Factors affecting little tern (*Sternula albifrons*) chick provisioning rates

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Abstract

The little tern (*Sternula albifrons*) is one of the UKs rarest breeding seabirds and has undergone a 37% decline in the last 30 years. This decline has been due to several factors including predation, human disturbance and habitat destruction, resulting in declines in breeding success. This study focuses on feeding frequency and the size of fish provided to chicks during the breeding season, another factor that can affect breeding success. The research identifies and explores the effect of various factors which affect feeding frequency and fish length. Observations were performed at a little tern colony in Yorkshire for 5 weeks, and analysed the effect of disturbances, wind, time of day, weather conditions, chick age, wave height and tidal cycles on feeding frequency, fish length, energy per fish, and total energy per hour. The feeding frequency rate and lack of chick deaths in the colony indicated that the little terns had sufficient food supply to feed their chicks. The results also showed that chick age had a significant effect on fish length, average energy and total energy, supporting previous research findings. Wave height also had a significant effect on fish length, average energy, and total energy, which has not been found in previous studies, and suggests an effect of stronger waves pulling larger fish to the sea surface. Human disturbance and wind direction were also found to be significant on energy per fish and fish length respectively, but a small sample size and lack of significance on other factors put the validity of these results into question. These results support the effectiveness of current conservation measures to protect fishing grounds, as well as informing future feeding studies in potential factors that could affect their results, and therefore improve the accuracy of future feeding studies and conservation measures on little terns.

Contents

Introduction

Seabirds are vital members of the marine food chain and play a vital role in transferring nutrients from the sea to the land, helping maintain soils and even whole ecosystems such as coral reefs (IUCN, 2021). Their role as top marine predators also results in them being important monitors for changes in fish stocks (Brodin et al., 2024). Unfortunately, globally, nearly one third of all seabirds are threatened with extinction, due to a number of threats, including entanglement with fishing gear, reduction in food supplies, environmental contaminants, oil spills and invasive species, as well as being threatened with climate change and ocean acidification (Jones and Kress, 2011).

In the UK, seabirds have experienced a 24% decline since 1986, with the primary threats being climate change and overexploitation of marine resources (State of Nature, 2023). Furthermore, seabirds in the UK are under increasing pressure from the avian flu epidemic, with bird flu becoming the biggest threat to many seabird species including common, sandwich, and roseate terns (Mills, 2024). While there is no evidence of little terns (*Sternula albifrons*) being significantly affected by bird flu, it has nevertheless undergone recent declines in the UK despite intensive conservation efforts (Wilson et al., 2020).

Little terns are a member of the Laridae family, and are one of the smallest, with a length of 22-24cm and a wingspan of 48-55cm (Sterry et al., 2009). Little terns breed colonially, with clutch sizes of 2-3 eggs, with chicks taking around 4 weeks to fledge (Noreikiene et al., 2011; Oro et al., 2004; Haddon and Knight, 1983). They are distributed across the eastern hemisphere, being found in much of Europe and Asia, as well as parts of Africa and Australasia (Jang et al., 2015). Little terns are currently listed as “least concern” on the list, although they are experiencing local declines in many regions, including the UK and much of Europe (Noreikiene et al., 2011; IUCN red list, 2018; Wilson et al., 2020).

Little terns are a long-distance migrant, with narrow habitat requirements, nesting at low elevations on open beaches or spits of sand, shingle, gravel, pebbles or rock, with very little or no vegetation present (del Hoyo et al., 1996; de Silva, 1991, pp.205–211; Wilson, 1990). They breed between May and July, with the nest consisting of a bare scrape, often located a few metres from shallow water, and a minimum of 2m from other little tern nests (Wilson, 1990; Snow and Perrins, 1998; del Hoyo et al., 1996). They are pioneer species, meaning they nest in areas where other birds have not yet colonised, although occasionally they nest amidst colonies of other species of terns (Wilson et al., 2020; Snow and Perrins, 1998). They breed mainly on the coast, although also along estuaries and on large islands, and more recently, due to habitat loss and destruction, have also utilised rooftops and Salinas as breeding grounds (Schekler et al., 2019).

In the UK, little terns breed exclusively on the seacoast (Brodin et al., 2024) before migrating to West Africa in the winter (Cabot and Nisbet, 2013). The little tern is one of the UKs rarest breeding seabirds (1900 breeding pairs in 2004), but they have declined by 37% over the last 30 years (Wilson et al., 2020), with their breeding range in the UK having contracted by over 25%, with 50% of the breeding population in 10 or fewer sites (Perrow et al., 2015). They are currently listed as Amber on the UK red list (Stanbury et al., 2021). Little terns are also legally protected as a Schedule 1 species under the Wildlife and Countryside Act 1981, meaning that it is illegal to recklessly disturb them when nest building or when near their nest containing eggs or young (Tipling, 2011).

The factors causing the decline of little terns have manifested primarily in declines in breeding success, rather than adult survival (Wilson et al., 2020). There are a number of drivers causing this decline, with the primary threat in the UK being predation (Wilson et al., 2020). The most recorded predators between 1995-2002 were foxes and kestrels (Wilson et., 2020). To reduce such predation, electric fences and population control have been used, and have been found to be effective against ground predators such as foxes. Aerial predators such as kestrels are more difficult to stop, although there has been some success in diversionary feeding (Wilson et al., 2020).

Human disturbance is also a major threat to little terns, with off-road vehicles, excessive recreational activities, and construction threatening their nesting habitats (Catry et al., 2004). Furthermore, human disturbances can exacerbate predation by flushing adults, leaving their vulnerable chicks and eggs more exposed to predators (Wilson et al., 2020). In some areas, warden schemes have been installed, to reduce predation and human disturbance (Wilson et al., 2020).

Little terns are also threatened by habitat destruction, partly due to coastal development, but also due to natural processes such as erosion, vegetation encroachment, wind-blown sand, and expansion of colonies from other, more dominant, and potentially predatory tern and gull species (Wilson et al., 2020; Schekler et al., 2019). Furthermore, due to little tern habitats being often close to the coast, they are becoming increasingly under threat from sea level rise and storm surges due to climate change (Wilson et al., 2020; Noreikiene et al., 2011). To combat habitat loss, habitat management, creation and restoration, have been implemented, as well as colony enhancement, with methods including vegetation clearance (Wilson et al., 2020).

Another driver that can affect breeding success, and the focus of this research, is provisioning of food for chicks. It is vital that the adults are able to provide enough nutrients to allow the chicks to fledge, and providing high quality prey can also reduce chick stress and reduce adult foraging effort (Brodin et al., 2024).

Little terns' main source of food is fish, although they are a generalist predator, known to eat crustaceans, insects, annelid worms and molluscs (del Hoyo et al., 1996). What they eat depends on what is available to them, favouring species such as sand smelts in southern Portugal, and sand eels and clupeids in the UK (Brodin et al., 2024; Ramos et al., 2013). Little terns are also restricted in their foraging range, travelling a maximum of 11km away from the colony per trip (Thaxter et al., 2012), due to their need to return to the nest, and feed their chicks (Greenwell et al., 2021).

Despite their status as a generalist predator, adults tend to select specific, high-energy fish during the course of one breeding season, to provide the necessary energy and nutrients to facilitate chick growth (Brodin et al., 2024). This suggests a reliance on a limited range of prey species, therefore making them sensitive to changes in prey distribution and abundance as alternate fish species may lack the energy to ensure successful breeding (Brodin et al., 2024; Ramos et al., 2013).

Feeding frequency and foraging success alone is generally not a good indicator of little tern breeding success, as predator and human disturbances are often more important in explaining variability (Ramos et al., 2013). However, food availability and foraging success can still impact chick survival and is also an important factor in the location and size of little tern colonies (Brodin et al., 2024). For example, piledriving activity during the construction of a wind farm in the North Sea affected herring breeding grounds and resulted in increased nest abandonment by little terns (Perrow et al., 2011). In another example, overfishing of one of the little terns' primary prey, lesser sand eels, resulted in the sand eels stock biomass crashing in the early 2000s (Lindegren et al., 2017), with reduced sand eel abundance being found to have led to breeding failure in Arctic tern (Uttley et al., 1989). Sand eels are also under threat from climate change, with higher sea surface temperatures potentially leading to reduced growth (Lindegren et al., 2017). To combat this decline, a ban on sand eel fishing has been implemented in English and Scottish sections of the North Sea since 2021 (UK government, 2023).

There are also a number of other factors that can affect feeding rates, and therefore breeding success (Darrah, 2020). For example, human and predator disturbance can flush adults, and reduce time available for foraging and/or to feed their chicks (Darrah, 2020). Previous research has found that avian predator disturbance of the least tern (*Sternula antillarum*; the sister species of the little tern), was negatively correlated with colony productivity (Darrah, 2020; Ramos et al., 2013). Environmental factors have also been found to affect feeding rates, with weather conditions (Hong et al., 2008), tidal cycles (Paiva et al., 2007), sea roughness (Paul Collins, personal communication), and time of day (Ramos et al., 1998) also being found to have an effect on feeding rates of tern species. However, due to the difficulty of observing little tern nesting behaviour, partly due to precocial chick behaviour and the species legal protection, little terns are relatively poorly studied, and therefore more research is required (Brodin et al., 2024).

Due to the importance of food provisioning for chick survival and the number of factors that affect it, this research gathers and analyses the factors affecting feeding rates in one specific little tern colony to see whether they have a significant impact on chick feeding rate and therefore potentially informing conservation decisions across the UK.

Aims and objectives

Aim: To discover the extent of different factors that affect little tern feeding rates and assess whether management is needed to boost feeding rates and therefore chick survival.

Objective 1: To use observation to determine the feeding rate of little terns, and the length of fish they catch, when they are feeding their chicks over a 5-week period.

Objective 2: To observe factors that may affect feeding rates and/or fish length over this period, including weather conditions, tidal cycle stage, human and predator disturbances, chick age, time of day, and sea roughness to determine the effect these factors have on feeding rates and/or fish length.

Methods

Study location

The study is located on the Spurn peninsula, East Yorkshire, where a little tern colony is located (figure 1). The little tern colony is the only one in Yorkshire. The colony is located between the North Sea and Beacon Ponds, a saline lagoon, in amongst sand dunes, with nests located closer to the lagoon than the marram grass vegetation (Griffin, 2023, figure 2). The little tern colony is protected during the breeding season (June to August) by an electric fence around the colony, and 24 hour a day wardening to prevent human and predator disturbance. During the observation period, the majority of little terns foraged south/ southeast of the colony, while some foraged directly east (multiple Spurn little tern wardens, personal communication). As well as little terns, oystercatchers, common ringed plovers, avocets, and black-headed gulls also breed at the colony at the same time. During the breeding season, a few colony walkthroughs were performed, with a gap of at least 2 weeks between each session, in order to locate scrapes and eggs, and to ring any chicks that were around.

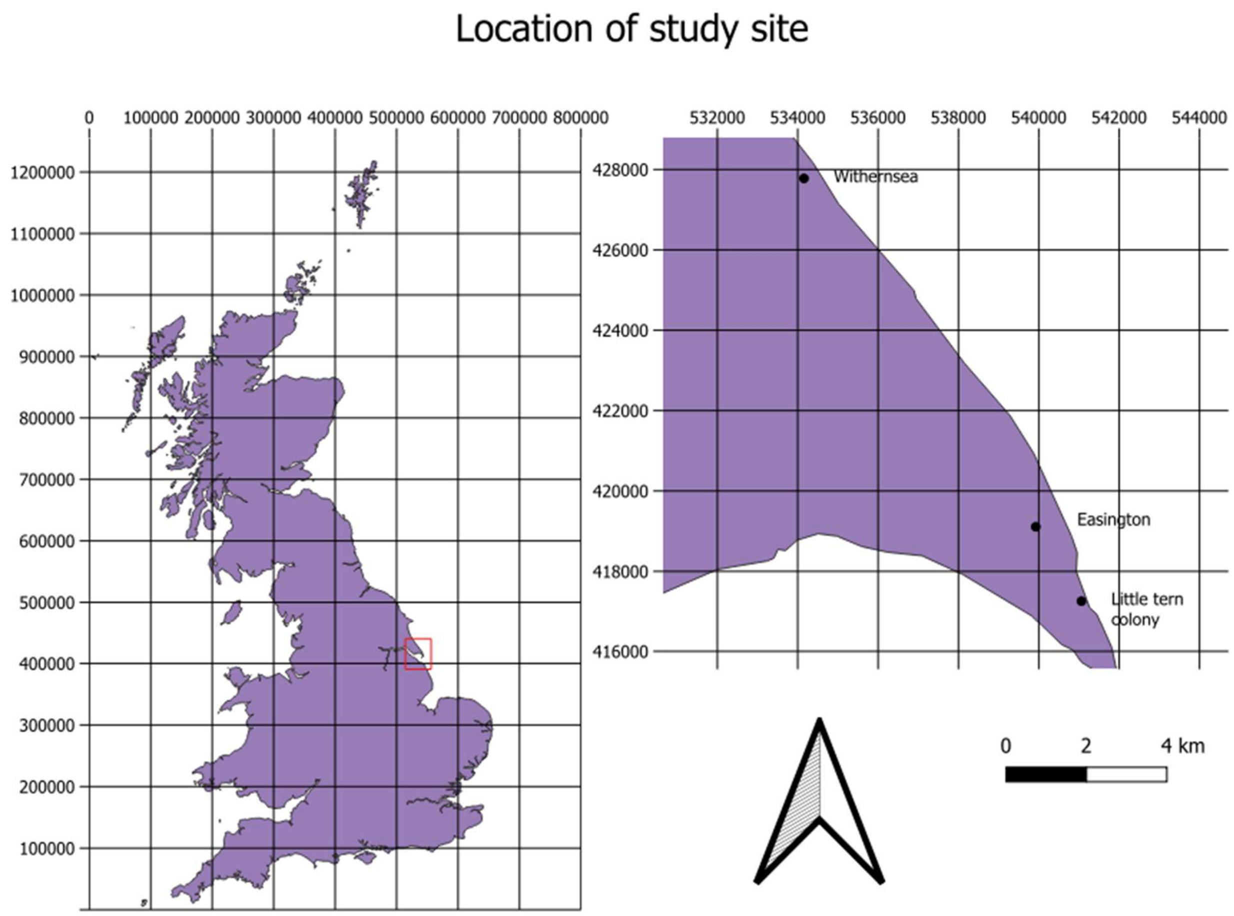

Figure 1: Location of study site in the UK. Scale bar represents scale of map on the right. Created using QGIS 3.28.1.

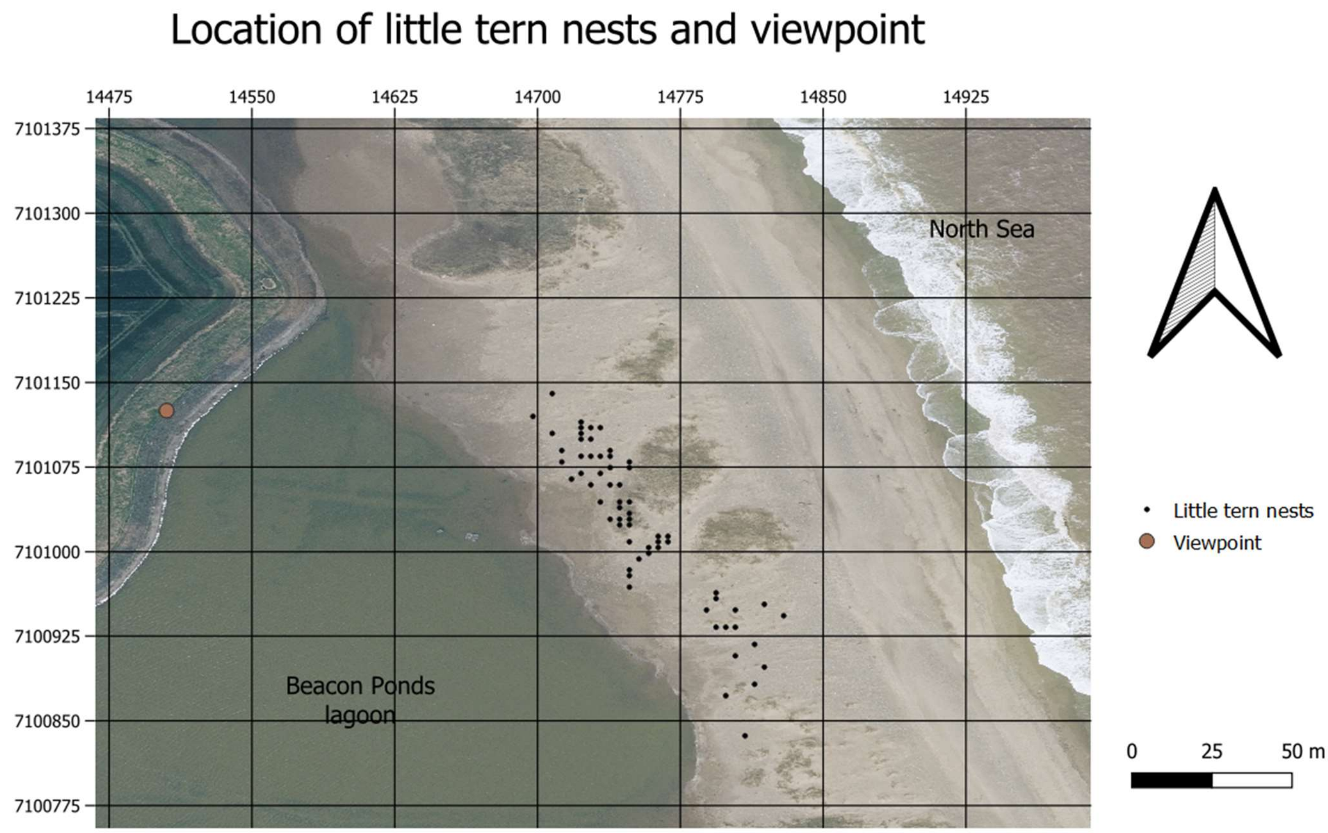

Figure 2: Aerial photograph of the study site. The viewpoint where observations were made, and the location of the little tern nests, are shown. The nest locations were obtained during colony walkthroughs. Created using QGIS 3.28.1.

Description of field methods and justification

Little terns were observed feeding their chicks, across the lagoon (figure 2), using a telescope (opticron ES 80 GA SD, with a maximum magnification of 60x), and binoculars (Zeiss conquest HD 8x42). The little tern nests ranged from a minimum of approximately 110m, to a maximum of approximately 250m, away from the viewing point (figure 2). The vast majority (85%) of observation sessions lasted 90 minutes although some sessions were reduced to a minimum of 1 hour, primarily due to bad weather causing poor visibility. These observations were performed 4 times a week, 3 times a day, in the morning (start times ranging between 6:29 to 10:30), afternoon (12:35 to 15:46) and evening (17:51 to 20:47). In total, 61 observation periods were done over a 5-week period (20/06/24 to 28/7/24), with the first observation occurring 2 days after the first chicks had hatched. For each observation period, a minimum of 1 nest and a maximum of 4 nests were observed, depending on how many nests were within one binocular view, to reduce the chance of feeding events being missed. Before each session, the temperature (°C) , weather conditions (separated into 3 categories, 1 = rain, 2 = cloudy, 3 = sunny), wind direction (the direction from which the wind was coming from) and speed (km/hr), tidal cycle (minutes from high tide), and sea roughness (in feet) are recorded, using google weather (https://weather.com) and a surf app (surfline – www.surfline.com) of the nearest towns (google weather used Easington, surfline used Withernsea (figure 1)), to ensure that factors which could potentially affect feeding rates were recorded. The number of chicks per nest was also recorded. During the observation period, all disturbances (defined as when the observed little tern sitter and the majority of the colony flies up) were recorded. The cause of the disturbance was noted, which was either unknown, a predator, or a human disturbance. If a predator was spotted, the species of predator was recorded. For each nest, the specific time was recorded each time an adult fed a chick. As members of the Laridae family, little terns tend to carry one fish at a time when feeding chicks, and so the quantity of food being brought back could also be estimated (Greenwell et al., 2021). The fish length was recorded, estimated on the length of the adult little tern bill, as done by previous projects with terns (Schweitzer and Leslie, 1996). The length of the little tern bill used was 30.5mm as reported by the UK little tern steering group. The fish species was observed but not always noted, due to the distance from the viewing point to the nests. Fish species counts should be regarded as rough estimates. Finally, for each nest, the number of chicks and the age of the chicks was recorded, the latter done using a guide from Haddon and Knight, (1983). The age groups were separated into 4 categories: 1 = 0-3 days, 2 = 4-10 days (figure 3), 3 = 11-14 days, and 4=15-28 days.

Figure 3: A little tern chick in the Spurn colony with an estimated age between 3-10 days – photo taken using camera trap.

A camera trap was also placed in the colony for 9 days (29/06/24 - 8/07/24), however, while being able to take some pictures of little tern, was unable to provide extra data to the experiment, possibly due to movement of the chicks away from the original nest.

Statistical analyses

As the majority of fish caught by the little terns were estimated to be lesser sand eels (around 70%) an estimate of the energy content of the fish brought back was calculated based on sand eel length, using the formula 0.0024*($Length^{3.806}$) provided by Hislop et al., (1991), where length is in cm. Statistical analysis was done using R 4.4.1 (R core team, 2024). To analyse the results, chick age, human disturbance, unknown disturbance, predator disturbance, temperature, wind direction, wind speed, time of day, wave height, minutes from high tide and weather conditions were all put in a mixed model, using the function lmer(), obtained from the lme4 package (Bates et al., 2015). These variables were put in 4 different mixed models, with the only change being the response variable. The 4 different response variables were: feeding frequency per hour per chick, the average fish length in cm, the average energy per fish, and the total energy provided per hour per chick, which was calculated by multiplying the feeding frequency with the average energy per fish. Due to missing fish length values, as I was unable to measure some due to the quickness of some feeding events, some rows of data were omitted to ensure that all data used in the mixed models was complete and there were no missing values. Unknown disturbances were not counted in the first few observation periods, so that data was removed from both models. To ensure there was no collinearity between these factors, the vif() function was used, from the car package (Fox and Weisberg, 2019) to analyse each model. There was found to be no collinearity between them in any of the models, and so the variables could be used together in the mixed models. All interactions between variables in all models were insignificant, so the interaction terms were removed from the models. To account for variance between observation periods, the observation periods were numbered individually and placed in the mixed model as a random effect. The mixed models were then tested to ensure that the data fits the assumptions of the model, by plotting the q-q plots of the residuals using the function qqnorm(). The mixed models with the feeding frequency and fish length fitted the assumptions, although the energy per fish and total energy needed to be $\log_{10}$ transformed to fit the assumptions better. To test whether the individual factors had a significant effect on each of the response variables, each model was compared to the same model without the specific factor that was being measured using an anova test. Significant results (where $P<0.05$) were noted. To display the results and the predictions of the models, R was used, using the packages ggplot2 (Wickham, 2016) and ggeffects (Lüdecke, 2018).

Results

Over the 5-week period, 61 total observations across 24 different little tern nests were made. The number of chicks per nest ranged from 1-3, with an average of 1.91 chicks per nest over all observations. The number of feeds per nest in one observation period varied from 0 to 20. No predation events occurred during the observations, but there was a total of 23 predator disturbances coming from 12 different species. A total of 4 human disturbances occurred, while unknown disturbances occurred much more frequently, averaging 4.3 per observation period. Temperatures ranged from 12 to 21°C (mean=16.3°C), with wind speeds ranging from 3-39 km/hr (mean=19.8 km/hr). Weather conditions were stable, with only 4 observations made during rain. Wave height ranged from 0-5 feet, with a mean of 1.8 feet.

The model looking at feeding frequency included 92% of observation periods (56/61), while the other 3 models used 90% (55/61). The results of the anova tests of each predictor variable for the 4 different response variables is shown in table 1.

Table 1: Results of the 4 mixed models, showing which variables had a significant effect on each of the response variables. A * represents a significant result, with * representing p<0.05, ** showing p<0.01, and *** representing p<0.001.

Predictor variable	Degrees of freedom	Response variable			
		Feeding frequency per hour per chick	Fish length (cm)	Log energy per fish	Total log energy <log(energy x feeding frequency)>
		P value (ANOVA)			
Human disturbance	1	0.604	0.066	0.042*	0.086
Chick age	1	0.204	<0.001***	<0.001***	<0.001***
Wind speed	1	0.467	0.311	0.374	0.355
Wind direction	7	0.59	0.044*	0.2316	0.559
Predator disturbance	1	0.587	0.530	0.402	0.771
Wave height	1	0.692	0.006**	<0.001***	<0.001***
Minutes from high tide	1	0.933	0.669	0.58	0.803
Weather condition	2	0.555	0.503	0.78	0.890
Temperature	1	0.163	0.793	0.907	0.2328
Unknown disturbances	1	0.896	0.834	0.917	0.971
Time of day	2	0.221	0.452	0.438	0.345

Feeding frequency

Feeding frequency ranged from 0 to 4.44 per hour per chick, with a mean frequency of 1.74 per hour per chick. As shown in table 1, there is no significant effect by any of the factors on feeding frequency.

Fish length (cm)

Fish length ranged from 1.73 cm to 9.15cm, with a mean of 4.37cm. As shown in table 1, a number of factors have a significant effect on the average fish length. The factor with the most significant effect (Chisq=63.675, df=1, P<0.001***) is chick age, with older chicks being fed longer fish (figure 4).

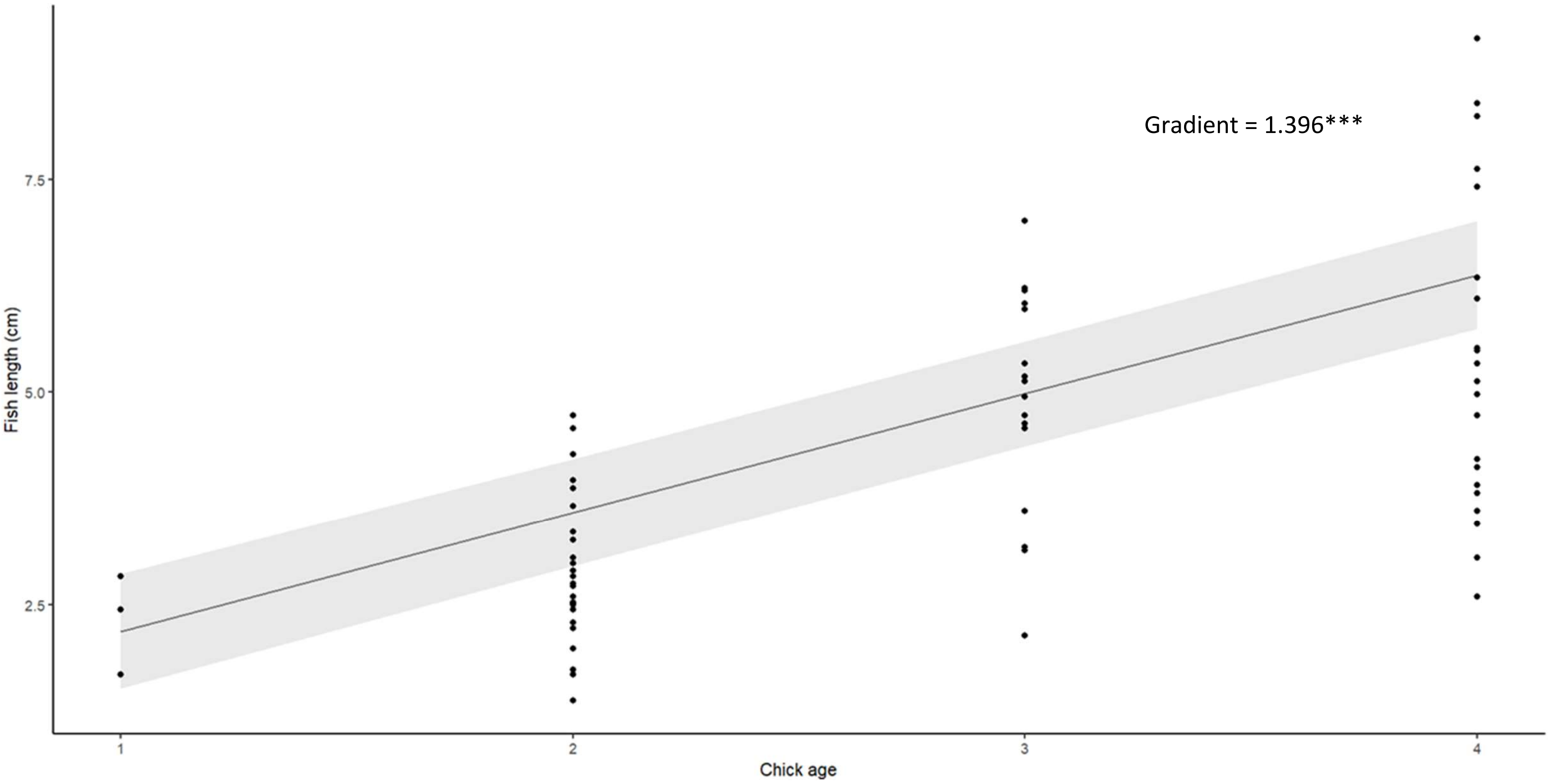

Figure 4: The effect of chick age on fish length. Chick age is split into categories (1=0-3 days, 2= 4-10 days, 3=11-14 days, and 4= 15 days and over). The line of best fit was generated by a mixed model with wind direction removed as it led to inflation of the line (1± SE).

Another factor that was significant was wave height (Chisq=7.516, df=1, P=0.006**). Higher waves correlated with longer fish (figure 5).

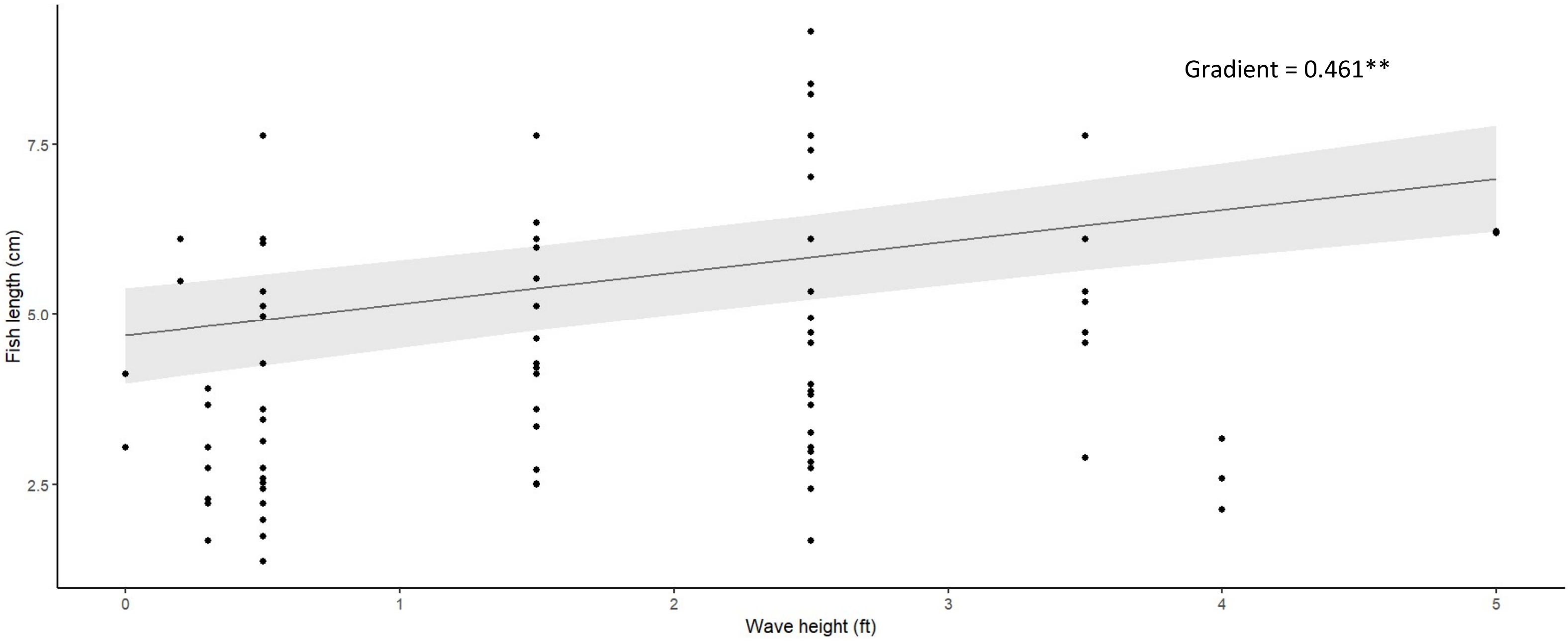

Figure 5: The effect of wave height on fish length. The line of best fit was generated using a mixed model (1± SE).

Wind direction was the final factor which had a significant effect (Chisq=14.402, df=7, P=0.044*) on fish length, with wind coming from the north and northwest correlating with significantly shorter fish being provided to little tern chicks, compared to wind coming from the east (figure 6).

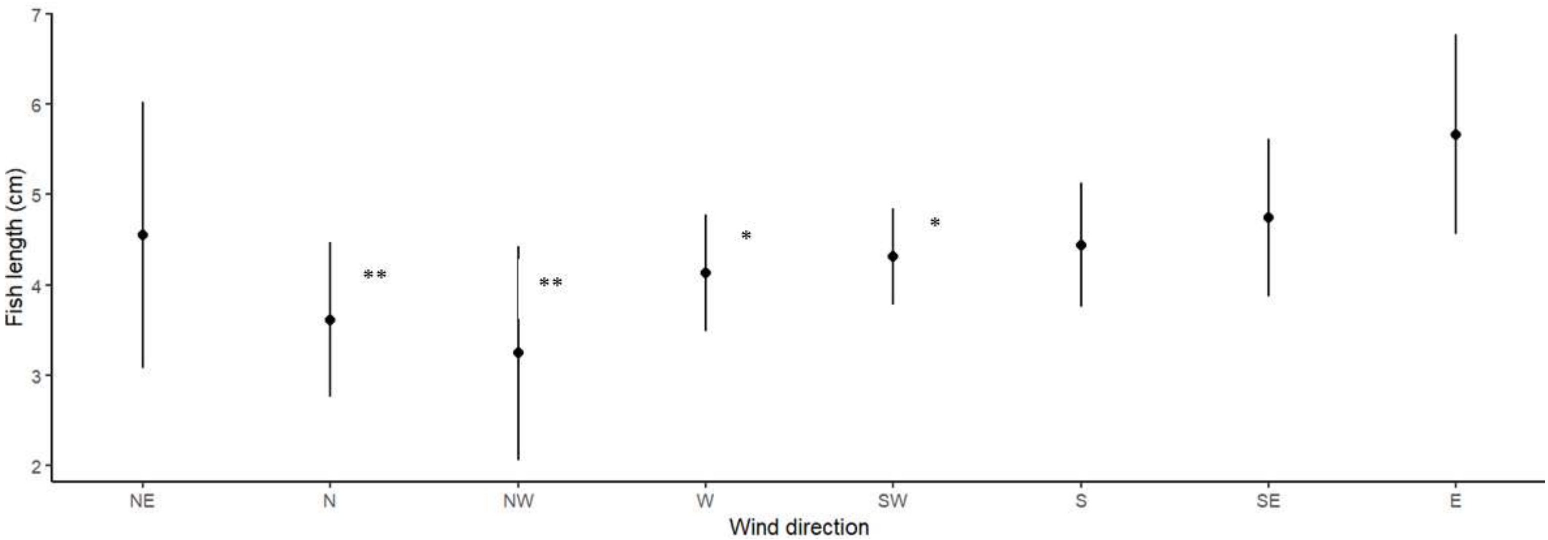

Figure 6: Effect of wind direction (direction of where the wind was coming from) on fish length. The values represent predictions generated by a mixed model. The stars represent a significance difference from wind blowing from the east.

No other factor had a significant effect on fish length, although human disturbance had some weak correlation (Chisq=3.375, df=1, P=0.066).

Energy per fish

Energy per fish ranged from 0.01 kJ to 10.95 kJ, with a mean of 1.82 kJ and a median of 0.66 kJ. For statistical analysis, the values were logged to fit the assumptions of the mixed model. Three factors had a significant effect on energy per fish provided to chicks including chick age (Chisq=64.939, df=1, P<0.001***) and wave height (Chisq=13.966, df=1, P<0.001***), with the relationship remaining the same as with fish length, unsurprisingly as energy was derived from fish length. The 3rd factor is human disturbance, which also had a significant negative effect (Chisq=4.125, df=1, P=0.042*) on energy per fish provided to chicks, despite not having a significant effect on fish length (figure 7).

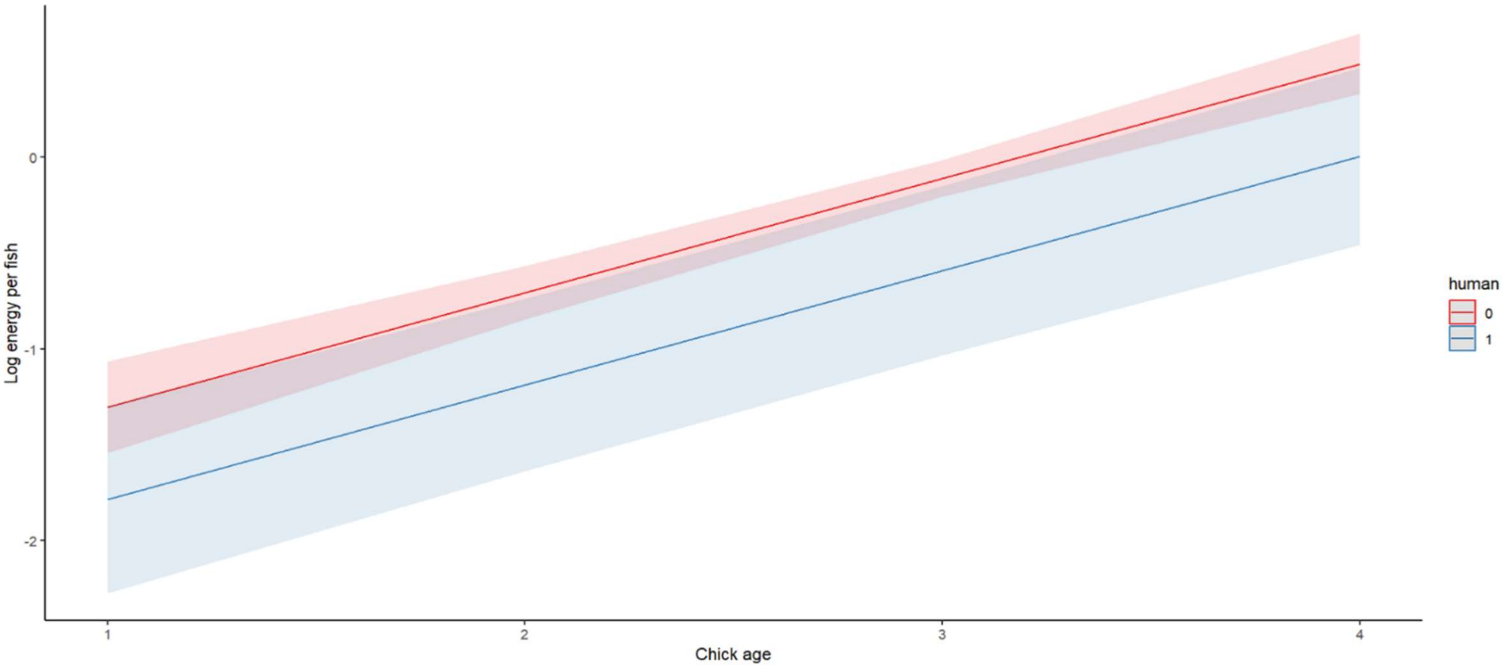

Figure 7: The effect of human disturbance on the relationship between chick age and log energy per fish, where no human disturbance is represented as 0. The lines of best fit were created using a mixed model.

However, wind direction did not have a significant effect (Chisq=9.304, df= 7, P=0.227), despite having a significant effect on fish length. All other factors did not have a significant effect on energy per fish.

Total energy per hour per chick

Total energy was calculated by multiplying feeding frequency and energy per fish and ranged from 0.02kJ to 19.23kJ, with a mean of 3.19 kJ and median of 1.08 kJ. For statistical analysis, the values were logged to fit the assumptions of the mixed model. Some of the same factors shared the same significance as in previous response variables. Age once again had the biggest effect (Chisq=67.517, df=1, P<0.001***), with chicks receiving more energy as they grew older (figure 8).

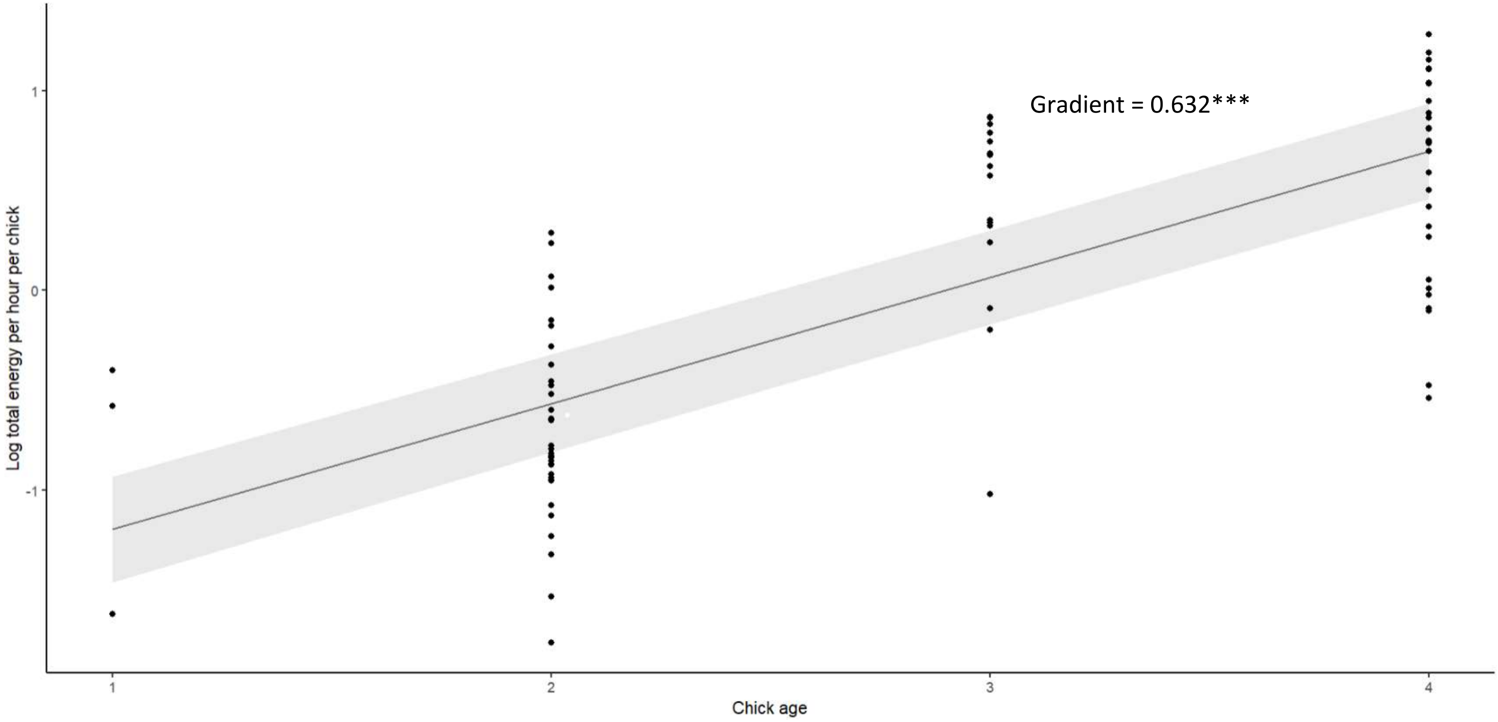

Figure 8: The effect of chick age on the log total energy per hour per chick. The line of best fit was created using a mixed model (1± SE).

Wave height was also significant (Chisq=14.482, df=1, P=0.002**), with higher waves leading to chicks receiving more energy per hour (figure 9).

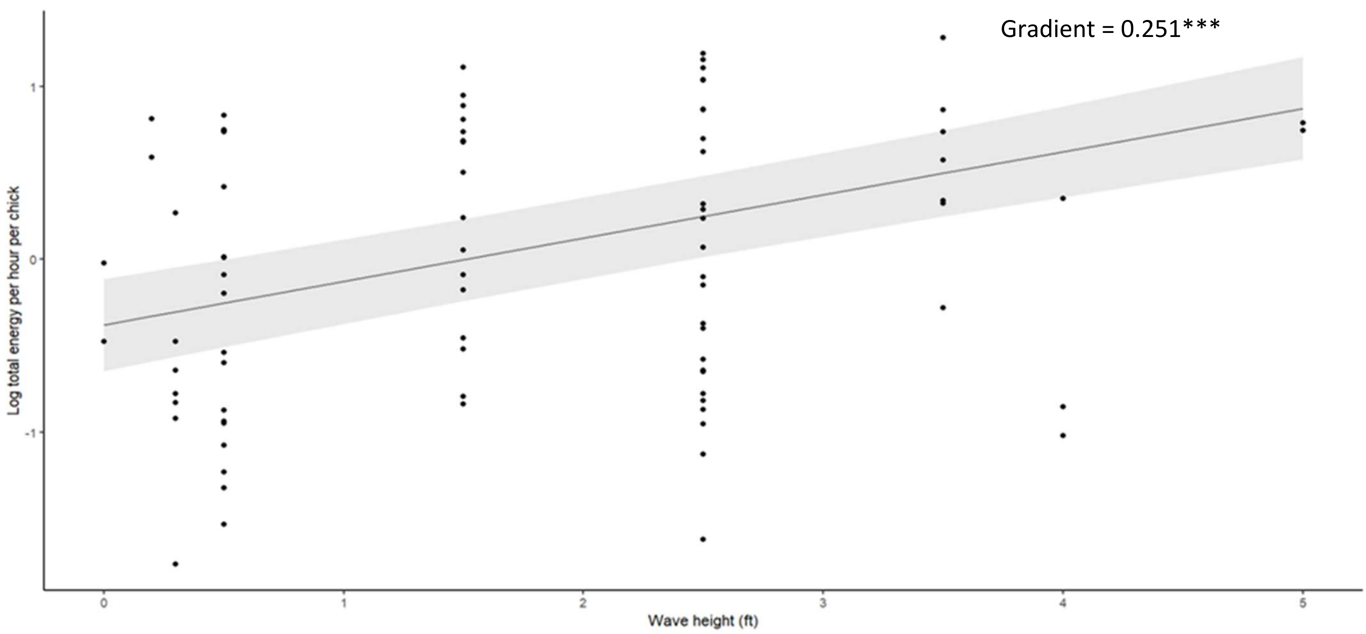

Figure 9: The relationship between wave height and log total energy per hour per chick. The line of best fit was generated using a mixed model (1± SE).

No other factor had a significant effect on total energy.

Discussion

The mean feeding frequency calculated was 1.74 per hour per chick, which is similar to a previous little tern study which found a feeding frequency of 1.44 per hour per chick (Paiva et al., 2006). The average feeding rate found here per nest was 3.32 fish/hr/nest and was higher than the least tern feeding rates (2 fish/hr/nest) found by Schweitzer and Leslie (1996). In both these previous studies there was sufficient food supply for the tern species to feed their chicks, suggesting that this was also the case during this study (Paiva et al., 2006; Schweitzer and Leslie, 1996). This is further supported by only 3 chicks being known to have died during the 5-week observation period, with one due to the electric fence and the other two for unknown reasons (Joe Griffin, personal communication). Nevertheless, the results suggest that a number of factors can affect the amount of energy that little tern chicks receive. These factors have affected fish length and total energy, rather than feeding frequency, with no factors having a significant effect on the latter. This is in contrast with previous studies of little tern and other tern species, who have found a number of factors affecting feeding frequency in terns.

The finding that tidal cycles have no effect on feeding frequency is unsurprising as in Spurn, the little terns obtain the vast majority of their fish from the sea (they occasionally feed on the Humber and in lagoons), which is consistent with the results found by Paiva et al. (2007), who found that feeding on the sea was independent of tidal cycles. While some previous studies have found that little terns tend to forage more during incoming and/or receding tides, it is in areas where little terns feed more on estuaries and main lagoon channels, as tidal cycles influence when juvenile fish enter these areas (Paiva et al., 2007). This suggests that tide is not an important predictor of feeding frequency of little terns that feed mainly in the sea, such as in the UK.

Wind speed has also previously been found to have had an effect on feeding frequency, as well as species selection, with stronger winds reducing feeding rates of tern species, as well as influencing cycles of nutrients, resulting in some species of fish being unavailable for foraging under certain wind speeds (Paiva et al., 2007; Frank, 1992). While fish species were not fully recorded in this study, wind speed had no effect on feeding frequency or fish length. This may be down to little terns in Spurn being more sheltered, as they tend to feed near the coast and therefore may be less affected by high wind speeds. Furthermore, previous studies seeing this pattern were located in Germany and southern Portugal, where the fish species differed to Spurn, and could have been more difficult to forage for in higher winds. A lack of significance could also be due to wind speeds being recorded inland (In Easington), rather than where the little terns forage, and so the wind speed is likely to be an underestimate of the true value.

Another factor that has been previously found to impact feeding rates is weather conditions and time of day. Hong et al. (2008) found that little terns in South Korea fed less frequently during cloudy and rainy days, compared to fine days. However, this data was obtained from a small sample size, with only 9 nests measured for 1 day each, and so these differences could be due to chance, or other confounding factors (Hong et al., 2008). Time of day has also been found to effect feeding rates in tern species, with feeding frequency being highest in the early morning, and lowest in the early afternoon (Ramos et al., 1998). However, this study was done with Roseate terns, as well as being in the Azores, where temperatures are hotter, and change more drastically during the day compared to Spurn (temperatures throughout the whole observation period only ranged from 12 to 21 °C). This may also explain why temperature did not have a significant effect on feeding frequency in Spurn, due to the lack of really cold or hot temperatures throughout the observation period.

Predator disturbance did not have a significant effect on feeding frequency, which is expected as all disturbances only lasted for around a minute, and the fact that previous studies only found predator disturbances to significantly affect colony productivity, rather than chick provisioning (Darrah, 2020), while Roberts et al. (2023) found no effect of predator disturbances on feeding rates. Unknown disturbances also had no significant effect, and none of these disturbances lasted more than a minute, and so also unlikely to impact feeding rates. While the species of predator was recorded, the sample size of the predator species was too small (some predators only appeared once) to be able to make any conclusions on whether predator species had an impact.

However, while human disturbance did not have an effect on feeding frequency, it was found to have a significantly negative effect on the amount of energy per fish provided. While human disturbance has been found to be a major cause for nest failure in terns, by reducing the time available to forage (Darrah, 2020; Searle et al., 2016), it has not been found to effect fish length. There is no previous evidence to support this pattern, suggesting this could be due to chance, which is supported by the fact that there was a very small sample of human disturbances (4) throughout the study. The relatively low impact of predator and human disturbance on little tern feeding rates on the colony could also be down to the predator-proof fencing and 24-hour wardening present, rather than these disturbances having little effect overall, and so these results could be more of an indication of the effectiveness of conservation in reducing the impact of predation and human disturbance rather than the normal impact of disturbance on chick provisioning. Furthermore, when calculating the effect of human, predator and unknown disturbances, the total amount of disturbances in the observation period were counted, regardless of when they occurred in relation to feeding events, meaning that the true effect of disturbances was not calculated, rather an average, potentially skewing the results. Therefore, further research on the effect of disturbances on feeding rates is required, especially in areas where there is less protection from them.

The factor which had the most significant effect on chick provisioning was chick age, with older chicks receiving longer fish, and more energy per fish. This is expected, as older chicks require higher energy requirements as they grow bigger, as well as smaller chicks being unable to eat bigger fish (Paiva et al., 2006; Safina et al., 1988). This pattern is consistent with previous studies on little tern and other tern species (Paiva et al., 2006; Fernández Ajó et al., 2011). While some studies on other tern species found an increase in feeding rate with chick age (Ramos et al., 1998), others have only found an increase in fish length to meet the higher energy requirements of older chicks (Paiva et al., 2006), therefore supporting these results. This is further supported with chick age also having a significant effect on the total energy received per hour per chick, showing that the higher energy requirements of older chicks are being met solely through an increase in fish size.

Another factor which affected fish length was wave height. Wave height had a significant effect on fish length, with higher waves correlating with larger fish being collected by little terns. This contrasts with anecdotal studies, which suggested a negative relationship between wave height and feeding success, due to reduced prey visibility (Uesaka et al., 2022). However, almost no studies have quantitatively measured the effect of wave height on seabirds foraging (Uesaka et al., 2022). As little terns tend to feed near the coast and in shallow water (Thaxter et al., 2012; del Hoyo et al., 1996), they are less likely to be affected by reduced visibility than other, deep diving, seabirds. This is supported by research on the wandering albatross, another seabird which does not dive deep for food (under 1m), being unaffected by wave height when foraging (Uesaka et al., 2022). However, this does not explain why fish length increases, as wave height increases. A possible theory could be that due to stronger currents, bigger fish (or different fish species) are pushed to the sea surface, allowing them to be caught more easily by little tern, compared to when the ocean is calm. However, there is no evidence to support or disprove this theory. It is also worth noting that wave height was recorded using data from Withernsea, and so may not be completely accurate.

The third factor which affected average fish length was wind direction. Wind direction had a significant effect on fish length, with wind blowing from the east correlating with longer fish, compared to wind from the west and southwest (*), and the north and northwest (**). As little terns in Spurn fly south and southeast to forage for the vast majority of the time, wind from these directions, especially the two most significant ones, blow directly against the terns as they attempt to fly back to the colony. While this does not affect feeding frequency, it may make it harder for the terns to carry bigger fish, as they are harder for the adults to manipulate (Fernández Ajó et al., 2011). They may instead opt to select smaller fish to make it easier for them to carry the fish back to the colony when flying against the wind. This theory is supported by wind coming from the northwest having the largest negative impact (figure 6), which is likely to be the exact opposite direction of returning adults, while wind blowing from the east (i.e. towards the colony), is correlated with larger fish. While other studies did not find this pattern, these did not measure wind direction, and instead only focused on wind speed (Paiva et al., 2006). However, the fact that wind direction did not have a significant effect on energy per fish provided or total energy per chick does raise questions about the validity of this finding, as this suggests that wind direction affects differences smaller fish, as energy differences between smaller fish are significantly smaller than differences between larger fish, as energy increases exponentially with increasing fish length. This goes against the theory that wind direction makes it harder for larger fish to be carried by the adults. Therefore, it is vital that more research is performed to see if this pattern is observed elsewhere and/or across different years.

No other factor was found to have a significant effect on fish length or energy, which is supported by Paiva et al. (2006), who only found effects on fish species or feeding frequency.

Conservation implications

The feeding frequency found in this study, and the lack of chick deaths in the colony suggest that there is sufficient food supply for adult little terns to feed their chicks in Spurn. As little tern feeding patterns can be an important indicator of fish species abundance (Brodin et al., 2024), this suggests that sand eel numbers in that area of the North Sea are sufficient, as this was the little terns primary prey species during the study. These findings suggest that current efforts to restore sand eel numbers are proving effective, such as the ban on sand eel fishing for the past 3 years, therefore supporting the continuing of the sand eel ban and ensuring that due consideration is given to fish breeding grounds when constructing wind farms or other forms of renewable energy until species have recovered sufficiently to allow limited fishing to resume. As climate change also threatens sand eels, it is vital that further conservation efforts are made to ensure that there is sufficient food supply for little terns and other seabirds in the future.

Furthermore, the findings found in this study can be of important value to future studies on little tern feeding rates in Spurn and the UK, as factors such as chick age, wind direction and wave height should be considered before any conclusions over food supply can be made in other colonies with higher nest failure. This will help increase the accuracy of future feeding studies, and therefore increase the chance that limited resources are put to good use in terms of little tern conservation.

Limitations

As observation was performed by one person from over 100m away, visibility was sometimes difficult, and with chicks often moving behind vegetation and around the colony, especially later in the season, it is likely that some feeding events were missed. When viewing multiple nests, it was also possible that feeding events were missed, especially if feeding events occurred simultaneously across multiple nests. As there was no way to identify individual chicks or adults, it is possible that feeding events of one nest were mistaken for another if they were in a similar location. Fish length was a subjective measurement, as it was based on bill length, and likely not very accurate from over 100m away. While in comparison to one another, fish length was relatively accurate, it is likely that energy calculations were less accurate due to the exponential relationship between energy and fish length. On the other hand, Schweitzer and Leslie, (1996) other studies found least terns consuming fish in the range of 2-9cm, which is very similar to what was gathered here (1.7 to 9.2cm).

In terms of statistical analysis, energy per fish was calculated assuming that all fish caught were sand eel. However, while sand eel was estimated to make up around 70% of prey, a significant amount consisted of Sprat and other fish species, meaning that energy values could have varied, as the energy content of fish varies between species (Paiva et al., 2006).

Conclusion

In conclusion, this study found that there are a number of factors that can affect the amount of energy that little tern chicks receive in a colony in the east of England. Little terns chicks receive larger amounts of energy as they get older, which is achieved by adults increasing the size of fish they catch, rather than increasing the feeding rate. Wind blowing from the north, northwest, west, and southwest had a negative impact on fish length, possibly due to the fact these meant adults were flying against the wind when returning to the colony. Higher waves in the sea had a positive relationship with the size of fish caught, which could suggest that stronger sea currents bring bigger fish to the sea surface. Finally, human disturbance was found to have a negative relationship with energy per fish, but this is likely due to chance due to the very small sample size obtained.

The results found here indicate that little terns in Spurn have sufficient food supply, thereby supporting current conservation measures on sand eel fishing. The results can also help future feeding studies, although further research is needed to ensure the accuracy of the patterns found here, as this study was only performed over one year, and so could be an anomalous year. Furthermore, future research should attempt to record the fish species being caught to improve the accuracy of energy values, as well as potentially explaining variation in fish length due to environmental conditions. Nevertheless, the data presented here can be a useful tool in informing future feeding studies in tern species in the UK.

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