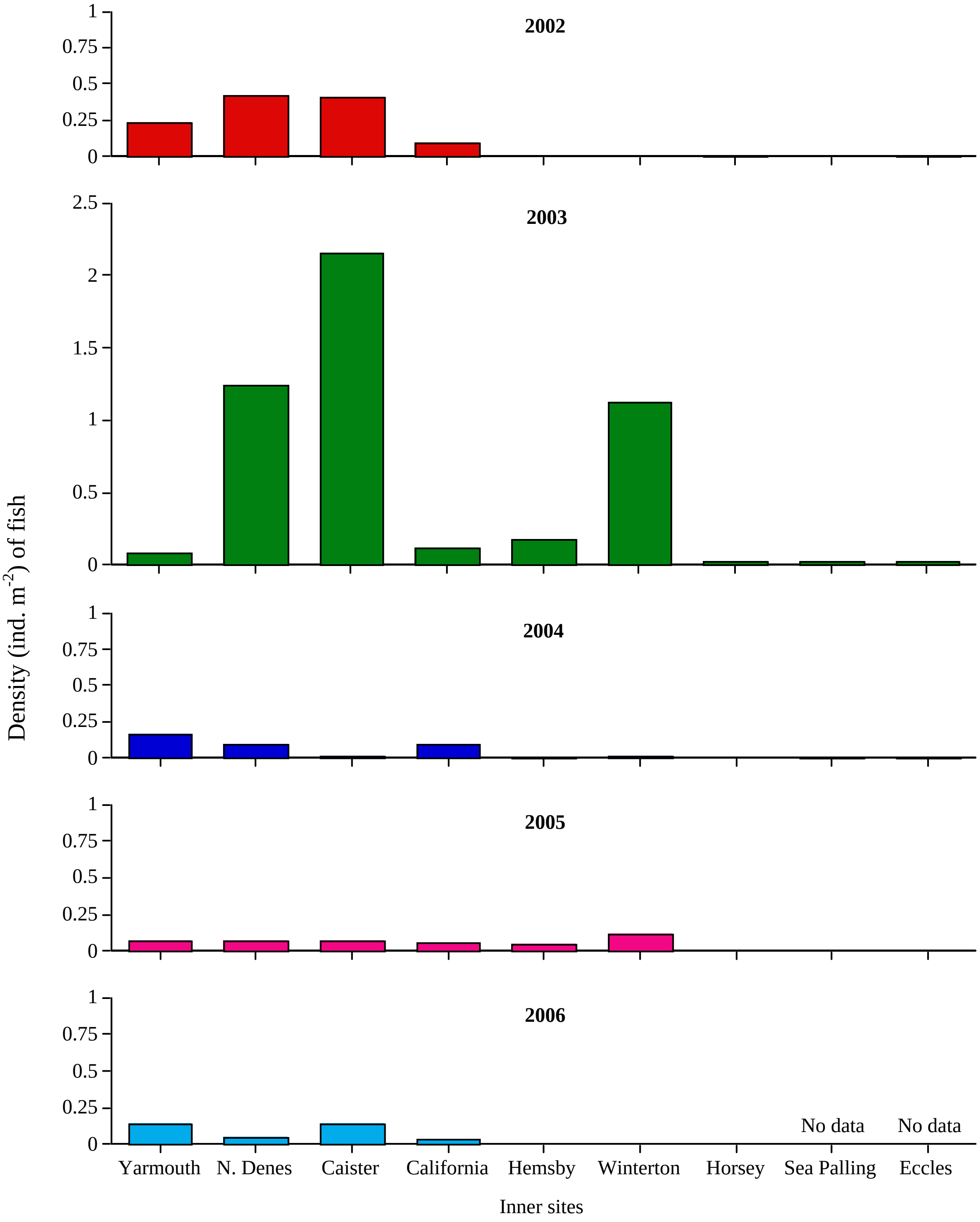

Figure 11. Maximum density (ind. m^{-2}) of fish (principally clupeids) recorded at all inshore sampling sites along the East Norfolk coast from Yarmouth in the south to Eccles in the north from early May to August/early September in 2002 to 2006 inclusive.

There was also some evidence of interchange, with low values in Site 10 in mid July 2004 corresponding to a peak in density at Site 12. In 2005, fish occurred at low density at all sites, although there is again some evidence of aggregation at times, with a lack of fish in late June at Site 9 corresponding to the highest densities recorded at the other sites (Appendix VIII).

The concentration of fish at a particular site may be partly explained by the general association between fish and water clarity or, rather, the lack of it (Table 10). However, the tendency for fish to occur at inshore sites, which tend to have much more turbid waters, may obscure the true nature of the preference. Certainly, any differences between the inshore sites on different occasions in any year could not always readily explained by water clarity and a number of other factors such as the state of the tide and the presence of food and predators (especially Little Terns) are also likely to be important.

Table 10. Spearman rank correlation coefficients (r_s, +/-) and their probability[1] from correlations between fish density (ind. m^{-2}) and water clarity (m), using all sites/occasions (*n*=95-108) and the inshore sites only (n=32-36) from 2003 to 2006 inclusive.

Variable	Year	Sites	Water clarity	Significance
Fish density	**2003**	All	-0.65	***
		Inshore	-0.58	***
	2004	All	-0.37	***
		Inshore	-0.15	ns
	2005	All	-0.62	***
		Inshore	-0.02	ns
	2006	All	-0.492	***
		Inshore	-0.503	***

Notes: [1]*= p<0.05, ** p<0.01 and *** p<0.001), [2] *n*=96 in 2002 & 2005, *n*=108 in 2003 and *n*=95 in 2004 and 2006, [3] *n*=32 in 2002, 2004 & 2005 and *n*=36 in 2003

In 2006, anecdotal observations of aggregations of foraging terns that formed and dispersed in a matter of minutes or even seconds suggested that shoals of fish became available in the upper layers of the water column in a highly temporally restricted manner. Occasional attempts to sample through such aggregations outside the sampling programme always proved to be unsuccessful as the aggregration dispersed before the vessel could be manœuvered into position to tow the net.

The highly transient occurrence of shoals of fish close to the surface, which had not appeared to be so restrictive in previous years may have been exacerbated by the large number of Little Terns present in 2006, whose repeated attempts at prey capture may have caused fish to rapidly abandon the surface layers which otherwise presumably also offered foraging opportunities to them. Such observations simply reinforce the range of factors that determine fish abundance and availability as well as the difficulty of sampling such ephemeral events even during what has been a relatively intensive sampling programme.

In accordance with inter-annual and seasonal variation of clupeid fish at Scroby, there is evidence of similar variation in fish abundance at other sites along the coast (Fig. 11) as far as Winterton. Sites further north than this to Eccles seemed to support extremely low densities of clupeids if any at all, although sampling was limited especially in the latter years of the study.

Thus, in four out of five years, clupeid fish achieved higher density values at North Denes and at other sites in the Scroby area compared to Winterton, suggesting the former is preferred. However, this can only be a tentative suggestion as this is likely to be biased by the reduced sampling intensity at Winterton. Nevertheless, considering maximal density in 2002 and 2003 when sampling intensity was similar between Winterton and sites in Scroby tends to reinforce this suggestion. For example, the maximum density yet recorded at Winterton and thus in the Would was 113 ind. 100 m^{-2} (1.13 ind. m^{-2}) in 2003. Whilst comparable with the maximum density at North Denes of 124 ind. 100 m^{-2} (1.24 ind m^{-2}), it was somewhat lower than the peak value of 215 ind. 100 m^{-2} (2.15 ind m^{-2}) at Caister (Site 11), within the range of foraging terns at North Denes.

In 2002, a year of moderate fish density, no fish were captured at Winterton at all either inshore or further offshore on five sampling occasions, whereas densities of up to 41 ind. 100m^{-2} were recorded at inshore sites at Scroby (Fig. 11). In these moderate (2002) and high (2003) fish density years, North Denes and Caister tended to support the highest densities of all sites at Scroby, although in poor years for fish (2004 & 2005) all inshore sites tended to have rather similar maximum density values (Fig. 11). In poor fish years, Winterton varied between supporting marginally higher density (0.12 ind. m^{-2} in 2005 despite limited sampling) to the lowest density of all the sites as far south as Yarmouth (2004 and 2006).

Despite what appear to be relatively high numerical density values of clupeids at some sites in some years, the small size of the young-of-the-year (YoY) captured (i.e. to a maximum of ~60 mm) particularly as larvae in early season (~30 mm) (Fig.'s 2 & 9) was responsible for what were thought to be low biomass values of fish at both Scroby and the Would (Appendix VIII). Maxima were just 17.8 g 100 m^{-2} (0.18 g m^{-2}) and 14 g 100 m^{-2} (0.14 g m^{-2}) respectively, both in 2003. In both areas, invertebrates (*S. spiritus* at Scroby and *C. crangon* in the Would) achieved higher maximum biomass values than fish.

5.6 Telemetry of individual Little Terns

5.6.1 Tag performance & impact of tagging

Of the seven birds fitted with back-mounted tags in 2003, the first three went on to show some aberrant behaviour patterns linked to the aerial breaking, although tracking data was gathered on one bird before this occurred (Appendix III). With re-fitted tags, all other birds in 2003 behaved normally. Useful data were thus gathered on five birds. In 2004, eight of the 14 birds tagged were subsequently contacted and appeared to show normal behaviour patterns in what was an abnormal season (ECON 2005). The 2005 season was particularly successful from a telemetry perspective as all 15 birds fitted with tags were subsequently contacted, with good data gathered on all but two of these (Appendices III & IV). These two birds (7.4 & 13.9) were excluded from any analysis of activity patterns and foraging parameters. No incidences of anything but normal behaviour were noted.

In 2006, of the 13 birds tagged, four birds were not contacted (Appendix XI), one of which (NV51860) had displayed aberrant behaviour upon being released. Of the other three birds at least two were known to have failed within a few days (maxima of 4-7 days), although the reason for failure was unknown. In similar fashion to 2003, three birds then went on to show what appeared to be aberrant behaviour patterns, including apparent refusal to incubate chicks, begging for food from a mate alongside the chicks with one female apparently complicit to the pre-copulation advances of another male carrying prey, that was then attacked and displaced by her mate. One bird, NW09982, displayed reluctance to incubate chicks several days after it had shed the tag.

The other two birds retained their tags for some time (18-23 days) and displayed what appeared to be entirely normal foraging ranging behaviour at sea in this period. It was thus assumed that these birds could be safely used in analysis, as was the case with a further bird in 2003. Nonetheless, it remains a possibility that some birds were affected by tagging procedure, with the most likely cause being the use of superglue activator. However, the actual mechanism of any impact or whether the birds actually suffer some form of injury or why this should be apparent in some years and not others all remain unknown.

Valuable data was thus gathered on 37 of the 51 birds tagged (73%) (Appendix XI). Of these five (14%) for suffered from a drifting signal. This created confusion with the other birds and in 2004, considerably reduced the amount of information gathered on one of the few birds nesting at North Denes (7.1 or 'mid-grey'). Otherwise, tag performance was primarily limited by battery life. In 2004, the maximum life of the tags varied considerably from 2-27 days (mean of 12 days). This was biased by Ag376 batteries, which lasted over twice as long on average (mean = 18.0 days) than the standard Ag379 battery (mean = 7.6 days), although the respective mean life of the tags was only 67% and 42% of maximum quoted values. Only Ag376 batteries were used in 2005 lasting for a mean of 12.4 days but with considerable range from 2-33 days. Lower values were minimum values as the tag was not contacted but may in fact have still been working. A similar pattern was observed in 2006, with a mean life of 12.2 days and a range of 1-23 days.

Of the 51 birds tagged in the study, eight (15%) are known to have shed tags as planned, with just three of these (one tail-mount and 2 back-pack tags) recovered (Appendix III). A relatively high proportion of tags (27%) were shed as planned in 2005, although only one of these (25%) was recovered. The high proportion in 2005 is thought to be the result of the increase in tracking time supported by observations on what was a relatively lengthy, albeit mostly unsuccessful breeding attempt at North Denes (see 5.1.1 above).

No tagged birds have ever been recovered either dead or in a distressed state, although one bird captured at Winterton that was not fitted with a tag (NW09891) was recovered dead some 12km away at north Denes 12 days later (Appendix IV). There was some evidence that tagging was a benign procedure that did not reduce the chances of a successful nesting attempt or future survival. These included one bird (BV87138 in 2003) seen with fledged or near fledged chicks, providing firm evidence of a successful breeding attempt. Another bird that had naturally shed a tag (NW09980) and had mistakenly been fitted with an upside-down colour ring was photographed feeding chicks (Plate 26) in 2005, Unfortunately, these chicks were almost certainly lost to a kestrel.

Plate 26. Colour-ringed Little Tern known to be NW09980 from the white over orange (W/O) colour ring (as opposed to O/W) feeding chicks on 19th July 2005, following the loss of its radio tag.

At the same site in the same year NW09930 that initially suffered nest predation by a fox (a number of nearby nests were also predated on the same night) re-nested at the same site ten days later.

A further bird that had been fitted with a tail-mount tag on 8th July 2003 at Winterton (NW09880) was controlled at North Denes on 23rd June 2004, fit and well. A colour-ringed adult (yellow on left leg) from the batch fitted with tags at Winterton in 2003 was seen (one day only) on the Eden estuary in Fife Scotland on 3rd June 2004. Finally, a bird seen at nest on 20th May 2007 in Wagejot, Texel, The Netherlands was carrying a green over white ring on its right leg. The best match for this bird from all colour ring schemes is the green over yellow (with yellow fading) from tagged birds at Winterton on 23rd June 2005, all of which failed, presumed abandoned, with 3 of the 4 birds later contacted at North Denes.

5.6.2 Tracking parameters

All birds with signals on a particular day were continuously tracked for varying amounts of time: in 2003 from 59-188 minutes (mean ±1SE = 132 ± 17 min), in 2004 from 4-230 minutes (58 ± 13 min), in 2005 from 3-319 mins (63 ± 9 min), and in 2006 from 8-346 minutes (106 ± 16 minutes). Birds were tracked for significantly longer in 2003 than in 2004 and 2005 and for significantly longer in 2006 than in 2005 (Kruskal Wallis test, H=15.37, df=, p=0.002, *n*=9 in 2003, *n*=22 in 2004, *n*=47 in 2005, *n*=30 in 2006).

However, the total tracking time for each bird was not different between years (2003, *n*=5, mean±1SE = 236 ± 47 min; 2004, *n*=8, mean±1SE = 165 ± 36 min; 2005, *n*=15, mean±1SE = 201 ± 35 min; 2006, *n*=9, mean±1SE =106.2 ± 16 min, Kruskal-Wallis test, H = 2.81, df=3, p=0.246) probably on account of considerable variation between birds (Appendix XIII).

The total time spent tracking birds in 2005 (3027 minutes, i.e. 51 hours), when compared against 2003 (1327 minutes, i.e. 22 hours) and 2004 (1188 minutes, i.e. 19 hours) indicates that the shorter tracking times are a consequence of having a greater number of tagged birds. Whilst total tracking time in 2006 was similar to 2005 (3186 minutes, i.e. 53 hours), it was divided amongst fewer birds thereby accounting for the significantly longer tracking times between 2006 in comparison to 2005.

The total number of fixes was far greater in 2005 (1353) and 2006 (1245) than in 2004 (366) and 2003 (282), not just as a result of a greater tracking time but also because fixes were taken at a faster rate (26.5 fixes hr^{-1} in 2005 and 24.41 hr^{-1} in 2006) than in 2004 (16.6 fixes hr^{-1}) and 2003 (15.4 fixes hr^{-1}). However, the number of location fixes for each bird was not significantly different between years (Kruskal Wallis test, H= 7.33, df=3, p=0.062) despite the fact that at least 66% more fixes per bird were taken in 2006 than in 2004 (2003, *n*=5, mean±1SE = 56 ± 15; 2004, *n*=8, mean±1SE = 46 ± 12; 2005, *n*=15, mean±1SE = 90 ± 14, 2006, *n*=9, mean ±1SE = 138 ± 36). In 2006 and 2005, the greater number of fixes was more likely to allow a more accurate assessment of home range size (see 4.3.5 & 5.6.4 below).

The number of fishing fixes per bird was not significantly different between years (Kruskal Wallis test, H=1.80, df=3, p=0.619), in line with the number of location fixes per bird and the fact that birds with active nests spend similar amounts of time foraging between years. In contrast, there appeared to be an underlying increase in the number of visual fixes, albeit biased towards a few birds which were maintained in sight for relatively long periods contributing visual fixes and a thorough record of foraging activity (Appendix XI). The fact that the number of fishing fixes did not increase accordingly tends to suggest these were adequately measured remotely by changes in signal strength and frequency (4.3.4 above).

5.6.3 Activity patterns

In 2003, birds (*n*=5) varied relatively little in the proportion of time engaged in various activities and, overall, a mean (±1SE) of 55.7 ± 3.5% of time was spent foraging, 35.4 ± 3.1 % at nest, 6.7 ± 1.5 % flying above the beach, usually in response to disturbance by people and their dogs, and 2.2 ± 2.0 % was spent in loafing sites on the beach away from the nest, with at least some time engaged in preening (Fig. 12). In contrast, in 2004 only three birds were recorded at/near the known nest site although all eight tagged had been captured at a nest illustrating that the nesting attempt of several birds failed during the period of telemetry[13]. The active birds (*n*=3) in 2004 spent a similar amount of time at nest 38.3 ± 8.2 % at nest with 45.6 ± 10.0 foraging, 9.3 ± 4.2 % flying above the beach and 6.9 ± 2.1 % loafing. Failed birds (*n*=3) with sufficient information[10] appeared to spend the time not at nest by foraging more (93.7 ± 4.2 %), with 6.3 ± 4.2% loafing. This pattern was not apparent in 2005, with failed birds (*n*=10[14]) spending 61.2 ± 1.8 % of time foraging, but with a relatively large amount of time (13.5 ± 10.4 % flying in disturbance events (see below) or engaged in display (perhaps looking to re-nest) with a large amount of time loafing 48.0 ± 5.8%. Active birds (*n*=5[11]), also spent a relatively large amount of time (10.4 ± 3.9 %) flying above the beach in 2005, but otherwise partitioned activities in a similar way to actively nesting birds in previous years with 49.8 ± 17.3% of time spent foraging, 36.5 ± 13.3 % at nest, and 3.2 ± 2.1 % loafing.

Specific investigation of disturbance at North Denes in 2005, where most of the radio-tagged birds were nesting suggested that despite the intense predation of chicks by Kestrels (see 5.1.1 above), disturbance of the colony by these predators was relatively infrequent (mean±1SE = 0.15 ± 0.07) compared to that of people and their dogs (mean ±1SE = 1.57 ± 0.40) (Table 11). Overall, birds were disturbed nearly twice per hour (mean ±1SE = 1.97 ± 0.41) with some individual birds disturbed very frequently, to a maximum of >5 hr^{-1} (i.e. every 11 minutes) presumably as the nests were close to a fence-line or access point.

Table 11. Rate of disturbance (number of times flushed from the nest hr^{-1}) for individual birds in relation to different causes of disturbance in 2005.

Bird tag ID	Disturbance rate hr^{-1}		
	Overall	People/dogs	Kestrel
0.3	1.77	1.77	0
4.7	1.47	0.98	0.49
7.4	0	0	0
10	3.81	3.81	0
1.2	2.50	2.5	0
3.8	2.93	0.98	0
6.4	1.50	0.75	0
8.8	5.29	5.29	0
2.6	2.48	2.48	0
12.8	3.30	2.60	0.51
1.9	0	0	0
3.1	0	0	0
5.6	1.37	1.03	0.34
8.1	3.11	1.33	0.88
13.9	0	0	0

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[13] Two birds were not contacted and birds 5.5 and 3.0 are excluded from statistical tests as a result of <50 minutes tracking time as either an active or failed bird, although 3.0 is included in the figure with a combined total >50 minutes as both active and failed.

[14] Two birds, 4.7 and 10.0, were tracked for more than 50 minutes as both active and failed birds.

This contributed to the adoption of a different management regime at the colony in 2006, weith fencing down to the beach line to limit human disturbance. Along with supplementary feeding of Kestrels limiting their impact on the colony (5.1.1 above) this may have contributed to a reduction in the time spent flying above the beach to 5.7 ± 1.8% akin to that recorded at Winterton in 2003 (see above). The other activities exhibited by the wholly activey nesting birds in 2006 (*n*=9) were rather similar to active birds in other years with a mean of 42.3 ± 5.6% of time foraging, 44.4 ± 6.2% at nest and 7.6 ± 4.9% loafing.

Partitioning between years for active birds only, revealed no significant differences in what were inter-related activities (i.e. if the bird is engaged in one activity it could not be engaged in another) (Table 12). A lack of inter-annual differences between active birds justified pooling samples to test between active and failed birds. Along with a significantly reduced proportion of time at nest (by definition no failed bird spent time at nest), failed birds spent a significantly greater proportion of time loafing rather than foraging as appeared to be likely from the small sample of birds in 2004 as documented above (Table 13).

Table 12. Inter-annual (2003-2006 inclusive) variation in selected parameters of activity within the time budget of actively nesting radio-tagged Little Terns (with >50 minutes tracking). Sample statistics from Kruskal-Wallis tests are shown.

Activity	Year	*n*	Median	Average Rank	df	H	P
% of time foraging	2003	5	55.00	19.2	3	2.49	0.391 ns
	2004	3	53.00	14.2			
	2005	10	45.35	13.5			
	2006	9	40.00	11.6			
% of time at nest	2003	5	37.00	12.3	3	0.53	0.853 ns
	2004	3	35.00	12.7			
	2005	10	37.00	13.7			
	2006	9	41.00	15.8			
% of time in air over beach	2003	5	7.00	14.1	3	4.21	0.647 ns
	2004	3	6.00	17.0			
	2005	10	13.50	15.4			
	2006	9	4.00	11.4			
% time loafing	2003	5	0.00	10.9	3	0.91	0.434 ns
	2004	3	7.80	19.8			
	2005	10	0.60	13.2			
	2006	9	3.00	14.7			

Table 13. Differences in selected parameters of activity within the time budget of actively nesting and failed radio-tagged Little Terns (with >50 minutes tracking) from all years (2003-2006) combined. Sample statistics from Kruskal-Wallis tests are shown.

Activity (% of time)	*n*	Median	Average Rank	df	H	p	Location of differences
Foraging	Active: 27	46.00	17.4	1	0.35	0.556 ns	
	Failed: 8	51.50	19.9				
At nest	Active: 27	0.04	22.0	1	18.22	0.000 ***	Active > Failed
	Failed: 8	0.00	4.5				
In air over beach	Active: 27	5.50	18.1	1	0.02	0.891	
	Failed: 8	10.00	17.6				
Loafing	Active: 27	1.00	15.2	1	8.94	0.003 ***	Active > Failed
	Failed: 8	34.00	27.3				

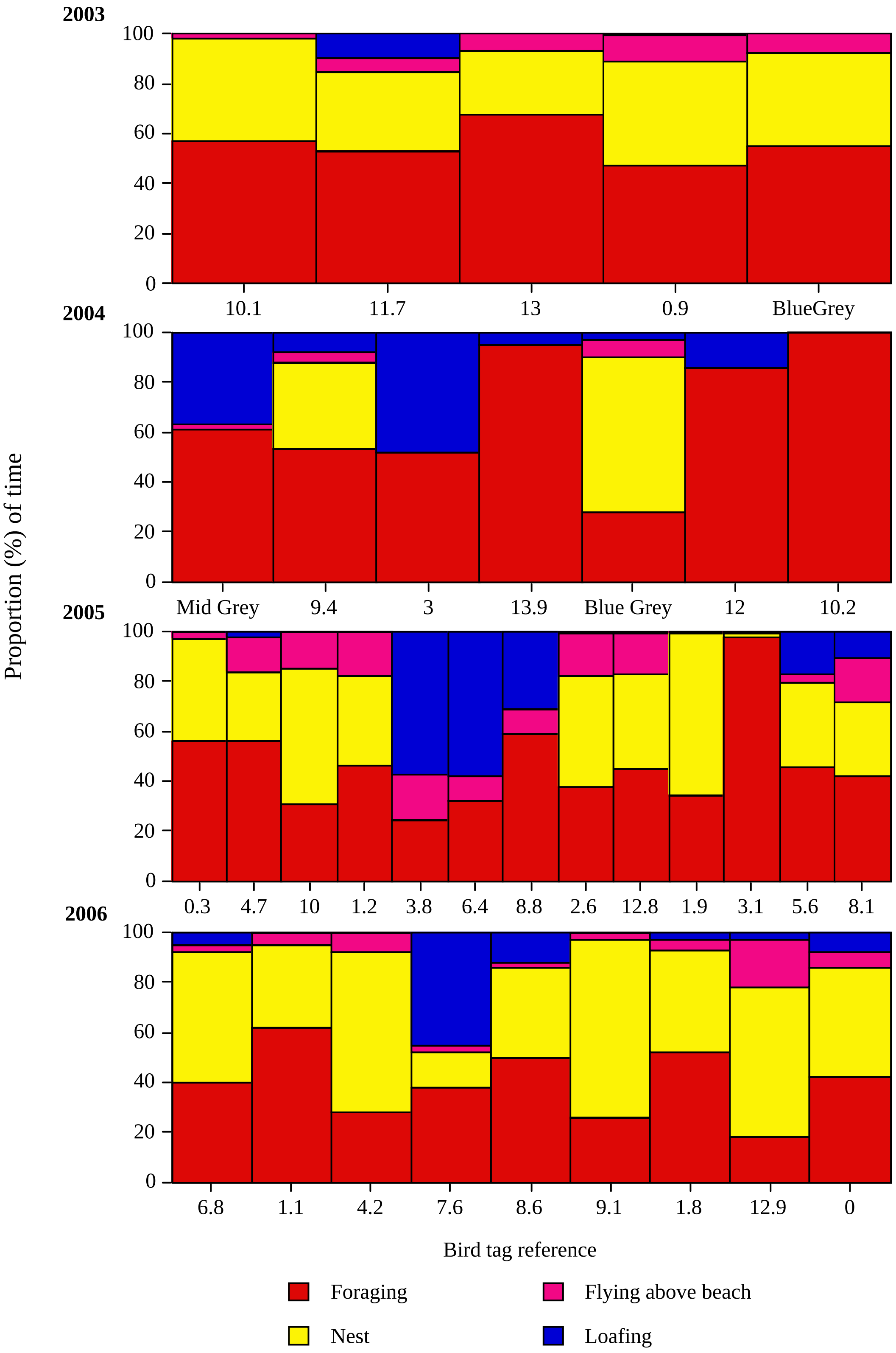


Figure 12. Proportion of time (%) tagged birds engaged in different activities in different years (2003 to 2006 inclusive).

5.6.4 Home range & foraging movements

Status of the nesting attempt had a clear effect on the foraging range utilised by Little Terns (Fig. 13). Failed birds, no longer confined to central-place foraging often exhibited wide-ranging behaviour with no less than eight of the 11 birds (73%) known to have failed at some stage in 2004 and 2005 being recorded at both Winterton and North Denes. It is also possible that birds ranged over greater distances than this, which could not be detected by the monitoring that focussed on the two colonies. The latter, combined with the fact that some failed birds did not obviously undertake wide ranging behaviour, may explain the lack of a clear difference in the corrected MCP's for 2005 alone (H=2.91, active *n*=7, failed *n*=5, df=1, p=0.09) or for a pooled 2004/2005 data-set (H=2.36, active *n*=9, failed *n*=7, df=1, p=0.125). However, there were significant differences in the more conservative 85% kernel contour foraging range for both 2004 and 2005 pooled (H=4.71, active *n*=9, failed *n*=7, df=1, p=0.03) and for 2005 alone (Kruskal-Wallis test, H=6.34, active *n*=7, failed *n*=5, df=1, p=0.012). These results supported the assumption that failed birds were likely to utilise a larger foraging range and potentially utilise it in a different way to birds with an active nest (as also shown by patterns in time budget - see 5.6.3 above).

Despite the small sample sizes and variation between birds (Appendix XIII), previously reported (ECON 2006), there were significant inter-annual differences in virtually all foraging parameters with only mean bout duration similar between years (Table 14). There was even a clear trend in the conservative MCP and resultant range span parameters although neither was significantly different between years (Table 14). In general, 2005 and 2006 tend to represent one extreme with 2003 at the other, with comparisons with 2004 apparently limited by reduced sample size. With no clear difference in the proportion of time foraging (see above) birds seemed to partition their foraging time in different ways in different years.

A comparison of median values showed that birds had foraging ranges of ~1200-1600 ha in 2005 and 2006, around twice that recorded in 2003 at around 500-600 ha (Table 13). Even kernel ranges reached nearly 900 ha in 2006 compared to <300 ha in 2003. Uncorrected range span increased at least 1.5 fold to ~5.4-6.0 km in 2005 and 2006 from 3.4-3.5 km in 2003 and 2004. To cover larger ranges, birds travelled >2.7-fold further in 2005 compared to 2003 with a maximum value achieved in 2006 of 57 km) (Table 15). Larger ranges also meant birds extended the distance from shore reaching median values of ~1300-1650 m in 2005 and 2006 compared to 400-500m in earlier years. Maximum values were much greater at 6300 m in 2005 and 4900 m in 2006 (Table 15). Therefore, birds routinely travelled offshore to an equivalent distance of the closest turbines (~2km).

Birds seemed to compensate for increased foraging range without allocating any more time to foraging (see above), by undertaking fewer bouts per hour (<1.9 compared to 2.4-3.9), but increasing flying speed to ~30 km hr^{-1} compared to a median of 10-13 km hr^{-1} in 2003 and 2004. Kernel analysis of all birds combined showed a tendency to exploit large areas in 2005 and especially 2006 rather than concentrating on smaller discrete patches (Fig. 14).

Interpreting the patterns produced using cluster analysis on all fishing fixes (Fig. 15) could only be undertaken with caution as the number of fishing fixes increased considerably in 2005 and 2006 in keeping with the larger dataset available (see above). Moreover, there is clearly an influence of birds at two different colonies upon the parameters of cluster analysis. The patchiness index in particular seems particularly sensitive to the presence of two colonies. However, comparing a single colony scenario such as Winterton in 2003 and North Denes in 2006 shows a clear increase in patchiness at the latter. Moreover, when data from North Denes is used in isolation in 2005, the patchiness index is 0.26, very similar to that for North Denes in 2006.

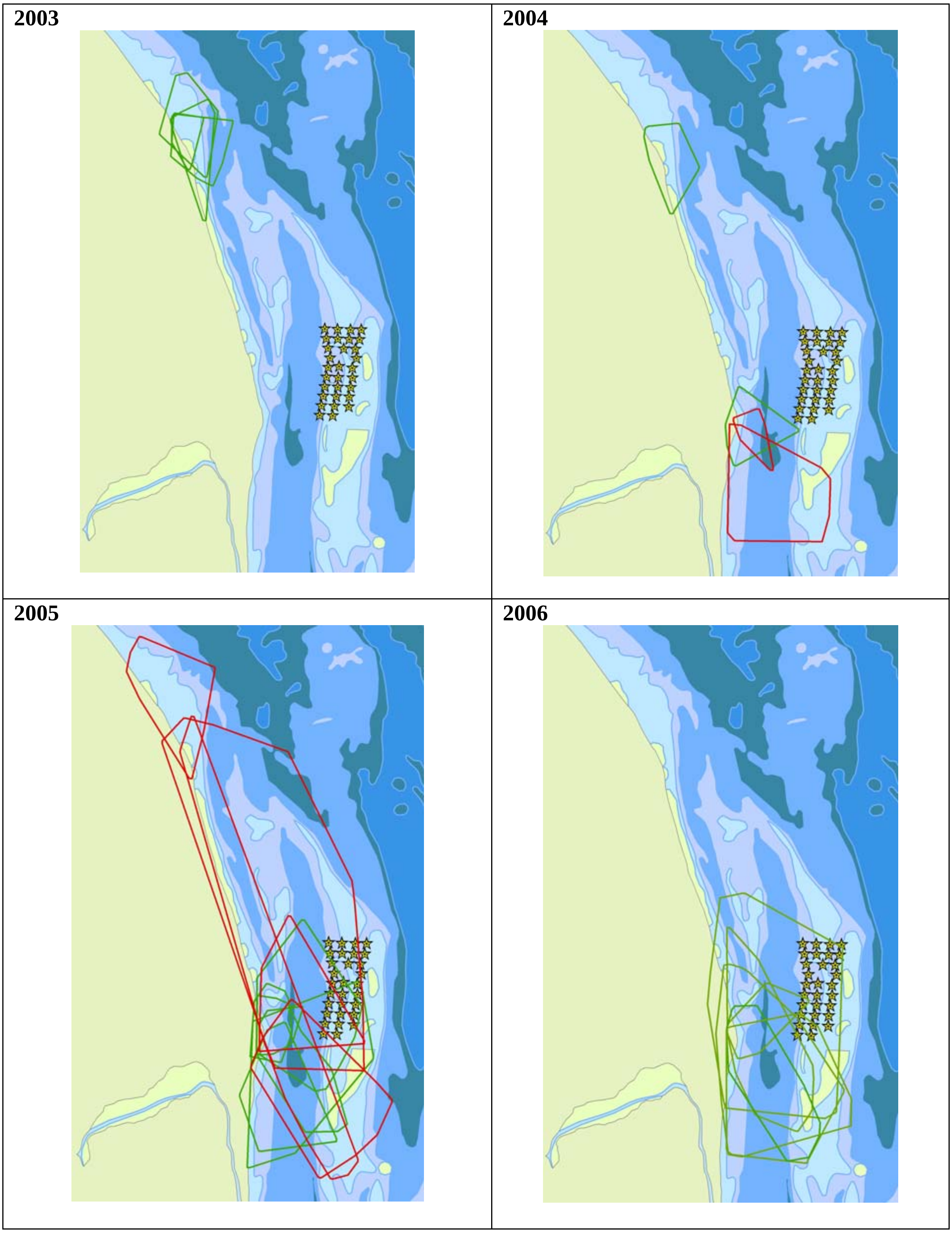


Figure 13. Uncorrected 100% maximum convex polygons (MCP's) generated for all radio-tagged Little Terns with >30 foraging fixes in each year (2003-2006 inclusive) from both the North Denes and Winterton colonies. Birds with active nests are shown in green, whilst birds with nests that failed are shown in red, whilst the locations of turbines in the Scroby Sands OWF are shown by yellow stars.

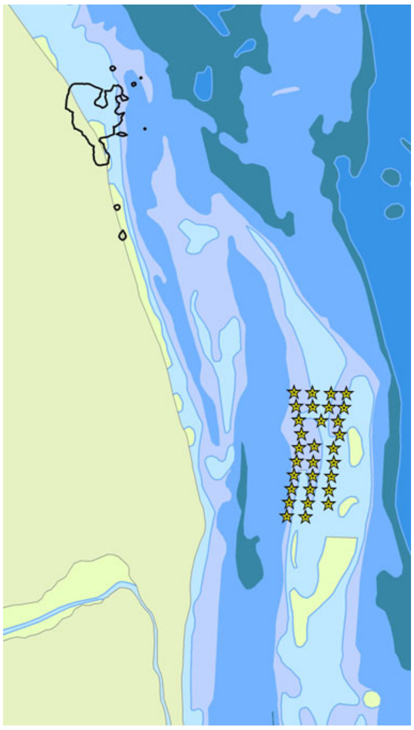
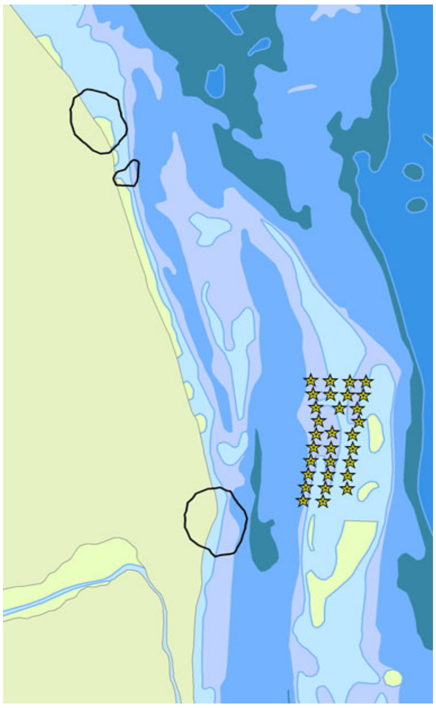
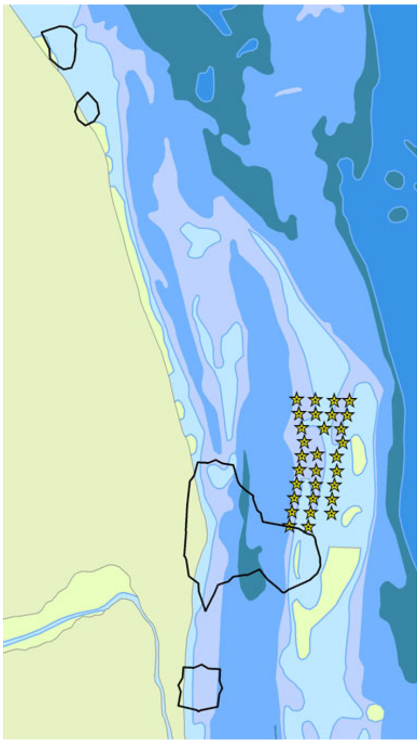
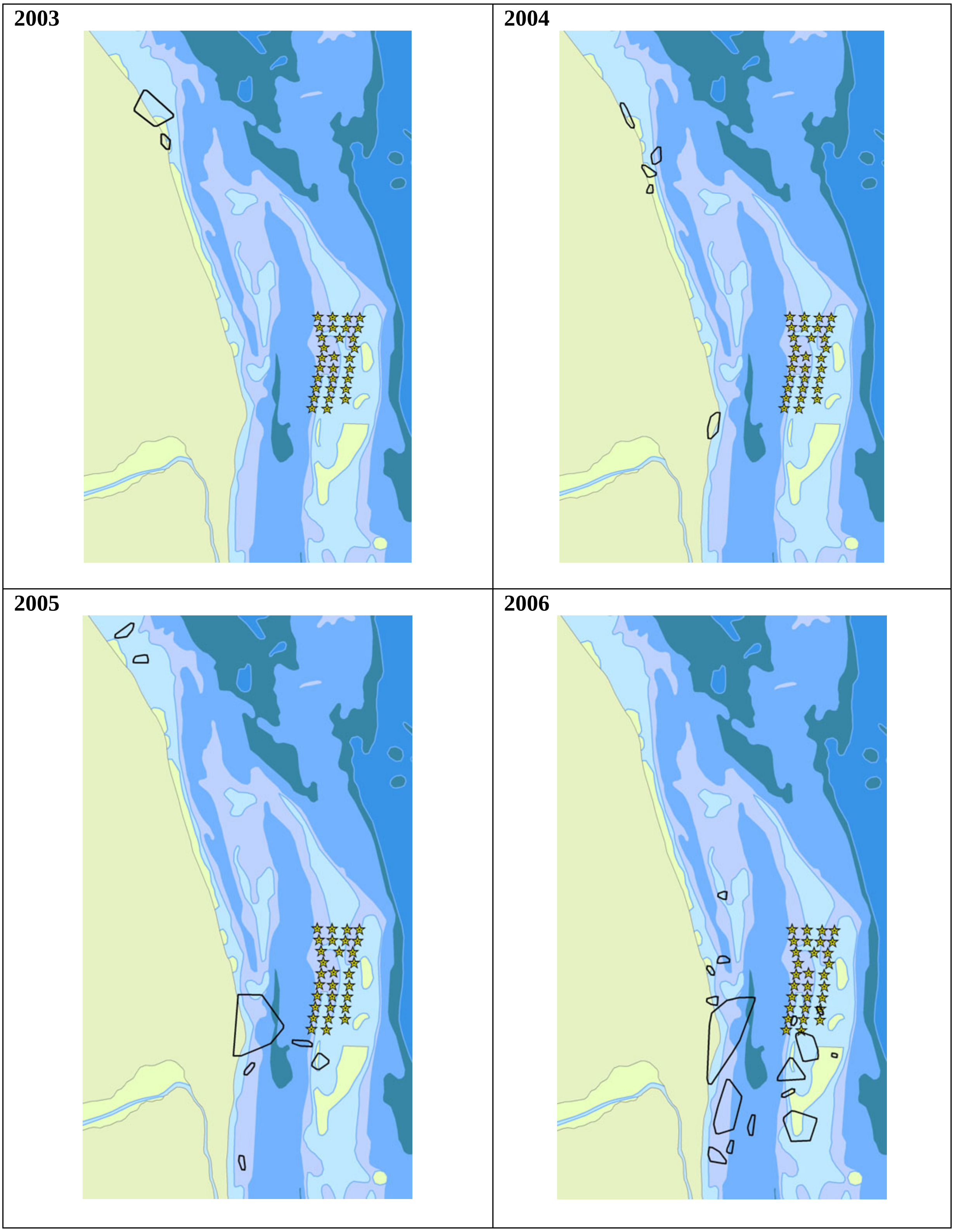
2003 Area = 197.394 ha 	**2004 Area = 441.859 ha** 
2005 Area = 1006.296 ha 	**2006 Area = 1695.112 ha** 

Figure 14. Kernel contours (85%) generated from all fixes of all radio-tagged Little Terns in each year (2003-2006 inclusive) from both the North Denes and Winterton colonies. The locations of turbines in the Scroby Sands OWF are shown by yellow stars.



2003

2004

2005

2006

Figure 15. Cluster analysis (85%) generated from all pooled fishing fixes of all radio-tagged Little Terns in each year (2003-2006 inclusive) from both the North Denes and Winterton colonies. The locations of turbines in the Scroby Sands OWF are shown by yellow stars.

Table 14. Inter-annual (2003-2006 inclusive) differences in selected parameters of foraging activity of radio-tagged Little Terns with active nests. Sample statistics from Kruskal-Wallis tests are shown.

Parameter	Years	*n*	Median	Average Rank	df	H	p	Location of differences
Mean distance from shore (m)	2003	5	349.0	11.6	3	7.965	0.047 *	2004<2005 & 2006
	2004	3	234.0	3.0				
	2005	10	608.0	16.1				
	2006	9	520.0	16.7				
Maximum distance from shore (m)	2003	5	538.0	8.8	3	8.74	0.033 *	Post-hoc reveals no significant differences between years
	2004	3	430.0	4.7				
	2005	10	1652.0	17.0				
	2006	9	1376.0	16.7				
Minimum distance from shore (m)	2003	5	188.0	20.0	3	6.14	0.105 ns	
	2004	3	80.0	11.7				
	2005	10	54.50	10.1				
	2006	9	100.0	15.7				
Mean bout duration (mins)	2003	5	15.20	11.9	3	2.10	0.553 ns	
	2004	3	10.22	11.0				
	2005	10	13.59	13.3				
	2006	9	20.88	16.9				
Mean speed (km hr^{-1})	2003	5	10.5	5.2	3	12.55	0.006 **	2003<2005 & 2006
	2004	3	13.14	6.7				
	2005	10	30.66	16.7				
	2006	9	29.69	18.3				
Mean distance traveled (m)	2003	5	2182	6.9	3	7.77	0.05 *	Post-hoc reveals no significant differences between years.
	2004	3	2278	9.3				
	2005	10	5624	18.0				
	2006	9	6325	16.4				
Mean number of bouts per hour	2003	5	2.35	20.2	3	11.09	0.011 *	Post-hoc reveals no significant differences between years.
	2004	3	3.88	24.0				
	2005	10	1.52	11.5				
	2006	9	1.90	10.0				
Corrected MCP of foraging range (ha)	2003	4	637.9	5.8	3	7.42	0.06	
	2004	2	508.3	5.0				
	2005	7	1198.6	10.9				
	2006	7	1502.8	14.4				
Corrected 85% kernel of foraging range (ha)	2003	4	271.7	6.0	3	10.34	0.016 *	2003<2006
	2004	2	177.7	4.5				
	2005	7	455.7	9.4				
	2006	7	884.8	15.9				
Uncorrected range span (m) from MCP	2003	4	3501	5.8	3	6.71	0.08	
	2004	2	3407	5.5				
	2005	7	5423	11.0				
	2006	7	6013	14.1				

Despite the influence of the number of fixes and colonies, the general patterns of increasing the area of the polygon used and the number of nuclei (Table 15) appeared to be ecologically meaningful especially as they are supported by other data. For example, by 2006, birds at North Denes appeared to be actively feeding in a large variety of locations including on Scroby Sands at an equivalent distance offshore to the wind farm (Fig. 15), a pattern that was also supported by bird survey data (see 5.2.1 above).

Table 15. Maximum values of selected parameters of foraging range and movement recorded in 2003-2006 inclusive and the maximum magnitude and location of difference between the different years.

Parameter	**2003**	**2004**	**2005**	**2006**	**Maximum magnitude of difference**	**Location of maximum difference**
Foraging bout duration (min)	56	134	72	120	1.9	2004>2005
Distance travelled (km)	9.35	26.84	25.91	57.42	6.0	2003<2006
Distance from shore (km)	2.3	3.4	6.3	4.9	2.7	2003<2005
Flight speed (km hr^{-1})	60.4	73.7	68.8	62.8	1.2	2003<2004
Corrected home range (km^2)	7.48	18.91	60.71	33.12	8.1	2003<2005

Table 16. Outputs of cluster analysis on pooled fishing fixes from all radio-tagged birds in each year from 2003-2006 inclusive.

Year	***n***	**Area (ha)**	**Number of nuclei**	**Index of patchiness †**
2003	40	105.08	2	0.71
2004	32	76.08	5	0.08
2005	155	307.89	7	0.08
2006	201	611.31	16	0.23

†Values decrease from 1 to 0 with increasing patchiness.

5.7 Foraging behaviour of Little Terns

5.7.1 Distance from shore

Observations showed that foraging birds may readily fly out of the range of comfortable evaluation of foraging parameters (~800-1000m) or even absolute detection (just over 2km with a 60x eyepiece[15]) of a shore-based telescope. In these situations an estimation of the distance from shore at which the bird was lost from view was recorded as a minimum estimate of foraging distance.

During radio telemetry between 23.1-47.4% of bouts in different years exceeded the arbitrary 1 km limit for adequate description of foraging parameters. However, between 64-100% of birds in the different years recorded a mean distance from shore of <1km, suggesting that the bulk of foraging activity was indeed likely to be described using a shore-based telescope. Moreover, despite any bias towards lower values in the range sampled by shore-based observations (from <2m when birds are foraging in the surf to around 1 km) there were still clear inter-annual and site differences in the distance of foraging from shore.

At North Denes, birds foraged consistently significantly further from shore during and following construction of the wind farm in 2004, 2005 and 2006 compared to before construction in 2002 and 2003 (Table 17, Fig. 16). In fact, the median foraging distance from shore increased year on year from 30m in 2002 to 50m in 2003, 300m in 2004, 475m in 2005 and 600m in 2006.

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[15] as established against buoys of known distance

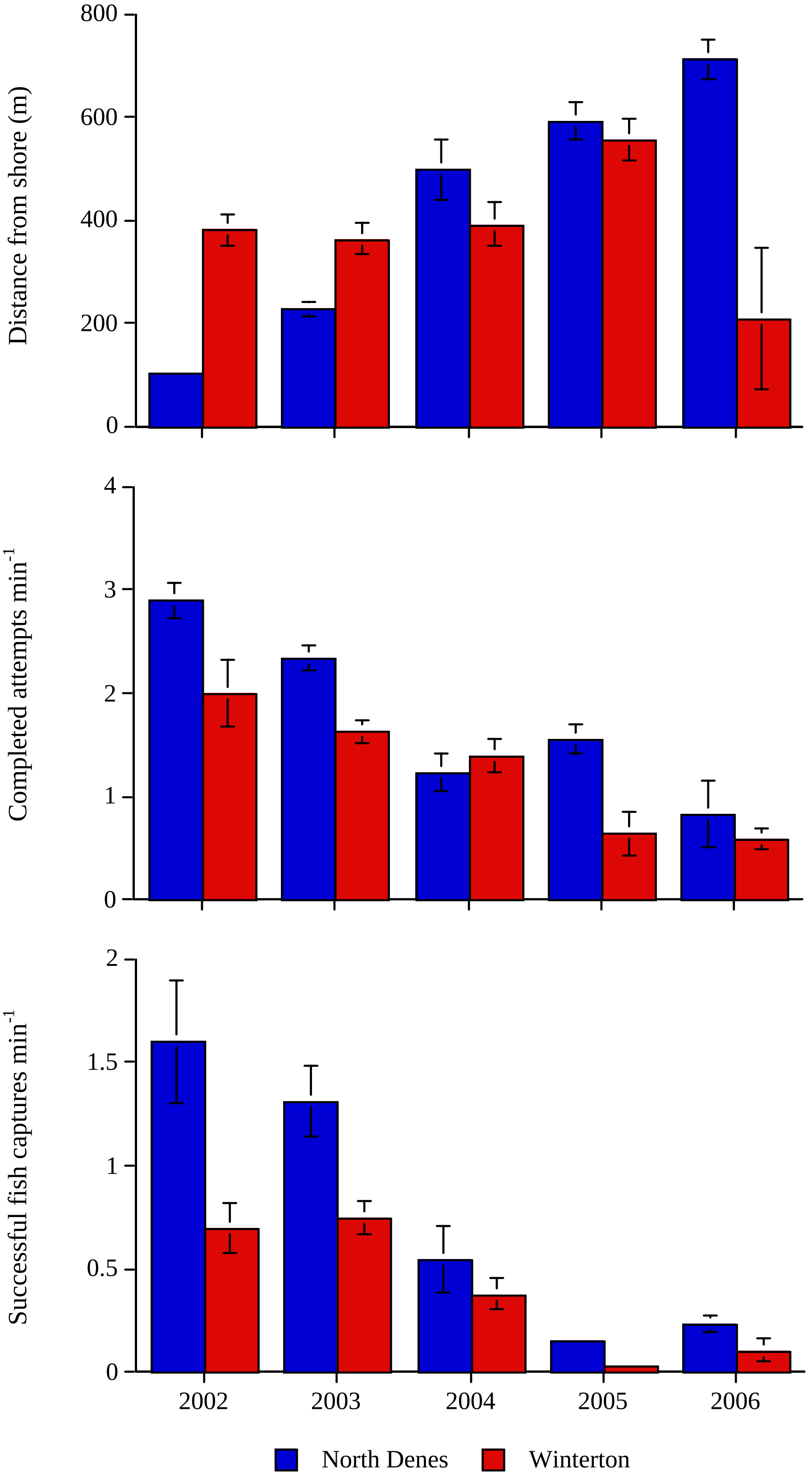

Figure 16. Inter-annual variation (mean ± 1 SE) of selected foraging parameters of Little Terns (foraging distance from shore and the rates of completed foraging attempts and successful fish captures) at the North Denes and Winterton colonies from 2002 to 2006 inclusive.

Table 17. Inter-annual variation (from 2002 to 2006 inclusive) in average foraging distance from shore, the rate of completed foraging attempts, the estimated rate of fish capture, and the time taken to complete a foraging bout exhibited by Little Terns at North Denes and Winterton colonies. Kruskal-Wallis test (H) statistics are shown.

Parameter	**North Denes**				**Winterton**			
	n	**H**	**p**	**Location of differences**	***n***	**H**	**p**	**Location of differences**
Distance from shore (m)	2002: 58 2003: 66 2004: 75 2005: 107 2006: 182	92.63	***	2002<2004, 2005 & 2006 2003<2004, 2005 & 2006	2002: 77 2003:103 2004:82 2005:58 2006:5	7.35	ns	-
Completed foraging attempts min^{-1}	2002: 58 2003: 68 2004: 85 2005: 140 2006: 197	95.99	***	2002>2004, 2005, 2006 2003>2004, 2005, 2006	2002: 74 2003:102 2004:89 2005:73 2006:8	79.21	***	2002>2003, 2005 & 2006 2003>2005 2004>2005
Successful fish captures min^{-1}	2002: 58 2003: 64 2004: 44 2005: 140 2006: 197	133.71	***	2002>2004, 2005 & 2006 2003>2004, 2005 & 2006	2002: 74 2003: 92 2004: 34 2005: 74 2006: 8	91.18	***	2002>2005 & 2006 2003>2005 & 2006
Time to complete foraging bouts (mins)	2002: 34 2003: 45 2004: 35 2005: 33 2006: 63	16.89	**	2004>2002 & 2003 2005>2003	2002: 30 2003: 74 2004: 17 2005: 17 2006: 4	3.30	ns	-

Notes: df=4 for all tests, *=p<0.05, **=p<0.01, ***=p<0.001, ns=not significant

In contrast to North Denes, there was no significant inter-annual variation in the distance birds foraged from shore (Table 17). In fact, apart from that (25m) derived from a very small sample size (*n*=5) in 2006, this was remarkably consistent with median values of 300m in 2002, 300m in 2003, 250m in 2004 and 275m in 2005 (cf with mean values in Fig. 16). The distance of around 300m offshore corresponds to the position of a relatively extensive and dynamic sand bar at Winterton, which although it may shift position within and particularly between seasons, appeared to be a consistent attraction for foraging birds.

An increasing annual trend at North Denes compared to the consistent distance offshore at Winterton meant that the initial significant difference between North Denes and Winterton, (with greater foraging distance at Winterton) had disappeared by 2004, but was again significant by 2005 but in a reverse pattern, with greater distance at North Denes (Table 18).

5.7.2 *Dive & fish capture rates*

The number of completed foraging attempts per min^{-1} varied significantly at both North Denes and Winterton in a broadly consistent manner, with the baseline years before construction tending to have significantly higher rates of successful foraging attempts than years during and after construction (Table 17). For example, median values at North Denes were 2.48 and 1.95 attempts per min^{-1} in 2002 and 2003 compared to 0.95, 1.32 and 0.0 attempts min^{-1} from 2004-2006 inclusive. In all years that could be tested, bar 2003, rates of completed attempts were higher at North Denes than Winterton (Table 18) with median values of 1.77 and 1.33 attempts min^{-1} in 2002 and 2003 respectively, compared to medians of 0.93, 0.02 and 0.56 attempts min^{-1} from 2004-2006 inclusive.

Table 18. Within-year differences (from 2002 to 2005[16]) in mean foraging distance from shore, the rate of completed foraging attempts, the rate of successful fish capture, and the time taken to complete a foraging bout exhibited by Little Terns at North Denes and Winterton colonies. Mann-Whitney (W) test statistics are shown.

Year	Parameter	Total *n*		W statistic	p	Location of difference
		ND	W			
2002	Distance from shore (m)	58	77	2277.0	***	W>ND
	Completed foraging attempts min^{-1}	58	74	4279.5	*	-
	Successful fish captures min^{-1}	58	74	4437.5	**	W<ND
	Time to complete foraging bouts (mins)	34	30	1095.5	ns	-
2003	Distance from shore (m)	66	103	4574.0	***	W>ND
	Completed foraging attempts min^{-1}	68	102	6403.0	ns	
	Successful fish captures min^{-1}	64	92	5554.0	ns	
	Time to complete foraging bouts (mins)	45	183	4643.0	ns	
2004	Mean distance from shore (m)	75	82	6118.0	ns	-
	Completed foraging attempts min^{-1}	387	89	95410.0	**	W<ND
	Successful fish captures min^{-1}	44	34	1743.5	ns	
	Time to complete foraging bouts (mins)	52	17	1911.0	ns	
2005	Distance from shore (m)	110	55	250.0	**	W<ND
	Completed foraging attempts min^{-1}	140	73	17211.0	***	W<ND
	Successful fish captures min^{-1}	140	74	16141.0	***	W<ND
	Time to complete foraging bouts (mins)	33	17	913.0	ns	-

Notes:*=$p<0.05$, **=$p<0.01$, ***=$p<0.001$, ns=not significant

The proportion of completed foraging attempts per min^{-1} producing fish as a subset of the completed foraging attempts min^{-1} declined over the years. In 2002 and 2003, the baseline years before construction, fish formed a large proportion of the prey captured: 67 to 97 % at North Denes and 41 to 82 % at Winterton. In subsequent years from 2004-2006 this had declined to 14 to 24 % at North Denes and 2 to 29 % at Winterton. This further exacerbated the significant inter-annual variation in fish capture rate between years at both sites (Table 17). Fish capture rate was significantly higher at North Denes compared to Winterton (Table 18) in two of the four years tested (2002 and 2005). Nonetheless, at both sites all median values in all years during and after construction had declined to 0, compared to 0.89 and 0.95 fish min^{-1} at North Denes and 0.37 and 0.68 fish min^{-1} at Winterton in 2002 and 2003 respectively. This clearly illustrated that many birds failed to capture a fish in a foraging bout from 2004 onwards.

5.7.3 Length of foraging bouts

It must be noted that the length of completed foraging bouts recorded by a shore-based telescope can only be a minimal subset of the actual range of values as there is greater chance of the bird being lost the longer the bout goes on and the further the bird travels from shore. To illustrate this point, median bout duration from radio telemetry in different years ranged from 9 to 20 minutes (Table 14), whereas from shore-based observations median values were much shorter ranging from 1-2.42 min at North Denes and 1.03-2.28 min at Winterton. Shore-based observations also showed that bouts could be extremely short (minimum of 10 secs to catch a fish and return) and in fact very short bouts may easily have been missed during telemetry as a result of the difficulty of separating records of birds flying over the beach in disturbance events from foraging close to shore.

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[16] 2006 is not included as a result of the lack of birds nesting at Winterton in this year.

Despite the potential problem of underestimating full bout duration in shore-based observations there were still significant differences consistent with other foraging parameters. These focused on North Denes which may have been influenced by the apparenty greater scope to extend foraging distance (see 5.7.1 above) and thus the time taken to complete a bout, which was significantly higher in 2004 and 2005 compared to some of the other years (Table 17). In these years, median values exceeded 2 mins (2.57 in 2004 and 2.17 in 2005), compared to values ranging from 1.00-1.58 mins in other years.

In contrast, at Winterton where birds tended to forage at a consistent distance from shore well within range of observations, there was no significant inter-annual variation at Winterton, with the median time for completed bouts varying between 1.18-2.0 mins. Moreover, there was no difference between the sites in the time taken to complete a foraging bout within any of the years tested (Table 18).

5.8 Chick provisioning

5.8.1 Type of prey presented to chicks

Despite the range of potential prey at sea, including a range of invertebrate and fish taxa, the provisions made to chicks (*n*= 498 at North Denes and 524 at Winterton for 1022 overall) were dominated by just two fish taxa, clupeids (Herring or Sprat) (60% and 69% overall at North Denes and Winterton respectively) and sandeels (6 % and 8% overall at North Denes and Winterton respectively), with a limited contribution by what was thought to be a limited range of invertebrates (of which only which *Idotea* was positively identified) (Fig.'s 17 & 18). However, a relatively large proportion (20-35% at North Denes and 16-18% at Winterton) of prey could not be identified, mainly because the item was simply not in clear view as the chick was fed, rather than a function of a particular difficulty in identifying different taxa.

Judging from bill length, clupeids ranged in size from 15-76 mm suggesting that the bulk of clupeids offered as prey were YoY. The proportionally longer-bodied Sandeels ranged from 22-76 mm in different years again suggesting that the bulk of these fish were also YoY. Invertebrates ranged from 7-46 mm and their small size meant that their contribution to the identified fraction of biomass presented to chicks generally became extremely small (0.1-1.3% between years at North Denes and 0.1-0.4% at Winterton). The contribution to the growth and development of chicks is thus likely to have been negligible, particularly since they have low calorific value as a result of a relatively high contribution of an indigestible exoskeleton and other chitinous body structures and a correspondingly low protein and fat content especially compared to fish (Phalan 2000).

Nevertheless, there was some evidence of compositional change in chick diet in different years, with clupeids overwhelmingly the dominant identified prey item presented to chicks at North Denes in 2002 and 2003 (Fig. 17). In 2005 and 2006, there was greater diversity of prey with invertebrates and Sandeels assuming greater importance, although the former still made a minimal contribution to ingested biomass.

It is of note that a marginally more mixed diet was also a feature of chick provisions at Winterton in 2002 and 2003, the only two years in which Little Terns bred at Winterton and significant numbers of chicks hatched upon which observations could be made (Fig. 18).

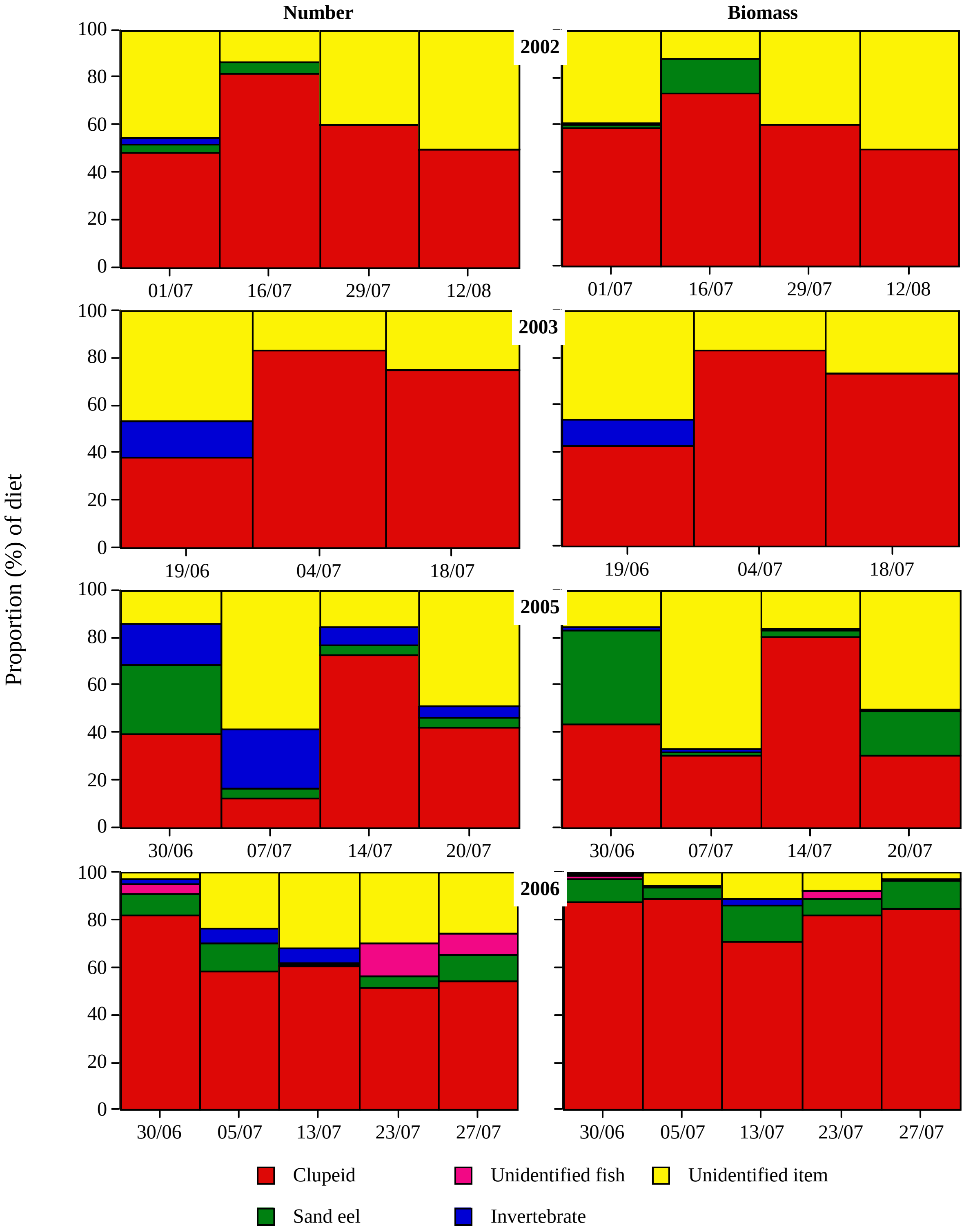

Figure 17. Seasonal composition (% by number and biomass) of prey fed to chicks by adult Little Terns at North Denes in 2002, 2003, 2005 and 2006.

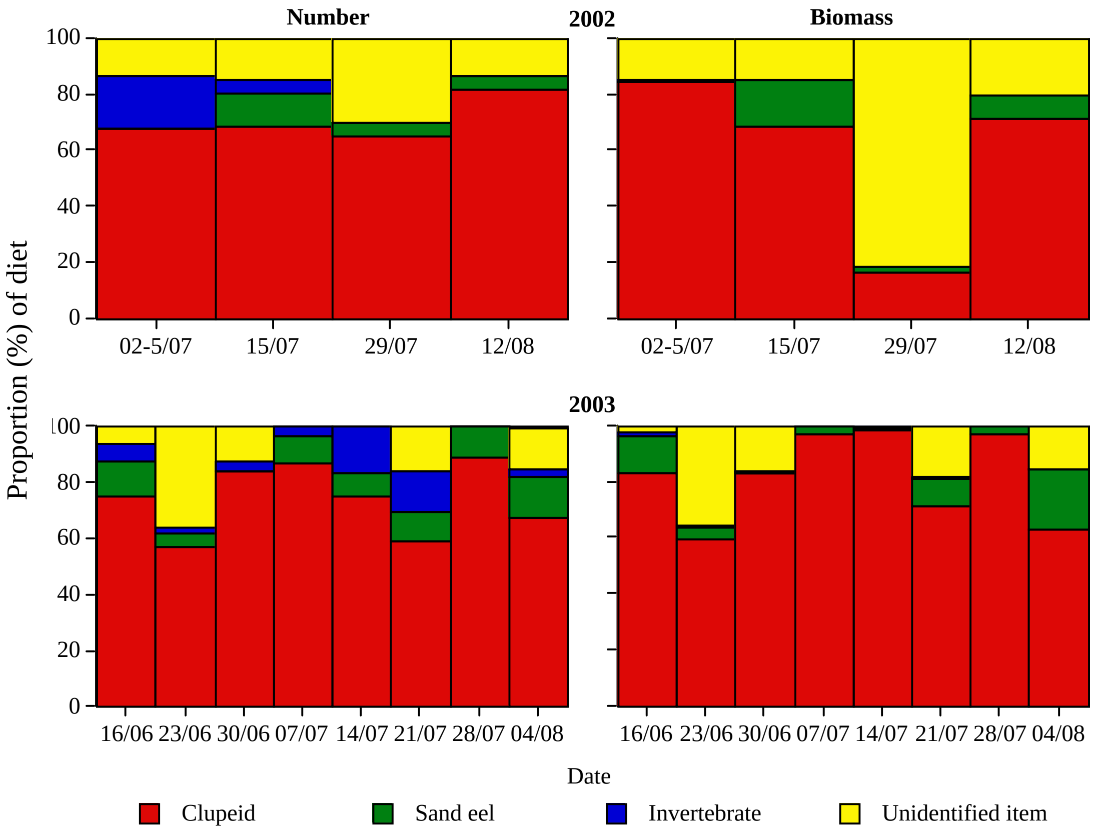

Figure 18. Seasonal composition (% by number and biomass) of prey fed to chicks by adult Little Terns at Winterton in 2002 & 2003.

5.8.2 Provisioning rates

The sample of broods of chicks of known age (*n*=56) at either site partitioned into different age categories revealed no significant effect of chick age on provisioning rate (Table 19). There was also no significant difference in provisioning rate to individual chicks at North Denes compared to Winterton in either 2002 or 2003, although the latter was partly constrained by small sample size at the former site (Table 20). Data from each year irrespective of site were therefore pooled to test for inter-annual differences.

There was a significant difference in individual chick provisioning rate (Table 21). But rather than this simply reflecting the huge variation in the relative abundance of prey (see 5.5.2 above) and the subsequent significant variation in various parameters of foraging and feeding behaviour (see 5.7 above) this was at its highest in 2006 (Table 21, Fig. 19).

Median values were some 2-3 times higher in 2006 compared to any other year. Although there were significantly higher brood sizes in some years compared to 2006 (Kruskal-Wallis test, H=35.47, total *n* =108, df=3, p<0.001; post-hoc test, 2003>2002 & 2006; 2005>2006[17], the latter also compared favourably as a brood provision rate, with the highest median value amongst the years tested (Table 21).

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[17] median values were 1 for 2002 and 2006 and 2 for 2003 and 2005

Table 19. Variation in provisioning rate (feeds hr^{-1}) per chick according to age using pooled samples from both North Denes and Winterton in all years (2002, 2003, 2005 & 2006). Kruskal-Wallis (H) test statistics are shown.

Age	*n*	Median	Average Rank	H	p
<4 days	18	2.820	26.6	1.22	ns
4--<8 days	19	3.950	29.8		
8-<12 days	5	4.380	34.7		
>12 days†	14	2.990	27.0		

†but still not fledged. Notes: df=3, ns=not significant

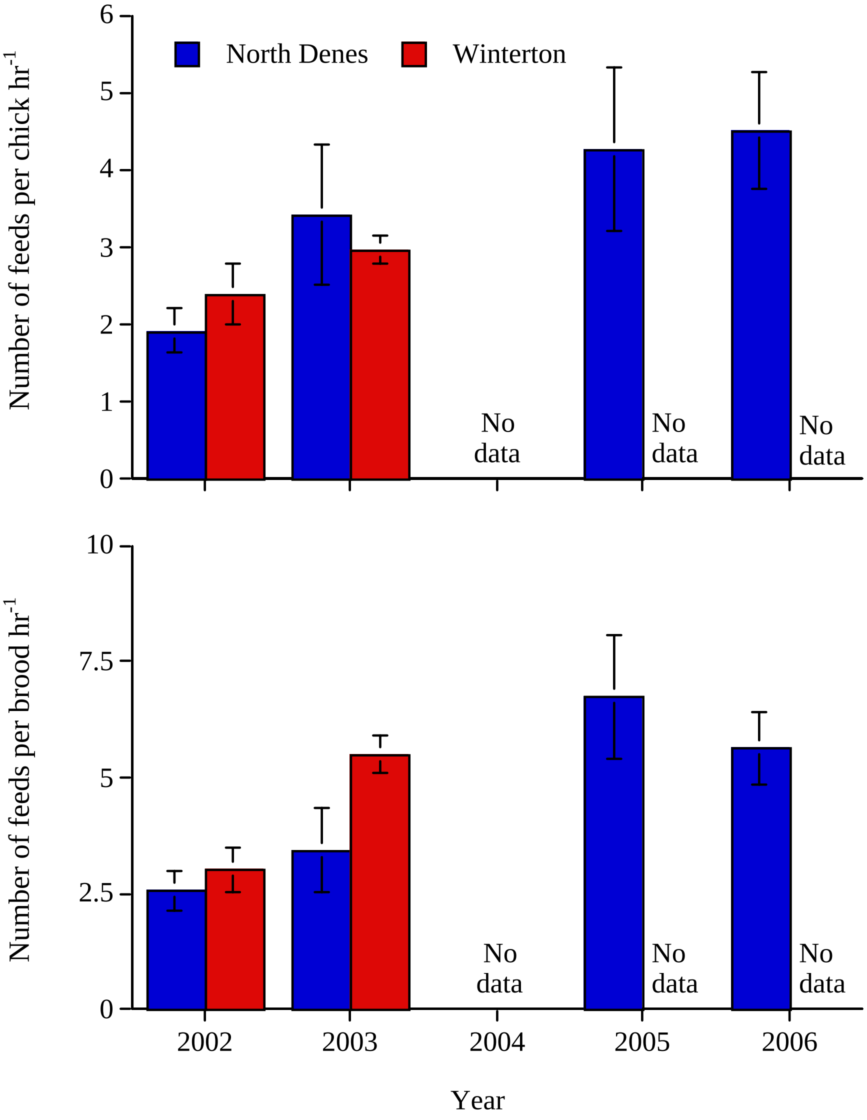

Figure 19. Inter-annual variation in provisioning rate (mean ± 1 SE) per chick (upper) and per brood (lower) at the North Denes and Winterton colonies from 2002 to 2006 inclusive. Note that no chicks were present at both colonies in 2004 and at Winterton in 2005 and 2006.

Table 20. Variation in provisioning rate (feeds hr^{-1}) to brood and chicks (ind. $^{-1}$) at North Denes and Winterton in 2002 & 2003. Mann-Whitney (W) test statistics are shown.

Year	Site	*n*	Unit	Median	W	p
2002	North Denes	10	Brood	2.375	107.0	ns
	Winterton	20		3.270		
	North Denes	10	Chick	1.875	148.0	ns
	Winterton	20		1.665		
2003	North Denes	3	Brood	3.790	46.0	ns
	Winterton	39		5.110		
	North Denes	3	Chick	3.790	79.0	ns
	Winterton	39		2.700		

Notes: df=3, ns=not significant

Table 21. Inter-annual variation in provisioning rate (feeds hr^{-1}) per brood and chick using pooled samples from both North Denes and Winterton in all years (2002, 2003, 2005 & 2006). Kruskal-Wallis (H) test statistics are shown.

Year	*n*	Unit	Median	Average Rank	H	p	Location of difference
2002	30	Brood	2.930	32.6	14.26	**	2006>2002 2003>2002
2003	42		4.820	56.9			
2005	13		4.950	57.3			
2006	23		5.450	61.1			
2002	30	Chick	1.875	36.1	29.28	***	2006>2002, 2003 & 2005
2003	42		2.750	51.8			
2005	13		2.784	56.0			
2006	23		5.455	82.6			

Notes: df=3, ** p<0.01,***p<0.001

5.9 Collision risk of Little Terns

The risk of collision to Little Terns is effectively a function of four factors: 1) the collision risk factor for Little Terns 2) the avoidance rate of the birds 3) the use of the wind farm and 4) the number of birds present at the North Denes colony.

The collision risk factor for Little Terns was calculated to be 18.2%, which is at the upper end of the typical range of values between 5% and 20%. This was primarily as a result of the low average flight speed of foraging birds (7.1 m sec^{-1} from telemetry data). Use of the wind farm by radio-tagged birds increased from 0% in 2004, 0.9% in 2005 to 2.05% in 2006. The effect of this, coupled with the large increase in the number of birds at the colony in 2006 generated a considerable increase in passage rate, which ultimately led to a considerable increase in the risk of collision for adult Little Terns over time (Table 22). At worst case in 2006, numbers of potential collisions ranged from 14-69 ind. for adults and 3-17 juveniles for a total of 17-86 ind. from 99-95% avoidance.

However, it must be noted that the number of collisions in 2004 was unlikely to be actually zero, as this is based on the lack of a single record of a tagged bird in the wind farm and as tagged birds comprised a very small proportion of the population, the true use is likely to be >0, although most likely to be so small to be of little meaning in terms of potential collision. Similarly, no telemetry was undertaken at North Denes in 2002 and 2003 when some birds were present and some collision risk was implied. However, with a smaller number of breeding pairs (and perhaps transitory birds) recorded, the passage rate through perspective rotors was again likely to be so low as to be effectively zero.

Table 22. The predicted annual number of collisions of Little Tern (adults, fledged juveniles and total) with no avoidance (0%) and 95 to 99% avoidance.

Lifestage	Year	Passage Rate	Collisions at various avoidance rates			
			0%	95%	98%	99%
Adults	2004	0	0	0	0	0
	2005	1877	342	17	7	3
	2006	7528	1370	69	27	14
Juveniles	2004	0	0	0	0	0
	2005	33	5	<1	<1	<1
	2006	1795	327	16	7	3
Totals	2004	0	0	0	0	0
	2005	1910	348	17	7	3
	2006	9323	1697	85	34	17

With no information on the use of the wind farm by fledged chicks (juveniles), a precautionary approach was adopted that was assumed to be the same as for adults. This seems reasonable given that although juveniles may not have ranged to the wind farm as easily as adults, this may have been balanced by their reduced flying abilities which may mean they actually exhibit a reduced avoidance rate. The large number of fledglings in 2006 meant that these contributed 27% of the overall total despite a small time period of occupancy of the area after fledging.

6. DISCUSSION

6.1 Insights into the ecology of Little Terns at the Great Yarmouth North Denes Special Protection Area (SPA)

6.1.1 Factors affecting colony location

Nesting habitat

Summarising the habitat requirements of Little Tern in a publication outlining conservation status of important European species, Tomialojc (1994) described the 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*'. However, this is a rather general description and more specific types of habitat may be selected under specific circumstances. For example, Catry *et al*. (2004) cited the importance of saline lagoons (salinas) as an increasingly important habitat compared to sandy beaches for Little Terns in Portugal.

Moreover, more recently, artificial habitats such as gravel-topped rooftops and artificial islands have been widely and successfully used for the closely related Least tern in the USA (Krogh & Schweitzer 1999). Indeed, this species has even been recorded nesting on extensive flat roofs of buildings (Cramp & Simmons 1985). Similarly, 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). 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 at Horsey Island and the recent findings of Ratcliffe *et al*. (2005) that the probability of occupancy of beaches in East Anglia increased significantly with the percentage cover of vegetation conflicts with the general statement of Tomialojc (1994), that dense vegetation is generally avoided. However, in a contradiction of this statement Tomialojc

(1994) also documented Little Terns nesting in fields containing low crops of sugar beet or barley. At North Denes, Wooden *et al*. (2003) perceived the continued encroachment of marram grass into areas used by Little Terns as detrimental, although there was no evidence that this had changed the focus of Little Terns on the site.

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). A focus on particular sites such as North Denes seems to have carried an implication that substrate type is in some way limiting and more importantly, that this is the prime factor driving the location of colonies. But this is clearly at odds with the relative adaptability of Little Terns in their nesting requirements when viewed from a wider perspective and inter-colony differences in that what seems to be readily accepted at one colony may not be used at another. It thus seems 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 nesting habitat being unoccupied. It must therefore be concluded that other factors are likely to be of at least equal and probably of greater importance in driving colony formation.

Human disturbance, predation & high tides

In a study of colony habitat selection in coastal East Anglia, UK Ratcliffe *et al*. (2005) showed that the probability of occupancy by breeding Little Terns declined significantly with human disturbance, with the prospect of Little Terns being excluded from sites that would otherwise be suitable as a result of human disturbance. Moreover, increases in disturbance at some sites were thought to have the potential to cause extant colonies to be abandoned in the future. From experiences at North Denes and other busy public beaches it seems clear that without exclusion of people, Little Terns would be unlikely to nest successfully, if attempt at all (see 2.1 above).

Intuitively, for birds to select a site on the basis of human disturbance, the level of disturbance must be obvious at the beginning of the season. In fact, Skeate *et al*. (2004) show that human use of beaches in the area is often lower in early season compared to later season, although dog-walking may not change or even decline with the presence of other humans. Notwithstanding this fact, in principle it seems impossible for a non-resident species to arrive after migration and predict in advance the level of disturbance that may be experienced later in the season. The same case may be made for predators and predation. The fact that some predators only switch to tern eggs or chicks, as they become available, as is the evidence for Kestrels (Smart & Ratcliffe 2000), makes it difficult to assess the likely level of predation in advance. This is particularly the case if the potential predator itself is virtually ubiquitous in its presence. In the study of Ratcliffe *et al*. (2005), foxes were recorded on 62% of beaches despite low trapping effort (sand traps for footprints). The authors concluded that foxes foraged on beaches irrespective of the presence of Little Tern colonies, but preyed upon them opportunistically should they occur within their territories. Foxes, like people, appear to be everywhere and it is perhaps no surprise that in the study of Ratcliffe *et al*. (2005) Little Tern occupancy was not significantly affected by the presence of foxes on the beach or even by the rate of predation of dummy clutches. The suggestion that Little Terns were poor at perceiving predation risk is therefore perhaps unfair, although the authors did qualify this by suggesting the threat of predation may only become obvious after the site has been selected.

In a similar manner to both humans and predators, whether or not a high tide will occur later in the season claiming clutches of eggs or chicks carries a low chance of predictability. Some high tides will inevitably occur during the season in the typical pattern of spring and neap tides, with the height of some high tides exacerbated by strong onshore winds. Such stochastic factors can only be mitigated by nest site selection above the current high tide mark should this be allowed by competition for nest sites or avoidance of areas in which predators or humans are likely to frequent.

There is no clear evidence to support what appears to be a general 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 simply not borne out by the pattern at North Denes, the largest UK Little Tern colony. Here, birds have nested in successive years despite complete failure in a previous year as a result of disturbance, high tides or predation of both eggs and/or chicks (see 2.1 above). In more recent times at least, nesting at Winterton appears to have been in response to the failure or displacement of birds from North Denes. For example in 2002, vandalism on 31st May and the loss of many nests led to the attempt at Winterton just two weeks later beginning on 14th June. 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 22nd May at Winterton. Even after the outstandingly successful year in 2003, the birds did not automatically set up at Winterton in 2004 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), largely to predators.

Thus, whilst previous experience with birds remembering the outcome of previous nesting attempts may help determine future events, it is more realistic to expect that Little Terns will make a fresh decision when they return from their wintering grounds. Little Terns are, after all, adapted to an ephemeral habitat, subject to changing coastal conditions and thus exploit suitable beach areas as they become available. Birds migrate around 5,000 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. No less than eight radio-tagged birds that failed at either Winterton or North Denes were then recorded at the other site illustrating the ranging behaviour of these birds. Moreover, the speed of occupancy of Winterton particularly following nesting failure at North Denes tends to suggest that Little Terns carry an awareness of the potential at other sites. This may include that at sites much further afield as is shown by the presence and preliminary attempts at nest formation of a dye-marked bird at Winterton in 1997, which had been apparently attempted to breed (and presumably failed) at Zeebrugge in Belgium earlier in the season.

Given the history of occupancy over the last 20 years or so, with the exceptional recent events of 2002 and 2003, it appears that North Denes and the surrounding Scroby area remains the premier choice for nesting Little Terns over Winterton (and Eccles) in the Would in North East Norfolk As argued in previous reports (ECON, 2003, 2004) and in Perrow *et al*. (2004) the preference for North Denes does not appear to be related to the nature of the beach, which is generally unremarkable if not reducing in its suitability with the encroachment of dune grasses (Wooden *et al*. 2003), as well as being particularly susceptible to human disturbance and a plethora of predators including hedgehogs and cats as well as foxes and kestrels (see 2.1 & 5.1.1 above). Conversely, it seems unlikely that birds could be readily ‘pulled’ to more convenient sites outside historically preferred areas simply through protective fencing and predator control, particularly as these have become the normal state of affairs at North Denes.

Available food supply

To follow a logical progession, if nesting habitat fits within a broad spectrum of suitability, future disturbance and predation levels cannot be predicted, and predators are not attuned to the potential prey source, by default, food supply becomes the prime candiate to determine colony location. In fact, as Perrow *et al*. (2004) have argued previously, an available food supply is likely to be the *ultimate* factor determining colony location with other factors being *proximal*. The case for this is reiterated below, beginning with the consideration of the type of prey needed by Little Terns.

Little Tern is adapted to foraging on small prey (maximum 9 cm and typically 3-5 cm) close to the surface. It does not appear to be particularly fussy about prey type as the diet includes all manner of fish and invertebrates (Cramp & Simmons 1985). But as a result of higher protein and fat (and thus energy) content, fish are likely to be preferred as food, especially for chicks (Phalan 2000). This is reflected in the dominance of YoY clupeids (Herring and Sprat) in chick provisions recorded by this study and are thus the mainstay of Little Tern reproductive success in North East Norfolk (ECON 2004, 2005). This may simply because these YoY clupeids dominate the spectrum of available prey in the study area. Elsewhere, other species such as young Sandeels (*Ammodytes*/*Hyperoplus*) or gobies (*Pomatoschistus* sp.) may be important (Phalan 2000). Whatever the available prey, 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 trigger colony formation.

Although this study has demonstrated that Little Terns are capable of relatively wide-ranging movements, the combination of small body size[18], relatively short wings[19], 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, relative to larger tern species. Little Terns are therefore not geared to travelling long distances (>10 and perhaps to 50 km or more) in search of prey like larger terns especially Sandwich Terns. Moreover, as Little Terns appear 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 showed that birds with an active nest had maximum corrected MCP home ranges from 301-3312 ha (i.e. 3-33 km^2) for a mean (± SE) of 1244.2 ± 191.5 ha, with corrected core ranges (kernels) of 536 ± 96.48 ha and mean uncorrected range spans of 5.03 ± 0.45 km with a range span between 2.3-7.9 km for a mean (± SE) of 4.33 ± 0.43 km. The latter is comparable to the general figure of a foraging distance of 'up to 6 km from the colony' (Cramp & Simmons 1985), although as birds routinely traveled further offshore than the 1.5 km documented by Cramp & Simmons (1985), foraging ranges were larger than anticipated.

Clearly, birds nesting at North Denes or Winterton, which are about 12 km apart are unlikely to share resources, with prey in the inshore waters of Scroby unavailable to birds with active nests at Winterton. Once birds have selected a colony, they are tied to central-place foraging around the nest site and the waters immediately around the colony must support the attempt. If birds are forced to consistently range further to find enough food, it is suggested that they must abandon their breeding attempt to do so. Once free from central-place foraging, as illustrated by radio-tagged birds in 2004 and 2005, they may range widely and commute freely between the two colonies and perhaps even further.

Samples taken during the pilot study upon breeding tern foraging ranges in North-West England and East Anglia in 2003 (Allcorn *et al*. 2004), showed that the density of small fish offshore was generally low at the sites surveyed in North Norfolk (as well as at Gronant, the largest site in North Wales) compared to Winterton and the Scroby area. In North Norfolk at least Little Terns appeared to rely on fish and invertebrates in the inter-tidal zone and associated harbours and creeks in the saltmarsh. It is of note that Clupeids were absent in samples in North Norfolk and tows undertaken on the return trip to dock at Great Yarmouth indicated that YoY clupeids were only present south of Cromer (P. Lines *pers. comm*.), which more or less represents the transition between the waters of North Norfolk and those of North-east Norfolk and the Would. The fact

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[18] being by far the smallest of the *Sterna* terns at 60% of the size of Common Tern

[19] 40% shorter than Common Tern

that this pattern was observed in a year in which the density of YoY clupeids, especially Herring, was exceptionally high and possibly at the maximum extent of what seems to be their typical distribution in North-East Norfolk, reinforces that in general, the Scroby area may generally support more YoY clupeids than much, if not all, the rest of the Norfolk Coast. This is notwithstanding the known inshore movement of older Sprat (>1+) into North Norfolk especially in late summer, which is exploited by larger tern species, such as Sandwich Terns (*pers obs*).

Despite their anecdotal nature and rather limited scope, these observations fit neatly with what is known of the spawning distribution of both Herring and Sprat (Coull *et al*. 1998 - Fig. 20). A particular 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 narrow spawning distribution apparently extending to Great Yarmouth (Fig. 20-A). A fishery survey as part of the assessment of the potential effects of replacement of the export cable in January 2008 recorded large, healthy adult Herring (>165mm-253mm) that appeared to have spawned some time previously (ECON 2008). These fish were concentrated in a zone landward of the main bank within one km of the southern edge of the wind-farm.

The nursery area for this Herring stock appears to extend from Scroby in the north to the Thames estuary in the south (Fig. 20-B). A different stock of herring spawning in August-October north of the Wash and further offshore may utilise the inshore area from the Wash to the Humber as a nursery area (Fig. 20-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. 20-C). The suggested nursery zone completely avoids the Wash and North and North-East Norfolk with its northern limit seemingly just to the south of Yarmouth (Fig. 20-D).

These known distributions, the relative abundance of fish and the small size of the individuals of both species encountered in the samples (i.e. <30 mm for Herring and 10-15mm for Sprat –Fig. 7) prior to metamorphosis of the drifting larvae into free-swimming juveniles, strongly suggests that the waters inshore of Scroby Sands form a nursery ground for both these species irrespective of their likely different origins (i.e. locally-spawned Herring and offshore-spawned Sprat drifting into the area). 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. A strong tidal flow effectively empties and flushes this system twice daily. This is likely to enhance the already potentially high productivity of the large extent of shallow waters, which may favour algal development and thus the zooplankton prey (principally calanoid copepods) of both species. The offshore banks themselves are also likely to form suitable habitat for Sandeels and a number of invertebrates such as Brown Shrimp (*Crangon*). In poor years for clupeids, such species may offer an alternative prey resource for Little Terns.

In contrast, although the beaches in the Would initially grade slowly out to sea the band of shallow water is narrow, and at around 1 km offshore moderate depth of 20-30m is achieved, dominated by extremely clear water, which does not appear to support dense algal populations and probably few zooplankton and thus fish. Moreover, any juvenile fish present in this zone may be unwilling to inhabit the upper layers, where they may be vulnerable to attack from the air. The area inshore around Winterton appears to be exceptional amongst the other parts of the Would and may even support comparable fish densities to North Denes in some years. The relatively large sand bar close to shore (300-400m) often targeted by foraging birds, appears to be a rare feature in the Would and may act as a holding and nursery area for small fish. The recently installed offshore reefs at Eccles may also perform a similar function, even supporting a range of other fish species more associated with rocky habitats.

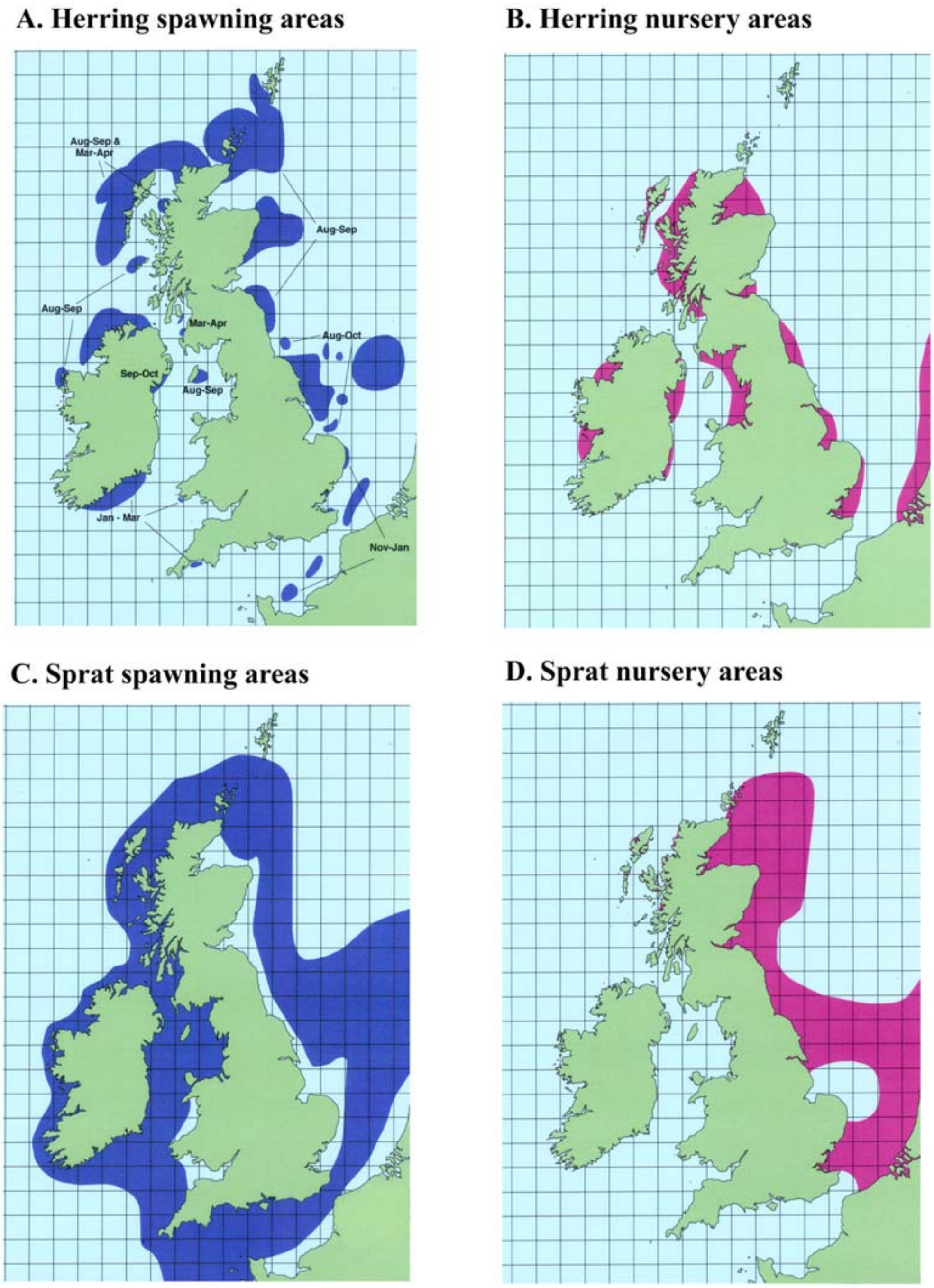

Figure 20. Known spawning (blue) and nursery (pink) areas of Herring (A & B respectively) and Sprat (C & D respectively) around the coast of Britain. Adapted from Coull *et al*. (1998).

The provision of suitable habitat for small fish prey seems likely to be the main reason that Little Terns have also selected Winterton at times over the last 100 years or so (see 2.1 above), and a small satellite colony recently became established at Eccles and which is used in some years.

Nevertheless, at both these sites the extent of suitable fish habitat is still very limited in extent compared to Scroby Sands, which covers around 12 km^2. This suggests both Winterton and to a lesser extent Eccles, are only likely to be good alternatives to North Denes in some years when clupeids are abundant and widely distributed. In years when clupeids are less abundant, such as 2004, 2005 and 2006, North Denes is likely to remain the site of choice.

6.1.2 Timing reproductive effort

The available prey resource for Little Terns has varied considerably between years and birds are thus likely to take the best available option in any particular year. As outlined above, the site of choice is likely to North Denes in the Scroby area rather than Winterton. But even in a good year for fish, birds are then likely to be faced with huge seasonal variation in fish density, with populations apparently climbing to a peak before reducing to very low levels[20]. The situation is further complicated by the fact that the peak in fish density has not only has varied hugely in scale (Figs 8, 10 & 11) but also varied temporally, with a ‘early’ peaks in June in 2003 and 2006 and a remarkably consistent (to the week) ‘late’ peak in late July in 2002 and 2004. The pattern in 2005 was somewhat different again with consistently low fish density more or less throughout June and July.

Investigation of fish growth patterns (length frequency distribution analysis supported by attempts to identify juvenile fish) led to the basic premise that the timing of peaks in abundance could generally be attributed to the two different clupeid species. Spawning in November to January in the area (Fig. 20) Herring have reached around 35-40 mm in length by early May when the first survey is typically conducted (Fig. 8). These fish appear to have grown little by the time numbers have declined dramatically in late June/early July (Fig 8 & 9), although this may be partly an effect of size-selective mortality or movement out of the area, such as further offshore out of the area to continue their development. However, simple changes in behaviour of the fish by swimming 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 is thought to spawn further offshore and later than Herring, probably early in May judging by the growth pattern suggested by Munk (1993) in which modes of fish of 12 and 16 mm corresponded to known modal ages (from otoliths) of 15 and 25 days. Thus at Scroby, larvae at <20 mm tended to appear in June (Fig. 8). At this stage, these fish are not capable of active swimming and must reach Scroby as a result of tidal drift. Numbers of larger Sprat reached a peak in July in 2002 and 2004. It is not clear if this is a result of the continued movement of young fish into the area or the concentration of fish in the surface waters or partly a result of increased efficiency of capture by the net used. In 2005, there was no obvious peak either perhaps because of the chance absence of fish in the upper layers on the days sampled or an earlier than usual offshore movement in later season, as also suggested for Herring (see above). In 2006, the peak in Sprat numbers occurred much earlier than experienced previously and at a time previously associated with a peak in Herring. Whilst the possibility of confusion over the identity of these fish cannot be completely discounted, this is not supported by growth patterns. It therefore seems as though Sprat either spawned earlier than normal and/or that drift, influenced by prevailing wind direction, was simply more consistent and concentrated in 2006.

Overall, Little Terns effectively have a three-month ‘window of opportunity’ in which at least some fish are available to feed themselves and any chicks. The breeding period incorporates an 18-22 day incubation period (Cramp & Simmons 1985), followed by a chick development period

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[20] although it is also difficult to judge whether the sampling of ‘available’ fish in the upper part of the water column consistently represents actual abundance

of 19-20 days. As a colonial species, Little Terns are often broadly synchronous in their nesting attempt, although the potential for re-nesting at a later date should the first clutch of eggs or possibly very young chicks be lost may confuse the general pattern and produce a long ‘tail’ of activity. For example, in 2006, despite the synchrony of nesting with a clear peak in active nests on 20th June, there was a long ‘tail’ of activity in what was a record year, with the last nests not lost until 5th August although most fledging had occurred by this time (Allen Navarro *et al*. 2006). Nevertheless, it is possible to define broad peaks of courtship and initial colony development, incubation and chick development, which may be maintained as standard time periods to ease interpretation.

Overlaying these periods as broadly documented by the RSPB at North Denes (see 5.1.1 above) over the temporal patterns of fish abundance in each year indicates that Little Terns tend to nest earlier in the season in association with an early season peak in fish abundance, which before 2006 was broadly synchronous with a peak in Herring abundance (Fig. 21). Even though birds largely avoided North Denes in 2003 as a result of disturbance during the period of establishment there was little delay in establishing at Winterton and the timing of nesting at Winterton is thus used in Fig. 21, thereby still giving the impression birds were seeking to exploit Herring. At North Denes, prior to 2002 , nesting was perceived to have become a synchronised event with nest establishment by 17th May, coincident with the erection of the perimeter fence around the colony. This tends to suggest that early peaks inYoY Herring occurred rather consistently in the past.

Conversely, when there were few early season Herring in 2004 and 2005, the peak of nesting activity was delayed to late June and even early July. In 2005, the last nest containing eggs was not lost until 28th July (Smart *et al*. 2005). However, in both years many birds appeared to re-nest at North Denes as a result of the loss of clutches at Winterton (Allen Navarro *et al*. 2004, Smart *et al*. 2005). But, regardless of whether late nesting birds were attempting for the first or second time, it appears the timing of the breeding attempt was geared towards the availability of YoY Sprat (Fig. 21).

There is growing evidence that Little Terns may adjust clutch size according to food availability, despite the fact that there seems to be limited scope for this with little range in the number of potential eggs laid (i.e. 1-3 eggs – Cramp & Simmons 1985). For example, Smart *et al*. (2005) noted that the average clutch size was just 1.89 in 2005 compared to the range of values between 2.05–2.45 in Cramp & Simmons (1985) and the RSPB’s use of a mean clutch size of 2.3. Allen Navarro *et al*. (2004) noted a similar situation with most nests at Winterton and North Denes in 2004 containing two eggs with a few with just one egg and just one with three. These observations were confirmed by Skeate *et al*. (2004) who recorded an average clutch size of 1.81 in a sample of 56 nests at Winterton. In contrast, when prey was abundant, the productivity of chicks fledged per pair was 1.92 (Wooden *et al*. 2003), suggesting the clutch size was likely to be at the upper end of the range documented by Cramp & Simmons (1985) or even higher. It is not just between seasons that variation in clutch size corresponding to prey availability has been noted, with Smart *et al*. (2005) commenting that the clutch size of earlier nests (1.71 to 7th July) was smaller than that of later nests (2.03 in nests from 7th-9th July) in 2005, contrary to the typical pattern of smaller re-lay clutches. Not only did this indicate that birds were focused on the availability of late season Sprats but also perhaps suggests that late nesting birds may even have been nesting for the first time (see above).

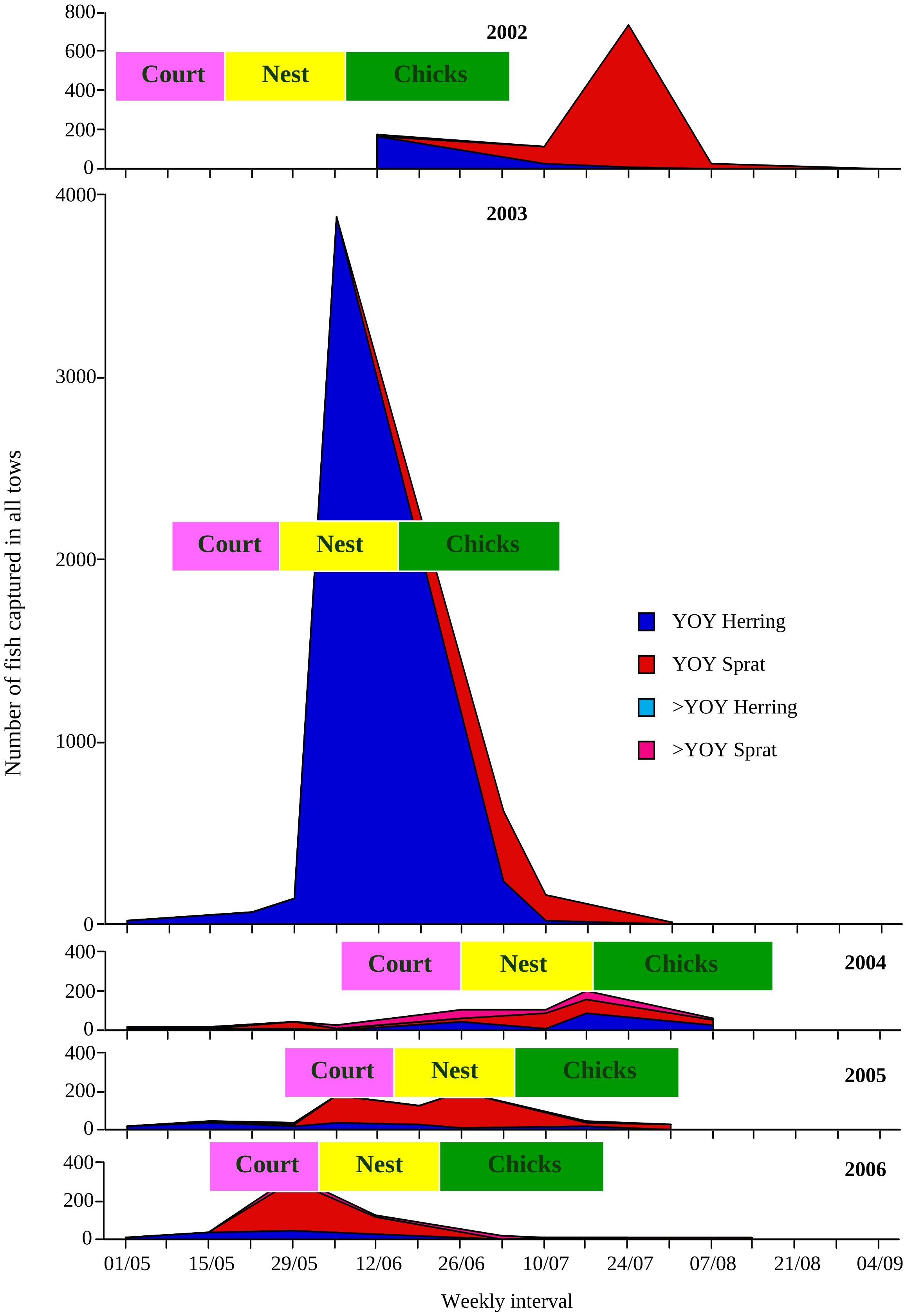

Figure 21. Inter-annual and seasonal abundance (catch-per-unit effort [CPUE] of all fish captured in all tows) of young-of-the year (YoY) and older Herring and Sprat at Scroby overlain by the known main periods, of the various components of the breeding attempt – courting, incubation and chick development – in each year.

Irrespective of whether Little Terns make an ‘early’ or ‘late’ season breeding attempt it appears that the availability of fish is likely to decline later in the season with potentially serious consequences for that attempt. In the early phase of incubation a provisioning male has itself and the female to feed. In the early stages of hatching, the number of mouths to feed increases to include some of the provisions to the female and the equivalent of most of the chicks. In later chick rearing when the female also appears to take some of the load (Cramp & Simmons 1985), provisioning 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 for larger chicks means that, if anything, the demand for prey increases during the chick development period and thus the demands exerted on each adult. It may thus be critical to ensure that chicks are fledged before prey density collapses if adults 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. It seems likely that the best site for fish was selected in the first place (see 6.1.1 above) and the new site may have an even lower fish density. 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. Conversely, the abandonment of nests at Winterton in both 2004 and 2005, with the prospect of subsequent re-nesting at North Denes to coincide with the availability of Sprat also appears to have been a tenable option. The fact that three of the four birds tagged at Winterton were subsequently quickly contacted at North Denes illustrates that birds readily have the potential to assess prey availability elsewhere along the coast.

6.1.3 Factors influencing foraging success

Successful foraging is the product of a relatively complex process involving searching for, locating and capturing prey. A number of factors play a role at each stage of this process resulting in a large range in success. For example, tidal cycle may have predictable effects on fish abundance and consequently on the foraging success of their bird predators, including terns. 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. Particular areas may become profitable according to the state of the tide, for example as shown for Kittiwakes *Rissa tridactyla* (Irons 1998). In the current study, radio-tagged birds at Winterton 2003, flew significantly faster at low tide, which was thought to be the result of birds commuting rapidly to favoured sandbanks both offshore and further down the coast which became exposed at low tide (ECON 2004).

Water clarity, inversely described as water turbidity, is also partly a function of tidal cycle, with shallow moving waters likely to have a greater concentration of suspended materials than still waters. Turbidity may greatly influence foraging success of visually foraging birds. In the study of Brenninkmeijer *et al*. (2002), food intake rate of Little and Sandwich terns was lower in the most turbid waters as a result of turbidity affording greater protection for fish against aerial attack. In contrast, in the current study, there was a clear relationship between greater turbidity and increased fish catches, which was attributed to fish moving closer to the surface to feed amongst the plankton. Contrary to turbidity reducing the opportunity for foraging this may be an essential prerequisite for shallow diving Little Terns, as it brings their small fish prey closer to the surface where they can be reached. It seems no coincidence that sites 10 and 11 (North Denes and Caister respectively) with the highest fish densities also tended to be the most turbid, and combined with site 10 being immediately adjacent to the North Denes colony, it is no surprise that it accumulated the largest numbers of birds.

Whilst it is anticipated that the inter-relationships between foraging birds, tidal cycle, wind direction and strength, wave action and turbidity may be a profitable area for future research, the impact on overall foraging success is thought to be relatively subtle particularly in the case of a species such as Little Terns, which appear to be extremely efficient, that is, they hardly seem to miss prey once it has been encountered. Thus overall foraging success was only likely to mirror gross changes in prey abundance or more specifically availability, which varies between seasons, within a season, within a day and even from one minute to the next.

In the current study, the mean number of dives recorded in each year was around 1-3 per minute at North Denes and <1-2 per minute at Winterton, both of which are at the lower end of the range of 1-7.3 for the species (Cramp & Simmons 1985). When fish were abundant, this may have been a function of the relative ease with which terns catch energy-rich fish prey particularly at North Denes. Fish were generally the target of foraging activity and when sufficiently abundant, dives producing fish constituted the bulk of all dives with mean rates over 1.5 fish min^{-1} in some years.

As to be expected the huge variation in fish abundance between years and between sites (in the region of 20 to 400 fold at North Denes and Winterton respectively) produced considerable variation in attack (dive) rates broadly in line with what would be expected. For example, the rate of attacks resulting in fish capture at North Denes was significantly higher in 2002 and 2003 when fish densities were higher, than when they were much lower in 2004 through to 2006. 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, and not different in 2003 when prey density was more or less equally high, or in 2004 when it was similarly low. In 2005, the worst year for fish to date, a greater rate was achieved at North Denes compared to Winterton although this was very low at both sites.

Despite broad agreement between prey abundance and foraging success there were a number of anomalies. First, the rate of completed attacks does not follow the same inter-annual pattern as the rate of attempts producing fish, as the highest overall attack rates were not achieved in the year of most abundant fish. Attempts producing fish also declined at a faster rate than overall attempts as the study progressed, as the proportion of attempts producing fish declined in line with overall fish density. Thus, birds may have boosted attempt rates to some extent by switching to other, less profitable prey such as invertebrates. Indeed, there may be occasions when invertebrate prey is particularly important, such as when fish prey are at low density 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. The peak in use of Scroby Sands themselves at the beginning and end of the season may be linked to some extent the availability of invertebrates, as fish are rarely recorded in samples in these habitats. But whilst invertebrates may be routinely exploited by adult birds and recently fledged chicks, which have yet to learn the skills required to catch fish efficiently and need to supplement any fish provided by their parents, data from 2003 and 2002 shows that dependent unfledged chicks (perhaps apart from very young individuals) are rarely presented with invertebrates (see 5.8.1 above). The generally low density of invertebrate prey in the study area as a whole (see 5.5.2 above) means that should fish prey also be limited, dive rates may then decline to very low levels. Thus, in 2005, dive rates just above (North Denes, mean ± 1SE = 1.56 ± 0.21) and even below (Winterton, mean ± 1SE = 0.64 ± 0.14) the lower end of the range recorded for the species (1-7.3 min^{-1} – Cramp & Simmons 1985) were recorded over the season.

Second, the rate of dives producing fish does not necessarily track fish abundance, particularly during the season. For example, the virtual collapse of fish populations from the beginning of July in the peak Herring year of 2003 did not have an obvious effect on foraging success, as 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 (ECON 2004). There are clear energetic advantages in foraging as close to shore as possible, and at North Denes in 2002 and 2003, with greater availability of prey birds foraged significantly closer to the shore ultimately leading to a significantly higher fish capture rate. However, this may represent an super-optimal situation and a fast-moving and relatively wide-ranging species such as Little Tern, may readily compensate for reduced prey densities

Data from radio-tagged birds showed the scope of ranging behaviour that may come into play in more extreme conditions. Comparing birds with active nests in 2003 with 2005 and 2006, birds travelled nearly 3-fold further simply by increasing flying speed by nearly 3-fold within ranges that were around 3-fold larger. In turn, this suggested rapid commuting between preferred foraging sites.

Whilst dive rates recorded from shore were lower from 2004 onwards it is of note that the provision rate of adults to chicks, which is perhaps the ultimate manifestation of foraging success was significantly higher in 2006 on a per chick basis, than other years. In order to achieve this in a year of apparently lower fish density it seems adult birds simply ‘worked harder’. Whether or not the adult birds suffered any energetic costs as a result of this increased activity and, for example, maintained lower body weight or condition, is unknown.

6.1.4 Factors influencing breeding success

The presence of a dense, high quality food supply close to a colony is intuitively an essential prerequisite for successful breeding. However, history (see 2.1 above) has also dictated that in the current scenario of the intense human use of beaches, few Little Terns would ever be successful in North East Norfolk without limitation of disturbance by of nesting terns by humans and their dogs, by means of fencing and wardening. Even where conditions are suitable to allow eggs to be laid, a number of other factors notably predation may have great impact on breeding success. Indeed, on a national scale, the RSPB (2002) attributed the long-term chronic decline in Little Tern populations to a decrease in productivity, which was argued to be ultimately linked to increased predation by foxes through an increase in their population size and range, particularly in East Anglia and eastern Scotland. The focus on predation runs contrary to what is documented for a range of other seabirds, where food supply is often seen as the liming factor. For example, the widely 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).

To understand what may be ultimately be limiting Little Tern populations it is useful to discuss potential limiting factors according to the various life history stages.

Losses of eggs: predation vs abandonment

At North Denes, egg predation by ground predators particularly foxes but also including hedgehogs, has long been thought to be a serious issue. In 1996 for example, foxes predated at least 65 nests, which contributed to total failure of the colony in that year. The use of electric fences has thus become the normal state of affairs, but even this may be insufficient to prevent serious losses. In 2004, in response to predation of three nests by a fox, electric fencing was installed. Unfortunately, predation of nests continued and ultimately 82% of the 55% of nests lost to predators (from a relatively small total of n=40) was attributed to foxes. Fortunately, where electric fencing is reinforced with twenty-four hour protection including regular nocturnal patrols around the colony perimeter with 2 million candlepower lamps, the impact of these predators seems considerably reduced. In 2005, with all preventative measures in place, just 5% (n=5) of monitored nests were predated by foxes; with 2% (*n*=2) predated by other species (Smart *et al*. 2005). Similarly in 2006, just 3% of the 89 monitored nests were lost to foxes, with 1% lost to a Hedgehog and 1% to an unknown predator (Allen Navarro *et al*. 2006). Overall, hatching success was high at 75% in 2005 and 73% in 2006.

It is of note that the same level of protection has never been undertaken at Winterton, despite it being fringed by a far more extensive dune system likely to contain greater numbers of predators, although foxes in particular are likely to have been reduced by the routine and intensive control that has historically been undertaken by the estate owners. Even so, the potential for predation remains and the failures of the Winterton colony in both 2004 and 2005 allows some exploration of the relative impact of disturbance and predation compared to any impact of the very low fish stocks in both years.

In 2004, it is unclear whether 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 from 6-8th June. This occurred at the same time as the 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. No such event occurred at Yarmouth in 2005 and there is no ready explanation for the slight delay in nesting at North Denes compared to Winterton, with 17 nests at Winterton by 31st May, the first day of incubation at North Denes (Smart *et al*. 2005).

In 2004, 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 was 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.

Whilst there is a strong indication that the contents of at least some of the nests were predated, 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 have been expected to quickly remove any abandoned eggs. Moreover, if a fox were involved it would have been 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 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. In 2005, an equivalent rapid decline in the number of nests was also noted: 83 nests on 13th June, 52 on 27th June and just 9 by 5th July. Whilst some predation of nest by crows was recorded (see 5.1.2 above), there was again no clear evidence of systematic predation of nests by ground predators.

In 2004, birds did not appear to, 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[21]. Moreover, birds captured at the nest in 2004 were marginally lighter (3.3%) than in 2003 (mean ± 1SE = 53.8 ± 0.8g, n=18, cf. 55.6 ± 5.1g, n=10). If anything, birds were even lighter in 2005 (mean ± 1SE = 53.7 ± 0.7g, n=16), particularly at Winterton (53.0 ± 1.64g, n=5), reinforcing the suggestion that body resources for egg-laying were at a premium in both 2004 and 2005.

Specific foraging observations at Winterton in June in both years indicated that birds were travelling large distances from the colony to forage. In 2004, 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. A similar pattern was noted in 2005, with 75% of birds recorded flying out of observation range with 57% (of those with a bearing) to the south. Wide ranging foraging to exploit scarce patchily distributed resources was reflected in the very poor dive and fish capture rates at Winterton in both years (see 5.7.2 above), with those in 2005 being the lowest (significantly) yet recorded. In such circumstances, birds may have been on a metabolic knife-edge of maintaining body condition whilst attempting to breed.

Whilst predation by ground predators especially foxes, may be a serious threat to Little Tern nesting success, this appears to be effectively controlled by electric fencing and intensive wardening effort at North Denes. At Winterton, it seems that neither measure may be required, as in 2003, a record number of chicks fledged from the beach illustrating a hugely successful hatching rate. In both 2004 and 2005 when few nests hatched chicks there was no evidence to suggest that this was caused by an increase in the intensity of predation, although some undoubtedly occurred. Overall, it is suggested to be no coincidence that prey availability was at its highest in 2003 and abysmally poor in 2004 and 2005. The lack of prey especially YoY Herring appears to have been the ultimate factor causing many birds at the Winterton colony in both years to lay few eggs and to subsequently abandon them. There has been no previous mention of mass abandonment in the life of any colony in North-East Norfolk (see 2.1. above) and thus such behaviour appears to be unprecedented.

To conclude, predation of eggs by ground predators may be a serious issue and lead to large losses. But equally, simple disturbance by people and dogs may also be devasting and effectively prevent birds from hatching any eggs if they nest at all. The answer to both problems lies with protection by electric fencing and 24-hour wardening and the RSPB sought to limit human disturbance even further in 2006 by fencing off the colony from human traffic following the beach line especially at low tide. Experiences of low predation rates at Winterton compared to North Denes illustrate a colony-specific level of predation. Most importantly, experiences at the former also show that large losses of eggs at the incubation stage may also be caused by mass abandonment, probably as a result of a failing food supply.

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[21] Unfortunately, there was no accurate monitoring of clutch size at Winterton in 2005.

Losses of chicks: the role of predation

Whilst predation of eggs by ground predators may be effectively controlled or alternatively, relatively unimportant particularly in relation to the ultimate effects of prey supply, predation of chicks may have a local devastating effect. This may occur when the population of chicks is small, as in 2003 at North Denes, when the loss of at least one near-fledged chick to a Kestrel had a marked impact, reducing the population productivity by 33%. Alternatively, the impact of predation may also be considerable when the population of chicks is large, with Kestrels predating virtually all (i.e. several hundred) chicks in some years (e.g. 1996) at North Denes (see 2.1 above). This phenomenon also occurred in 2005, with at least 143 chicks taken. In fact, given the high visitation rate of Kestrels (284 visits were documented) coupled with their virtually unerring success rate (see below), the true number of chicks predated is likely to be much higher. Indeed, the vast majority if not all of the unaccounted 393 chicks estimated to have hatched and not fledged were thought likely to have been predated by Kestrels (Smart *et al*. 2005).

Unlike previous years the attacks on chicks in 2005 appear to have perpetrated by one pair nesting at Great Yarmouth Racecourse (the ‘Racecourse pair’). The male of this pair was seemingly responsible for the bulk of attacks with a male bird being recorded by wardening staff on 200 occasions, ten times more than documented for a female. The timing and frequency of attacks coupled with the fact that the male bird, which is the principal provider to the brood in Kestrels as well as other raptors (Shrubb 1993**)**, supports the contention that Little Tern chicks were primarily targeted as prey for the Kestrels’ own brood of five chicks. In accordance with this, the male began to visit the colony from 25th June, just a day after the first chicks began to hatch and subsequently increased the number of visits to at least 19 per day by the middle of July. This corresponded to the period of the successful fledging of all five Kestrel chicks and the peak of their metabolic requirements as they continued to be fed by their parents. After this time, with a sharp decrease in the number of Little Tern chicks on the beach following predation, it appears that despite the maintenance of Kestrel activity, the rate of successful attacks began to diminish (Smart *et al*. 2005), although any chicks that did hatch were immediately taken. On one occasion (7th July), two day-old chicks were seen to be simultaneously captured, one chick in either foot, although one was subsequently dropped from height to its death as the Kestrel flew away. Moreover, even chicks observed during chick provisioning studies were not immune to attack; as on 20th July, when the Kestrel approached low from behind and within a few metres of the observers, successfully capturing one of the chicks in the observed brood.

It has been suggested that the extent of Kestrel predation upon Little Terns is linked to local populations of small mammals, with Kestrels likely to switch to, and concentrate on, Little Tern chicks only in poor years for mammals and particularly early in the season when the availability of chicks is at its peak (Smart & Ratcliffe 2000). At Winterton in 2003, although Kestrels were seen frequently over the colony, particularly at the end of season, there was no evidence of predation and 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. However, breeding urban Kestrels such as those in Yarmouth reputedly feed mainly on birds rather than mammals in the absence of suitable habitat for large populations of small mammals, particularly those of Field Vole *Microtus agrestris*, the preferred prey species (Shrubb 1993). Field Vole is principally an animal of unmanaged grassland and although it may be present in the densest vegetation of the dune system of North Denes, the site appears to be generally rather too sparsely vegetated and too disturbed by people and their dogs to support good populations. In fact, there is anecdotal evidence that the Racecourse pair of Kestrels typically prey upon Meadow Pipits *Anthus pratensis* and Skylarks *Alauda arvensis* in the North Denes SSSI. The relatively late timing of nesting of the Racecourse pair with young not fledging until July also points to the link with nesting Little Terns.

Kestrels thus appear to pose a uniquely serious threat to Little Terns compared to other avian predators such as corvids, gulls and other raptors. Amongst these, corvids have never been reported as a particular threat at North Denes, although they may be present on the beach and were reportedly important predators of eggs/chicks at Winterton and Eccles in 2005. Although Common Gull *Larus canus* has been noted as an important predator of Little Tern chicks in North Norfolk (Michael Rooney *pers comm*.) and large gulls such as Herring Gull are an omnipresent threat, Little Terns, especially in numbers, appear to be able to offer effective defence against such predators by harassing them from behind in flight as well as dive bombing them when they are on the ground.

In contrast, raptors may be particularly dangerous as they are quite capable of also taking adult birds as well as chicks. Observed responses to both Hobby *Falco subbuteo* and Sparrowhawk *Accipiter nisus* have typically involved birds climbing into the air calling in panic and seeking refuge in numbers, typically over the sea. In 2005, an attacking Sparrowhawk at North Denes actively pursued a tardy adult over the sea for a short distance over the sea before giving up. At Winterton in 2003, a pair of Sparrowhawks frequently attacked the colony (several times a day) and almost certainly took at least some chicks, fledglings and maybe even some adults. However, estimates of the numbers of chicks alive from ringing returns and subsequent counts of fledglings, suggests any losses to these raptors were unimportant to the population. 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. Considering that this total is, if anything, an underestimate, suggests that predation of chicks was relatively unimportant.

In contrast to faster moving and/or larger raptors, there is little evidence to suggest adult Little Terns are at any particular risk from Kestrels and will mob an attacker with great determination. Pursuit of the male Kestrel by adult terns at North Denes was often seen to continue across the dunes to the road >0.5km away. Moreover, incredibly, on one occasion as the Kestrel flew away with a captured chick, an adult tern, presumably its parent, was seen to grab the chick from below and all three birds were briefly connected before the Kestrel released the chick (Mark Smart *pers comm*.). Unfortunately, it is thought the chick did not survive the fall and/or its injuries. Despite a lack of fear, adult terns appear to be unable to deflect an attacking Kestrel from an attack once it had been initiated. This is presumably as no actual bodily contact appears to be made by dive-bombing terns. The reason for this is unclear especially since there does appear to be contact with large gulls. It may be that any contact with a raptor even a relatively slow and small one such as a Kestrel is generally too risky. Alternatively, it may be a more subtle reflection of experience and development of a suitable defence strategy. For example, unlike gulls, with which Little Terns have shared similar habitats over the millennia, Kestrels may pose a more recent threat in evolutionary terns as tern colonies have tended to become larger and more fixed and Kestrels have learnt to exploit the potential food resource. It may be that Little Terns have not yet learned how to defend effectively against Kestrels and determined ones in particular. Certainly, the male Kestrel at North Denes seems to perceive no threat from the pursuing mob of adults terns and once a chick, particularly a small one, has been spotted and selected, thereby neutralising its primary defence mechanism (i.e. its camouflage), capture appeared to be inevitable.

To summarise, where Kestrels become focused on the colony, perhaps even timing breeding to coincide with this potential prey resource, losses of chicks of Little Tern chicks may be enormous. Predation of chicks may thus determine the success of the colony, potentially over-riding any effect of a good food supply, as even where this is sufficient to allow adults to spend more time on defence of eggs and chicks against potential predators, this is meaningless as no effective defence can be mounted against Kestrels. This ultimately means that human intervention will be required. In theory, this may conceivably be achieved through aversion of attacks by scaring, manipulation of the nest site to make it unsuitable, provision of an alternative food supply, replacement of the eggs with dummies or lethal control of the adult Kestrels or their or chicks or eggs (i.e. pricking). Of these options, various attempts to scare the attacking bird have not proved successful and attempts to supplementary feed breeding Kestrels with white mice have been rather inconclusive (Smart & Ratcliffe 2000). However, with a lack of support from the Racecourse owners to discourage Kestrels from nesting, the unacceptability of more drastic control measures against a protected, declining species, and with its relevance to other avian predation isues (e.g. Hen Harrier and Red Grouse *Lagopus lagopus*), the RSPB embarked on a six-year study of supplementary feeding beginning in 2006. This sought to alternate feeding with no feeding, with 2006 being the first year supplementary feeding would be undertaken.

Supplementary feeding was seen to be successful, with 284 items (white mice and day-old chickens) taken by the Kestrels from the feeding tray near the nest (Lewis 2006). All three of the eggs that hatched (from seven laid) fledged chicks. There were just 81 recorded visits by Kestrels leading to 27 recorded predations for a possible total of 41 Little Tern chicks lost in 2006. This compares to 284 recorded (extrapolated to 861) visits in 2005, leading to 143 recorded predations and a possible total of 455 lost in 2005. At peak, up to six Little Tern chicks were lost per day in 2005, perpertrated by the male Kestrel who had become something of a specialist. This male had presumably died over the autumn/winter of 2006 as another male was paired to the Racecourse female. This bird appeared to be much less confident and skilful in catching Little Tern chicks, which may also have exacerbated the magnitude of the difference in predation levels between the two years. The experiment is set to continue.

Whilst Kestrel predation may ultimately be within the realm of management of the colony, it is intuitively much more difficult to influence the prey supply at sea. Although birds may abandon eggs in the face of a poor food supply, there was enough prey at North Denes in 2004 and 2005 to at least lay eggs with many birds also hatching chicks in 2005. The key question is that if there had been no predation of eggs in 2004 or more importantly, predation of chicks in 2005, would chicks have fledged or ultimately starved? Although it cannot be definitively established retrospectively, there is circumstantial evidence to suggest that birds had the potential to cope with the reduced prey densities in 2004 and 2005.

First, the abundance of Sprat later in the season at North Denes was of similar magnitude to the abundance of Herring as they declined sharply in early July 2003. At this time, an enormous number of chicks were present on the beach and the lack of potential prey at the beginning of July appeared to have serious consequences for their survival. But 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.

Second, there is no clear relationship between fish density and provisioning rate, the latter reaching 4-5 feeds chick hr^{-1} in 2005 and 2006 (significantly higher in 2006) at significantly lower fish density (Fig. 19). The provisioning rate in this study is at the lower end of the range documented in the general literature of Cramp & Simmons (1985), particularly considering this increases with age (i.e. 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 immediately prior to fledging fed at 10.4 chick hr^{-1}). There was no such relationship between provisioning rate and age in this study, although this could have been partly confounded by differences between sites and years. Also, the type of prey fed to chicks is not described in Cramp & Simmons (1985) and it may be that the quality of the mainly YoY fish fed to chicks at North Denes may compensate for a low provision rate. Even so, there is clear value in increasing provision rate with the increased demands of progressively larger chicks, with faster growth potentially allowing faster development with chicks fledging and leaving the beach earlier (15-17 rather than 19-20 days is known), thereby reducing the length of exposure to predators.

Third in order to maintain provisioning rate in the face of reduced prey density adult terns may travel further to reach an exploitable stock. There is anecdotal evidence that this was the case in July 2003, as during a pilot study of tern foraging ranges for the DTi Allcorn *et al*. (2004) recorded Little Terns carrying prey back to the Winterton 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. Radio telemetry in 2004 and 2005 then provided an unequivocal demonstration that these sort of distances were achievable, with maximum distances in a single foraging being up to 26km. Individuals may also fly faster to compensate for travel time as 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.

In 2003, adult birds were able to bear the costs of greater foraging distance and still successfully raise chicks, achieving the incredibly high productivity of 1.92 in the process. This was considerably higher than the productivity of 0.5 chicks pair^{-1} achieved in 2002 and, in fact, higher than anything yet seen at North Denes (see Table 1 in 2.1 above). Whilst at first glance the overall provisioning rate between 2002 and 2003 at Winterton appears little different, at 2.6 feeds hr^{-1} compared to 2.99 feeds hr^{-1} respectively, 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 in 2003. But, rather than viewing the production in 2003 as being remarkable, it is perhaps the raising of chicks in 2002, when fish density was some two orders of magnitude lower that is the more interesting.

The final and most compelling demonstration of compensatory behaviour is the raising of 673 chicks in 2006, the single highest total ever recorded at a single colony since records began (breaking the record from Winterton in 2003). Whilst there is some dispute over the exact total as wardens recorded lower numbers and only 564 chicks are estimated to have hatched (Allen-Navarro *et al*. 2006), chick productivity was still clearly exceptional. In simple terms, apart from the early pulse of Sprat in 2006, the overall prey supply was directly comparable with that in 2005 and 2004. This tends to suggest that in 2004, particularly as they had already selected for a small clutch size, 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). If all measures (e.g. electric fencing, 24 hour protection and the lethal control of predators) had been implemented, 2004 may not be remembered as the worst year on record (with 1996) for Little Terns at North Denes. Similarly in 2005, despite a poor prey supply, it seems likely that many more chicks would have fledged if not for mass predation by Kestrels.

Overall, in contrast to the abandonment of breeding attempt at the egg stage, there is little evidence to suggest that once chicks have hatched, Little Terns will neither abandon nor fail to raise at least some chicks simply as a result of what seems to a low prey supply. This is in direct contrast with the mass starvation of chicks as a result of a failed food supply documented in other species (see *Recent failures of seabirds in the North Sea* below). The fact that the foraging range of birds at North Denes encompasses the dynamic sand-bar system at Scroby as well as a range of inshore waters along the coast, intuitively providing a range of foraging opportunities, could conceivably mean that this phemonenon is largely unique to North Denes and not even mirrored at Winterton just a few km along the coast. This again reinforces the designation of Great Yarmouth/North Denes as the only SPA for Little Terns in the UK, and just how critical this may be for the long-term survival of the species in a UK and even European context.

6.2 The impact of the Scroby Sands offshore wind farm

6.2.1 Establishing the potential impact scenarios

The impact of any wind farm or indeed from any development or even natural factor, is manifested through effects on individual birds, which compound to impact on the population as a whole. In this case, the population is the North East Norfolk population of Little Terns, which is largely contained within the Great Yarmouth North Denes SPA comprising two colony sites at North Denes and Winterton. The colony at North Denes has traditionally been the more important and is in fact the most important colony of this endangered bird in the UK. Any assessment of the impact of the wind farm on Scroby Sands upon the North Denes colony and thus the Great Yarmouth North Denes SPA effectively depends on whether Scroby Sands 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 6km offshore (i.e. well beyond the 1.5km suggested as the maximum distance Little Terns would forage offshore – 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 (ECON 2003, 2004, 2005, 2006, Perrow *et al*. 2006). Moreover, this study showed that the foraging range and distances covered in a single bout (up to 57km) enabled by a direct flight speed of up to 74km hr^{-1}, are far greater than thought, bringing Scroby within easy reach of birds from the North Denes colony. In contrast, birds nesting at Winterton and tied to central-place foraging are unlikely to be able to utilise Scroby. Nonetheless, should they fail, birds from Winterton or indeed from a much wider area including North Norfolk or even possible overseas may then re-distribute accordingly and gravitate towards North Denes and Scroby.

The use of Scroby Sands and the wind farm area as a foraging ground compared to waters closer inshore appeared to depend largely on the abundance of fish. When these were more abundant, Little Terns simply concentrated on inshore waters immediately around the colony and undertook short foraging trips of limited distance from shore. In years of low fish density ranging behaviour increased and birds routinely traveled to Scroby. Although no specific investigation was undertaken there was also some suggestion that Scroby could be used under particular phases of the tidal cycle and particularly in relation to water clarity inshore. As clarity increases, perhaps in high or low water slack periods, fish may be prompted to drop deeper in the water column and 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 then 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).

Even without specific use of Scroby, and as documented in the previous reports (ECON, 2003, 2004), Scroby Sands appears to 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 any impact of the wind farm upon Little Terns could conceivably 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 geomorphological change offering alternative habitat for prey species.

In contrast, possible negative impacts upon Little Terns included:

- 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.
- Changes in the nature of the prey resource 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).

Of these, direct mortality would be restricted to within the wind farm itself, whereas displacement may also extend to the surrounding area i.e. a buffer zone, which birds also avoid. The size of this buffer zone is difficult to determine in advance and is likely to be species-specific with more sensitive species being displaced from a wider area. A precautionary distance used in many offshore wind farms is 1 km from each of the turbines. This dramatically increases the area affected. Changes in geomorphological conditions or the nature of the prey resource may conceivably affect an even larger, but unquantified area.

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.

The worst-case scenario of avoidance of the proposed wind farm by Little Terns was considered to be that all birds would be displaced from North Denes. Even if this occurred, birds 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, could conceivably be considered as mitigation.

The general perception seems to have been that Little Terns were unlikely to be affected by collision risk, largely as they spend much of their time well below the strike zone. For example, Cramp & Simmons (1985) document a range of foraging height flights to a maximum of 12m. However, this study has shown that birds do spend a proportion of time at >20 m taken to fall within the strike zone of the turbines, especially in commuting flight and also when in display. The sheer number of foraging bouts of a colony of several hundred pairs of birds over the course of the season means that mortality of birds through collision becomes a tangible impact of the wind farm, especially for a long-lived seabird such as Little Tern. This is considered in operational impacts of the wind farm below in the sequential treatment of potential impacts from installation to operation.

6.2.2 Potential impacts during installation

It was not possible to monitor the short-term impact of the installation of turbine monopiles beginning in late October (21st) 2003 and continuing to the beginning of January (6th) 2004**,** directly on Little Terns simply as they are in their winter quarters off the west coast of Africa mainly in the waters of Guinea-Bissau at this time (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 apparently 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 kilometres 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 attraction for foraging Little Terns. In 2005, there was also an apparent lack of recruitment of Herring. Birds again abandoned at Winterton and although a greater number of Little Terns nested at North Denes, very few chicks (c. 11) fledged. Whilst the major cause of mortality was predation by Kestrels and there is reason to suggest that more chicks would have survived without the attentions of these predators (see 6.1.5 above), 2005 may still have been a relatively poor year. However, despite the continued absence of Herring YoY in 2006 and with supplementary feeding of predatory Kestrels the fledging success in 2006 was the highest ever recorded from a single colony (673 ind.) in the UK. Whilst this introduces questions of whether Little Terns specifically need YoY Herring at North Denes or are equally able to shift to alternative prey species or shift breeding patterns or patterns of foraging to compensate, a key question relating to the effect of the wind farm still remains: Was either the construction of the wind farm or the subsequent presence of the wind farm likely to be responsible what appeared to be exceptional events in the history of the Little tern colony at North Denes or were these simply coincidental?

Clearly, without a much longer data set it is extremely difficult to judge just whether the events observed in 2004 and 2005 were within the expected range of natural variation, particularly in relation to recruitment of prey fishes. Consequently, to begin with, it is useful to place the failure of Herring recruitment and initial failure of Little Terns in the area in the intial lifetime of the wind farm, 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 failures of seabirds 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 zooplanktivorous 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 ecological signal from the lower trophic levels are thus highly sensitive to environmental fluctuations (Stenseth *et al*. 2002).

In the North Sea, there is increasing evidence of regime shift associated with the NAO. Reid *et al.* (2001) documented that after 1988 onwards the pressure difference between Iceland and the Azores increased to its 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[22]. In February 2004, wrecks of dead Fulmars hit the coasts of France, Belgium, Germany and the Netherlands as well as the UK. Post-mortem of the female biased (90%) samples revealed starvation was the main cause of death. The effect continued into the breeding season with the poorest season on record for Fulmars in south-east Scotland, unprecedented breeding failure of Guillemots on Fair Isle in Shetland and generally poor success of Kittiwake on the British North Sea Coast (e.g. Bempton Cliffs in Yorkshire - Pitches 2004a). Decline in the stock of Lesser Sandeel 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 was 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 dependence on a single species in those locations. In contrast, the breeding success of Kittwake in North-east Scotland was improved in 2004 and the production of Guillemot chicks on Skomer and of Fulmar chicks in North-west Scotland was also rather typical. Moreover, even at the worst affected colonies Atlantic Puffins *Fratercula arctica* did not experience the same low breeding success as other sandeel feeders, which the JNCC (2004) speculated 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 sandeels, 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 prevent 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, 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[23]. Inundation of Puffin burrows also 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, where they fed on other prey the same bird species fared much better. Whilst impacts on birds in 2004 were part of a wider phenomenon associated with climatic fluctuation mediated through the NAO, not all species of fish and bird

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[22] http://www.birdlife.net/news/features/2005/01/north_sea_seabirds.html, http://www.climateark.org/articles/reader.asp?linkid=33959)

[23] http://www.birdlife.net/news/features/2005/01/north_sea_seabirds.html.

could be affected in the same way. Impacts depend, in part, on the ability of both fish and birds to adapt their breeding cycles and choice of prey.

The fate of the UK's Little Tern colonies in 2004, 2005 & 2006

As outlined in annual newsletters produced by Sabine Schmitt of the RSPB (Schmitt 2005, 2006, 2007), Little Tern colonies suffered a range of fates in 2004, 2005 and 2006, ultimately with relatively poor breeding seasons in 2004 and 2005 with around 0.41 chicks pair^{-1} and 0.38 chicks pair $^{-1}$ respectively, with 0.80 chicks pair^{-1} in 2006. The latter was heavily biased by the success at North Denes and excluding North Denes was similar to 2004 and 2005 with 0.46 chicks pair^{-1}. The influence of the fortunes at the Great Yarmouth North Denes SPA was also strongly felt in previous years such as in 2003, with the similar number of chicks to 2006 mainly due to the Winterton and Gronant (North Wales) colonies where virtually two chicks per pair fledged in 2003. Interestingly, Gronant maintained high productivity in 2004 and 2006, but not in 2005. Hodbarrow in North-West England also fledged a record number of chicks in 2004, but produced few in 2005 despite a record number of adults attempting to breed, with just 16 pairs in 2006. In contrast, the relatively small colony in Coll in Scotland maintained high productivity in 2004 and 2005 fledging 1.26 chicks pair^{-1} in 2004 and 1.16 chicks pair^{-1} in 2005 but none in 2006. In a similar vein, Kilcoole in south-east Ireland was the most successful site overall in both 2004 and 2005 with 189 and 161 chicks fledged respectively, but produced just 21 in 2006.

Many of the colonies in the east of England, which is the stronghold of Little Terns in the UK, struggled throughout 2004 -2006 In 2004, 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, 1,000 broods of Sandwich Tern and 100's of Black-headed Gull chicks (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).

In 2005, the unseasonably cold spring (with frosts on several dates in May) was cited as the reason for the rather delayed start to breeding in North Norfolk (24th May at Blakeney Point ad 29th May at Scolt Head). At Scolt, a record number of pairs (105) attempted to breed, but were thought to be constrained by a lack of prey, poor weather and high tides (Lawton 2006). In fact, many birds appeared to abandon nests in early June, with some subsequently re-nesting in late June. Ultimately, 25 young fledged. At Holkham and Blakeney, similarly low productivity was noted with 8 chicks from 62 nests at the former and 11 chicks from around 50 nests at the latter. Predation and high tides appeared to account for most nests (Harold 2006, Wood 2006). As in 2004, the situation in the south-east of England was rather different, with food seemingly abundant despite the late start (Schmitt 2006). However, only at Hamford Water in Essex (35-45 chicks) and Rye Harbour in Sussex (20 chicks) was any number of chicks fledged. Predation, including by rats on Hayling Island, was the most commonly cited reason for failure.

In 2006, a cold spring again seemed to cause a late start to the season at many colonies in the UK (Schmitt 2007). But in East Anglia, although one of the sites was abandoned at Scolt Head as a result of storms and the resulting high tides, foam and sand blow; fox predation and local food shortages were cited as the more important factors responsible for the production of just five fledged young from 82 pairs. Other tern species seemed less affected by food shortage (Lawton 2007). Similarly, at Blakeney Point, a minimum of 56 pairs, and probably many more, fledged just 17 young. There was a distinct lack of feeding in and around the harbour and thus a local shortage of food was thought responsible for low success in the absence of other obvious factors (Wood 2007). At Holkham, a good start at the Burham Overy colony was again noted, although numbers of nests dwindled from 32 on 10th June to 12 by 1st July. Despite the similarity to the trends at Scolt and Blakeney, there was no obvious single factor in this decline, with no signs of predators and reputedly good weather and plentiful prey (Bloomfield 2007).

Overall, most regions and sites suffered contrasting fortunes throughout 2004, 2005 and 2006 with the reasons for any success or failure in one year not necessarily being the same in the next. Only in Norfolk was there some degree of consistency for failure, although inclement weather conditions appear to have been particularly important in North Norfolk. This is perhaps not surprising given its exposure to virtually the whole of the North Sea and any wind from the North or East. There was some suggestion of prey shortage in North Norfolk in 2004 and 2005 and especially continued into 2006, although as no detailed observations are made, this can only be an anecdotal impression.

But what is clear from the overall picture is that the fortunes of birds at Yarmouth make a huge contribution to the success or failure of Little Terns in the UK. Moreover, success or failure of the colonies within the Great Yarmouth North Denes SPA as at other colonies appears to be very much dependent on local factors. The clear shortage of prey for Little Terns in North-east Norfolk in both 2004 and 2005 was largely 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). The latter may also prove to be important in North Norfolk, where ‘whitebait’ is perceived to be an important prey item that seemed to be especially scarce in 2006. Despite a similar relative lack of prey at North Denes in 2006 compared to 2002 and especially 2003, birds appeared to compensate effectively resulting in high productivity (documented as 1.82 chicks pair^{-1} by Allen-Navarro *et al*. 2006). This contrasts sharply with the wholesale failure at the egg stage through abandonment by adults at Winterton in both 2004 and 2005, which was unprecedented in the history of the Great Yarmouth North Denes SPA and the colony at North Denes since monitoring began in 1986.

The failure of Herring recruitment at Scroby in 2004, 2005 & 2006

The largely autumn-spawning Herring stock in the North Sea collapsed between the 1960s and 1976 as a result of the combined effects of over-fishing of adults and immature fish on their nursery grounds leading to poor survival of young fish and subsequent poor recruitment (Scottish Natural Heritage 2004, Fisheries Research Services 2004). A ban on fishing from 1977 to 1983 then allowed stocks to recover.

The spawning stock increased from relatively low levels in the mid 1990’s to its highest level since prior to the collapse of stocks, by 2004 (ICES 2006). This was the result of a succession of strong recruitment events and management measures to reduce exploitation, which remains under the strict control of The International Council for the Exploration of the Sea (ICES). The 1998 and 2000 year classes were very strong, but despite the increase in spawning stock biomass to 2004, there was poor recruitment from 2001 until 2007 (ICES 2008). Recruitment in 2007 was the lowest in 17 years since 1979 (ICES 2007). A combination of poor recruitment and continued exploitation of the available stock at a level above the recommended level of 0.35 means that in order to bring the stock above a biomass (B_{pa}) of 1.3 million tones ICES have recommended there should be no fishing in 2008.

Slower maturation of the strong year classes of 1998 and 2000, which constitute the bulk of the spawning stock, was initially thought to have had some influence on poor recruitment (ICES 2004), but in fact, spawning stock biomass (SSB) 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). Poor recruitment is now thought to stem from factors during the larval phase (ICES 2006). The available 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 to 2003 at least. No figures have been available subsequently.

To the best of the knowledge of the authors there is 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 with general figures for the North Sea. Whilst low recruitment of Herring was reported for the North Sea as a whole in 2003 (and 2002), it was clearly spectacularly good around Scroby, with unprecedented success for the Little Terns at that time, even at Winterton. Success at Winterton is only sporadic, possibly beacause fish concentrated around Scroby may not always ‘overspill’ northwards along the coast and reach similar abundance at Winterton. Nonetheless, Little Terns also recruited well at Winterton in 2002, which also suggests numbers of fish were good in early season. In general, it seems the local stock of Herring is unlikely to exhibit the general trend of fish in the North Sea and in turn, tends to suggest that the birds themselves may depend on relatively local recruitment of YoY.

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 bred successfully even at Winterton and then suffered unprecedented failure through abandoning their nests in 2004, with further abandonment at Winterton in both 2004 and 2005 is therefore strongly suggestive of an unprecedented event in the recruitment dynamics of the Herring, which appears to be their main prey species.

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’, after which mortality of young fish is inevitable.

In the opposite of the examples cited above for sandeels, 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. Herring would thus be predicted to benefit from warmer waters in a similar manner to the zooplanktivorous Horse Mackerel (see *Recent Failures of Seabirds in the North Sea* above) and assuming 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, which has persisted in subsequent winters including to 2005/2006 (http://www.cru.uea.ac.uk). 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. Herring is both disfavoured by the presence of large numbers of *Aurelia* in cooler waters and by the reduction in plankton and thus zooplankton.

The fact that the NAO index is only slightly negative suggests any influence on Herring recruitment would be slight at best, although some effect cannot be discounted. Moreover, 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 ecologically very similar Sprat was of similar abundance in all years (Fig. 8). The peak in abundance occurred earlier in 2005 and then even earlier in 2006, which may reflect the occurrence of suitable drift conditions. The occurrence of Sprat in the area in 2006 at a time normally dominated by Herring also illustrates that there was no obvious factors restricting the growth and survival of young clupeid fish such as competing or predating jellyfish.

Moreover, if Herring had suffered through food limitation this would be expected to show if differences in growth rate between years. The rate of growth of the few Herring present was be relatively low in 2004 although this occurred later in the season and there was no evidence to suggest that the early growth of Herring was affected as the fish appeared in samples at their ‘normal’ length of 30-40 mm at the beginning of the sampling season in both 2004 and 2005. The generally 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. Up until 2004 the spawning stock in the North Sea as a whole was at it highest levels for the last 40 years and fishing mortality was at its lowest for the last 20 years and within safe biological limits (Fisheries Research Services 2004). Whilst a slight increase in fishing mortality coincident with the downturn in spawning stock biomass has now led to the recommendation to cease commercial fishing in the North Sea as a whole, Herring are still relatively abundant. But, this does not mean local effects on local stocks may not occur. 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, although there was some observation by local people (*pers comm*.) of trawling apparently for Sprat/Herring by a large Dutch or Danish vessel in the winter of 2003/2004 in the Lowestoft area.

In relation to disturbance of spawning grounds, Herring are known to spawn in the local area between November and January (Coull *et al*. 1998), coinciding exactly with the period of piling. Whilst there is no indication that Scroby Sands themselves are the location of the spawning grounds as coarser substrate such as gravels are preferred, bathymetric survey does show that gravels occur in Yarmouth Road amongst materials of glacial origin. There is anecdotal information on the occurrence of Herring spawning grounds just offshore of Britannia Pier as well as further offshore east of Scroby Sands themselves (local fishermen *pers. comm*.). Surface trawl samples taken in early 2008 (31st January) in relation to the proposed cable replacement recorded a concentration of Herring dominated by large (>165mm) individuals in an area immediately to the west and within 500 m of the wind farm opposite Snickham's Point and the location of the Little Tern colony. A large shoal of fish was recorded on the echo-sounder simultaneous with the trawl. Examination of these fish revealed them to be in good condition, although long and thin with no evidence of gonad. It was concluded these fish had spawned some time previously (ECON 2008).

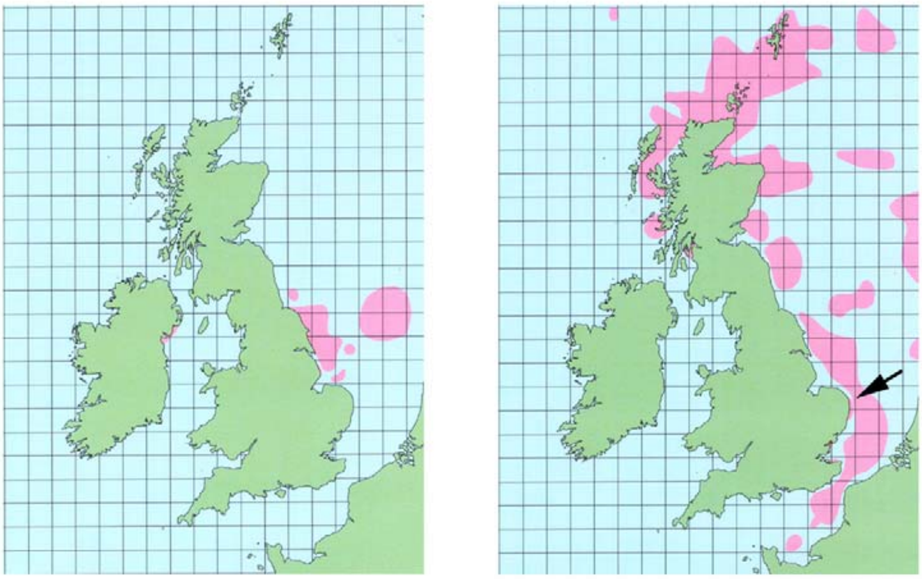
Herring and other related fish are known to be particularly sensitive to underwater noise with the potential for damage to internal organs and the swim-bladder (Nedwall & Howell, 2004). As a result of the sensitivity of fish to noise, Coull *et al*. (1998) produced maps of seismic sensitivity. Primarily 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. 22). Unfortunately, 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.

Pile-driving is an extremely noisy activity generating a Sound Pressure Level (SPL) of between 192-261 dB (Nedwall & Howell 2004). Recent assessment of the potential behavioural and physical effects of pile driving noise on a range of fish species indicates that hearing specialists such as Herring are likely to be able to detect pile-driving at up to 80 km from the source (Thomsen *et al*. 2006), although there is no indication that fish are likely to respond adversely at the limit of their hearing. Moreover, 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.

Despite the sensitivity of the fish species involved, Engell-Sørensen & Holm Skyt (2001) working at Rødsand, Denmark concluded that avoidance reactions were only likely to occur up to just 30 m from the source. Measured noise levels were thought capable of harming the hearing ability of clupeids such as Herring and Sprat, but that this could regenerate over time. In contrast, other studies have shown much more severe reactions than mere avoidance and minor physiological damage.

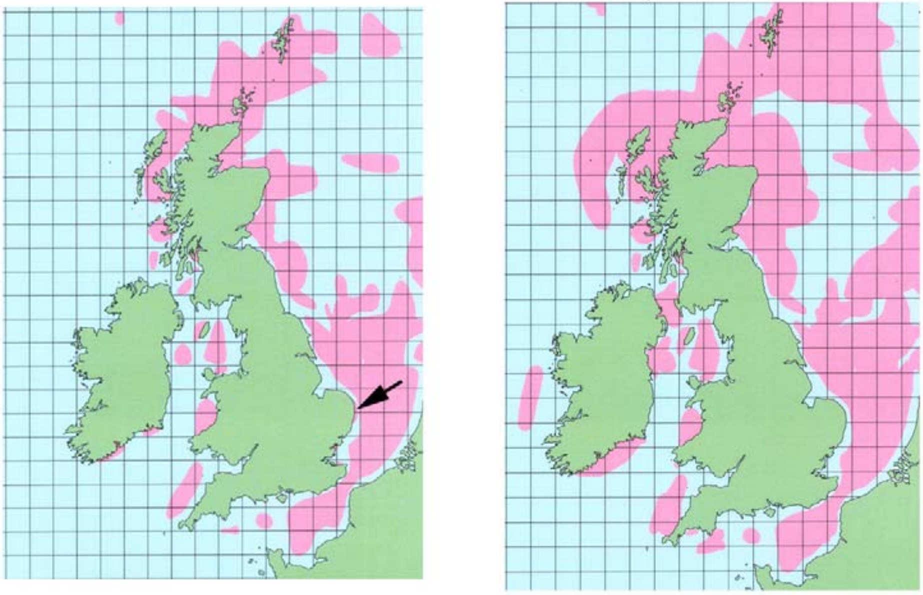
In an experimental study on Shiner Surfperch *Cymatogaster aggregata* in northern California, caged fish were placed at various distances from pile driving being undertaken for a major road crossing. At a sound level of 261 dB, fish within 10-12 m of the pile driving died immediately, with the zone of delayed mortality (i.e. in which fish suffered such injuries that they were likely to die from) extending to at least 150m and possibly up to 1000m from the pile (Caltrans 2001). The impact of pile driving was predicted to vary with species, size and physiological condition of the fish and in relation to environmental conditions. Again, fish with swim bladders were identified as being particularly sensitive. Potential impacts of undertaking pile driving over the winter months were identified for Chinook Salmon *Oncoryhnchus tshawytscha*, Steelhead *O. mykiss* and Pacific Herring *Clupea harengus* (the same species as in the UK). For Herring, mitigation included avoidance of the peak spawning season and should spawn be found within 200m of piling activity, then the latter was to be suspended for at least 14 days until the larvae had hatched and redistributed.

The sort of noise experienced during pile driving at Scroby, which could even 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 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 realistic.



A. October

B. November



C. December

D. February

Figure 22. 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).

From this discussion, it seems plausible that adult Herring would have been displaced from the waters around Scroby if they do indeed spawn around there as suspected. 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, because larvae usually hatch within about three weeks (although this is temperature dependent[24]) 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).

The scenario described above does not account for the continued lack of recruitment of YoY Herring in 2005 and 2006, as any adult Herring displaced in the winter of 2003/04 would be expected to return to spawn. This is unless Herring avoided the area completely, perhaps responding to the noise and vibration of the turbines, however slight. Such an effect seems improbable, as any effect is likely to be local and only operate around a limited area around each turbine. Moreover, even if the effect occurred over a wider area of the wind farm or even the wider area, acclimatisation of Herring to a low level of underwater noise may be expected to occur, as happens in relation to a range of underwater noise associated with vessels and other operations. The fact that numbers of adult Herring were captured within 500 m of the wind farm in the winter of 2007/08 also tends to suggest that displacement was hghly unlikely in the intervening period.

Alternatively, and far more serious, it remains plausible that the pile driving in 2003/2004 severely impacted the local spawning stock of adult Herring through injury and subsequent mortality of enough individuals to generate a population-size impact. There were anecdotal reports from the area of large numbers of moribund fish that were quickly consumed by large gulls (local fishermen *pers. comm*.). Whilst it may seem unlikely a large enough part of the population could have been affected, there is currently insufficient evidence to discount this possibility, particularly since the size (amongst other variables) of the local population is completely unknown. The presence of numbers of adults by the winter of 2007/08 fits with suggestions in previous reports that if the spawning stock was damaged, recovery would be expected within a few years (ECON 2006) following further recruitment into the adult population would be expected to occur fairly rapidly and within a few seasons. The fact that this took several seasons (four years) is consistent with the development of Herring, which may take three or four years to reach sexual maturity and the fact that only small numbers of recruits would have been available from the intervening years.

Continued monitoring of the recruitment of YoY fish from 2007 onwards would clearly have been advantageous to further define the extent of natural fluctuation in YoY Herring recruitment and perhaps even provide retrospective support for one theory over another. For example, a continued lack of recruitment even after the discovery of adults in 2008 would implicate other casual factors rather than construction in the lack of YoY Herring recruitment. A lack of food supply and predation in the larval phase, as suggested to explain poor recruitment of the species in the wider North Sea in the last few years may then have been implicated. However, even if monitoring had continued this could never have compensated for the lack of a detailed specific

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[24] http://www.gma.org/herring/biology/life_cycle

fisheries monitoring programme undertaken at the time of construction. Thus, the link between recruitment failure of YoY Herring and construction activity (pile-driving) could only ever have been circumstantial within the monitoring programme conducted. This link will also remain circumstantial even if further work elsewhere demontrates a clear relationship.

6.2.3 Potential impacts during operation

As outlined above (see 6.2.1) the main impacts upon Little Terns in the operational phase of the turbines requiring evaluation were:

- 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.

Potential collision of Little Terns with turbines

Direct mortality of birds through collision with moving turbine blades and even the stationary monopile structures is the most dramatic of the potential impacts, and the one that typically carries the greatest weight of public perception of a negative effect of wind farms. However, with correct siting of turbines, mortality as a result of collision has generally been found to be insignificant (Percival 2000), although it is notoriously difficult to quantify accurately, both in advance and even once the turbines are in operation. In the case of the latter, quantifying the birds killed by the turbines by searching for and gathering corpses is seriously constrained by the removal of bodies by scavengers and in the offshore environment, by the action of the tide.

Both in advance and even during operation, the likelihood of a potential impact has been evaluated by calculation of the risk of collision. In the UK this has been most typically undertaken through a mathematical model (the ‘Band model’) developed by Scottish Natural Heritage (2000). 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 to the best of the authors knowledge this has not previousy been achieved using radio telemetry to estimate both the time spent in the wind farm and passage rate of any seabird species in relation to an OWF or indeed any species and site combination on land.

Despite Little Terns spending relatively little time in the wind farm and at strike height, the the large number of passages through rotors, which increased markedly during the study, meant that the potential collisions remained in tens of individuals even at an avoidance rate of 99%. Clearly, if Little Terns avoided turbines at a lower rate, the number of collisions would be much higher, reaching something in the value of 69 adults and 17 juveniles per annum. The selection of a meaningful avoidance rate is critical in the assessment of the impact of collision upon the population.

Unfortunately, there is no information on the avoidance rates of Little Terns from other constructed offshore wind farms partly as a result of the relative infancy of the offshore wind industry and the fact that few sites have undertaken detailed post-construction monitoring where terns are a significant component of the bird assemblage. The exception is Zeebrugge in Belgium where the impact of 25 turbines around the port of Zeebrugge, where up to 150 pairs of Little Terns, 1,832 pairs of Common Terns and up to 4,067 pairs of Sandwich Terns breed communally on a created peninsula, has been evaluated (Everaert & Stienen 2006). Zeebrugge differs from an offshore site as the wind turbines are aligned along a breakwater with turbines ranging from ~50-

400 m to different parts of the colony The main difference between the situation at Zeebrugge and Scroby Sands is that at the former breeding birds have to cross a line containing six wind turbines to get to sea, whereas at Scroby birds have to travel ~2 km to reach the turbines and may exert more choice in whether or not to avoid the turbines. The situation at Zeebrugge is therefore likely to provide a 'worst case' scenario.

At Zeebrugge, between 2-10 ind. Little Terns were killed (corrected for scavenging and search efficiency) per year from a daily number of flights of between 1,749 and 375 in 2004 and 2005 respectively in accordance with the varying number of breeding pairs, which was 138 and 11 respectively (i.e. 276 and 22 ind.) in the two different years studied. Notably the proportion of birds within the strike zone (16-50 m) varied considerably between years at 12% and 64% respectively with the latter possibly influenced by smaller sample size, but also perhaps by wind conditions. The avoidance rate was not specificially calculated for any of the tern species. However, working backwards from known bird mortality averaging 42 ind. per annum for Sandwich tern (and 119 ind. per annum for common tern), the number of passages per day at rotor height through the six wind turbines and the wind turbine dimensions, SCIRA Offshore Energy Ltd (2006) estimated avoidance rates in the region of 99.6 per cent for Sandwich Tern and 98.0 per cent for Common Tern with collision risk factors of 25.7% and 23.5% respectively. Assuming all other sources of mortality to be equal, the estimates of additional mortality for all species presented by Everaert & Stienen (2006) suggest Little Tern is closer to Common Tern than Sandwich Tern in its vulnerability to turbine strike. It thus seems likely that avoidance rate is likely to lie somewhere between 98-99% for Little Tern.

In a worst-case scenario of 98%, which is currently favoured as a precautionary avoidance rate for terns in relation to OWF's by Natural England, up to 27 adults and 7 fledglings were estimated to be killed per annum by the end of the study in 2006. With the mean values for breeding pairs and fledged chicks from the Great Yarmouth North Denes SPA (i.e. including both the North Denes and Winterton colonies) should the current rate of predicted mortality be continued then collision mortality from the OWF may represent an average mortality of 6.6% of adults and 4.5% of fledglings per year. The value for adults is remarkably similar to the greater of the two values presented for Zeebrugge at 6.7% (the other being 1.8%). At Zeebrugge, Everaert & Stienen (2006) concluded that estimated additive mortality of >1% for any tern species would result in a significant impact upon that population.

In contrast, other studies have suggested that increases of between 0.5-1% additive mortality may be a significant threat, with some models suggesting that decline could occur in long-lived species at increases of around 0.1% (Everaert & Stienen 2006). In fact, judging the impact of additive mortality is fraught with difficulty as detailed knowledge of population turnover rates and behaviour is required. In theory, some levels of additive mortality may be compensated by density-dependent release of constraints upon breeding productivity. A Population Viability Analysis (PVA) style of approach in which the population is modelled under different scenarios of productivity and mortality may be the most appropriate means of determining the long-term impact of such losses. However, in the absence of this, some idea of the likely impact may be gained from what has become standard matrix analysis in relation to ornithological impacts of wind farms.

The *sensitivity* (Table 23) of the species and the *magnitude* (Table 24) of any negative effect are combined to determine the level of *significance* of an impact (Table 25). This process is based on the Environmental Assessment Regulations 1999 (HMSO 1999) and on the Institute of Environmental Assessment Guidelines (1995). The definitions of sensitivity and magnitude follow those developed by Scottish National Heritage (SNH) and the British Wind Energy Association (BWEA) (Percival *et al*. 1999) that have become the industry standard in recent offshore wind developments in the Thames (eg London Array Ltd 2005) as well as proposed sites in the Wash including Sheringham Shoal (SCIRA Offshore Energy 2006) and Lincs (Centrica Energy 2007).

Table 23. Definition of terms relating to the sensitivity of a bird species during ornithological impact assessment.

Sensitivity	Definition
Very High	Cited interest of SPAs, SACs and SSSIs. Cited means mentioned in the citation text for the site as a qualifying species for which the site is designated (SPAs/SACs) or notified (SSSIs)
High	Other species that contribute to the integrity of an SPA or SSSI (e.g. within an assemblage criterion) An impact on a local population of more than 1% of the national population of a species. An impact on ecologically sensitive species (e.g. large birds of prey or rare birds - <300 breeding pairs in the UK)
Medium	Regionally important population of a species, either because of population size or distributional context EU Birds Directive Annex 1, EU Habitats Directive priority habitat/species and/or W&C Act Schedule 1 species (if not covered above) UK BAP priority species (if not covered above)
Low	Any other species of conservation interest (e.g. species listed on the Birds of Conservation Concern not covered above)

Table 24. Definition of terms relating to the magnitude of an effect upon of a bird species during ornithological impact assessment.

Magnitude	Definition
Very High	Total loss or very major alteration to key elements/ features of the baseline conditions such that post development character/ composition/ attributes will be fundamentally changed and may be lost from the site altogether Guide: >80 per cent of population/habitat lost
High	Major alteration to key elements/ features of the baseline (pre-development) conditions such that post development character/composition/attributes will be fundamentally changed Guide: 20-80 per cent of population/habitat lost
Medium	Loss or alteration to one or more key elements/features of the baseline conditions such that post development character/ composition/ attributes of baseline will be partially changed Guide: 5-20 per cent of population/habitat lost
Low	Minor shift away from baseline conditions Change arising from the loss/ alteration will be discernible but underlying character/ composition/ attributes of baseline condition will be similar to pre-development circumstances/patterns Guide: 1-5 per cent of population/habitat lost
Negligible	Very slight change from baseline condition Change barely distinguishable, approximating to the ‘no change’ situation Guide: <1 per cent of population/habitat lost

Table 25. The level of significance of an impact resulting from each combination of sensitivity and magnitude of the effect during ornithological impact assessment.

Magnitude	Sensitivity			
	Very High	High	Medium	Low
Very High	Major	Major	Major	Moderate
High	Major	Major	Moderate	Minor
Medium	Major	Moderate	Minor	Minor
Low	Moderate	Minor	Minor	Negligible
Negligible	Minor	Negligible	Negligible	Negligible

Table 26. Interpretation of significance categories produced during ornithological impact assessment.

Category	Definition
Major	The impact gives rise to serious concern and should be considered unacceptable
Moderate	The impact gives rise to some concern but may be tolerable (depending on its scale and duration)
Minor	The impact is undesirable but of limited concern
Negligible	The impact is not of concern

As the cited interest of the Great Yarmouth North Denes SPA, the sensitivity of the Little Tern population is of the highest order. This is reinforced by the fact that the population comprises on average some 10.7% of the GB population, 3.5% of the north and western European population and 0.6% of the entire European population including the large, although undefined populations in Russia and Turkey (BirdLife International 2004). At the maximum population size of 369 pairs recorded in 2006, these proportions almost double to 19.4%, 6.3% and 1.1% respectivey.

In theoretical terms, as Little Terns are both a rare species with small population size as well as being long-lived (like most seabirds) with low population turnover, they are especially vulnerable to slight changes in the level of background mortality, which may quickly be felt at a population level. Ultimately, even the loss of a few individuals, raising the level of background mortality of adults in particular, by even fractions of a percentage could result in an unacceptable impact.

Taking the maximum loss of 34 ind. (27 adults and 7 fledglings[25]) per annum through impact assessment reinforces this suggestion, with the local/regional population severely impacted on an *annual* basis. Although there is an undesirable impact at larger population scales this may be seen as tolerable in the short-term.

Table 27. Predicted significance of the additive mortality of 34 ind. Little Terns as a result of collision at the Scroby Sands OWF, at a range of population scales.

Parameters	Local/ regional	Great Britain	Britain & Ireland	Western & Northern European	European
Estimated breeding population (ind.)	410	3,800	4,220	11,746	70,000
Proportion (%) of population affected	8.29	0.90	0.81	0.29	0.05
Magnitude	Medium	Negligible	Negligible	Negligible	Negligible
Significance	Major	Minor	Minor	Minor	Minor

Notes: in order of the minimum number of pairs countries contributing to the Western & Northern European population include the UK (1900 prs), France (1500), Germany (730), Netherlands (463), Denmark (450), Sweden (400), Belgium (224), Republic of Ireland (206), (BirdLife International 2004).

However, the prospective life of the wind farm is over 20 years and assessment of a repeatable annual impact of additive mortality is unlikely to reflect its true importance in population terms. Consequently, expressing the loss of individuals in relation to the level of background mortality is thought to be more appropriate (SCIRA Offshore Energy Ltd 2006, Centrica Energy 2007). Unfortunately, the annual adult mortality of Little Terns is unknown and only an estimate for

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[25] treating fledglings as though they are part of the future population breeding population

other similar species (*Sterna* and *Chlidonias*) of 0.88 may be applied in the manner adopted by Garthe & Hüppop (2004). Using this figure, an assessment of the impact of the mortality of 27 ind. per annum at Scroby Sands on each part of the European breeding population may then be conducted.

As can be seen in Table 28, the loss of 27 adults raises background mortality for the 'average' colony at the Yarmouth North Denes SPA considerably (>55%), which again gives rise to a major and unacceptable impact (Table 28). Moreover, at increases of just over 5%, an impact of major significance extends to the entire GB and Britain & Ireland population. Even at the Western & Northern European population level, the moderate significance of impact is of concern and as it seems unlikely to be of short duration, but extend into the longer term, must be seen as undesirable. Only at the much larger (albeit not well defined) European population level, does an impact of collision mortality at Scroby seem unlikely to be felt.

Table 28. Predicted significance of collision mortality of adult Little Terns (27 ind.) as a percentage over and above the level of background mortality (0.12) at a range of population scales.

Species	Local/ regional	Great Britain	Britain & Ireland	Western & Northern Europe	Europe
Estimated breeding population (ind.)	410	3,800	4,220	11,746	70,000
Number of birds lost per annum	49	456	506	1,410	8,400
Per cent increase above background mortality	55.10	5.92	5.34	1.91	0.32
Magnitude	High	Medium	Medium	Low	Negligible
Significance	Major	Major	Major	Moderate	Minor

It must be stressed that this assessment is theoretical and there is as yet no evidence to prove or disprove such a level of impact. However, the potential for significant impact upon Little Terns at a national and even international scale is of clear concern and this should trigger further monitoring of the situation. Unfortunately, measurement of actual mortality through collision at offshore wind farms is difficult in practical terms as collision victims are simply washed away by the tide as well as removed by scavengers such as large gulls or possibly even large fish.

To date, only the studies at Kalmar Sound through extensive visual observation from a permanent tower structure (Pettersson 2005) and the studies at Horns Rev and Nysted in Denmark using both radar and the TADS system, both of which also record movement of birds at night (Desholm & Kahlert 2005, Desholm *et al*. 2006), have successfully tackled the difficulties of monitoring actual collision of birds in relation to offshore turbines. Nonetheless, as well as these techniques, the use of video cameras and the basic practical approach of installation of net structures (similar to the safety net in human circus acts) to 'catch' victims at selected turbines show promise and may also prove to be applicable at Scroby Sands.

Disturbance/displacement of Little Terns by the wind farm

Disturbance may be defined as an action that causes a bird to change its behaviour in a subtle way as well as resulting in an actual flight or dive response to a perceived threat. The severity of the disturbance event may then be judged by how far and for how long the bird is displaced from the area. Displacement may thus be temporary, associated with a specific disturbance event such as occurs in construction, or may become permanent as birds subsequently avoid the area completely, such as is possible during operation.

Especially with continuous forms of disturbance, birds may habituate over time and re-occupy areas that became unavailable after the initial disturbance. Whether or not habituation occurs depends on a number of factors, and may be highly species or group specific. The extent and availability of the habitat from which the bird was initially displaced in relation to nearby alternatives is also likely to determine the speed of habituation.

During its operation, birds like Little Terns that spend much time on the wing may avoid and thus be displaced from a wind farm, as a result of the presence of moving structures and/or the additional level of background and regular noise. As the latter is regular and does not appear to be at a particularly loud level, and as birds are generally more responsive to visual compared to sound stimuli, it is generally perceived that it is the moving structures that are likely to cause any disturbance/displacement (SCIRA Offshore Energy Ltd. 2006, Centrica Energy 2007). However, it is not known if birds understand whether turbines offer a risk of deadly collision and they respond accordingly or if any response is governed by a more general perception of risk of the novel.

The response of a species to moving structures may be based on the individuals’ perception of its ability to avoid mortality as a result of a threat. Thus, highly manoeuvrable flying species, which are unlikely to suffer mortality from aerial predators may be rather insensitive to any threat. Thus, Garthe & Hüppop (2004) suggest terns, gulls and skuas have lowest sensitivities to disturbance compared to seaduck, divers and auks. At Scroby Sands, the perception was that Little Terns would be unlikely to be displaced by the turbines given that there are no other similar cases for a range of bird species (Percival 2000).

A lack of suitable prey in waters closer to shore was suggested to cause of greater ranging behaviour of Little Terns (see also Perrow *et al*. 2006), which led to an increase in the use of Scroby Sands and the wind farm itself (Figure 23). In 2004, the largest number of birds yet encountered at a site recorded in the southern part of Scroby in early season. In addition, in both 2004 and 2005, birds were recorded on several occasions on the outer edge of Scroby near the wind farm, where they had never been recorded before. During radio telemetry in 2005, birds were recorded at up to 6km offshore, suggesting frequent use of Scroby within the zone in which the wind farm is located. By 2006, 2% of all location fixes were within the wind farm itself. A larger number of birds were also recorded during boat-based surveys although variation between surveys meant this was not significant. It is clear then that there was no evidence of displacement of Little Terns from the operational wind farm.

Changes in the distribution of Little Terns at Scroby

As detailed above, radio telemetry, boat-based surveys and observations of birds leaving the beach at North Denes to forage, confirmed the increased relative use of Scroby Sands following construction (Fig. 23). Although this was thought to result from the reduced supply of fish prey closer to shore, it also implies that at least some prey were available further offshore. However, relatively few prey animals have generally been recorded in offshore sampling points (Figs 7 & 10), with the notable exception of the huge catch of Ghost Shrimp at Site 1 in early season in 2004. Whilst this is thought to have contributed to the overall significant increase in invertebrate abundance in 2004 it remains difficult to judge whether there was actually any increase in prey abundance offshore. The perception is that prey are extremely patchy, both spatially and temporally, and centred on extremely shallow waters on flooding and ebbing tides around the sand banks of Scroby. Such areas may be readily exploited by Little Terns, but could not be adequately sampled by the vessel and the sampling programme in this study and the finer details of prey distribution remain unclear.

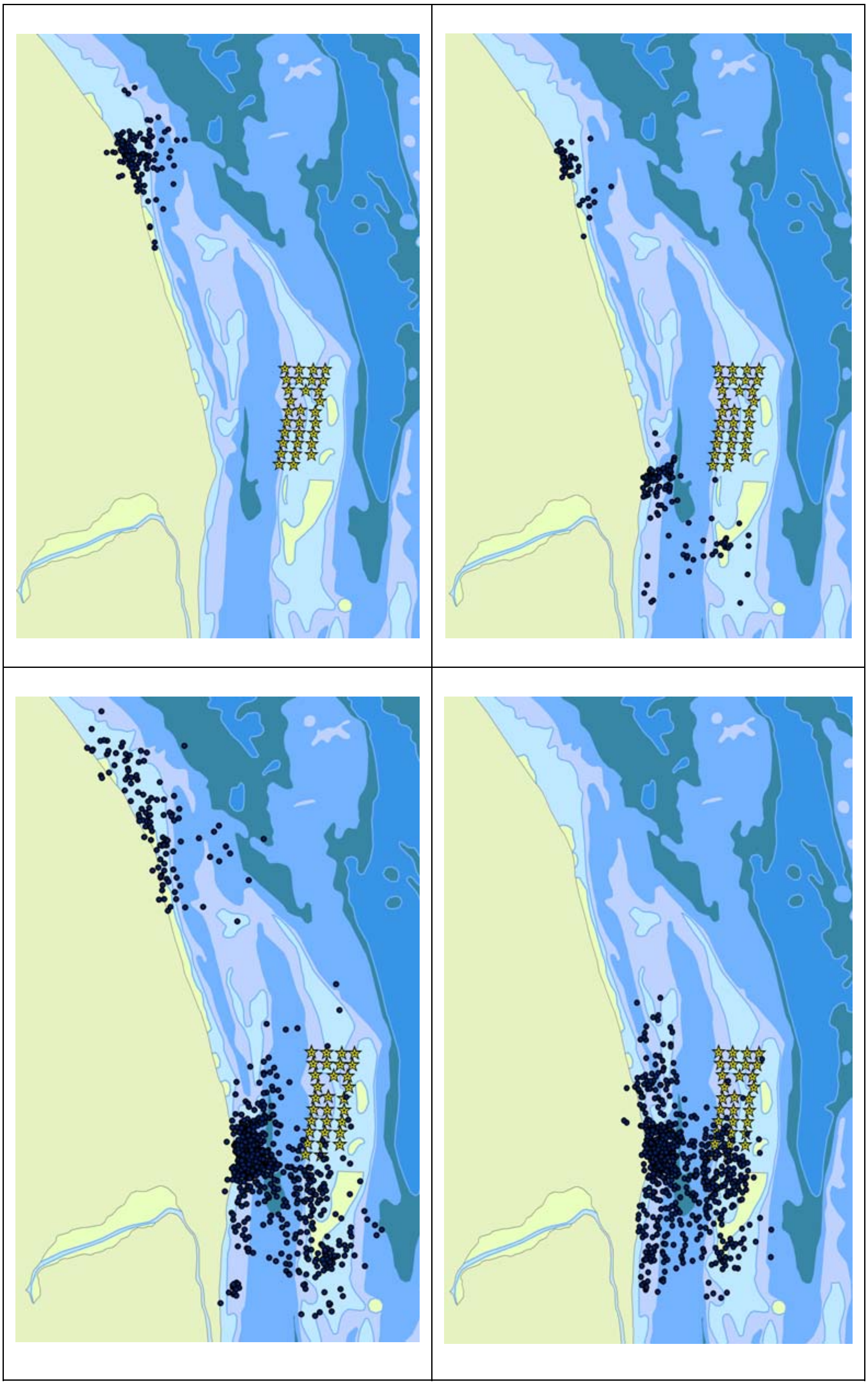

Figure 23. Foraging fixes of all radio-tagged Little Terns from each year at both North Denes (ND) and Winterton (W): 2003 (W) above left, 2004 (W & ND) above right, 2005 (W & ND) below left and 2006 (ND) below right. The location of turbines is indicated by yellow stars.

Consequently, it is unknown whether the increased use of Scroby by Little Terns tracks an increase in relative abundance of prey, which in turn is linked observed changes in the nature of Scroby beginning in 2004 and continuing to 2006, especially the formation and persistence of a subsidiary sand bar through the wind farm (Plate 19) and further sand bars near the wind farm. An increase in the area and/or number of exposed sand bars is thought to have increased the foraging opportunities for Little Terns. It then remains important to determine whether the geomorphical changes observed may be attributed to the presence of the wind farm.

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 1cm) compared to the natural variations of ±3m over the last 150 years*.' The displacement of the sand bar system was also predicted to '*be small (of the order of 10m) compared with the extent of the banks (1.5km–2km wide and 10-12km long)*'. The report also stresses the roughness of this calculation, and states that this figure may in fact be anywhere between 1m and 30m. 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).

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 poor 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 - 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.

The collaborative monitoring programme conducted at Scroby following construction as well as a number of other sites led by Jon Rees at CEFAS, was seen to be of crucial importance in developing understanding of geomorphic changes resulting from turbine bases. To the best of the authors' knowledge final reporting is yet to be completed, although presentations of monitoring results have been made in a number of meetings, both internally and externally, including at the international Marine Renewable Energy & Environment (MAREE) conference in June 2008. It is understood that scour pits around each turbine base were readily detected, extending to a radius of around 7m around each turbine and that scour protection in the form of rock/stone at straetegic points around each turbine base also led to secondary scour pits. The material from scour appeared to be deposited downdrift (i.e. in a broadly southerly direction) from each base creating a 'tail' that extended over several hundred metres some way to the next turbine downdrift. However, as the monitoring was conducted within the wind farm concentrating around the turbines themselves, it remained impossible to determine whether the turbines were responsible for wider scale changes such as the formation of the subsidiary sand bars and ultimately the build-up of the main head of Scroby Sands several kilometers to the south which remained emergent at all states of the tide in 2006, the first time this is thought to have occurred for over 30 years. Analysis of the nature of the system compared to other sites revealed just how dynamic Scroby Sands may be with both winter and summer storms theoretically re-modelling large parts of the system (J. Rees *pers comm*.).

Whatever the cause of the subsidiary sand bar within the wind farm, it is plausible that this represents an increase in available foraging habitat, especially in years of low prey availability. Even prior to construction of the turbines, ECON (2003) speculated that the presence of 30 large structures anchored to the bed would have at least a local effect, with possible repercussions for the prey base of Little Terns. Any effects were thought more likely to be *positive* rather than negative, as for example, small fish may concentrate around the structures, as they do around reefs and wrecks, or currents around structures would tend to bring small prey animals such as Ghost Shrimp closer to the surface where they become available to Little Terns. However, any increase in prey availability resulting in the attraction of Little Terns to the wind farm must then be tempered by the increased risk of collision with turbines.

7. CONCLUSIONS & RECOMMENDATIONS

The described in-depth single-species study in relation to an offshore wind farm is without precedent in the UK. It is suggested to have more than achieved its FEPA license requirements. Moreover, the monitoring undertaken has significantly advanced understanding of the foraging and breeding ecology of Little Terns at their most important breeding colony in the UK, which is also of international importance. The information gained may prove invaluable to the species' future conservation.

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 2003 to early January 2004 and during turbine construction itself until August 2004. Post-construction impacts were to be evaluated in monitoring conducted in 2005 and 2006.

Throughout the study an attempt was made to extend monitoring to include Winterton cSAC (candidate Special Area of Conservation), a traditional breeding site located some 12km to the north included in the Great Yarmouth North Denes SPA for Little Terns, which had only been sporadically used in recent times (over the last 20 years). Further sampling in other areas to the north (e.g. Eccles), occupied by what may be termed the North East Norfolk population of Little Terns was also attempted. The displacement of many Little Terns from North Denes to Winterton from 2002 through to 2004 seemingly largely as a result of disturbance reinforced the value of this inclusive approach. Although the relative lack of breeding terns at North Denes in this period inevitably hampered the establishment of baseline conditions upon which the impact of the wind farm was to be judged, detailed monitoring of specific aspects of foraging ecology including the successful use of radio telemetry on Little Terns for the first time coupled with the judgement of the potential impact on the entire SPA population, enlightened the potential impacts both positive as well as negative, of the wind farm. However, it must be noted that in relatively short-term studies of this type in which interactions are likely to be complex between the birds, their prey and predators, stochastic factors such as climate and disturbance as well as the focus of the study, in this case the offshore wind farm, it is extremely unlikely that cause and effect can be unambiguously determined. A carefully reasoned approach must therefore be adopted to try and establish the *most likely* cause of observed patterns. Given the conservation importance of the species and the site the precautionary principle was also applied throughout.

The nature of the prey resource was suggested to the driving factor behind North Denes as the site of choice for breeding Little Terns in North-East Norfolk. Although data was limited and subject to intra and inter-seasonal differences, as a general rule, fish were more abundant at Scroby and North Denes reaching 2 ind. 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 clupeid fish were thus often significantly associated with more turbid water.

Whilst adults may feed on a wide range of invertebrates and fish, observations showed that YoY Herring/Sprat (clupeids) were by far the most important prey resource for chicks underpinning the success of the colony. In accordance with the known distribution of spawning and nursery areas the area around Scroby Sands appeared to be by far the most important nursery area for clupeids along the stretch of coast sampled (possibly including into North Norfolk). What were thought to be locally born Herring appeared in the first samples in May at about 35mm in length. Peak numbers were then recorded in June, before numbers rapidly declined, perhaps as they fish moved further offshore. Judging from the previous pattern documented by the RSPB with colony inception often underway by mid-May, the breeding cycle of Little Terns in the area seems 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. An abundance of YoY Herring was therefore thought to be a prime determinant of successful breeding, similar to the established links between other seabirds and particular prey species.

In contrast, Sprats spawn offshore with larvae probably transported into the area through residual drift. Sprats typically appeared in samples at about 20mm 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 Sprats although they may still experience a decline in the abundance of available prey for chicks.

Whilst a good food supply is an essential prerequisite of breeding performance this may be modified by disturbance and predation and it becomes important to judge the relative impacts of different factors on the SPA including both colonies at North Denes and Winterton. In 2002, the colony at North Denes (98 nests) was destroyed by a single act of vandalism, although a small number of pairs (~7) managed to persist and fledge chicks (~5 ind.). In 2003, helicopter patrols were thought to displace birds from North Denes before breeding was attempted, although 10 pairs did eventually nest, fledging just 2 chicks. It appears there was sufficient prey available at Winterton in both 2002[26] and 2003 for birds to switch sites and be successful. This was below the SPA average in 2002, when a minimum of 124 pairs (SPA average = 205 pairs) raised a minimum of 43 chicks (SPA average = 157 ind.) but was spectacularly successful in 2003 with 233 pairs fledging 447 chicks. At the time, this was a greater total and productivity per pair (1.92) than had ever been achieved at North Denes and indeed, was the largest number of chicks fledged from a single colony since records began in 1969. The impact of this recruitment event was thought likely to be positively felt for years, even decades (ECON 2006). It was also thought to be no coincidence that only in 2003 did maximum fish density (in excess of 1 ind. m^{-2}) match values recorded at North Denes (see below).

Despite success in 2003, unprecedented failure at the egg stage through abandonment was recorded at Winterton in 2004[27] and then again in 2005. Mass abandonment involving most of the 150 nests in 2004 (compared to 40 at North Denes) and 83 nests in 2005 had not been documented at the colonies at North Denes and Winterton since the inception of colony protection at the former in 1986. Just 2% of the nests were believed to have hatched chicks in 2004, with the

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[26] Assessment of fish abundance at Winterton at 2002 was limited by the late start of sampling.

[27] Although there was also a disturbance event most likely perpetrated by humans and their dogs in 2004.

few chicks that did so thought to have been consumed by Kestrels as was also the case at Eccles. This pattern was repeated in 2005.

Conditions were similar at North Denes in 2004, with just 2.5% of the 40 nests put down over the course of the protracted season hatching chicks. Predation by foxes was the most significant cause of egg loss. Ultimately, with no fledged chicks from either site in 2004, this was the worst year on record from the SPA. Even in 1996 when Kestrel predation decimated chick numbers at North Denes colony, a few **(X)** chicks fledged at Winterton.

In 2005, 60% more nests were laid, with the bulk of these at North Denes (peak of 221 active nests). However, this was still below the SPA average and far lower than expected as a result of the predicted return of individuals from the 2003 cohort to breed for the first time[28]. The bulk of these nests were put down extremely late in the season in both 2004 (early July) and 2005 (30th June) rather than the typical period of mid- to late May.

The exceptional response of delayed breeding, mass abandonment at the egg stage, extremely low foraging success and ultimate failure of all colonies in North East Norfolk in 2004 were thought to mirror an exceptionally acute shortage of prey, seemingly beyond the typical inter-annual variation in recruitment of YoY clupeids. 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, especially given that larval recruitment of many species is a notoriously variable affair.

Indeed, recruitment of Herring in the wider North Sea appears to have poor since 2002 following the strong year class of 2001. Little is known of the factors responsible although it is speculated that these are operating on the larval phase (e.g. food supply or predation) implying fecundity is not limiting. The clear mismatch between trends in the wider North Sea and the Scroby area where there is a clear reduction only after 2004 illustrates the difficulty of applying gross patterns to a species with discrete spawning stocks susceptible to local impacts.

Of the factors considered, the potential for a short-term impact of the piling of the turbines at Scroby conducted from November-December 2003, coincident with the documented spawning and initial development period for Herring in the area could not be discounted, especially given recent research on the impact of underwater noise from pile driving on fish showing the considerable avoidance, injury and mortality at surprisingly large distances from the source of the noise. However, the continued lack of recruitment of YoY Herring in 2005 and 2006 cannot be explained by an impact of construction activity in the winter of 2003/04 unless it was the adult spawning stock of the area that was severely impacted. If this was indeed the case, the capture of large mature Herring in early 2008 that appeared to have spawned (ECON 2008) may indicate recovery of the stock and the prospect of resumed recruitment of YoY Herring. It is recommended that a ‘watching brief’ be maintained on numbers of YoY fish, especially Herring, through resumption of the annual monitoring of prey at sea.

The reduction in available prey from 2004 onwards produced clear effects on the ranging behaviour and foraging success of Little Terns. Birds significantly increased kernel home range, foraging significantly further from shore within the range of the wind farm, flew faster to reach more distant foraging areas whilst suffering a significantly lower rate of dives producing fish. Nonetheless, through these and possibly other compensatory mechanisms (perhaps including the respective roles of each parent and an overall reduction in attendance of the chicks), Little Terns maintained and even significantly increased the provisioning rate to chicks in 2006.

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[28] All but one of the 17 controlled Little Terns initially ringed as pulli were born at North Denes (15) or Winterton (1) indicating a high degree of site fidelity.

This, as well as an earlier peak in YoY Sprat abundance more akin to the typical pattern for Herring promoting more ‘normal’ timing and synchrony of reproduction aided the unprecendented success of the North Denes colony in 2006. However, production of a record number of fledged chicks (673 ind.)[29] also owed much to the resumption of supplementary feeding of Kestrels, with 2006 marking the initiation of a six-year programme alternating ‘feeding’ with ‘no feeding’. This was in response to the decimation of the colony in 2005 when just 11 Little Tern chicks are thought to have fledged after >400 were systematic predated by the Racecourse pair of Kestrels, as they successfully raised their own brood of five chicks. This was after high clutch survival (74% - itself perhaps linked to an increase in wardening effort at the colony, compared to 2004).

Clearly, even if there was a negative indirect impact of construction of the wind farm upon the prey resource of Little Terns, the birds were generally able to compensate for the effects of a reduced prey supply through a series of behavioural mechanisms apart from perhaps in 2004 when prey was at a particular low level. Any impact of construction thus appeared to be short-lived.

However, the increase in foraging range resulting from a decline in prey abundance coupled with the changes in the nature of the habitat within the wind farm, namely the formation of a subsidiary sand bar led to an increasing use of the wind farm area by Little Terns. Whether the change in habitat was linked to the installation of the turbines and thus a true positive indirect impact or was simply coincident remains unknown. Whatever the case, there was no evidence for one of the main perceived impacts of a wind farm, that of avoidance leading to displacement. In fact, usage of the wind farm area increased in the operational phase of the wind farm as birds utilised the increased area of foraging habitat. But, this potentially potentially positive impact of Little Terns to the wind farm was tempered by their increased risk of collision, which was further exacerbated by an increasing number of breeding birds at North Denes by 2006.

Despite the relatively low use of the wind farm area and the tendency of Little Terns to fly below turbine height, such was the number of passages through the wind farm area during the period of colony occupancy by Little Terns that modelling the risk of collision showed the number of Little Terns potentially colliding with turbines could have population-scale effects from a local-regional scale up to an international scale, particularly when considering the impact on likely background mortality.

However, it should be stressed that this is a theoretical impact and further work is required to assess whether this is indeed likely to occur. The following is recommended:

- Actual monitoring of the rate of collision – which will require development of novel techniques such as capture of collision victims at selected turbines with net structures, adaptation of video cameras, TADS or radar, or extended visual monitoring from fixed structures.
- A form of Population Viability Analysis (PVA) to determine thresholds of ‘acceptable’ mortality levels below which population-scale effects are unlikely.

Should measured and predicted levels of mortality prove to be unacceptable, this should trigger mitigation measures. The most obvious of these is shutdown of turbines most obviously during colony occupation (May to August), although this may be effective only during especially vulnerable periods if these can be established (perhaps later in the chick development period as fish density declines). An alternative approach to ‘compensate’ for collision victims could be

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[29] Whilst this remains the official figure, this is determined by a single experienced individual and is considerably higher than predicted by the detailed monitoring of number of nests and mean clutch size undertaken by the wardens and the average number of chicks in broods observed in this study.

even more intense proactive wardening/ protection to ensure maxiumum productivity from the colonies, although further production of chicks cannot compensate for loss of breeding adults on a one to one basis, but needs to account for the mortality of juveniles until they breed

Alternative mitigation could even extend to creation of suitable nesting and foraging habitat at alternative sites such as Winterton or even Caister where birds also used to nest, perhaps with the intention of drawing birds away from the wind farm area. The establishment of a small colony at Eccles where birds are thought to forage around the offshore reefs illustrates the potential for this idea. However, the expense may be prohibitive and the installation of the Outer Harbour at Yarmouth may already provide such an alternative structure.

Finally, it must be highlighted that should Herring recruit in coming years as effectively as they did in the early years of this study (e.g. 2003 and possibly also 2002) prior to construction, Little Terns are unlikely to have to routinely range as far as the wind farm area, or if so, may simply concentrate on Scroby Sands themselves. In this case, the risk of collision will inevitably decline. With the cessation of monitoring in 2006, nothing is known of the subsequent recruitment of YoY Hering in the area, save that adult Herring may have spawned successfully in the winter of 2007/08. More information on spawning grounds, the impact of local small-scale drift fisheries on adults and perhaps the factors promoting larval recruitment could lead to protection of important sites and reduction of fishing through no-take zones/seasons (requiring the full support of local fishermen).

However, this assumes maintenance of a known *status quo* of habitat conditions for Little Terns at North Denes. Given that a major new development in the form of the Outer Harbour, has been initiated over the last two years which is within 2km of the colony and thus well within the foraging range of the birds from the colony, with prospective impact at a range of scales, this perhaps seems unlikely. As there appears to be no requirement for monitoring of any prospective link to the Great Yarmouth North Denes SPA and its Little Terns, their prey and habitat conditions in relation to this massive development, again points to a resumption of baseline monitoring of selected aspects undertaken in this study. The logic being to at least attempt to determine if any future observed changes could be linked to the wind farm or are more likely to be attributed to the Outer Harbour or other stochastic factors. Such monitoring may also provide a measure of the value of any mitigation measures adopted.

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