



## Literature review of tern (*Sterna* & *Sternula* spp.) foraging ecology



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## 1 Introduction

The JNCC is currently working to identify important marine areas around the UK that are used by breeding terns to inform the identification of areas suitable for designation as marine Special Protection Areas (SPAs).

This report aims to inform this process and is a synthesis of the current knowledge of the foraging ecology of five species of tern; little tern *Sternula albifrons*, Sandwich tern *Sterna sandvicensis*, common tern *Sterna hirundo*, roseate tern *Sterna dougallii* and Arctic tern *Sterna paradisaea*. For each species, a brief introductory synopsis of the breeding distribution, nesting requirements and body size is given to provide context. The main body of text then covers foraging range, foraging habitat, foraging behaviour, and diet of adults and chicks (although focussing on chick provisioning, as this is what is predominantly covered in the literature) during the breeding season. A summary of foraging ecology closes each species account.

The geographical scope of the review is worldwide, although there is a heavy bias in the published literature towards Europe and the US.

## 2 Methods

An initial search was carried out for each species using the search engine Scirus ([www.scirus.com](http://www.scirus.com)). For each species in turn, the following search terms were used; species\* + foraging, species\* + “prey preferences”, species\* + “chick diet”, species\* + “chick provisioning”, species\* + “foraging range”, species\* + “foraging habitat”, species + “feeding behaviour”. The use of \* allowed the species name in both singular and plural to be searched for.

A relatively high proportion (often >80%) of the papers delivered by the search engine were not relevant, which required manual removal. Titles were scanned and potentially relevant articles were downloaded to the reference manager, Zotero, where the abstracts were read to allow further filtering and removal of irrelevant papers. Key references within papers were also located where possible, along with relevant PhD theses and colony reports. The recent publication on terns by Cabot & Nisbet (2013) was consulted as were records for each species in Birds of the Western Palearctic (BWPi 2006), and other general books on or including seabirds (i.e. Cramp *et al.* 1974, Lloyd *et al.* 1991, Mitchell *et al.* 2004, Brown & Grice 2005, Forrester *et al.* 2007) and the website <http://seabird.wikispaces.com> (Lascelles *et al.* 2013).

A list of studies showing foraging ranges is presented in Appendix 1 and lists of prey items recorded for each species can be found in Appendix 2.

## 3 Species accounts

### 3.1 Little tern

### *Sternula albifrons*

Little tern colonies are widely scattered, but with a distinct concentration in south-east England (Mitchell *et al.* 2004, Brown & Grice 2005). The little tern is the smallest of the five UK species, with a body length of 22–24 cm and a wingspan of 48–55 cm (BWPi 2006). Colonies in England tend to be small, on shingle or shell beaches with little vegetation, holding on average around 30 pairs, although numbers can reach up to 300 (Brown & Grice 2005). In Europe, nesting historically

occurred inland along rivers and lakes (Cramp *et al.* 1974), although this now seems to be quite rare now owing to canalisation of water courses.

### 3.1.1 Foraging range

Little terns have the smallest foraging range of the five species; maximum range = 11 km, mean maximum range ( $\pm$  S.D) =  $6.3 \pm 2.4$ , mean = 2.1 km (Thaxter *et al.* 2012), although the authors give low confidence to this assessment, due to a small number of studies (12) quantifying foraging range, and even fewer (one) direct tracking study (Perrow *et al.* 2006). Most studies, including those giving anecdotal evidence, report a foraging radius of less than 4 km from the colony (Fasola & Bogliani 1990, Phalan 2000, Allcorn *et al.* 2003, Bertolero *et al.* 2005, BWPI 2006, Fujita *et al.* 2009, Perrow *et al.* 2006, 2008, Langston 2010).

There is variation in foraging range, between years and between colonies. The only study using radio-telemetry found large inter-annual variation in foraging activity, with birds travelling more than 2.5 fold further in one of the study years (mean distance travelled ( $\pm$  S.E) 2004: =  $5.6 \pm 1.5$  km; 2003: =  $2.2 \pm 0.3$  km, Perrow *et al.* 2006). It was suggested that the larger distances in 2004 were related to the lack of herring *Clupea harengus* recruitment, causing the birds to fly further to find food (Perrow *et al.* 2006).

Variation between colonies is likely to be due to different habitat conditions and prey availability offshore. For example, in years of high prey availability, Perrow *et al.* (2004) showed birds from North Denes, Norfolk, tended to forage very close to shore whilst birds at the nearby colony at Winterton, tended to forage at twice the distance, with activity focussed on a sandbank a few hundred metres from shore. However, when prey became scarce, birds from North Denes were able to utilise the shallow waters of Scroby Sands parallel to the coast at around 2 km offshore. At Winterton, however, foraging was still restricted to the same sandbank as within ~1 km the waters are deep (>30 m) and clear (*pers obs*) and potentially unsuitable for foraging (Perrow *et al.* unpubl. data).

Within colonies, variation has been found during different stages of breeding; with foraging ranges being significantly greater during incubation (April-May ~1.6–2 km) than during chick rearing (June-July ~1–1.2 km) as a result of the constraint of chick feeding duties (Paiva *et al.* 2008). Within colony variation may also be related to tides; birds that were sighted at larger distances from their colonies in a study in Portugal were observed during intermediate tidal states (receding and incoming tide), when the currents are stronger, suggesting that adults may invest more in travelling longer distances to reach areas with stronger currents (Paiva *et al.* 2008).

There is virtually no information on the effects of weather on foraging range, with only Howe (2003) suggesting that wind strength and wave height affected the distance of foraging from the colony. As both wind strength and wave height increased, birds foraged further from shore, but at the highest wind speeds recorded they resumed foraging at the same distance as the lowest wind speeds. At the highest wave heights, birds concentrated their activity in the surf line closer to the colony than in any other category. It is noteworthy however, that at the colony concerned, foraging activity was concentrated within about 500 m of the shore anyway.

### 3.1.2 Foraging habitat


Little terns are almost exclusively coastal preferring areas with abundant food such as channels and lagoons where stronger currents may increase prey availability, rather than deeper marine habitats (Allcorn *et al.* 2003, Taylor & Rowe 2004, Bertolero *et al.* 2005, Paiva *et al.* 2008). However, little terns will fish over sandbanks out to sea if conditions/prey availability dictate (Allcorn *et al.* 2003) and at North Denes, Norfolk the preferred foraging area behind the promontory around which the colony is located is relatively deep water of 15-30 m (Perrow & Eglinton 2014). Otherwise, little terns may forage in very shallow waters less than 1 m deep, and frequently in the breaking shoreline (Davies 1981, Allcorn *et al.* 2003) and in some areas, foraging preferentially at low tide when prey may be more available (Paiva *et al.* 2008). Perrow *et al.* (2008) found 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. Thus, turbid waters may be an essential prerequisite for this shallow diving species, as it brings their small fish prey closer to the surface where they can be reached. A similar conclusion was reached by Cyrus (1991), who noted little terns concentrated their foraging activity in a plume of turbid water from a large river mouth. Most studies on habitat use are descriptive studies only, but these have shown variation in the habitats used between and within colonies. Within colony variation is likely to be linked to changes in key areas of high prey abundance (see above). Between colony variation in foraging habitat is likely to be largely influenced by habitat availability close to the colony, but can be influenced by the presence/absence of predators and competitors. In the Ebro Delta, Spain, adults from several colonies tended to forage over fresh and brackish waters and not the available marine habitats, which the authors hypothesised was a means of avoiding interspecific competition (through predation and kleptoparasitism) with larger gulls and terns (Bertolo *et al.* 2005). Paiva *et al.* (2006a) suggested the presence of a high energy-content euryhaline fish species as well as more sheltered conditions and no tidal influences, was important in explaining the use of salinas by little terns, despite the fact that chick growth was slower here than on sandy beaches.

There are few detailed studies of within year variation in foraging habitat, although Perrow *et al.* (2008) reported a peak in the use of sand banks at Scroby at the beginning and end of the season, suggesting that this may be linked to the availability of invertebrates, as fish are rarely recorded in samples in these habitats. In an Irish colony, Phalan (2000) suggested a shift in foraging habitat over the season as shown by the switch from a chick diet predominated by brackish water species to marine species. There is a lack of information looking at between year variation in habitat use or the effects of weather.

### 3.1.3 Foraging behaviour

Little terns typically forage from a height of 4-8 m, but sometimes higher, and feed by plunge diving from a hover or dip or splash (partly immerse) to take prey at the water surface (Dunnet *et al.* 1990, Cabot & Nisbet 2013). They hover adeptly with very rapid wingbeats and do so more frequently and for longer than larger species. There is little information on how deep this species dives, but photographs reveal that full immersion does not tend to occur and the wings remain visible, suggesting that prey are captured at no more than 30 cm from the surface (M. Perrow pers. obs).

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Little terns often forage into a headwind, presumably as this aids hovering, but foraging becomes more difficult in strong winds or when the water is choppy (Davies 1981). In strong winds, birds may 'sail' to the surface with wings held aloft rather than fold them and dive (M. Perrow *pers obs*). Tide and wind speed also influence the prey delivered to chicks by influencing the availability of prey. Paiva *et al.* (2006a) for example, found that larger *Fundulus* sp. individuals were delivered during high and incoming tides and that more *Atherina* spp. were delivered during windy weather, whilst more *Pomatoschistus* sp. were delivered in calm conditions.

Davies (1981) suggested that foraging rate at a colony in the Wash, UK increased during last two hours of the rising tide, and to a lesser extent, on falling tides (Davies 1981). The study of Howe (2003) at Winterton in East Norfolk showed a similar pattern with nearly 50% of all foraging activity occurring on an incoming flowing tide, with a further 24% of activity as the tide ebbed. Prey capture rate and dive rate were not significantly different across tidal states, however, although the largest fish were captured on flowing tides. Wind speed and wave height also influenced foraging activity, although not in a linear fashion. Whilst dives per minute initially reduced with increasing wind speed, they recovered to a maximum level at the highest wind speeds recorded. Both dive rate and prey capture rate were also significantly higher at the highest wind speeds. The reason for this success appeared to be linked to the creation of good foraging conditions in the surf as a result of strong winds and especially larger waves presumably bringing small fish and invertebrate prey to the surface, where they are readily available to the birds.

Howe (2003) found no diurnal pattern of foraging activity in contrast to the study of Davies (1981) that suggested a peak of activity in early mornings and late evening, although this was coincident with tidal patterns in the period of observation.

### 3.1.4 Adult & chick diet

Little tern adults and chicks consume a relatively wide variety of prey types although diet consists predominantly of small fish such as clupeids (e.g. herring and sprat *Sprattus sprattus* in the UK and sardine *Sardina pilchardus* in the Mediterranean) and sandeels *Ammodytes* spp. and crustaceans, annelid worms and even insects (Davies, 1981, Fasola *et al.* 1989, Bogliani *et al.* 1994, Paiva *et al.* 2006b, Phalan 2000, del Hoyo *et al.* 1996, Perrow *et al.* 2008, 2011a).

Little tern chicks in the UK are generally fed on small (30–70 mm) often young-of-the-year (YOY) clupeids and sandeels, (Davies 1981; Cramp 1985; Phalan 2000, Perrow *et al.* 2004, 2006, 2011a). There is less information on adult diet but this often consists of larger proportions of invertebrates than chick diet, including ghost shrimp *Schistomysis spiritus* and sea slater *Idotea linearis* (Perrow *et al.* 2008) while chick diet tends to be characterised by a higher proportion of prey with higher energetic value (Catry *et al.* 2006).

Adults select prey according to the size of chicks, with smaller prey of the same species given to smaller chicks (Davies 1981, Bogliani *et al.* 1994, Phalan 2000, Paiva 2006a, Brockless *et al.* 2010). Phalan (2000) also found that smaller chicks received a more diverse selection of prey items than older chicks, with common gobies *Pomatoschistus microps* being the most important prey item for chicks 0-7 days old and sandeels becoming more important for older chicks. This may be an artefact of higher sample sizes for smaller age classes but if the relationship is real it implies a shift in foraging habitat through the season as gobies are more typically found in brackish and estuarine waters, whereas sandeels are marine fish. Diet of



both adults and chicks differs between colonies due to availability of different habitat types in different locations, and probably matches the abundance of the main prey, confirming the opportunistic foraging character of this species (Catry *et al.* 2006). The relative importance of crustaceans in chick diets seems to be highly variable, but is usually more significant in colonies where adults primarily forage in brackish water (Davies 1981, Bogliani *et al.* 1994, Catry *et al.* 2006). In nutritional terms, invertebrates are poor prey for chicks compared to lipid-rich fish (Phalan 2000).

Annual variation in prey availability is likely to be the most important factor explaining annual variation in diet. For example, when young-of-year (YOY) herring failed to recruit near a colony in Norfolk in 2004, adult little tern were observed feeding in large numbers offshore on ghost shrimp and chick diet contained more sandeels and invertebrates than normal (Perrow *et al.* 2008). Although prey availability seems important in determining diet, there is also clearly selection of preferred prey, which seems mainly to be based on profitability (Phalan 2000).

### 3.1.5 Summary

Little terns have a short foraging range and so rely on abundant food supplies of small fish close to the colony to provision their chicks. Young-of-the-year clupeids and sandeels appear to be particularly important in this context. Little tern is thus thought to be rather specialised in its habitat requirements.

The number of studies documenting foraging range of little terns is limited and although Thaxter *et al.* (2012) report the following values: maximum range = 11 km, mean max range ( $\pm$  S.D) =  $6.3 \pm 2.4$ , mean = 2.1 km, they assign low confidence to this assessment. Variation within a colony may be due to breeding stage of the birds as distances travelled tend to be greater during incubation than during chick rearing, when adults are constrained by chick feeding duties. Intra-colony variation may also be due to tides, with birds travelling further during intermediate tidal states, perhaps to reach areas with stronger currents. Most studies report a radius of less than 4 km from the colony, although there is some variation between colonies, thought to be due to differences in offshore foraging habitat. There can be variation between breeding seasons, and this is thought to be due to availability of prey, although evidence for this is based on one study (Perrow *et al.* 2008). Very limited data on the effects of weather on foraging range suggest that under rough conditions, birds may select the most profitable areas, which may be in the surf-line where disoriented prey are brought to the surface.

The foraging distribution of little terns is consistently focussed on coastal areas, rather than deeper marine habitats, centred particularly on areas with abundant food such as channels and lagoons where stronger currents may increase prey availability. Turbid waters may also be important, by making fish more available closer to the surface. Inter-colony variation in habitat is likely to be related to habitat availability close to the colony, due to the small foraging range of little tern, but may also be effected by the presence/absence of competitors and predators. Intra-colony and inter-annual variation in the use of foraging habitat is likely to be determined by variation in prey availability within different habitats, but direct studies on this and the effects of weather are lacking.

The majority of information relating to diet is focussed on chick diet and information on adult diet is sparse. Although little tern chicks consume a relatively wide variety of prey types, diet consists predominantly of small, often YOY energy-

rich fish, mainly clupeids and sandeels. Variation in prey availability is the most likely cause of variation in little tern diet, both between colonies and between years, although adults have been documented selectively offering smaller prey to smaller chicks and selecting certain species. Tide appears to be particularly important and wind speed may also influence the type and rate of prey delivered to chicks as a result of changing availability. The majority of information available is descriptive and studies focussing on specific causes of differences between the diets are largely absent.

### 3.2 Sandwich tern

### *Sterna sandvicensis*

The Sandwich tern is the UK's largest breeding tern species, with a body length of 36–41 cm (bill 5.2–5.8 cm) and a wingspan of 95–105 cm (BWPi 2006). Sandwich terns are widely distributed around coastal countries of Europe, breeding in a few, often large high-density colonies in the UK mainly around the east coast, with further colonies in Ireland (Mitchell *et al.* 2004, Brown & Grice 2005). Sandwich tern is exclusively a coastal breeder in Britain, but breeds on inland loughs in Ireland (Cramp *et al.* 1974). It is a colonial breeder, typically nesting sympatrically with black-headed gulls *Chroicocephalus ridibundus* and occasionally other tern species often on sandy substrate in embryonic dunes, but also in other patchily vegetated habitats. The relationship with gulls is complex with increased potential for colony defence outweighed by intense and specialised kleptoparasitism and predation of chicks (Stienen 2006).

#### 3.2.1 Foraging range

Sandwich terns often fly >30 km from their colony to feeding sites with a maximum range of 54 km quoted by Thaxter *et al.* (2012) alongside a mean maximum ( $\pm$  S.D) value of  $49 \pm 7.1$  km and a mean value of  $11.5 \pm 4.7$  km). The level of confidence assigned to this assessment was only moderate as of the 14 studies only two were direct tracking studies.

In contrast, Langston (2010) reported a larger maximum range of 70 km (42.3 km mean maximum, 14.7 km), based on a sample of 17 studies. The difference may be a function of the quality of the information accepted or number of studies found. It is of note however that by using an energetics model Perrow *et al.* (2010) demonstrated that Sandwich terns could conceivably reach an upper limit of 60–74 km from the colony although the maximum distance a bird was tracked (and lost – see also Perrow *et al.* 2011b) was 54 km (the figure quoted by Thaxter *et al.* 2012 above)

There is wide variation between colonies; for instance, birds were recorded travelling mean maximum distances of just 4.4 km from shore and 6.6 km from the colony at Blakeney Point, whereas they travelled a mean maximum distance of 15.8 km from the colony but just 1.8 km offshore at Cemlyn Bay (Perrow *et al.* 2010). It was suggested that this was linked to different environmental conditions, with the deep water and rocky coast at Cemlyn resulting in the birds foraging nearer to the shore but travelling greater distances along the coast to reach the few sandy bays in the area. Despite these differences, maximum distances from the colony reported were quite similar at 33 km for Blakeney and 27 km for Cemlyn Bay.

A study using a larger sample size over more years from the Blakeney colony resulted in a maximum range of 54 km from a breeding site, over total distances

travelled of up to 72 km (Perrow *et al.* 2011b), demonstrating that the inter-annual variation and sample size can influence figures reported. There is also wide variation between individuals within colonies, with 61% of birds observed foraging <2 km from the Cemlyn Bay colony compared to the maximum distance of 27 km. Tidal state can influence intra-colony variation, as birds tend to forage preferentially during flooding tides, as these may concentrate shoaling fish in inshore waters, increasing their availability to foraging terns (Perrow *et al.* 2010, Steinen *et al.* 2000).

Foraging range may vary according to reproductive state and thus season. A plot of tracks from Scolt Head and Blakeney Point colonies in Centrica Energy (2009) shows longer tracks during incubation compared to the chick-rearing periods. This could be linked to the seasonal inshore movement of sprat later in the breeding season as well as indicating adults being more 'tied' to the colony by chick provisioning duties.

There is a lack of studies on the influence of weather on foraging range, although Stienen *et al.* (2000) suggest that birds breeding on a coastal area in the Netherlands may switch from using offshore areas to more sheltered areas within the Wadden sea during windy weather, implying a reduction in foraging range under such conditions.

### 3.2.2 Foraging habitat

Sandwich terns are almost exclusively marine feeders, although there are a few anecdotal records of this species foraging over freshwater (Greenwood 1986 *op cit* Lascelles *et al.* 2013). At sea, Sandwich terns have been observed actively and successfully foraging in waters of up to 18 m deep by Perrow *et al.* (2010) and up to 50 m by (Stienen 2006), although typically, offshore feeding areas for breeding birds may be <15 m deep (Perrow *et al.* 2011b).

Sandwich terns appear to prefer waters with sandy bottoms, and so usually feed at sea, sometimes following the tide into sandy parts of estuaries and lagoons (Cabot & Nisbet 2013). Key habitats include shallow marine waters such as bays, inlets and outflows, gullies, shoals, inshore waters, reefs, and sandbanks, as well as more open waters, including the open sea. The edges of gullies and fronts are likely to be especially important (Stienen 2006), probably because stronger currents increase the availability of prey in these areas.

Very few studies have specifically focussed on foraging habitat choice in Sandwich terns so detailed comment on variation in habitat use between colonies is difficult. Nonetheless, at Cemlyn Bay in North Wales, most birds avoided the dominant deep water areas immediately offshore and travelled almost exclusively in an easterly direction to target the few sandy bays and inlets in the area, presumably as this was where part of their favoured prey base, sandeels (*Hyperoplus* and *Ammodytes* spp.) were concentrated (Perrow *et al.* 2010). In the Wadden Sea, only a minority of the Sandwich terns fed in larger tidal gullies or nearby shallow waters, with most feeding offshore (Garthe & Flore 2007), presumably because foraging conditions were better there. Stienen *et al.* (2000) suggested that it was likely that birds breeding on a coastal area in the Netherlands may switch from using offshore areas to more sheltered areas within the Wadden sea during windy weather conditions.

Götmark (2000) comments that Sandwich terns feed on food sources that are unpredictable in time and space, which may readily result in variation in specific foraging locations within colonies between years and seasons. As yet, there is no

specific information to test this idea, apart from perhaps the switch to inshore waters later in the season reported by Centrica Energy (2009). Whether or not birds show radically different patterns between years is not known as a result of the short-lived nature of the studies conducted to date.

### 3.2.3 Foraging behaviour

Sandwich terns fly faster, make longer trips, dive deeper from greater heights and catch larger fish than any of the other four British tern species (Cabot & Nisbet 2013). Dunnet *et al.* (1990) and BWPI (2006) suggest the species is less versatile in fishing techniques than smaller *Sterna* species, although it is only perhaps the capture of insects either in the air or gleaned from the surface and vegetation that has not been observed. From the aspect of marine prey, Sandwich tern has greater scope than the other tern species, taking items from ~1-25 cm; from larval fish or invertebrates to the largest Greater sandeel *Hyperoplus lanceolatus*. Subtly different foraging prey handling techniques are used including 'toss and catch' of invertebrates such as brown shrimp *Crangon crangon* to align spiky antenna and allow head-first swallowing (M. Perrow *pers obs*).

Certainly, Sandwich terns may snatch or pick very small items from the sea surface and surface splash with partial immersion as well as plunge dive with full immersion. Foraging height is greater than the other species and in the study of Perrow *et al.* (2010) birds on foraging spent 49% of time at >20 m above sea surface. Foraging attempts may even be initiated at heights of >40 m (M. Perrow *pers obs*). Hovering may be undertaken before diving, although birds often simply fold their wings into a dive in the manner of gannets and boobies (*Morus* and *Sula* spp) and launch downwards. Where the item is close to the surface, birds control descent speed with braking in a series of 'steps' before reaching the surface and appear to adjust their velocity according to the size, nature and depth of the item. Dive depth is not specifically known although observations suggest birds may reach ~1.5 m below the surface (Dunn 1972 *op cit* Cabot & Nisbet 2013). Observations of tracked birds show that birds may disappear for 1-2 secs and emerge at a different point from entry, although whether they are capable of swimming underwater by using their wings or they simply rely on their momentum is unknown.

The birds tracked by Perrow *et al.* (2010) tended to forage alone and aggressively interact with each other calling and chasing where one bird impinges on another's area of restricted search. Searching is typically undertaken by circling over a relatively wide area. Birds are however attracted to other actively foraging individuals and will associate with predatory fish, auks and cetaceans such as harbour porpoise *Phocoena phocoena* (Veen 1977 *op cit* Lascelles *et al.* 2013, Perrow *et al.* 2010).

In North Norfolk at least, tracks from the colony often show remarkably little deviation as the birds commute to a pre-determined foraging location (Centrica Energy 2009, Perrow *et al.* 2010). Opportunities are taken as they arise however, and area restricted search may be undertaken for a time perhaps in response to other foraging Sandwich terns. Once the prospect of successful prey capture has gone, birds may return to the original trackline.

Sandwich terns can forage successfully in wind speeds up to 55-80 km an hour (Dunn 1972 *op cit* BWPI 2006, Taylor 1983). Food transport to the colony can also be severely curtailed by very strong winds, but was also relatively low at low wind speeds in the study of Stienen *et al.* (2000). The latter authors also showed that prey

composition changed as conditions worsened, with a decreasing proportion of herring being delivered (see 3.2.4 below). Despite this effects, wind appears to be less of an issue for this species compared to other smaller species (Dunn 1972 *op cit* BWPI 2006, Taylor 1983, Perrow *et al.* 2010).

Tides can also have an influence; along the seashore or over offshore reefs and sand-banks, fishing success and diving rate can be 2–3 times higher (and more birds forage) at low tide when the water is shallower and the fish are more accessible (Dunn 1972 *op cit* BWPI 2006).

Sandwich terns can be susceptible to kleptoparasitism by other species including skuas *Stercorarius* spp., gulls and even other terns (Ratcliffe *et al.* 1997, Stienen 2000, Stienen *et al.* 2001, Stienen & Brenninkmeijer 2002), resulting in reductions in foraging success. At sea, skuas may specialise on Sandwich terns in the vicinity of colonies in late summer, stopping-over passage to do so (Taylor *et al.* 1999).

### 3.2.4 Adult & chick diet

Adult diet is not well studied, but it is clear that it may be rather different from that of chicks. For example, Perrow *et al.* (2010, 2011b) found that a relatively high proportion of invertebrates (24–26%) were captured by self-feeding adults but constituted <1% of prey delivered to chicks. Moreover, young-of-the-year clupeids frequently occurred in adult diet whereas older fish tended to make up more of the chick diet (Perrow *et al.* 2010). Young-of-the-year sandeels were less important for both adults and chicks, across three seasons of study (Perrow *et al.* 2010). As with most tern species (see Shealer 1998, Phalan 2000, Stienen 2000, Danhardt *et al.* 2010), smaller fish tend to be swallowed by adults and larger ones taken back for chicks.

Sandwich tern chicks are, mainly fed on a highly specialised diet that is less diverse than that of common and Arctic terns and dominated by a few fish species of high nutritive value; namely clupeids (herring and sprat) and sandeels (both *Ammodytes* and *Hyperophus*). There is some local variation and some gadoids (including Atlantic cod *Gadus mohura* and whiting *Merlangius merlangius*) and more unusual species such as three bearded rockling *Gaidropsarus vulgaris* (at Cemlyn Bay – Perrow *et al.* 2010) fish may be presented, whilst squid, crustaceans, insects and worms have occasionally all been reported (Götmark 2000, Stienen *et al.* 2000, BWPI 2006, Vanaverbeke *et al.* 2007, Fuchs 2008, Perrow *et al.* 2010, 2011b, Cabot & Nisbet 2013). As with most other terns, Stienen (2000) reported that parents meet the increasing energy demands of growing chicks by adjusting prey size, rather than increasing delivery rates or switching species. Increasing prey size over the course of the season was observed at the colony at Cemlyn Bay (Wilde & Wright 2013).

Kleptoparasitism by black-headed gulls in particular, is intense in some colonies. For example, some 18% of the  $n = 16,650$  prey items delivered to the Griend colony were robbed by gulls (Stienen *et al.* 2001). Higher attack (24%) but lower rob (5.5%) rates were recorded at Blakeney Point (Perrow *et al.* 2010). At Griend, sandeels appear to be particularly targeted, with little evidence that black-headed gulls could differentiate between the species. As such, lipid-rich but smaller clupeids are fundamentally important to breeding success (Stienen 2006). At Blakeney Point, modelling of attack rates and the resulting energetic gains supported the view that gulls could differentiate between types and sizes of prey carried by terns and clupeid carriers had a higher likelihood of being attacked once the prey item exceeded ~ 8



cm in length on account of their higher energy content per unit length compared to sandeels.

Whilst there seems to be a considerable amount of consistency in chick diet, there is some inter-annual variation around the importance of the principal items. For example, at Lady's Island Lake, Newton & Crowe (2000) showed clupeids were the more abundant prey type presented during the incubation period in 1997, but sandeels predominated provisions in 1998. Overall, sandeels were the most frequent prey item in chick diet in both years and it is suggested that this reflects prey availability, although this remains to be tested. In contrast, Brenninkmeijer & Stienen (1994) found that the species composition of the fish delivered to the chicks in 1992-1993 was virtually identical to that in 1969-1974.

Weather conditions can result in variability in diet composition; sandeels tend to predominate chick diet during windy weather whereas clupeids tend to be more important in other weather conditions (Stienen 2000, 2006). This is thought to be due to the descent of clupeids in the water column during bad weather, making them less available. This may also have an effect on foraging range and habitat (see 3.2.1 and 3.2.2 above respectively), as was found in birds breeding in coastal areas in the Netherlands that switched to more sheltered areas in the Wadden Sea with an abundance of sandeel in rough weather (Stienen *et al.* 2000).

The proportion of herring relative to sandeel presented may also vary according to diurnal and tidal patterns. In relation to the former, Stienen *et al.* (2000) showed that more herring were presented at the beginning and end of the day which may coincide with the upward vertical migration in the water column of herring in lower light levels. The same authors also showed that the rate of provisioning of sandeel was highest at high water, whilst that of herring varied little

Where Sandwich tern occurs sympatrically with common tern, Perrow *et al.* (2010) found a strong indication of a niche differentiation between the two species, with common terns exploiting a more diverse range of small prey items in inshore waters, whilst Sandwich terns exploit larger fish prey in offshore waters. There is no particular indication that the occurrence of sympatric species particularly affects the diet of Sandwich tern chicks however. In contrast, kleptoparasitism by black-headed gulls can result in higher frequency of smaller clupeids being brought in to chicks (Perrow *et al.* 2010).

### 3.2.5 Summary

The detailed studies of Sandwich terns that have been undertaken to date, in particularly in colonies in the Netherlands, point to their rather specialist nature compared to other species, with dependence upon a few prey species (e.g. clupeids and sandeels including *Hyperoplus*) that may be gathered across a much wider foraging range (> 50 km) than the other species. There are however few detailed studies of the foraging ecology of Sandwich terns at sea, save recent visual tracking studies in the UK

Variation in the spatio-temporal availability and distribution of Sandwich tern prey seems likely to influence the foraging distribution and diet of the birds, both within and between seasons. Variation in foraging range between colonies has been documented and is probably related to the different foraging conditions in different places. There is limited evidence that range reduces according to reproductive status (i.e. incubation compared to chick-rearing). Within colonies, foraging range can be influenced by tide, as birds take advantage of flooding tides where prey availability is

higher. There is little information on the influence of weather, although this may be less important than for the smaller species

Detailed studies on foraging habitat choices of Sandwich terns are lacking. However, in general, Sandwich terns forage in shallow marine waters, especially inlets and outflows, gullies, shoals, sandbanks as well as the open sea. Sandwich terns feed on food sources that are unpredictable in time and space, that may result in variation in specific foraging locations between colonies and years. There is little information on the effects of weather on foraging habitat, although limited evidence suggests birds may switch from offshore areas to more sheltered areas in rough weather where this habitat is available (which will also have implications for foraging range).

Adult diet is poorly known, but adults do tend to eat smaller items including fish and invertebrates and select larger fish to carry back to chicks. Chick diet tends to be fairly consistent both across colonies and years and is dominated by a few species of high nutritive value: namely clupeids and sandeels. Variations in proportions of each species are due to differences in availability according to patterns of tide, time of day, weather and season. Herring may be more prevalent at the beginning and end of the day according to their vertical movement in the water column in lower light levels. They may descend in rough weather resulting in a preponderance of sandeel in the diet in windy weather. There is limited evidence of the inshore movement of clupeids as the season progresses in at least some years, which can also influence chick provisions (and foraging range). The presence/absence of kleptoparasitising black-headed gulls can also cause variation in chick diet between colonies, with these showing a predilection for terns carrying large clupeids in some colonies (North Norfolk) but not others (North Wales and the Netherlands).

### 3.3 Common tern

### *Sterna hirundo*

Common terns are the most widely distributed tern in the UK although it is absent from mainland Wales and SW England (Mitchell *et al.* 2004). It nests on rocky islands, beaches, saltmarsh or industrial areas along the coast as well as inland on lakes, reservoirs and gravel pits, where it now often uses artificial nesting platforms ('tern rafts'). There is also recent evidence of nesting on flat roofs (Taylor & Marchant 2011). Nest density is higher on artificial platforms than in natural habitats where common tern occurs in loose single species colonies or mixed colonies with other terns and black-headed gulls.

In accordance with nesting habitat selection, Common terns are generalist and opportunist feeders, using more varied habitats, a wider range of feeding techniques and taking a wider variety of prey than other tern species (Brown & Grice 2005). In terms of body size, common terns are similar to Arctic terns, with a body length of 31–35 cm and a wingspan of 77–90 cm (BWPi 2006).

#### 3.3.1 Foraging range

Thaxter *et al.* (2012) state the foraging range of common terns is 20–30 km (30 km maximum foraging range,  $15.2 \pm 11.2$  km, mean maximum range ( $\pm$  S.D) and  $4.5 \pm 3.2$  km mean range ( $\pm$  S.D)). This was based on 22 studies and they assign moderate confidence in this assessment. Langston (2010) gives a similar maximum figure of 37 km, but with greater mean maximum (33.7 km) and mean (8.7 km) values. Actual values vary widely: for example some birds in the Wadden Sea travelled a total distance of 70 km per flight (suggesting a maximum range of around 35 km although

this is not specified) although the mean radius of tracked flights was only 6.3 km (Becker *et al.* 1993). In line with this, most studies report maximum foraging ranges of 10 km or less (*e.g.* Duffy 1986, Wanless *et al.* 1998, Newton & Crowe 2000, Rock *et al.* 2007a). Perrow *et al.* (2010, 2011b) tracked common terns in Norfolk and found that some birds ranged to ~9 km but never more than 2 km offshore. At another site in Teesside, birds travelled over 6 km from their inland colony to reach the estuary and from there ranged nearly 10 km out into the open sea and 14 km along the coast.

The distribution of foraging tracks at Teesside was thus rather fan-like after birds had reached the estuary implying birds had a specific target foraging location, and thus in complete contrast to the back-and-forth quartering pattern of tracks at Blakeney Point (Perrow *et al.* 2010 and see Cabot & Nisbet 2013). The pattern of ranging behaviour coupled with the capture of relatively large fish by common tern at Teesside was therefore similar to Sandwich tern (see 3.2.1 above) and Perrow *et al.* (2010) speculate that in the absence of the larger species, common tern at Teesside may have filled the more profitable niche that was available (see 3.3.4 below).

Foraging ranges may also be influenced by the stage of the tidal cycle with Schwemmer *et al.* (2009) reporting that birds travelled greater distances at high tide, due to reduced prey availability at this time. There is little evidence relating to within or between season variation in foraging range, or the effects of weather, although this is likely to be linked to prey availability.

### **3.3.2 Foraging habitat**

Foraging habitats include the open sea, brackish waters, lagoons, estuaries, rivers, lakes, reservoirs, ponds and marshes (Becker *et al.* 1997, Frank 1992, Safina & Burger 1988, Monticelli *et al.* 2006, Schwemmer *et al.* 2009, Perrow *et al.* 2010, 2011).

In some colonies terns switch between marine and freshwater habitats depending on different conditions such as weather or state of the tide. Common terns breeding on the mainland coast of Germany fly inland to feed from fresh water mainly at high tide and during unfavourable weather, when food availability is reduced in the Wadden Sea (Becker *et al.* 1993, Becker *et al.*, 1987, Becker *et al.* 1997, Schwemmer *et al.* 2009). In other areas they only utilise one habitat type. For example, they used only marine habitats in Spain (Cotin *et al.* 2011) and showed a strong preference for marine habitats in Teesside, flying over a variety of freshwater pools, a large river and a range of brackish creeks and pools to reach the estuary and sea beyond (Perrow *et al.* 2010).


Zones of intense foraging activity are often located in areas of high water flow velocity, in both shallow areas and in areas of around 15–20 m depth (Schwemmer *et al.* 2009, Perrow *et al.* 2010). Small-scale physical processes are thought to be especially important in directly influencing prey availability and hence foraging areas used. There is little information on within or between year variation in foraging habitats, but this seems likely to be driven by variation in prey availability.

### **3.3.3 Foraging behaviour**

Common terns use a variety of foraging methods including plunge diving, diving to surface, dipping, hawking, kleptoparasitism and perch-feeding. Diving to surface



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and plunge diving are the most characteristic and some birds show territoriality over feeding areas (BWPI 2006, Cabot & Nisbet 2013). Perrow *et al.* (2010), reported that at Blakeney Point the sample of visually tracked birds (see Perrow *et al.* 2011b for methodology) nearly 50% of time was spent flying <1 m above the surface and no bird was ever seen to completely immerse when plunge diving. This was probably linked to the small size of prey captured and, in turn, to the specific selection of inshore habitats at this site, which was accompanied by a specific quatering mode of foraging. These patterns may be linked to the presence of large numbers of Sandwich terns occupying the 'offshore' niche at this site., Profitable feeding on small prey may be particularly reliant on high water velocities to concentrate prey at the surface (see 3.3.2 above). In the Solent, common terns were noted to routinely forage in the wake of the large passenger ferries on their journey across the stretch of water separating the isle of Wight from the mainland. After following a ferry to dock, birds then appeared to rest on poles and other structures until a vessel undertook a return journey (M Perrow *pers obs*).

Capture of larger prey less prone to reach the surface may be particularly reliant on the activities of foraging auks and other marine predators (Newton & Crowe 2000, Perrow *et al.* 2010). Common terns also often tend to use other terns to identify foraging areas by focussing on aggregations of feeding flocks (Perrow *et al.* 2010). Kleptoparasitism may then occur. A study in Germany found birds using kleptoparasitism had higher breeding success than birds catching fish themselves (Garcia *et al.* 2010).


Wind speeds can effect composition of prey caught, with fewer clupeids and more sandeels brought to chicks at increasing wind speeds, as clupeids descend to deeper during bad weather whereas the preference of sandeels for shallower water makes them generally more available (Frank 1992). At wind speeds of more 6 m<sup>-s</sup>, feeding rates were reduced regardless of the species captured (Frank 1992). Fletcher (2002) found that females had a lower provisioning rate and delivered a higher proportion of smaller fish and a lower proportion of energy-rich clupeids in the two study years on Coquet Island. The reasons for these differences are unclear.

### 3.3.4 Adult & chick diet

Common tern adults take a wide range of prey including fish, crustaceans, squid and marine worms, and feed on aquatic and terrestrial insects more frequently than other tern species. As is the case for most terns, invertebrates, and lower quality food items invariably appear to be consumed by adults at sea and are not generally taken back to chicks (Granadeiro *et al.* 2002, Danhardt *et al.* 2010, Perrow *et al.* 2010). However, adult diet is poorly studied and most studies focus on chick provisions. The main prey delivered to chicks in the marine environment are herring, sprat, sandeel, saithe *Pollachius virens*, whiting and cod, although this appears to vary greatly between years and locations, largely depending on prey availability (Becker *et al.* 1987, Uttley *et al.* 1989, Granadeiro *et al.* 2002, BWPI 2006, Danhardt 2010, Perrow *et al.* 2010, Cabot & Nisbet 2013).

Common terns can show extreme plasticity in foraging and provisioning strategy, displaying their capacity to exploit diverse prey resources utilising varied foraging methods. In line with this, differences between common tern diet in different colonies can be striking. For example, in Norfolk, small probably YOY clupeids (~4 cm) were the dominant item presented to chicks. Larger (older) clupeids (probably sprat) were the most important item at a colony in Teeside, but with a greater prevalence of larger items of a range of species such as gadoids including poor-cod

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*Trisopterus minutus* (Perrow *et al.* 2010). These differences were tentatively suggested to be due to competitive release in the absence of sympatric breeding Sandwich terns at Teeside, allowing common terns the opportunity to exploit the offshore environment with the potential to encounter a wider range of prey species (Perrow *et al.* 2010).

At other locations in the UK, clupeids and sandeels have also been found to be the mainstay of chick diet (Newton & Crowe 2000, Langham 1968 *op cit* Lascelles *et al.* 2013), although saithe was particularly important at some colonies in Scotland, probably because sandeels in this area were less abundant (Uttley *et al.* 1989). Differences between years are also apparent, such as the switch from sandeel to saithe in chick diet in Shetland during a period of sandeel population crash (Uttley *et al.* 1989), again illustrating the importance of prey availability in determining diet.

Herring and sprat tend to become more important in chick diet than sandeels as the season progresses, which may influence or reflect choice of foraging habitat and therefore range (Pearson 1968, Langham 1968 *op cit.* BWPi 2006). There is also a tidal influence upon availability and capture of different species. For example, in the Ythan Estuary, sandeels and sprat were the main food for chicks at high tide, whilst shrimps and blennies were taken at low tide, whilst on the Ribble estuary sprats were important at high tide, and whiting and saithe were provisioned at low tide (Taylor 1975 *op. cit.* Cabot & Nisbet 2013, Greenhalgh and Greenwood 1975 *op. cit.* Cabot & Nisbet 2013). In the German Wadden Sea, clupeids were again the most important component of chick diet at high water with sandeels at low water (Frank 1992).

Few studies have looked at inter-annual variation in diet, but Rock *et al.* (2007) found a significant year effect in their study, with the proportion of hake and sandeel differing between years. Frank (1992) also found variation in chick diet composition between three years of study, and suggests that this reflects changes in abundance of different prey items. Wind speed can also influence chick diet, with fewer clupeids and more sandeels brought in during windy conditions, although this was only apparent in one of the three study years (Frank 1992). It is also noteworthy that brood size has been found to have very little effect on the species, sizes, and most importantly, energy content of prey delivered to nestlings (Robinson 1999).

Information is sparse on the diet in freshwater habitats in the UK. However, in Europe, chick provisions include a variety of freshwater fish and insects, including a range of cyprinids (e.g. roach *Rutilus rutilus*, bleak *Alburnus alburnus*) percids (perch *Perca fluviatilis* and ruffe *Gymnocephalus cernua*) three-spined sticklebacks *Gasterosteus aculeatus* and smelt (*Osmerus eperlanus*) (Becker *et al.* 1987, 1997, Frank 1992, Danhardt & Becker 2011). Three-spined sticklebacks or common shrimps seem to be an important additional energy source in times of low availability of high-energy food, enabling the chicks to temporarily maintain their body mass and thus prevent starvation (Masias & Becker 1990).

### 3.2.5 Summary

Common terns are generalists and display considerable plasticity in foraging and provisioning strategy, with a capacity to exploit diverse prey resources by utilising a variety of foraging methods. Despite being a relatively well-studied species especially in the Wadden Sea, there remains much to learn about the foraging ecology across the range of habitats used. All parameters of foraging also have the scope to vary

between colonies and years and no two colonies may be the same, resulting in much wider spatial and temporal variation than in more specialist species such as the Sandwich tern.

Foraging habitat of common terns varies widely between colonies, partially depending on habitat availability within foraging range of the colony, which typically appears to be a maximum of 20-30 km. although wide variation both between and within colonies, is reported in the literature. There is little definitive evidence of the cause of inter-annual variation in foraging range, although this seems likely to be linked to prey availability. It is also possible that foraging range and habitat between colonies may also be linked to the presence/absence of other tern species, which compete for resources at a site.

There is little detailed information relating to variation in foraging range within colonies, although this is invariably linked to differences in the proximity of suitable habitat and prey availability. The state of the tide under which observations were made may affect the figures reported as some studies have found that birds travel greater distances at high tide. There are no specific studies of the influence of weather on foraging range, although this clearly will have an impact through its effects on foraging distribution (see above).

Foraging activity is often concentrated in areas of high water flow and small-scale physical processes are thought to be especially important in directly influencing prey availability. The weather can also influence foraging distribution, as birds may choose to use more sheltered freshwater habitats in high winds or storms, thus resulting in temporal variation in distribution.

The diet of adults is poorly known but is likely to include a higher proportion of invertebrates and less energy-rich items than are provisioned to chicks. Chick diet varies between colonies and within colonies in different years, which is likely to reflect changes in availability of different prey types. Clupeids, sandeels and gadoids appear to be particularly important in marine habitats, although prey preferences in freshwaters are less well known. Where both marine and freshwater prey are available each may appear to be the more profitable in different circumstances. Prey availability may vary according to weather conditions (i.e. increasing wind speeds as clupeids remain deeper during bad weather) and also be a cause of the shift from marine to freshwater foraging.

### 3.4 Roseate tern

### *Sterna dougallii*

Roseate tern is essentially a tropical species, breeding in widely scattered colonies in marine habitats, often on small islands around the world, with temperate 'outposts' in the northeastern US/southeastern Canada and the other in western Europe (Cramp *et al.* 1974, Lloyd *et al.* 1991, Cabot & Nisbet 2013). Up to 75% of the European population breeds in the Azores, whilst in the UK, Roseate tern is a rare and declining bird on the Red list of birds of conservation concern (Eaton *et al.* 2009). The majority of the UK population breed at a single colony on Rockabill, Ireland (Brown & Grice 2005), with much smaller colonies at Lady's Island lake in County Wexford in Ireland and Coquet Island in Northumberland (Cabot & Nisbet 2013). Nesting habitat is unusual in that it often uses dense vegetation including low growing shrubs, or amongst large rocks and even burrows. This is assumed to be an adaptation to aerial predation in particular. Purpose built terraces with nest boxes

are routinely used in the British colonies, and Roseate tern exclusively uses boxes at Coquet Island (Cabot & Nisbet 2013).

Body size is similar to both Arctic and common terns (body length of 33-38 cm and wingspan of 72-80 cm -BWPI 2006) but with proportionally shorter wings and a longer tail in the breeding season generating a different flight action with faster, shallower wingbeats.

### 3.4.1 Foraging range

Thaxter *et al.* (2012) reported a maximum foraging range of 30 km ( $16.6 \pm 11.6$  km mean maximum range ( $\pm$  S.D) and  $12.2 \pm 12.1$  km mean range ( $\pm$  S.D), from 10 studies only one of which was a direct tracking study. As such they give low confidence in this assessment. Extremely similar values are given by Langston (2010).

Several studies report short foraging including 3-10 km from the colony in Ireland (Newton & Crowe 1999) and <10 km from colonies in North America, (Heinemann 1992 *op cit* Lascelles *et al* 2013, Gochfield *et al.* 1998 *op cit* Lascelles *et al.* 2013, Rock 2007a), with 20-30 km reported in a variety of locations (Safina 1990, Shealer 1996, Gochfield *et al.* 1998 *op cit* Lascelles *et al.* 2013). There are few quantitative observations of foraging range from north-west Europe and it has generally been assumed that most foraging is done relatively close to the colony, although this could be an artefact of land-based observers (Newton & Crowe 2000).

Distances can vary between years, as documented by Heineman (1992) in the US, where birds were found using different foraging locations over two seasons, at distances of 7.5 - >25 km from the colony. The author speculated that this was due to changes in prey distribution at the different feeding grounds.

Within season variation can result from the stage of breeding, as adults have been found travelling greater distances during courtship and incubation than during the chick rearing period (Newton & Crowe 2000). The variation in prey species documented by Heinemann (1992, see below) is also likely to result in differences in foraging habitat, and therefore range, over the season. There are no studies looking at the effect of weather on foraging range.

### 3.4.2 Foraging habitat

Roseate tern forages in the open sea or in habitats linked to the sea. Temperate populations often feed in shallow areas (<5 m deep) near the shore, using bays, inlets and nearshore surf, and are typically associated with tide-rips, shoals and upwellings over sandbanks or reefs that concentrate fish near the surface, but they may also forage over brackish lagoons or estuaries (Safina 1990, Heinemann 1992, Nisbet & Spendelov 1999, Rock *et al.* 2007b, Newton & Crowe 2000, Cabot & Nisbet 2013).

In the tropics, roseate terns tend to prefer deeper (20-30 m) water, using other predators to drive fish close to the surface (Shealer & Burger 1993, 1995, Shealer 1996, Ramos 2000). The pattern is similar in Europe and North America with the use of offshore, relatively deep water and an association with pursuit-swimming seabirds or predatory fish (Gochfield *et al.* 1998 *op cit* Lascelles *et al.* 2013, Newton & Crowe 2000).



Evidence explaining the cause of any variation in foraging habitat between colonies is sparse, but it is likely that habitat choices are driven by the distribution of habitats relative to the colony and the availability of prey within different habitats at different locations. Variation in foraging habitat between seasons was documented by Heinemann (1992), who found adults used different areas with either strong tide rips or sandy shoals in different years and hypothesised that these changes reflected changes in the distribution of prey.

The same study also documented a shift in diet of chicks over the season (see below), which again may indicate a seasonal shift in foraging habitat but as no information on prey abundance was available to this study, it is unclear whether the birds switched habitats because prey availability changed at a preferred foraging location, or whether they were selectively foraging for different prey species and so switched foraging habitat. There are no studies on the role of weather as a cause of variation in selection of foraging habitats.

### 3.4.3 Foraging behaviour

The main capture method is plunge diving (Dunnet *et al.* 1990) using a characteristic angled dive using its wings to increase speed as it descends ('power-diving') from relatively low height (typically 3-6 m and up to 12 m – Cabot & Nisbet 2013). Full immersion is achieved and it may remain submerged for 1-2 seconds suggesting it may reach depths of >0.75 m and perhaps up to 1.2m (Dunn 1972 *op cit* BWPI 2006, Cabot & Nisbet 2013). It may also snatch fish and other prey from the water surface and may quarter back and forth as it searches for prey. It is less adept at hovering than Arctic or common terns and its general foraging behaviour resembles Sandwich tern more than its similarly-sized congeners. Some individuals are specialist kleptoparasites, stealing from other terns, especially common tern around mixed colonies, which tends to be a successful strategy (Langham 1968 *op cit* BWPI 2006, Shealer *et al.* 2005).

Foraging success is lower in strong winds and wind speeds higher than 19 km hr<sup>-1</sup> hour depressed chick growth rates (Langham 1968 *op cit* Cabot & Nisbet 2013, Dunn 1973 *op cit* Cabot & Nisbet 2013). Tidal rhythm also influences capture success in inshore waters where water depth affects visibility and accessibility of prey. In such conditions, fish capture rate increased from zero at high tide to 0.5 min<sup>-1</sup> two hrs after low tide (Dunn 1973 *op cit* BWPI 2006).

### 3.4.4 Adult & chick diet

There are few studies on diet composition of roseate terns in Europe although the limited evidence suggests that the diet of adults and chicks is predominately sandeels (*Ammodytes marinus* and *A. tobianus*) herring and sprat (Langham 1968 *op cit* BWPI 2006, Dunn 1972 *op cit* BWPI 2006, Mundy 1997, Newton & Crowe 2000). This is apart from in the Azores, where a range of pelagic deepwater fish species (e.g. Trumpet fish *Macroramphosus scolopax*, sauri *Scomberesox saurus* and *Nanichthys simulans*, blue jack mackerel *Trachurus picturatus*, garfish *Belone belone gracilis*, and lanternfish of the family Myctophidae) were important (Ramos 2000, Martins *et al.* 2004). Sandeels seem to be more important in North America (Richards & Schew 1989 *op cit* Lascelles *et al.* 2013, Rock *et al.* 2007b, Safina *et al.* 2009). Roseate terns occasionally catch small prey like crustaceans, or other surface prey (BWPI 2006).

Whilst there is variation between colonies, depending on location, there can be consistency within colonies across years. For example, Newton & Crowe (2000) found that whilst sandeels were consistently important at the colony at Lady Islands Lake, clupeids were the main item in chick diet over all three years of their study at Rockabill. Ramos (2000) also noted a consistent chick diet of up mainly Mullidae between 1997 – 1999, although secondary prey items varied.

Seasonal variation in chick diet has been documented by Heinemann (1992), with >95% sandeel *Ammodytes americanus* until mid-June, after which diet was more diverse and included herring, mackerel *Scomber scombrus* and bluefish *Pomatomus saltatrix*. This was a consistent pattern over the two years of study and it was suggested this pattern arose from a strong dependence on one or two foraging sites over sandy shoals where sandeels were abundant, although the authors did not know how environmental factors influenced prey availability at those sites.

Seasonal variability of roseate tern chick diet in the Azores was explained by changes in the availability of fish species and changes in the adults' selection criteria as their chicks grew (Ramos *et al.* 1998). Indeed, the seasonal change in diet may often be determined by roseate terns preferentially selecting smaller prey for smaller chicks and larger prey for older chicks (Shealer 1998a, Phalan 2000). There are no studies reporting variation in diet due to varying weather conditions, although this is not to say this does occur, especially as diurnal variation in prey type was noted in the Azores (Ramos *et al.* 1998).

### 3.4.5 Summary

In many ways, Roseate tern is more similar to Sandwich tern than to common and Arctic terns in terms of its foraging behaviour (i.e. specialising on a few fish species captured by plunge diving to depth beyond body length). It is also rather specialised in terms of a selection of offshore islands and its nesting behaviour favouring vegetation, rocks or burrows, which has been exploited by the use of nest boxes as a conservation tool.

There is widespread variation in foraging range between colonies with a maximum of ~30 km but often much less (3-10 km). Very few studies specifically investigate reasons behind the distance travelled to foraging sites but most authors conclude that they must be driven by the location of the best foraging areas in relation to the colony. At only one colony was inter-annual variation considered and here the birds used different foraging habitats, and thus travelled varying distances over two seasons, presumably because of differences in the distribution of prey. Seasonal variation in range has also been recorded with greater distances travelled during courtship and incubation than during chick feeding. The effect of weather on foraging range (or foraging habitat) has not been documented.

The foraging habitat used by Roseate terns depends on location with temperate populations often feeding in shallow areas (<5 m deep) at tide-rips, shoals and upwellings over sandbanks or reefs that concentrate fish near the surface; whilst in the tropics, birds tend to prefer deeper (20-30 m) water, using other predators to drive fish close to the surface. Habitat use can vary between years, for example preferring tidal rips in some years and sandy shoals in others. Choice of foraging site is presumably influenced by prey distribution although there are no studies investigating the specific causes of these differences.

Little is known about the specific locations of roseate tern foraging areas in north-west Europe, or what factors influence the availability of prey fish in the upper part of the water column to plunge diving terns (Newton & Crowe 2000).

The diet of adults and chicks in Europe is predominately sandeels, herring and sprat, apart from around the Azores where deepwater fish species predominate. Sandeels seem to be more important in North America. Within colonies, the main species in chick provisions tend to be fairly consistent, although there may be seasonal variation as adults select different prey sizes for their growing chicks, and even diurnal variation in prey type where a range of species are taken.

Little is known about the environmental factors that influence prey availability and there are no studies reporting variation in diet due to varying weather conditions, although windy conditions have been reported to make foraging more difficult, resulting in slower chick growth.

### 3.5 Arctic tern

### *Sterna paradisaea*

Arctic terns are slightly smaller than common terns with a body length of 33–35 cm and a wing span of around 75–85 cm (Lloyd *et al.* 1991). This species breeds up to higher latitudes than any other tern, and this is reflected in its distribution in the UK, being confined mainly to the coast north of a line from Northumberland to North Wales with only a few scattered small colonies further south (Mitchell *et al.* 2004, Brown & Grice 2005). It is otherwise abundant in the Northern Isles and the Outer Hebrides and overall is easily the most abundant tern species in the UK. In Ireland, it is patchily distributed around the coast, with some nesting inland on two large loughs, which is otherwise very rare in the UK, although this does occur in other parts of Europe, especially Iceland (BWPI 2006). Large colonies occur in North Wales, Northumberland (Farne Islands) with the Outer Hebrides, with easily the largest concentrations in the Northern Isles (Cramp *et al.* 1974, Forrester *et al.* 2007).

Despite their abundance and ability to take a range of prey by a range of means, Arctic terns may be more vulnerable to reductions in food supply than other terns, seemingly linked to their dependence on sandeels especially in the Northern Isles (Sudderby & Ratcliffe 1997).

#### 3.5.1 Foraging range

Thaxter *et al.* (2012) report a maximum foraging range of 30 km ( $24.2 \pm 6.3$  km mean maximum range ( $\pm$  S.D) and  $7.1 \pm 2.2$  km mean range ( $\pm$  S.D)) from 14 studies including three using direct tracking of one form or another. A moderate level of confidence is given to this assessment. In contrast, Langston (2010) reports somewhat different figures with 20.6 km maximum range, 12.24 km mean maximum range and 11.75 km mean range.

Estimates of range thus appear to vary greatly in different studies. Most studies record Arctic terns foraging some 3 - 10 km from the colony (Boecker 1967, *op cit* Lascelles *et al.* 2013, Cramp 1985, Hartwig *et al.* 1990 *op cit* Lascelles *et al.* 2013, Wright & Bailey 1993, Wanless *et al.* 1998, Rock 2007b), with Schwemmer *et al.* (2009) noting the first feeding attempts just several hundred metres from the colony. In contrast, Perrow *et al.* (2011b) visually tracked seven birds in Anglesey, North Wales following one bird for 57 km until it was last recorded at a maximum

distance of 29 km out to sea. In the same study, considerable individual variation in the areas selected was noted by Black & Diamond (2005) who recorded Arctic terns from <5 km and >30 km from the nest site. The cause(s) of this variation is unclear, although as the actual reproductive status of the bird tracked could not be confirmed in the study of Perrow *et al.* (2011), it is possible some of the birds may not have been constrained by an active nest. The effect of other factors such as prey abundance and weather conditions have not been studied.

### 3.5.2 Foraging habitat

In Iceland and Norway, Arctic terns frequently forage over freshwater lakes (Cramp *et al.* 1974, Vigfúsdóttir 2012), demonstrating between colony variation. In the UK however Arctic tern feeds exclusively over marine habitats, often over the open sea but sometimes along edges of sandy or rocky shores, tidal flats or shoals, tending to concentrate over tide rips or along drift lines (Dunn 1972 *op cit* Lascelles *et al.* 2013, Langham 1968 *op cit* Lascelles *et al.* 2013, Uttley *et al.* 1989, Hall *et al.* 2000, Cabot & Nibset 2013). Areas with strong water currents are thought to be important as they bring small prey to the surface (Schwemmer *et al.* 2009).. Foraging areas are usually 10-20 m deep (Schwemmer *et al.* 2009, Perrow *et al.* 2011b), although foraging mainly takes place where prey is within 20 cm of the surface (Hatch *et al.* 2002 *op cit* Lascelles *et al.* 2013). Arctic terns often feed above predatory fish and pursuit-swimming seabirds such as auks that drive prey to the surface (Pierotti 1988, Perrow *et al.* 2010).

Inter-colony variation in foraging habitat selection may result from the presence/absence of other tern species. Rock *et al.* (2007b) for example suggested partitioning in foraging habitat used by common and Arctic terns, with the latter foraging more offshore in deeper water. It is not known if the reasons behind this habitat segregation are resource partitioning or different habitat preferences between the two species. There is a lack of evidence relating to inter-annual variation in foraging habitat or the influence of weather or variation within seasons and within colonies.

### 3.5.3 Foraging behaviour

Arctic tern is highly manoeuvrable, adept at hovering and even capable of capturing swarming insects in flight or gleaning insects from vegetation (BWPI 2006, Cabot & Nisbet 2013) or snatching benthic worms, shrimps and crabs from inter-tidal areas in the Wadden Sea (Ens *et al.* 2004). Small prey items such as crustaceans and insects are caught by dipping-to-surface or by oblique plunge-dive (with partial immersion). Fish however are caught mostly by plunge-diving from a mean dive height of 3 m with dives suggested to be just below the water surface, probably not deeper than 0.5 m (Cabot & Nisbet 2013). However, photographic evidence to date suggests that full immersion may not be achieved with the wings remaining above the water surface (M. Perrow pers obs).

The fishing success of adults is likely to be influenced by environmental factors, with the highest success often being in dry, calm weather, declining with increasing wind and rain, while fog and cloud has also been reported to reduce foraging efficiency (Hawksley 1950 *op cit* BWPI 2006). Feeding rates are often highest at low tides, where adults are hunting over shallow reefs (Boecker 1967 *op cit* BWPI 2006).



### 3.5.4 Adult & chick diet

In the UK, sandeels *Ammodytes* sp. are the most important prey species for chicks, with clupeids (especially herring and sprat) making up most of remainder of the diet (Langham 1968 *op cit* BWPi 2006, Dunn 1972 *op cit* BWPi 2006, Monaghan *et al.* 1989, 1992, Uttley *et al.* 1989, Horn 1995, Schreiber & Kissling 2005). Elsewhere, such as in Canada, hake *Urophycis* sp. was an important alternative prey to sandeel, (Rock *et al.* 2007b), while capelin *Mallotus villosus* was an alternative at colonies in North East Iceland where sandeels weren't present (Vigfúsdóttir 2012).

Specific diet composition varies according to reproductive state and location (BWPi 2006). For example, during courtship, adult Arctic terns in Shetland appear to be specialist feeders on sandeels whilst sprat made up the bulk of prey on Coquet (Monaghan *et al.* 1989, Uttley 1989). Chick diet was however consistently focussed on sandeel at these two colonies, although larger sandeels were also caught on Shetland as compared to Coquet. Saithe comprised the bulk of the non-sandeel prey for chicks in Shetland, whereas on Coquet it was mainly sprat (Monaghan *et al.* 1989). Presumably, these differences were related to variation in the distribution of prey species, although the authors did not collect data on prey abundance so it was not possible to confirm this. A study in Iceland also reported variation in the diet of chicks between colonies and the regions studied, with varying proportions of marine, estuarine and terrestrial prey being delivered (Vigfúsdóttir 2012). This study reported that non-sandeel prey may have facilitated better fledging success when and where they were available, possibly because sandeel availability was low .

Few studies have looked at inter-annual variation in diet but Rock *et al.* (2007) found a significant year effect in their study, with the proportion of hake and sandeel differing between years. Horn (1995) also found inter-annual variation in diet, with significant variation in the sandeel component of chick diet over the two year study. Neither study presented any evidence as to the causes of this variation. There is a lack of evidence relating to the effects of weather on diet or variation within seasons and within colonies.

Using a series of criteria from body size, cost of foraging per unit time, constraint to short foraging range, ability to dive for prey and ability to switch diet, Furness & Tasker (2000) developed a vulnerability index to the reduction of sandeel abundance and applied it to 25 breeding seabird species. Arctic tern was judged to be the most vulnerable in terms of breeding success largely from a dependence on sandeel in the diet and to sensitivity to low sandeel abundance. In turn, sandeels appear to be vulnerable to aggressive human commercial fisheries (see Daunt *et al.* 2008) and there is a growing concern of the effects of climate change upon some populations of sandeels (Arnott & Ruxton 2002).

There appears to be link between sea temperature and prey availability to YOY sandeel through changes in the composition of zooplankton (e.g. from *Calanus finmarchicus* to *C. helgolandicus* - van deurs *et al.* 2009), although this is far from being fully understood. There also appears to be local variation in the effect and response of the birds, with this being particularly acute in the Northern Isles. In response to an apparent lack of fish prey of suitable type and size Miles *et al.* (2011) observed many adult Arctic terns hawking for insects over the meadows on Fair Isle from May onwards. Such prey is not suitable for chick growth and development and breeding success has been very low or even non-existent. For example, productivity was zero for eight years in one decade on Fair Isle (Miles *et al.* 2011). Elsewhere, such as for the English colonies, Arctic tern production has generally fluctuated

widely but has not been as consistently low as that recorded in Scotland (JNCC 2013)

### 3.5.5 Summary

Arctic tern is capable of taking a wide variety of prey items by a number of techniques, but at the same time is dependent on a few important prey items, especially sandeels in the UK. As a specialist it has proved to be vulnerable to declines in the abundance of sandeels potentially driven by commercial fisheries and climate change, although the casual mechanisms remain poorly understood.

Systematic investigation of Arctic tern foraging range and distribution is limited with a maximum range of ~30 km, but with wide variation both between and within colonies. Important foraging habitats are the edges of sandy or rocky shores, tidal flats or shoals, and especially over tide rips and upwellings which bring prey closer to the surface. It is assumed that differences in range and foraging habitat relate mainly to the distribution and relative profitability of prey and the available habitat around different colonies. The presence/absence of other tern species can also result in inter-colony variation with evidence of habitat segregation when Arctic terns occur sympatrically with common terns. There is a lack of evidence relating to inter-annual variation or the influence of weather but it is likely that any variation that does exist will be driven by changes in prey availability.

Diet appears to be relatively consistent between colonies, with sandeel being especially important to both chicks and adults, although the latter may exploit small prey even including insects. Exact composition varies in different locations with certain species being more dominant at certain locations. for example, sprat is more important on Coquet and hake is important in Canada, presumably depending on the availability of different prey. There is little evidence documenting inter-annual variation in diet although one study that did look at this found the proportion of hake and sandeels varied between years.

## 4 Conclusions

All five species of UK terns are capable of a number of foraging techniques and whilst a range of prey may be taken by adults, chicks are dependent on energy-rich fish for successful growth and development. Although superficially similar, this belies key differences in their basic foraging ecology.

Little tern for example, is a short-ranging species dependent of abundant supplies of especially YOY clupeids and sandeels close to the colony. In contrast, Sandwich tern is a highly colonial wide-ranging species specialising on relatively large individuals of the same two groups. Roseate tern is generally a tropical or sub-tropical species more similar to Sandwich tern than the similar-sized Arctic and common terns. It is restricted to offshore islands more likely to meet its unusual nesting requirements within cover, and surrounded by deeper waters. Common tern is a generalist, capable of taking a wide range of prey in both marine and freshwater habitats. Whilst Arctic tern may also occupy both habitats in its wider range, it is typically marine in the UK and largely dependent on sandeel in its Scottish strongholds. Arctic tern is the most vulnerable to climate change.

In general, understanding of the complex relationships between marine features and tern foraging behaviour is increasing if still fairly limited and there is still much to

learn. One factor influencing the wide variation in foraging ranges reported across species is the variation in data collection methods and there are few direct studies in which terns are proven to originate from a particular colony through tracking techniques. Visual-tracking studies have the potential to produce the most detailed and accurate information especially in relation to foraging behaviour and relatively large sample sizes. Tagging studies can provide detailed information on ranging and habitat use but tend to produce smaller sample sizes and in general, terns are not the best subjects to carry tags. Where birds are not tracked and their breeding status is unknown, higher ranges may be reported as non-breeders range further. Targetted surveys can provide good information on the distribution of birds at sea, particularly when accompanied by robust data on environmental variables.


In general, it is expected that foraging range, habitat use and the diet of both adults and chicks will vary both spatially and temporally in relation to the distribution and availability of prey. There is limited evidence of greater range in the incubation compared to chick-rearing periods. Where species occur sympatrically this may also refine the ecological niche available, with impacts on foraging ecology of the species present. In general terms, environmental variables are important in influencing foraging, but the role of different factors is likely to vary amongst species and particularly in relation to locality and the specific prey base and conditions encountered.


## 5 References

- Allcorn, R., Eaton, M., Cranswick, P.A., Perrow, M.R., Hall, C., Smith, L., Reid, J., Webb, A., Smith, K.W., Langston, R.H.W., Ratcliffe, N. (2003). *A pilot study of breeding tern foraging ranges in NW England and East Anglia in relation to potential development areas for offshore windfarms*. RSPB/ WWT/JNCC Sandy. UK: 27pp.
- Anon (2004). *Breeding of four species of tern and black-headed gull at Forvie National Nature Reserve 2004*. Unpublished report:18pp..
- Anon (2012). *Farne Islands breeding bird report 2012*. Unpublished report: 34pp.
- Arnott, S.A. & Ruxton, G.D. (2002). Sandeel recruitment in the North Sea: demographic, climatic and trophic effects. *Martine Ecology Progress Series*, 238: 199-210
- Becker, P.H., Frank, D., Walter, U. (1987). Geographische und jährliche Variation der Ernährung der Flußseeschwalbe (*Sterna hirundo*) an der Nordseeküste. *Journal für Ornithologie* 128: 457-475.
- Becker, P.H., Frank, D. & Sudmann, S.R. (1993). Temporal and spatial pattern of common tern (*Sterna hirundo*) foraging in the Wadden Sea. *Oecologia* 93: 389-393.
- Becker, P.H., Frank, D. & Wagener, M. (1997). Luxury in freshwater and stress at sea? The foraging of the Common Tern *Sterna hirundo*. *Ibis* 139: 264-269.
- Bertolero, A., Oro, D., Vilalta, A.M. & López, M.A. (2005). Selection of Foraging Habitats by Little Terns (*Sterna albifrons*) at the Ebro Delta (NE Spain). *Revista Catalana d'Ornitologia* 21: 37-42.
- BirdLife International (2000). *The Development of Boundary Selection Criteria for the Extension of Breeding Seabird Special Protection Areas into the Marine Environment*. OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic. Vlissingen (Flushing).
- Black, A.L. & Diamond, A.W. (2005). Feeding areas of Arctic Terns (*Sterna paradisaea*) and common terns (*Sterna hirundo*) breeding on the Machias Seal Island, New Brunswick.

- Pp. 101-105. In J.A. Percy, A.J. Evans, P.G. Wells, S.J. Rolston (eds) *The Changing 12 Bay of Fundy: Beyond 400 years*. Proceedings of the 6th Bay of Fundy Workshop, Cornwallis, Nova Scotia, September 29th –13 October 2nd. Environment Canada – Atlantic Region, Occasional Report No. 23. Dartmouth, N.S. & Sackville, N.B.
- Bogliani, G., Fasola, M., Canova, L. & Saino, N. (1994). Prey selection by parents and chicks of the Little Tern *Sterna albifrons*. *Avocetta* 18: 9–11.
- Booth, V.J. (2006). *The breeding ecology of common and Arctic terns in N.E. England over a period of environmental change*. PhD thesis, University of Leeds: 166pp.
- Brenninkmeijer, A. & Stienen, E.W.M. (1994). *Pilot study on the influence of feeding conditions at the North Sea on the breeding results of the Sandwich Tern *Sterna sandvicensis**. IBN Research Report 94: 51pp.
- Brockless, A., Milling, N. & Silk, A. (2010). *Long Nanny Tern Colony*. Report 2010: 37pp.
- Brown, P. & Grice, P. (2005). *Birds in England*. T&AD Poyser, London, UK: 694pp. ISBN 0 7136 6530 0.
- BWPI (2006). *Birds of the Western Palearctic interactive DVD ROM 2.0*. Oxford University Press, UK.
- Cabot, D. & Nisbet, I. (2013). *Terns*. Harper Collins, London: 461pp.
- Catry, T., Ramos, J.A., Martins, J., Peste, F., Trigo, S., Paiva, V.H., Almeida, A., Luis, A., Palma, J. & Andrade, P.J. (2006). Intercolony and annual differences in the diet and feeding ecology of little tern adults and chicks in Portugal. *Condor* 108(2): 366-376.
- Centrica Energy (2009). *Environmental Statement for Race Bank Offshore Wind Farm: Volume 1 Offshore Works*. Centrica (in association with AMEC), Windsor, UK.
- Cotin, J., García-Tarrasón, M., Sanpera, C., Jover, L., & Ruiz, X. (2011). Sea, freshwater or salt pans? Foraging ecology of terns to assess mercury inputs in a wetland landscape, The Ebro Delta. *Estuarine, Coastal and Shelf Science* 92: 188–194.
- Cramp, S., Bourne, W.R.P. & Saunders, D. (1974). *The seabirds of Britain and Ireland*. London, Collins: 287 pp.
- Cramp, S. (1985). *The birds of the Western Palearctic*. Vol. 4. Oxford University Press, Oxford: 970pp.
- Cyrus, D.P. (1991). The influence of turbidity on the foraging behaviour of Little Terns *Sterna albibifrons* off the St Lucia Mouth, Zululand, South Africa. *Marine Ornithology* 19: 103-108
- Dänhardt, A. (2010). *The spatial and temporal link between common terns *Sterna hirundo* and their prey fish in the Wadden Sea*. PhD thesis, Hamberg. 117 pp.
- Dänhardt, A., Freseman, T., & Becker, P.H. (2010). To eat or to feed? Prey utilization of Common Terns *Sterna hirundo* in the Wadden Sea. *Journal of Ornithology* 152: 347–357.
- Dänhardt, A. & Becker, P.H. (2011). Herring and sprat abundance indices predict chick growth and reproductive performance of Common Terns breeding in the Wadden Sea. *Ecosystems* 14: 791–803.
- Daunt, F., Wanless, S., Greenstreet, S.P.R., Jensen, H., Hamer, K. & Harris, M.P. (2008). The impact of sandeel fishery closure on seabird food consumption, distribution, and productivity in the northwestern North Sea. *Canadian Journal of Fisheries and Aquatic Science*, 65: 362-381.
- Davies, S. (1981). Development and Behaviour of Little Tern Chicks. *British Birds* 74: 291–298.
- del Hoyo, J.; Elliott, A. & Sargatal, J. (1996). *Handbook of the Birds of the World, vol. 3, Hoatzin to Auks*. Lynx Edicions, Barcelona, Spain: 821pp.


- Duffy, D.C. (1986). Foraging at patches, interactions between common and roseate terns. *Ornis Scandinavica* 17: 47-52.
- Dunnet, G.M., Furness, R.W., Tasker, M.L., & Becker, P.H. (1990). Seabird ecology in the North Sea. *Netherlands Journal of Sea Research* 26: 387-425.
- Eaton, M.A., Brown, A.F., Noble, D.G., Musgrove, A.J., Hearn, R.D., Aebischer, N.J., Gibbons, D.W., Evans, A. & Gregory, R.D. (2009). Birds of Conservation Concern 3: the population status of birds in the United Kingdom, Channel Islands and Isle of Man. *British Birds* 102: 296-341. (BoCC3)
- Ens, B, van de Kam, J., Piersma, T. & Zwarts, L. (2004). *Shorebirds: an illustrated behavioural ecology*. KNNV Publishers, Utrecht. ISBN 90-5011-192-0: 368pp.
- Fasola, M., Bogliani, G., Saino, N., & Canova, L. (1989). Foraging, feeding and time-activity niches of eight species of breeding seabirds in the coastal wetlands of the Adriatic Sea. *Bolletino di zoologia* 56: 61-72.
- Fasola, M. & Bogliani, G. (1990). Foraging ranges of an assemblage of Mediterranean seabirds. *Colonial Waterbirds* 13: 72-74
- Fletcher, K.L. (2002). *Sex-specific breeding ecology of common terns in N. E. England*. PhD theses, Durham University. Available at Durham E-Theses Online: <http://etheses.dur.ac.uk/3868/> 171 pp.
- Forrester, R.W., Andrews, I.J., McInerny, C.J., Murray, R.D., McGowan, R.Y., Zonfrillo, B., Betts, M.W., Jardine, D.C. and Grundy, D.S. (2007). *The Birds of Scotland*. Scottish Ornithologists' Club, Aberlady: 1600pp.
- Frank D. (1992). The influence of feeding conditions on food provisioning of chicks in Common Terns *Sterna hirundo* nesting in the German Wadden Sea. *Ardea* 80: 45 - 55.
- Fuchs, E., (2008).. Kleptoparasitism of Sandwich terns *Sterna sandvicensis* by black-headed gulls *Larus ridibundus*. *Ibis* , 119: , 183-190.
- Fujita, G., Totsu, K., Shibata, E., Matsuoka, Y., Morita, H., Kitamura, W., Kuramoto, N., Masuda, N. & Higuchi, H. (2009). Habitat management of little terns in Japan's highly developed landscape. *Biological Conservation* 142: 1891-1898.
- Furness, R.W. & Tasker, M.L. (2000). Seabird-fishery interactions, quantifying the sensitivity of seabirds to reductions in sandeel abundance, and identification of key areas for sensitive seabirds in the North Sea. *Marine Ecology Progress Series* 202: 253-264.
- Gallagher, V., Kidd, H. , Kouzarides S., Whiston L. (2013). *Long Nanny Tern Colony*. Tern report 2013. 33 pp.
- García, G.O., Becker, P.H. & Favero, M. (2010). Kleptoparasitism during courtship in *Sterna hirundo* and its relationship with female reproductive performance. *Journal of Ornithology* 152: 103-110.
- Garthe, S. & Flore, B.-O. (2007). Population trend over 100 years and conservation needs of breeding sandwich terns (*Sterna sandvicensis*) on the German North Sea coast. *Journal of Ornithology* 148: 215-227.
- Glenister, L., Newton, S. & McAvoy, S. (2008). *Rockabill tern report 2008*. BirdWatch Ireland Seabird Conservation Report. 43 pp.
- Glenister, L., Money, S., Newton, S.F. & Foley, K. (2009). *Rockabill Tern Report 2009*. BirdWatch Ireland Seabird Conservation Report No. 09/S-3. 47 pp.
- Götmark, F. (1990). A test of the information-centre hypothesis in a colony of Sandwich terns *Sterna sandvicensis*. *Animal Behaviour* 39: 487-495.
- Granadeiro, J.P., Monteiro, L.R., Silva, M.C. & Furness, R.W. (2002). Diet of Common Terns in the Azores, Northeast Atlantic. *Waterbirds* 25: 149-155.
- Hall, C.S., Kress, S.W. & Griffin, C.R. (2000). Composition, Spatial and Temporal Variation of Common and Arctic Tern Chick Diets in the Gulf of Maine. *Waterbirds* 23: 430-439.

- 
- 
- Heaney, V. (1997). *Within brood trade-offs in reproductive effort: an experimental study on the common tern *Sterna hirundo**. PhD thesis, University of Glasgow
- Heinemann, D. (1992). *Foraging ecology of Roseate Terns on Bird Island, Buzzards Bay, Massachusetts*. Unpubl. report to U.S. Fish and Wildlife Services, Newtown Corner, MA: 50pp.
- Horn, W. (1995). Prey selection, foraging effort and breeding performance of Arctic (*Sterna paradisaea*) and Common (*Sterna hirundo*) Terns. PhD thesis, University of Glasgow.: 235pp.
- Howe, R. (2003). *The effect of physical factors on the foraging ecology of little terns (*Sterna albifrons*) at Winterton-on-Sea, Norfolk, 2003*. Unpubl. BSc thesis, University of East Anglia, Norwich: 33pp.
- JNCC (2013). Arctic Tern *Sterna paradisaea*. <http://jncc.defra.gov.uk/page-2896>
- Langston, R.H.W. (2010). *Offshore wind farms and birds: Round 3 zones, extension to Round 1 and Round 2 sites and Scottish Territorial waters*. RSPB Research Report No 39, RSPB, The Lodge, Sandy, Beds, UK: 42pp.
- Lascelles, B., Varty, N., Tanner, K. and McCann, R. (2013). *Birdlife Seabird Wikispaces*. <http://seabird.wikispaces.com>
- Lewis, S., Sherratt, T.N., Hamer, K.C. & Wanless, S. (2001). Evidence of intra-specific competition for food in a pelagic seabird. *Nature* 412: , 816–819.
- Lloyd, C., Tasker, M.L. & Partridge, K. (1991). *The Status of Seabirds in Britain and Ireland*. T. & A.D. Poyser, London: 355pp.
- Martins, I., Pereira, J.C., Ramos, J.A. & Jørgensen, S.E. (2004). Modelling the effects of different quality prey fish species and of food supply reduction on growth performance of Roseate Tern chicks. *Ecological Modelling* 177: 95–106.
- Massias, A. & Becker, P.H., (1990). Body-mass and nest reliefs in common terns exposed to different feeding conditions. *Ornis Scandinavica* , 21:, 187.
- Miles, W. T. S., Parnaby, D., Moss, J. W., Gunn, C-M. & Hughes, R. D. (2011). *Fair Isle Seabird Studies 2011*. Submitted to Joint Nature Conservation Committee: 36pp.
- Mitchell, P.I., Newton, S.F., Ratcliffe, N. & Dunn, T.E. (2004). *Seabird populations of Britain and Ireland (Results of the Seabird 2000 Census 1998-2000)*. T. & A.D. Poyser; London: 511pp.
- Monaghan, P., Uttley, J.D., Burns, M.D., Thaine, C. & Blackwood, J. (1989). The relationship between food supply, reproductive effort and breeding success in Arctic terns *Sterna paradisaea*. *Journal of Animal Ecology* 58: 261-274
- Monaghan, P., Uttley, J.D. & Burns, M.D. 1990. The influences of changes in prey availability on the breeding ecology of terns. *Acta XX Congressus Internationalis Ornithologici*, pp 2257-2262.
- Monaghan, P., Uttley, J.D. & Burns, M.D. (1992). Effects of changes in food availability on reproductive effort in Arctic Terns *Sterna paradisaea*. *Ardea* 80: 71-81.
- Monticelli D., Ramos, J.A. & Pereira, J. (2006). Habitat use and foraging success of Roseate and Common Terns foraging in flocks in the Azores. *Ardeola* 53: 293-306.
- Moore, D.J. (1993). *Foraging ecology and parental care of Common Terns (*Sterna hirundo*) nesting in Windermere Basin, Lake Ontario*. Master's Thesis. Brock Univ. St. Catharines, Ontario: 153pp.
- Mundy, R. (1997). *Diet and chick provisioning rates of Roseate Terns in relation to chick age on Rockabill*. In Monteiro, L.R. (Ed.), *Proceedings of the 7th Roseate Tern Workshop*, pp 25-27, University of Azores, Horta.

- 
- 
- Newton, S.F., Cowles, A., O'Sullivan, G., & Merne, O.J. (2005). *Rockabill tern report 2005*. Birdwatch Ireland Conservation Report No. 05/12: 28pp. Newton S.F. & Crowe O. (2000). *Roseate Terns - The Natural Connection*. Maritime Ireland / Wales INTERREG Report No. 2: 70pp.
- Nisbet, I.C.T. (1983). Territorial feeding by Common Terns. *Colonial Waterbirds* 6: 64-70
- Nisbet, I.C.T. & Spendelow, J.A. (1999). Contribution of Research to Management and Recovery of the Roseate Tern: Review of a Twelve-Year Project. *Waterbirds* 22: 239-252.
- Nisbet, I.C.T., Spendelow, J.A., Hatfield, J.S., Zingo J.M. & Gough, G. (1998). Variations in growth of Roseate Tern chicks. II. Early growth as an index of parental quality. *Condor* 10: 305-315.
- Paiva, V.H., Ramos, J.A., Catry, T., Pedro, P., Medeiros, R. & Palma, J., (2006a). Influence of environmental factors and energetic value of food on Little Tern *Sterna albifrons* chick growth and food delivery. *Bird Study* 53: 1-11.
- Paiva, V.H., Ramos, J.A., Machado, D., Penha-Lopes, G., Bouslama, M.F., Dias, N. & Nielsen, S., (2006b). Importance of marine prey to growth of estuarine tern chicks, evidence from an energetic balance model. *Ardea* 94(2): 241-255.
- Paiva, V.H., Ramos, J.A., Martins, J., Almeida, A. & Carvalho, A. (2008). Foraging habitat selection by Little Terns *Sternula albifrons* in an estuarine lagoon system of southern Portugal. *Ibis* 150: 18-31.
- Pearson, T.H. (1968). The feeding biology of sea-bird species breeding on the Farne Islands, Northumberland. *Journal of Animal Ecology* 37: 521-552.
- Perrow, M.R. & Eglinton, S.M. (2014). Securing a future for East Norfolk's Little Terns. *British Wildlife* 25(4): 237-245.
- Perrow, M.R., Tomlinson, M. L., Lines, P., Benham, K., Howe, R. & Skeate, E. R. (2004). *Is food supply behind little tern *Sterna albifrons* colony location? The case of the largest colony in the UK at the North Denes/Winterton SPA in Norfolk*, pp. 39-59. In Allcorn, R.I (Ed) *Proceedings of a symposium on little terns *Sterna albifrons**. RSPB Research Report No. 8, RSPB, Sandy.
- Perrow M. R. Skeate E. R. & Tomlinson M. L. (2008). *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*. For and on behalf of E-ON UK Renewables Offshore Wind Limited, ECON Ecological Consultancy, Norwich.
- Perrow, M. R., Skeate, E. R., Lines, P., Brown, D. & Tomlinson, M. L. (2006). Radio telemetry as a tool for impact assessment of wind farms, the case of Little Terns *Sterna albifrons* at Scroby Sands, Norfolk, UK. *Ibis* 148: 57-75.
- Perrow, M.R., Gilroy, J.J., Skeate, E.R. & Mackenzie, A. (2010). *Quantifying the relative use of coastal waters by breeding terns: towards effective tools for planning and assessing the ornithological impacts of offshore wind farms*. ECON Ecological Consultancy Ltd. Report to COWRIE Ltd. ISBN: 978-0-9565843-3-5: 148pp.
- Perrow M.R., Gilroy J.J., Skeate E.R. & Tomlinson M.L. (2011a). Effects of the construction of Scroby Sands offshore wind farm on the prey base of Little tern *Sternula albifrons* at its most important UK colony. *Marine Pollution Bulletin* 62(8): 1661-70.
- Perrow, M.R., Skeate, E.R., Gilroy, J.J. (2011b). Visual tracking from a rigid-hulled inflatable boat to determine foraging movements of breeding terns. *Journal of Field Ornithology* 82: 68-79.
- Phalan, B. (2000). *The Diet and Early Growth of Little Terns (*Sterna albifrons*) at Kilcoole, Co. Wicklow in 1999*. BA, University of Dublin, Trinity College: 65pp.

- Pierotti, R. (1988). *Associations between marine birds and mammals in the northwest Atlantic Ocean*, pp 31–58. In: Burger, J. (Ed.) *Seabirds and other marine vertebrates, competition, predation and other interactions* Columbia Univ. Press, New York.
- Ramos, J.A. (2000). Characteristics of Foraging Habitats and Chick Food Provisioning by Tropical Roseate Terns. *The Condor* 102: 795–803.
- Ramos, J.A., Sola, W., & Monteiro, L.R. (1998). Prey Delivered to Roseate Tern Chicks in the Azores. *Journal of Field Ornithology* 69: 419-429
- Ratcliffe, N. Richardson, D., Lidstone Scott, R., Bond, P.J., Westlake, C. & Stennett, S. (1997). Host selection, attack rates and success rates for Black-headed gull kleptoparasitism of Terns. *Colonial Waterbirds*, 20, 227-234
- Robinson, J.A. (1999). *The comparative breeding ecology of sympatric common and arctic terns in N.E. England*. PhD thesis, Durham University. Available at Durham E-Theses Online: <http://etheses.dur.ac.uk/4350/>: 154pp.
- Rock J.C., Leonard M.L. & Boyne A.W. (200a). Do co-nesting Arctic and Common Terns partition foraging habitat and chick diets? *Waterbirds* 30(4): 579-587.
- Rock, J.C., Leonard, M.L., & Boyne, A.W. (2007b). Foraging habitat and chick diets of Roseate Tern, *Sterna dougalli*, breeding on Country Island, Nova Scotia. *Avian Conservation and Ecology - Écologie et conservation des oiseaux*, 2, online.
- Safina, C., (1990). Foraging Habitat Partitioning in Roseate and Common Terns. *The Auk*, 107: 351–358.
- Safina, C., Wagner, R.H., Witting, D.A., & Smith, K.J. (1990). Prey delivered to Roseate and Common Tern chicks composition and temporal variability. *Journal of Field Ornithology* 61: 331–338.
- Safina, C. & Burger, J. (1988). Prey dynamics and the breeding phenology of common terns (*Sterna hirunda*). *The Auk* 105: 720-726.
- Schreiber, J. & Kissling, W.D. (2005). Factors affecting the breeding success of Arctic Terns *Sterna paradisaea* in a colony at Kaldbraksbotner, Faroe Islands. *Atlantic Seabirds* 7: 97–106.
- Schwemmer, P., Adler, S., Guse, N., Markones, N. & Garthe, S. (2009). Influence of water flow velocity, water depth and colony distance on distribution and foraging patterns of terns in the Wadden Sea. *Fisheries Oceanography* 18: 161-172
- Shealer, D.A. (1996). Foraging habitat use and profitability in tropical Roseate Terns and sandwich terns. *The Auk* 113(1): 209-217.
- Shealer, D.A. (1998a). Size-Selective Predation by a Specialist Forager, the Roseate Tern. *The Auk* 115: 519–525.
- Shealer, D.A. (1998b). Differences in Diet and Chick Provisioning between Adult Roseate and Sandwich Terns in Puerto Rico. *The Condor* 100: 131–140.
- Shealer, D.A. & Burger, J. (1993). Effects of interference competition on the foraging activity of tropical Roseate Terns. *The Condor* 95: 322-329.
- Shealer, D.A. & Burger, J. (1995). Comparative foraging success between adult and one-year old Roseate and Sandwich Terns. *Colonial Waterbirds* 18: 93-99.
- Shealer, D.A., Saliva, J.E., & Pierce, J. (2005). Annual Survival and Movement Patterns of Roseate Terns Breeding in Puerto Rico and the U.S. Virgin Islands. *Waterbirds* 28: 79–86.
- Stienen, E.W.M., Van Beers, P.W.M., Brenninkmeijer, A., Habraken, J.M.P.M., Raaijmakers, M.H.J.E. & Van Tienen, P.G.M. (2000). Reflections of a specialist, patterns in food provisioning and foraging conditions in Sandwich Terns *Sterna sandvicensis*. *Ardea* 88: 3–49.



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- Stienen E.W.M. (2006). Living with gulls. *Trading off food and predation in the Sandwich Tern* *Sterna sandvicensis*. Alterra scientific contributions 15, Alterra Wageningen. Ph.D. Thesis, Groningen University, Groningen: 192pp.
- Stienen, E.W.M., Brenninkmeijer, A. & Geschiere, C.E. (2001). Living with gulls, the consequences for Sandwich Terns of breeding in association with Black-headed gulls. *Waterbirds* 24: 68-82.
- Stienen, E.W.M. & Brenninkmeijer, A. (2002). Foraging decisions of Sandwich Terns in the presence of kleptoparasitising gulls. *The Auk* 119: 473-486.
- Suddaby, D. & Ratcliffe, N. (1997). The Effects of Fluctuating Food Availability on Breeding Arctic Terns (*Sterna paradisaea*). *The Auk* 114: 524-530.
- Taylor, I.R. (1983). Effect of wind on foraging behaviour of Common and Sandwich Terns. *Ornis Scandinavia* 14: 90-96.
- Taylor, I.R. & Roe, E.L. (2004). Feeding ecology of little terns *Sterna albifrons sinensis* in south-eastern Australia and the effects of pilchard mass mortality on breeding success and population size. *Marine and Freshwater Research* 55(8): 799-808.
- Taylor, M. & Marchant, J.H. (2011). *The Norfolk Bird Atlas: summer and winter distributions 1999-2007*. BTO Books, Thetford. ISBN 978-1-906204-82-2: 528pp.
- Taylor, M, Seago, M, Allard, P & Dorling, D. (1999). *The Birds of Norfolk*. Pica Press, East Sussex: 552pp. ISBN 1 873403 86 0: 552pp.
- Thaxter, C.B., Lascelles, B., Sugar, K., Cook, A.S.C.P., Roos, S., Bolton, M., Langston, R.H.W., Burton, N.H.K. (2012). Seabird foraging ranges as a preliminary tool for identifying candidate Marine Protected Areas. *Biological Conservation* 156: 53-61.
- Uttley, J., Monaghan, P. & White, S. (1989). Differential Effects of Reduced Sandeel Availability on Two Sympatrically Breeding Species of Tern. *Ornis Scandinavica* 20, 273-277.
- Vanaverbeke, J., Franco, M.A., Remerie, T., Vanreusel, A., Vincx, M., Moodley, L., Soetaert, K., van Oevelen, D., Courtens, W., Stienen, E.W.M., van de Walle, M., Deneudt, K., van den Berghe, E., Draisma, S., Hellemans, B., Huyse, T., Volckaert, F.A.M.J. & van den Eynde, D. (2007). *Higher trophic levels in the southern North Sea "TROPHOS": Final report EV/25*. Belgian Science Policy, Brussels: 71pp
- van Deurs, M., van Hal, R., Tomczak, M.T., Jónasdóttir, S.H. & Dolmer, P. (2009). Recruitment of lesser sandeel *Ammodytes marinus* in relation to density dependence and Zooplankton composition. *Marine Ecology Progress Series* 381: 249 – 258.
- Vigfúsdóttir, F. (2012). Drivers of productivity in a subarctic seabird: Arctic Terns in Iceland. PhD thesis, University of East Anglia, Norwich: 126pp.
- Wanless, S., Harris, M.P. & Greenstreet, S.R. (1998). Summer sandeel consumption by seabirds breeding in the Firth of Forth, southeast Scotland. *ICES Journal of Marine Science* 55: 1141-1151.
- Wendeln, H. & Becker, P.H. (1996). Body mass change in breeding Common Terns *Sterna hirundo*. *Bird Study* 43: 85-95.
- Wilde, D. & Wright, D. (2013). Cemlyn. North Wales Wildlife Trust Nature Reserve warden's report.: 30pp. Wright, P.J. & Bailey, M.C. (1993). *Biology of sandeels in the vicinity of seabird colonies at Shetland*. SOAFD, Marine Laboratory, Aberdeen. Report No. 15/93: 64pp.

## 6 Appendices

### Appendix 1. Summary of studies reporting foraging distances

#### 6.1.1 Little tern

Location	Foraging range information (method)	Reference
Australia	A high percentage of the population fed within 0.5 km of the colony. (Visual observations)	Taylor & Roe 2004
Ebro Delta, Spain	95% of the foraging terns were observed less than 4 km from the nearest colony. (Boat transects)	Bertolero <i>et al.</i> 2005
Gibraltar Point, England	Rarely travelled more than 1 km to forage from the breeding colony. (Visual observations)	Davies 1981
Ireland	Foraging up to 1.5 km from colony, mostly within 30 m of shore. (Beach transects)	Phalan 2000
Italy	Average radius of 2.1 km from the colony, with 90% of birds foraging within 3 km and a maximum of 6 km. (Boat surveys).	Fasola & Bogliani 1990
Japan	Terns mainly foraged within a distance of 1 km from the colony. The maximum distance from the colony to the foraging point was around 6 km. (Beach surveys).	Fujita <i>et al.</i> 2009
Norfolk	With an active nest, birds occupied a range of < 6.3 km <sup>2</sup> with a range span of up to 4.6 km. In comparison, failed birds ranged widely, occupying ranges up to 52 km <sup>2</sup> and travelling up to 27 km in a single foraging bout. (Radio-tracking).	Perrow <i>et al.</i> 2006
Norfolk	Maximum foraging ranges of ~1200-1600 ha in 2005 and 2006, over twice that recorded in 2003 at around 500-600 ha. Uncorrected range span was ~5.4-6.0 km in 2005 and 2006, increased from 3.4-3.5 km in 2003 and 2004. Distance from shore was a median value of ~1.3-1.65 km in 2005 and 2006 compared to 0.4-0.5 km in earlier years. (Radio-tracking)	Perrow <i>et al.</i> 2008
Nummer Een, Westerschelde, Germany.	Foraged within 7 km of the colony site, yet mostly with 3-4 km. (method unknown)	Brenninkmeijer <i>et al.</i> 2002 <i>op cit</i> Lascelles <i>et al</i> 2013.

Spain	Most (95%) of the foraging terns were observed less than 4 km away from the nearest colony (Beach transects)	Bertolero <i>et al.</i> 2005
UK	Birds foraged close to colony, often in breaking tide line. 90% were observed within 2 km of their colony. (Boat surveys)	Allcorn <i>et al.</i> 2003

### 6.1.2 Sandwich tern

Location	Foraging range information	Reference
Cemlyn Bay	40 km from the colony, although never more than 8 km offshore. Mean distance travelled ( $\pm$ S.E) : $7.6 \pm 0.8$ km, mean maximum distance from colony: $15.8 \pm 0.2$ km, mean maximum distance offshore : $1.8 \pm 0.1$ km. (Visual tracking)	Perrow <i>et al.</i> 2010
Coquet Island	Foraged up to 20-25 km offshore but tended to forage closer to Coquet Island in July, when chicks were fledging, than in June, before fledging occurred. (Method unknown).	Breakwell <i>et al.</i> 1996 <i>op cit</i> Lascelles <i>et al</i> 2013
Dutch Delta area	Foraging distance between the colonies of Hompelvoet and Hooge Platen and their foraging area at the Voordelta in the North Sea was estimated at 15-40 km. (Method unknown).	Brenninkmeijer <i>et al.</i> 2002 <i>op cit</i> Lascelles <i>et al</i> 2013
Farne Islands, UK	Estimated that Sandwich Terns could forage at a maximum distance of c. 24.5 km from the colony if they spent a negligible amount of time actually fishing. (Based on foraging trip observations)	Pearson 1968 <i>op cit</i> Lascelles <i>et al</i> 2013
German North Sea coast	Maximum foraging range: ca. 45 km for Trischen, ca. 35 km for Norderoog and ca. 30 km for both Scharhörn/Nigehörn and Juist. Overall flight ranges for all colonies: 33.8 km for 95% of the birds, 26.2 km (95% CI 21.7–33.8 km) for 90% of the birds and 18.4 km (16.5–22.0 km) for 75% of the birds. Transect counts.	Garthe & Flore 2007
Griend, the Netherlands	Radio-tracked terns appeared to catch fish at a mean distance of c. 16 km (n=4) from the colony. (Radio-tracking)	Stienen 2006
Norfolk	Visually tracked for periods up to 126 min over	Perrow <i>et al.</i> 2011b

	distances up to 72 km and as far as 54 km from the breeding colony. (Visual tracking)	
Norfolk	Visually tracked to maximum of 24 km, although many birds were observed foraging <2km from the shore. Models predicted foraging range of 7–36 km.  Mean distance travelled ( $\pm$ S.E): 15.4 $\pm$ 3.6 km, mean maximum distance from colony: 6.6 $\pm$ 1.5 km, mean maximum distance offshore : 4.4 $\pm$ 1.4 km (Visual tracking)	Perrow <i>et al.</i> 2010
Northeast Italy	Birds observed foraging 17 km from the colony (mean = 13.1 km with 90% of birds within 15 km). (Boat surveys)	Fasola & Boglioni 1990
Sweden	Most birds observed foraging within 2 – 3 km of the colony. (Beach surveys)	Gotmark 2000

### 6.1.3 Common tern

Location	Foraging range information	Reference
Coquet Island, UK	Fished up to 20-25 km offshore but tended to forage closer to Coquet Island in July, when chicks were fledging, than in June, before fledging occurred. (Method unknown)	Breakwell <i>et al.</i> 1996 <i>op cit</i> Lascelles <i>et al.</i> 2013
Country Island, Canada	Foraged within 9 km of the breeding colony (range 0.4-24.6 km, mean 9.3 km) and within 1.5 km of land (range 0.1-5.7 km, mean 1.5 km). (Radio-tracking)	Rock <i>et al.</i> 2007b
German Wadden Sea	Approximately 30 km per feeding flight. Completely tracked flights had a mean radius of 6.3 km (but considered to be an underestimate). (Radio-tracking)	Becker <i>et al.</i> 1993, Becker <i>et al.</i> 1997
Isle of May, UK	Usually located Common terns within 10 km of colony. (Boat transects).	Wanless <i>et al.</i> 1998
Long Island, US	Fed most commonly at a site 5.5 km from a Long Island (New York, U.S.A.) colony, but with some travelling as far as 18 km. (Beach observations)	Duffy 1986
Maine, US	Most Common Terns returned to a colony in Maine from the direction of the mainland (4 km away) and suggested that	Hopkins <i>et al.</i> 1972 <i>op cit</i> Lascelles <i>et al.</i> 2013

	the adults were probably feeding in the shallow water along the coast. (Method unknown)	
Machias Seal Island, Canada	Found birds very near the nesting site (within 5 km) as well as up to 30 km away. (Radio-tracking)	Black and Diamond 2005
Norfolk	Mean distance travelled ( $\pm$ S.E): $6.6 \pm 1.8$ km, mean maximum distance from colony: $2.2 \pm 0.4$ km, mean maximum distance offshore : $1.0 \pm 0.1$ km. (Visual tracking)	Perrow <i>et al.</i> 2010
Ontario, Canada	At a freshwater lake in Ontario, Canada up to 75% of feeding trips were in the direction of a point around 7-8 km from the colony. Method unknown.	Burness <i>et al</i> 1994 <i>op cit</i> Lascelles <i>et al.</i> 2013
Ontario, Canada	Most birds flew either 0.9 km to a small pond (30% of trips) or 1–8 km to foraging sites on the lake with a mean trip distance 2.4–4.2 km (max. 20 km, n=99 males, >1,000 trips. Method unknown.	Moore 1993, Moore 2001 <i>op cit</i> Lascelles <i>et al</i> 2013
Rockabill, Ireland	Found primarily within 10 km of colony. (Boat transects)	Newton & Crowe 2000
Saltholme	Mean distance travelled ( $\pm$ S.E): $4.0 \pm 0.5$ km, mean maximum distance from colony: $8.1 \pm 0.3$ km, mean maximum distance offshore : $1.9 \pm 0.2$ km. (Visual tracking)	Perrow <i>et al.</i> 2010

#### 6.1.4 Roseate tern

Location	Foraging range information	Reference
Bird Island, US	Most foraged over 3 small sandbars within 5 km of the colony, although sometimes flew to a tide rip 30 km away (Boat surveys)	Heinemann 1992
Cedar Beach, New York	Birds observed feeding in an inlet 5-8 km from the colony. (Beach observations)	Gochfield <i>et al.</i> 1998 <i>op cit</i> Lascelles <i>et al</i> 2013
Falkner Island, US	Birds observed feeding on sandbanks over 25 km away. (Boat observations)	Gochfield <i>et al.</i> 1998 <i>op cit</i> Lascelles <i>et al</i> 2013
Lady's Island, Ireland	Birds foraged within 3 km of shore and 5	Newton & Crowe 1999 <i>op cit</i> Lascelles <i>et al</i>

	km from the colony. (Boat surveys)	2013
Long Island, US	Most commonly fed at a site 5.5 km, but with some travelling as far as 18 km (Observations)	Duffy 1986
Massachusetts	Travelled up to 30 km from the breeding colony to forage and were attracted both to biotic (predatory fish), as well as physical (shoals and tide rips) features. (Boat observations)	Shealer 1996
Northeastern US	Birds foraged up to 25 km from the colony, over shallow sand shoals and tide rips. (Radio-tracking)	Safina 1990
Novia Scotia	Birds foraged approximately 7 km from the breeding colony. (Radio-tracking)	Rock 2007b
Puerto Rico	Fed within 2 km of the colony, often within 200 m. (Observations).	Shealer & Burger 1993, 1995
Ram Island, Massachusetts	Fish were caught within 300 m of colony. (Observations).	Gochfield <i>et al.</i> 1998 <i>op cit</i> Lascelles <i>et al</i> 2013
Rockabill, Ireland	Birds foraged within 10 km of colony during chick rearing. (Boat surveys)	Newton & Crowe 2000

### 6.1.5 Arctic tern

Location	Foraging range information	Reference
Anglesea, Wales	Maximum: up to 57 km distance, and 29 km from the colony. Mean distance travelled ( $\pm$ S.E): $24.5 \pm 7.4$ km, mean maximum distance from colony: $8.1 \pm 3.2$ km, mean maximum distance offshore : $8.5 \pm 3.5$ km. (Visual tracking)	Perrow <i>et al.</i> 2010
Fair Isle, UK	Foraging took place within 10 km of the colony. (Boat surveys)	Wright & Bailey 1993
Isle of May	Foraging took place within 10 km of the colony. (Boat transects)	Wanless et al 1998
Country Island, Canada	Adults foraged within 9 km of the breeding colony (range 2.4-20.6 km, mean 8.5 km) and within 5 km of land (range 0.3-17.2 km, mean 4.6 km). (Radio-tracking).	Rock <i>et al.</i> 2007b

German Wadden Sea	Foraging radii 4-6 km. (Method unknown)	Boecker 1967 <i>op cit</i> Lascelles et al 2013
German Wadden Sea	Foraging radii 4-6 km. Method unknown)	Hartwig et al 1990 <i>op cit</i> Lascelles et al 2013
Farne Islands, UK	Foraged at a maximum distance of about 20 km from the colony, based on a mean trip length of 50.2 min during chick-rearing and a flight speed of 48 km/h	Pearson 1968 <i>op cit</i> Lascelles et al 2013
Machias Seal Island, Canada	A low rate of detection of Arctic Tern foraging grounds suggests that perhaps the Arctic Terns are travelling further than the estimated 30 km range. (Radio-tracking)	Black and Diamond 2005

## Appendix 2 Summary of studies reporting diet of adults or chicks

### 6.2.1 Little tern

Location	Adults or chicks	Main prey species	Reference
Crimea, Russia	Unknown	Stomach contents and regurgitations comprised mostly fish (in 91%) and fewer shrimps and crabs (27%).	Borodulina 1960 <i>op cit</i> BWPI 2006
Eastern North Sea coast	Unknown	49 stomachs contained 95% fish, and only 5% crustaceans; 75 stomachs, summer, all contained fish, with insects in only 4–5	Nadler 1976 <i>op cit</i> BWPI 2006
Ireland	Adults Chicks	76% of prey were sandeels. Sandeels 35% of chick diet. 0-7 day old chicks fed gobies (40% of diet), older chicks, sandeels (70% of diet of older chicks). Provisioning observations.	Phalan 2000
Italy	Chicks	Young chicks fed more sandeels <i>Atherina boyeri</i> than older chicks. Opposite for crucian carp <i>Carassius carassius</i> . Older chicks fed more crustaceans than younger chicks. Observational study	Bogliani <i>et al.</i> 1994
Lake Baykal, Russia	Adults	Insects plucked in flight off vegetation. Method unknown	Polivanova 1971 <i>op cit</i> BWPI 2006
Long Nanny, UK	Chicks	91% and 92% of recorded prey items presented to chicks were sand eel species in 2010 and 2013 respectively, with occasional shrimps and sprats being recorded. Provisioning observations..	Brockless <i>et al.</i> 2010, Gallagher <i>et al.</i> 2013
Lower Volga, Russia	Unknown	Diet exclusively fish (gobies and roach of 4–5 cm). Method unknown.	Borodulina 1960 <i>op cit</i> BWPI 2006
Norfolk	Chicks	14 sp. of fish and 32 sp of invertebrate. Dominated by two fish taxa, clupeids (Herring or Sprat) (60% - 69%) and sandeels (6 % - 8%), with a limited contribution from a limited range of invertebrates (of which only which <i>Idotea</i> was positively identified). Provisioning observations.	Perrow <i>et al.</i> 2004, 2008, 2011



Portugal	Adults  Chicks	Sandeels ( <i>Atherina</i> spp.) and gobies ( <i>Pomatoschistus</i> spp)  Primarily <i>Atherina</i> spp., but also sardines ( <i>Sardina pilchardus</i> ), garfish ( <i>Belone belone</i> ), and killifish ( <i>Fundulus</i> spp). Provisioning observations.	Catry <i>et al.</i> 2006
Rigby Island, Australia	Chicks	Juvenile fish of the families Clupeidae, Engraulidae, Pomatomidae and Carangidae, including pilchard, southern anchovy and blue sprat. Provisioning observations.	Taylor & Roe 2004
Scotland	Chicks	Small fish and invertebrates, including herring, sandeel, and shrimps ( <i>Crangon vulgaris</i> ). Provisioning observations.	BirdLife International 2000
Scotland	Chicks	20% of diet made up of sandeel. Provisioning observations.	Furness & Tasker 2000
Sivash, Ukraine	Chicks	Insects occurred in 99% of regurgitations, fish in 54%, and crustaceans in only 2.1%. Method unknown	Borodulina 1960 <i>op cit</i> BWPI 2006
Southern Portugal	Chicks	Main prey items were <i>Atherina</i> sp., <i>Fundulus</i> sp. and shrimps in salinas; and <i>Sardina pilchardus</i> , <i>Atherina</i> sp. and garfish on sandy beaches. Provisioning observations.	Paiva <i>et al.</i> 2006b
St Cyrus, Scotland	Chicks	Bulk of food brought to young was <i>C. harengus</i> (3.8–6.7 cm) and <i>Ammodytes</i> . Method unknown.	N K Atkinson <i>op cit</i> BWPI 2006
The Dutch Delta	Adults and chicks	Diet consists mainly of small marine fish (c. 4–8 cm), such as young sandeel and clupeids, but also of small flatfish, sticklebacks, shrimps and insects. Method unknown.	Brenninkmeijer <i>et al.</i> 2002, Beijersbergen 1989, Den Boer <i>et al.</i> 1993, all <i>op cit</i> Lascelles <i>et al</i> 2003.
The Wash	Chicks	>90% was crustaceans, mainly prawns ( <i>Natantia</i> ). Other prey was fish, including sandeels . Provisioning observations..	Davies 1981
UK	Adults	4 stomachs contained only fish, 1 being full of sand-eels.	Witherby <i>et al.</i> 1941 <i>op cit</i> BWPI 2006
UK	Adults	6 stomachs contained by volume 97% crustaceans (including Mysidacea) and annelids, 2% fish, and 1% marine molluscs.	Collinge 1924 – 27 <i>op cit</i> BWPI 2006

Ukraine	Unknown	28 stomachs contained mainly fish (Cyprinidae in 29%, bleak 25%, pike 11%, perch 7%, and at least 7 other species), a few insects including ants <i>Formica</i> and dragonfly larvae, and isopod crustaceans.	Kistyakivski 1957 <i>op cit</i> BWPI 2006
Ythan estuary, Scotland	Unknown	All birds in 26 observations took shrimps <i>Crangon vulgaris</i> , averaging 1.9 cm. Provisioning observations..	Taylor 1975 <i>op cit</i> BWPI 2006

### 6.2.2 Sandwich tern

Location	Adult or chick	Prey types	Reference
Banc d'Arguin, France	Chicks	Main prey fed was sand-eel <i>A. tobianus</i> ; also anchovy <i>Engraulis encrasicolus</i> and scad <i>Trachurus trachurus</i> . Method unknown.	Davant 1967 <i>op cit</i> BWPI 2006
Banc d'Arguin, France	Chicks	1975, 39 regurgitated fish comprised 77% anchovies, also sandeel <i>Atherina presbiter</i> ; in 1976, of 318 fish, 74% anchovies, 21% sand-smelt, c. 2% sand-eels	Campredon 1978 <i>op cit</i> Lascelles <i>et al</i> 2013
Blakeney Norfolk	Adults Chicks	A high proportion of clupeids and sandeels 52% of 33 observed items were clupeids, supplemented by a relatively high proportion of sandeels (27%), with fewer fish of other species (18%). Provisioning observations.	Perrow <i>et al.</i> 2010, 2011,
Camargue, France	Chicks	Fed consistently on sardines <i>Sardina pilchardus</i> . Method unknown.	Lévêque 1957; Isenmann 1972 both <i>op cit</i> BWPI 2006
Cemlyn Bay, Wales	Chicks Adults	Mainly fed sandeels and clupeids, together with smaller numbers of gadoids (cod and their allies) and rockling, probably Three-bearded Rockling <i>Gaidropsarus vulgaris</i> (5.8% and 1.4% of observed items by number respectively. Provisioning observations.  At sea, sandeels and clupeids made up a much lower proportion of items ingested by adults. Relatively high proportion of unidentified fish items (21.9%). Also prevalent within the sample of items ingested offshore were small larval fish (generally < 3cm in length), which could not be identified to species. Invertebrates of similar size were also	Perrow <i>et al.</i> 2010

		recorded. Foraging observations.	
Chernomorski (Black Sea)	Adults	Fed mainly on gobies (Gobiidae); occasionally, isopod <i>Idotea baltica</i> , prawn Leander, bush-cricket <i>Tettigonia caudata</i> , and beetle <i>Anisoplia austriaca</i> . Method unknown.	Borodulina 1960 <i>op cit</i> Lascelles 2013
Coquet Island	Chicks	88% Clupeidae and 11% Ammodytidae in 1965, but 54% and 46% respectively in 1966. Method unknown.	Langham 1968 <i>op cit</i> BWPI 2006
Dutch Wadden Sea	Chicks	Mainly Clupeids and Ammodytidae. Other species included Gobidae, cod, whiting, <i>Trisopterus</i> spp., Pipefish and sea lamprey (6-21% of diet). Provisioning observations.	Vanaverbeke <i>et al</i> 2007
East coast of North America,	Unknown	Small fish such as mullets (Mugilidae), sand-eels, young garfish (Belonidae), and occasionally shrimps or squid. Method unknown.	Bent 1921 <i>op cit</i> Lascelles 2013
Farne Islands	Chicks	74% Ammodytidae, 15% Clupeidae (all <i>C. harengus</i> ), 6% Gadidae, 2% Gasterosteidae, and 1% each of <i>Pholis gunnellus</i> , crustaceans, and cephalopod molluscs. Method unknown.	Dunn 1972 <i>op cit</i> BWPI 2006
Farne Islands	Chicks	Ammodytidae 74%, clupeids 15%, Gadoids 6%, marine inverts 2%, other fish 3%. Method unknown.	Pearson 1968 <i>op cit</i> Cramp 1974
Farne Islands	Chicks	Equal quantities of clupeids and Ammodytidae. Method unknown.	Taylor 1974 <i>op cit</i> Cramp <i>et al.</i> 1974.
Forvie Sands, UK	Chicks	70% sandeels, 30% sprat and herring. Some shrimp and gadoids also seen. Provisioning observations.	Anon. 2004
Griend, Dutch Wadden Sea	Chicks	99% of diet was herring, sprat and sandeels. Other species recorded included gobies, cod, whiting, smelt, eelpout <i>Zoarces vivipaus</i> , three-spined stickleback, pipefish, sea lamprey, flounder <i>Platichthys flesus</i> cephalopods <i>Sygnathus</i> spp. And brown shrimp <i>Crangon crangon</i> . Provisioning observations.	Stenien <i>et al.</i> 2000
Norfolk	Adults	Stomachs from 9 birds (7 ♂, 2 ♀), contained (by number) 35% sand-eels, 31% other 'food' fishes, 33% Annelida, 1% marine molluscs	Collinge 1924-7 <i>op cit</i> Lascelles 2013
North	Chicks	48% anchovies ( <i>Anchoa</i> sp.), 39% herring	McGinnis, and

Carolina, U.S.A		/jacks (Carangidae)/mackerel (Scombridae), and 9% drums (Sciaenidae/porgies (Sparidae) / mullets <i>Mugil</i> sp.) Provisioning observations.	Emslie, (2001). <i>op cit</i> Lascelles 2013
Peurto Rico	Adults  Chicks	Silversides <i>Hypoatherina harringtonensis</i> and sardines ( <i>Harengula</i> and <i>Opisthonema</i> sp.),  >65% of the prey items delivered to chicks in all three years of the study were sardines and Dwarf Herring <i>Jenkinsia lamprotaenia</i> ); rarely squid <i>Sepioteuthis sepoides</i> and few silversides. Provisioning observations.	Shealer 1998
Scotland	Chicks	Predominantly fed sandeels, clupeids and gadoids. Provisioning observations.	Fuchs 2008
Sea of Azov (Black Sea)	Adults	Fed almost exclusively on sand-smelt <i>Atherina</i> . Method unknown.	Borodulina 1960 <i>op cit</i> Lascelles 2013
South Carolina	Adults	Shrimps and insects were a major component of diet, in addition to fish. Method unknown.	Blus <i>et al.</i> 1979 <i>op cit</i> Lascelles 2013
UK	Adults	Adults seen foraging on dult mayflies <i>Ephemera danica</i> . Observations	Greenwood 1986 <i>op cit</i> Lascelles <i>et al</i> 2013
Zeebrugge, Denmark	Chicks  Adults	Fed on high proportion of sandeels and clupeids, with clupeids being most dominant. Also fed on Gobidae, Atlantic cod, whiting, <i>Trisopterus</i> spp., pipefish <i>Sygnathus</i> spp. and sea lamprey <i>Petromyzon marinus</i> . Provisioning observations.  Fed on a high proportion of sandeel, sprat, herring, cod, whiting, Bib <i>Trisopterus iuscus</i> , poor cod <i>Trisopterus minutes</i> and ragworms <i>Nereidae</i> . Nereid jaws compromised 31% of prey in fecal samples. Observations.	Vanaverbeke <i>et</i> <i>al.</i> 2007

### 6.2.3 Common tern

Location	Adult or chick	Prey types	Reference
Arable fields in Fife	Adults	Observed hawking for crane-flies	Baxter & Rintoul 1953 <i>op cit</i> Cramp <i>et al.</i> 1974
Azores	Chicks	Diet based on a few small species of pelagic fish. 84% Trumpet Fish ( <i>Macroramphosus</i> spp.) This species, together with Boarfish ( <i>Capros aper</i> ), Blue Jack Mackerel ( <i>Trachurus picturatus</i> ) and lantern fish (Families Myctophidae, Sternoptychidae, Diretmidae), accounted for more than 96% of the prey. Insects occurred in 10% of all pellets. Food pellet analysis.	Granadeiro <i>et al.</i> 2002
Belfast Harbour, Ireland	Chicks	58% clupeids, 28% crustaceans, 11% pleuronectidea (flounders) 3% other fish. Method unknown.	Chivers 2011 <i>op cit</i> Cabot & Nisbet 2013
Black Sea, Russia	Unknown	Smelts, Clupeonella, pike-perch, sticklebacks, and shrimps. Method unknown.	Borodulina 1960 <i>op cit</i> BWPI 2006
Blakeney Point	Chicks	25% fish (whiting, herring etc) 14% sandeel, 26% crustacea and marine worms, 10% molluscs, 20% insects and 5% other. Method unknown.	Collinge 1926 <i>op cit.</i> Cramp <i>et al.</i> 1974
Blakeney Point	Chicks	High proportion of clupeids (59% of 97 observed items), but with a relatively large proportion of other fish species that were not specifically identified (21%). Sandeels only formed a small fraction of chick diet (6%). Provisioning observations.	Perrow <i>et al.</i> 2010
Coquet Island	Chicks	Clupeids were more than twice as important as sandeel. Method unknown.	Langham 1968 <i>op cit</i> BWPI 2006
Coquet Island	Chicks	Diet made up of 71% sandeel, 28% clupeids. Provisioning observations.	Heaney 1997
Coquet Island	Chicks	Percentage sandeel in diet varied between 52 and 93% from 1996-2004. Provisioning observations.	Booth 2006

Coquet Island	Chicks	1999: males delivered 20% clupeids and 80% sandeels, females delivered 15% clupeids and 83% sandeel. Provisioning observations.  2001: males delivered 30% clupeids and 70% sandeel, females delivered 20% clupeids and 80% sandeel Provisioning observations.	Fletcher 2002
Coquet Island	Chicks	Diet made up of 82% sandeel, 17% herring and sprat. Provisioning observations.	Robinson 1999
Coquet Island	Adults  Chicks	Females were fed sandeels, sprat and rockling during courtship.  Chicks were fed sandeels, sprat and rockling, making up 97.6% of observations. Provisioning observations.	Horn 1995
Country Island	Chicks	Hake ( <i>Merluccius</i> sp.; <i>Urophycis</i> sp.) (36%) and sandeels (30%). Provisioning observations.	Rock <i>et al.</i> 2007a
Farne Islands, U.K.	Chicks	68% (by weight) clupeids, with 19% gadoids and just 10% sandeels <i>Ammodytes</i> sp.. Method unknown.	Pearson 1968 <i>op cit</i> BWPI 2006
German Wadden Sea	Adults  Chicks	Herring, sprat, smelt and in some years also cod and whiting. Observations.  Mainly herring. Provisioning observations.	Danhardt 2010
German Wadden Sea coast	Adults (females)	Prey most commonly taken during courtship was three-spined stickleback. Varying proportions of clupeids and smelts depending on year. Observations.	Wendeln & Becker 1996, Becker <i>et al.</i> 1987
Gulf of Maine, U.S.A	Chicks	Atlantic Herring <i>Clupea harengus</i> (33.3%), hake <i>Urophycis</i> sp. (38.7%), American Pollock <i>Pollachius virens</i> (4.8%), butterfish <i>Pholis gunnelus</i> (3.7%) and sandeel (13.6%). Provisioning observations.	Hall <i>et al.</i> 2000
Kustavi archipelago Finland	Adults  Chicks	Pellet analysis showed 70% of diet was sticklebacks in inner archipelago, but equal amount of fish, isopods and insects in outer archipelago, during laying period (fish predominated later, including Cyprinidae, especially bleak and perch).  Mainly sticklebacks	Lemmetyinen 1973 <i>op cit</i> BWPI 2006
Lady's Island Lake, Ireland	Chicks	Diet made up of 55% sandeels, 38% clupeids, 6% other fish, 1% Gadidae. Provisioning	Newton & Crowe 2000

		observations.	
Maine, US	Adults	155 stomachs contained mainly herring, mackerel, and shrimps; 3 contained berries and vegetation	Mandall 1935 <i>op cit</i> BWPI 2006
Mainland Germany	Chicks	Three-spined Sticklebacks <i>Gasterosteus aculeatus</i> , but also marine prey; clupeids and sandeels. Provisioning observations.	Frank 1992
Minsener Oldeog, German Wadden Sea	Chicks	Almost exclusively of marine prey, predominantly clupeids. Pellet analysis and provisioning observations.	Frank 1992, Becker <i>et al.</i> 1987
Moussa	Chicks	Chicks up to a week old fed mostly on Saithe ( <i>Pollachius virens</i> ), with sandeels making up only about 20% of the diet. Provisioning observations.	Uttley <i>et al.</i> 1989
North American colonies	Adults	116 stomachs contained 95.5% fish (mostly freshwater minnows and sandeels), 3.5% insects (mostly moths), and 1% all other invertebrates (molluscs, crustaceans, and worms)	McAtee and Beal 1912 <i>op cit</i> BWPI 2006
North Carolina, U.S.A	Adults	Fish (82%), insects (23%), crustaceans (6%), and squid (4%). Method unknown.	Moser <i>et al.</i> 1992 <i>op cit.</i> Lascalles <i>et al.</i> 2013
Petit Manan Island, US	Chicks	Exclusively herring. Method unknown.	Hopkins & Wiley 1972 <i>op cit</i> BWPI 2006
River Elbe Germany	Adults	17 stomachs, contained mostly smelt, sandeel, and a few mayfish <i>Alosa vulgaris</i> and grundling <i>Gobio fluviatilis</i>	Peters 1933 <i>op cit</i> BWPI 2006
Rockabill, Ireland	Adults	2005: 85% of prey made up of sandeels during courtship and incubation. Rest mainly clupeids, plus a single gadoid. 2008: 4 adult feeds observed and all were sandeels. Observations. 2009: 58.3% sandeel, 37.5% clupeid	Newton <i>et al.</i> 2005, Glennister <i>et al.</i> 2008, 2009
	Chicks	2005: 70.5% of prey presented to chicks was clupeids, 19.7% gadoids, and 9.8% sandeels. 2008: 100% clupeids 2009: 52% gadoid, 45% clupeid, 3% sandeel.	

		Provisioning observations.	
Saltholme, Teemouth	Chicks	Mainly clupeids (probably sprat), with sandeels, gadoids, and sticklebacks. Provisioning observations.	Perrow <i>et al.</i> 2010
Shetland	Chicks	Switched from sandeel to Saithe because sandeel crashed. Provisioning observations.	Uttley <i>et al.</i> 1989
Sugarloaves Maine, US	Adults & chicks	Largely herring and sand-eels. Method unknown.	Palmer 1941 <i>op cit</i> BWPI 2006
US	Chicks	Most important prey were sandeels, anchovies, and butterfish. Also bluefish. Provisioning observations.	Safina & Berger 1988
Volga delta, Russia	Unknown	529 stomach regurgitations contained predominantly fish; bream, roach, rudd, bleak, sticklebacks, and carp varying seasonally. Method unknown.	Borodulina 1960 <i>op cit</i> BWPI 2006
Wangerooge, Germany	Chicks	75% were fish (85% by weight, half of fish Clupeidae), 25% invertebrates; crustaceans 18% of total (mostly shrimps and shore crabs), also polychaete worms, cephalopods, and adult caddisflies <i>Stenophylas permistus</i> . Method unknown.	Boecker 1967 <i>op cit</i> BWPI 2006

#### 6.2.4 Roseate tern

Location	Adult or chick	Prey types	Reference
Coquet Island, England	Unknown	Clupeids were much more important than sandeels, in some, but not all years. Method unknown.	Dunn 1972, Langham 1968 <i>op cit</i> BWPI 2006
Lady's Island Lake, Ireland	Chicks	Sandeel 60–92% in the chick-rearing season. Clupeids making up most of remainder and gadoids being rare (0–3%). Provisioning observations.	Newton & Crowe 1999 <i>op cit</i> Cabot & Nisbet 2013
North America	Chicks	Mainly sandeels <i>Ammodytes</i> spp. fewer (as available) Clupeidae ( <i>Clupea harengus</i> , <i>Alosa aestivalis</i> , <i>Etrumeus teres</i> , <i>menhaden</i> <i>Brevoortia tyrannus</i> , <i>mackerel</i> <i>Scomber scombrus</i> ), rarely silversides <i>Menidia menidia</i> , <i>cunner</i> <i>Tautogolabrus adspersus</i> , and invertebrates. Method unknown and	Hays <i>et al.</i> 1973 <i>op cit</i> BWPI 2006, Nisbet <i>et al.</i> 1998, Richards & Schew 1989 <i>op cit</i>



		provisioning observations.	Lascelles <i>et al.</i> 2013, Safina <i>et al.</i> 1990
Nova Scotia, Canada	Chicks	Sandeel, <i>Ammodytes</i> spp. followed by hake, <i>Urophycis</i> spp. These accounted for 82% of food items in 2003 and 72% in 2004. Other species included herring and cod. Provisioning observations.	Rock <i>et al.</i> 2007a
Puerto Rico	Adults  Chicks	Fed primarily on dwarf herrings ( <i>Jenkinsia lamprotaenia</i> ) and anchovies ( <i>Anchoa</i> spp.)  Mostly dwarf herrings and sardines ( <i>Harengula</i> and <i>Opisthonema</i> spp.); few anchovies were fed to chicks. Regurgitations and provisioning observations.	Shealer 1998b
Rockabill, Ireland	Adult  Chicks	Sandeel 55-75% of diet during courtship and incubation. clupeids (10-35%) and gadoids (5-25%) making up the remainder.  Clupeids became more frequent than sandeels (32-45% vs. 13-30%, respectively), with gadoids comprising 5-10% and unidentified prey 12-25%. Provisioning observations.	Newton & Crowe 1999 <i>op cit</i> Cabot and Nisbet 2013, Newton & Crowe 2000
Rockabill, Ireland	Chicks	1996, immature rockling (probably <i>Ciliata mustela</i> ) 27% of diet. proportions of rockling and sandeels in diet declined with chick age, while those of clupeids and gadoids increased. Provisioning observations.	Mundy 1997
Rockabill, Ireland	Adults  Chicks	2005: 87% of prey made up of sandeels during courtship and incubation. Rest mainly clupeids.  2008: 62.5% sandeels, 25% clupeids, 12.5% gadoids.  2009: 92.3% sandeel, 7.7% clupeid,  2005: 76.7% of prey presented to chicks was clupeids, 2% gadoids, and 21.3% sandeels.  2008: 96% clupeids, 3% sandeels, 0.5% gadoids, 0.3% shrimps  2009: 87% clupeids, 8% gadoid, 5% sandeel. Provisioning observations.	Newton <i>et al.</i> 2005  Glennister <i>et al.</i> 2008, 2009
South Africa	Chicks	Common prey species are ratfish <i>Gonorhynchus gonorhynchus</i> , sardine <i>Sardinella</i> , and Cheilodactylidae. Method	Randall & Randall 1978 <i>op cit</i> BWPi

		unknown.	2006
The Azores	Chicks	Mainly Trumpet fish <i>Macroramphosus scolopax</i> but sauri ( <i>Scomberesox saurus</i> and <i>Nanichthys simulans</i> ), mackerel ( <i>Trachurus picturatus</i> ), garfish ( <i>Belone belone gracilis</i> ), and lanternfish (Myctophidae) also taken. Provisioning observations.	Ramos <i>et al.</i> 1998
The Azores	Chicks	Mainly deep water fish; <i>Trachurus picturatus</i> , <i>Scomberesox saurus</i> , <i>Macroramphosus scolopax</i> and <i>Capros aper</i> . Provisioning observations.	Martins <i>et al.</i> 2004

### 6.2.5 Arctic tern

Location	Adult or chick	Prey types	Reference
Alaska, US	Unknown	Arctic cod <i>Boreogadus saida</i> and amphipod <i>Apheruse glacialis</i> . Method unknown.	Boeckelheide 1978 <i>op cit</i> BWPI 2006
Bird Island, US	Adults	12 pairs, 14% of items ♂♂ fed to mates during courtship were fish (52% by weight), and 86% shrimps (48% by weight). Observations.	Nisbet 1973 <i>op cit</i> BWPI 2006
Coquet Island, UK	Chicks	60-8% fish Ammodytidae, 39.2% Clupeidae. Clupeidae became relatively more important in late July. Method unknown.	Langham 1968 <i>op cit</i> BWPI 2006
Coquet Island, UK	Adults Chicks	45% sandeels, rest made up of sprat with occasional Saithe, herring, stickleback (Gasterosteidae) and small prawns. 66% sandeels, with the rest sprat. Provisioning observations.	Monaghan <i>et al.</i> 1989, 1992
Coquet Island, UK	Chicks	61% of fish in the diet were sandeels and 39% clupeids, the latter increasing in importance during the course of the season. Method unknown.	Langham 1968 <i>op cit</i> Lascelles <i>et al.</i> 2013
Coquet Island, UK	Chicks	Percentage sandeel in diet varied between 73-96% from 1996 – 2004. Provisioning observations.	Booth 2006
Coquet Island, UK	Chicks	96% sandeel, 4% herring and sprat. Provisioning observations.	Robinson 1999

Coquet Island	Adults  Chicks	Females were fed sandeels, sprat, saithe and rockling during courtship.  Chicks were fed sandeels, sprat and rockling. Provisioning observations..	Horn 1995
Country Island, Canada	Chicks	Hake ( <i>Urophycis</i> sp.) and sandeel ( <i>Ammodytes</i> sp.). Arctic Terns delivered proportionally more hake and less sandeel than Common Terns and the sandeel they delivered were smaller on average than those delivered by Common Terns. Provisioning observations.	Rock <i>et al.</i> 2007a, b
Fair Isle, UK	Adults	From May onwards, adult Arctic Terns were seen hawking for insects over meadows.	Miles <i>et al.</i> 2011
Farne Islands, UK	Chicks	95% fish (by number), 2% crustaceans, 2% cephalopods, and 1% insects; most important fish were Ammodytidae (65% of total food) and Clupeidae (22%). Method unknown.	Pearson 1968 <i>op cit</i> BWPI 2006
Farne Islands, UK	Chicks	Chicks fed on sand eels. Provisioning observations.	Anon 2012
Faroe Islands, Denmark	Chicks	Almost entirely fish species, mainly sandeels. Provisioning observations.	Schreiber & Kissling 2005
Gulf of Maine, US	Chicks	Atlantic herring (17.4%), hake <i>Urophycis chuss</i> (39.5%), American pollock <i>P.virens</i> (<1%), butterfish <i>Pholis gunnellus</i> (3.3%), sandlance (2.6%), and invertebrates (35.1%) were the main prey items. Method unknown.	Hall <i>et al</i> 2000 <i>op cit</i> Lascelles <i>et al.</i> 2013
Iceland	Adults	60% of birds seen feeding on antler moth <i>Cerapteryx graminis</i> . Also take spider (Araneae), weevil (Curculionidae), fly (Diptera), caterpillars, and parasitic wasps (Hymenoptera).	Roberts 1934 <i>op cit</i> BWPI 2006
Iceland	Unkown	Large numbers of flies taken in Iceland from surface of lakes.	Bannerman 1962 <i>op cit</i> Cramp <i>et al</i> 1974
Iceland	Chick	Chicks at colonies in the West of Iceland were fed on mainly sandeels. Chicks at colonies in the North East fed largely on capelin and prey of non-marine origin.	Vigfúsdóttir 2012

Kandalaksha Bay, Russia	Adults	Of 63 stomachs, 59% contained fish, 15% crustaceans (especially amphipods), 5% <i>Nereis pelagica</i> , and 19.5% insects; also traces of plant material.	Bianki 1977 <i>op cit</i> BWPI 2006
	Chicks	Diet of 93 juveniles: 62% fish, 8% crustaceans, 20% <i>Nereis</i> , and 2% plant material	
Kongsfjord area, Spitsbergen	Chicks	<i>Gammarus setosus</i> main food. Method unknow.	Lemmetyinen 1972 <i>op cit</i> BWPI 2006
Kustavi, Finland	Adults	Inner archipelago: sticklebacks comprised 70% of diet. In outer islands, fish, isopods, and insects evenly represented in laying period, though fish predominated later. Method unknow.	Lemmetyinen 1973 <i>op cit</i> BWPI 2006
Long Nanny, UK	Chicks	Majority of recorded prey items presented to chicks were sand eel species. Provisioning observations.	Brockless <i>et al.</i> 2010
Machias Seal Island, US	Unknown	Fish most commonly taken were hake, lumpfish <i>Cyclopterus lumpus</i> and Dollarfish <i>Poronotus triacanthus</i> , although shrimp were the most regularly used food source. Method unknown.	Abraham & Ankney 1984 <i>op cit</i> Lascelles <i>et al.</i> 2013
Murmansk coast of Barents Sea	Adults	51% fish (mostly sandeels and herring), 25% crustaceans, 22% insects (obtained mostly at sea). Remainder polychaetes and plant material (berries). Adult females showed a sharp reduction in sea food and increase in terrestrial insects in July towards end of incubation and during chick rearing. In general, insects and sandeels were relatively more important in late summer, crustaceans and herring less so.	Belopol'ski 1957 <i>op cit</i> BWPI 2006
	Chicks	Ate proportionately more fish (88%), fewer insects (12%) than adults, and no crustaceans. Method unknown.	
Petit Manan Island Maine, US	Chick	Almost exclusively herring. Method unknown.	Hopkins & Wiley 1972 <i>op cit</i> BWPI 2006
Shetland	Chicks	Predominantly sandeels. Provisioning observations.	Uttley <i>et al.</i> 1989
Shetland and	Chicks	Mainly Sandeel, some Saithe. Provisioning	Ewins 1985, Furness 1982

Orkney, UK		observations.	both <i>op cit</i> Lascelles <i>et al.</i> 2013 Monaghan <i>et al.</i> 1989, 1990, 1992
Spitsbergen	Chicks	Crustaceans, especially <i>Thyanoessa inermis</i> and <i>Gammarus locusta</i> dominate diet of young. Methods unknown.	Hartley & Fisher 1936; Burton & Thurston 1959; Korte 1972; Løvenskiold 1964 all <i>op cit</i> BWPi 2006
The Skerries & Ynys Feurig, Wales	Adults and chicks	Fed almost exclusively on sandeel. Provisioning observations.	Newton & Crowe 2000
Wangerooge, Germany	Unknown	~50% fish, mostly Clupeidae, and 50% crustaceans, mainly shore crabs. Also a few cephalopods and gastropods. Method unknown.	Boecker 1967 <i>op cit</i> Lascelles <i>et al.</i> 2013