The ecology of an urban colony of common terns *Sterna hirundo* in Leith Docks, Scotland

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Abstract

The Imperial Dock Lock Special Protection Area (SPA) in Leith Docks on the Firth of Forth currently supports the largest common tern (*Sterna hirundo*) colony in Scotland. The nest site, a former lock wall in an operational port, was designated as an SPA for the species in 2004 but very little is known about the ecology of common terns in this man-made environment. This thesis examined their ecology using a combination of long-term data for the Firth of Forth region and field research at the colony. The dynamics of the Firth of Forth breeding population of common terns was linked both to local influences of predators and the regional status of their main food source, the Firth of Forth sprat stock. Colonisation of Leith Docks resulted from relocation of birds from natural islands in the Firth of Forth which were abandoned due to unsustainable levels of predation by gulls. Herring gulls (*Larus argentatus*) and lesser black-backed gulls (*L. fuscus*) are active predators in Leith Docks but at relatively low levels. Predation attempts by mink present a serious threat and could be highly detrimental to the colony. Foraging studies revealed that terns are feeding primarily in the Forth of Forth rather than within the docks, and that their diet consists mostly of sprat, but also sandeels and gadoids. The importance of sprat in the diet is discussed in relation to the potential reopening of the sprat fishery. Surveys of birds commuting between the colony and the feeding grounds showed that a range of flight lines are used but to different extents, and found no evidence of collisions with buildings or other man-made structures. Terns were well-habituated to regular human activity but were sensitive to unusual or high-level human disturbance factors. Gulls and crows, rather than humans, were the greatest disturbance factors for nesting birds overall. Currently the Imperial Dock Lock SPA is the only site in the region that could support common terns breeding in considerable numbers, and so the future of the Firth of Forth population of common terns is now dependent on this one site. There are a number of management options available, and the future persistence of the population relies on the continued monitoring of breeding numbers of terns, of predation levels and further assessment of the sprat stock.

Table of Contents

List of Tables

List of Figures

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Author's Declaration

I declare that the work in this thesis is entirely my own unless otherwise cited or acknowledged. No part of this thesis has been submitted for any other degree or qualification. Data presented in Chapter 3 has been published as the following paper:

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1 General Introduction

The common tern *Sterna hirundo* is a small, migratory seabird with a widespread breeding distribution ranging from temperate to subtropical latitudes throughout the northern hemisphere (Ratcliffe, 2004). The breeding population of Britain and Ireland is of international importance, at an estimated 14,497 pairs in 2002 and, unlike other tern species, is found in both inland and coastal areas (Ratcliffe, 2004). The focus of this thesis is a colony at the Imperial Dock Lock Special Protection Area in Leith, east Scotland. This is currently the largest common tern colony in Scotland, supporting approximately 5% of the common tern breeding population of Britain and Ireland (Ratcliffe, 2004) and it was designated a Special Protection Area (SPA) for the species in September 2004. The site is located within Leith Docks, an operational port on the Firth of Forth, owned by Forth Ports Limited. Terns nest on a former lock wall, a small (0.11 Ha), roughly rectangular, concrete structure, surrounded by water which is essentially an island. In 2007, Forth Ports Limited submitted an Outline Planning Application for the development of the surrounding port area for housing, offices and recreational use. The application was supported by an Environmental Statement detailing potential environmental impacts of the proposed development, which highlighted the need for further information regarding the tern colony. Forth Ports commissioned two environmental consultancies, Arup and Environ, to undertake surveys on the colony in 2004 and 2008 respectively, to provide information on aspects of tern ecology and it was subsequently considered an appropriate topic for a PhD study. Forth Ports highlighted several areas of interest and, based on the needs of their requests I decided to study the following aspects of tern ecology at the site.

One of the most striking features of the colony is the use of a man-made structure for nesting; the use of urban and industrial environments by breeding terns is reviewed in Chapter 2. The history of the Firth of Forth population of common terns is then explored in Chapter 3, including analysis of long-term breeding numbers and investigation of distributional shifts which resulted in the colonisation of Leith Docks.

The next four chapters are based on detailed observational field work performed at the Imperial Dock Lock SPA during the PhD study. Chapter 4 investigates the foraging ecology of the terns and includes information on their diet, chick provisioning rates and foraging locations. The flight lines of terns passing between the nest site and their foraging grounds are presented in Chapter 5. Chapter 6 describes predation activity at the colony and the responses of terns to predators. Terns typically prefer isolated nesting sites and can be sensitive to human disturbance, so the topics of habituation and disturbance at the colony are investigated in Chapter 7. Within each chapter, the findings of these field studies are considered in relation to changes in site use and conservation and Chapter 8 brings together these findings in a general discussion.

All statistical analyses were performed using the program R (version 2.14.1).

2 A review of the use of urban and industrial environments by breeding terns

2.1 Introduction

This is a review of terns (family Sternidae) nesting at man-made sites in urban and industrial environments in Europe and North America. Terns are threatened throughout their breeding distribution by a range of factors including habitat loss, predation and pollution. Traditionally, terns nest on undisturbed mainland shores and natural islands but where natural habitat has been lost or becomes unsuitable, terns can be encouraged to utilise purpose built islands, sand pits and rafts for breeding (e.g. Dunlop *et al.*, 1991; Lampman *et al.*, 1996; van der Winden, 2000). Additionally they may use man-made structures that are not intended for breeding, such as rooftops and piers in urban or industrial areas. While this may seem atypical, it is not uncommon, and some of the largest tern colonies are now to be found in such areas.

The habitat requirements of terns are simple, key requirements being a suitable nesting substrate and a good food supply nearby. Generally, an open, well-drained area with sparse vegetation cover for nesting is preferred; one which facilitates predator detection whilst also providing cover for chicks (Nisbet, 2002). Naturally, such conditions occur where vegetation succession and overgrowth is prevented by storms and floods. Due to such simple requirements, the nesting conditions offered by many man-made sites do not differ greatly from those found at natural sites. As the environment becomes increasingly urbanised, there is a growing need for understanding the trend of breeding in urban and industrial environments if conservation of terns is to be successful. The aim of this review is to survey existing literature to assess the scale at which terns are utilising urban and industrial environments for breeding, to assess breeding success at there sites and to consider the findings in the context of conservation management for terns.

2.2 Seabirds in urban environments

Gulls are a familiar sight in many towns and cities and are the best known example of seabirds breeding in urban environments. The subject of urban gulls has received considerable attention since the 1970s (Belant, 1997; Monaghan, 1979) but the first reported incidence was over a century ago, of herring gulls (*Larus argentatus*) nesting on buildings near the Black Sea in 1894 (Goethe, 1960). The rise in numbers of gulls breeding in urban areas is not just a result of overall population growth. In Scotland for example, where urban numbers of gulls are increasing, overall populations of some species, including herring gull, black-headed gull (*Chroicocephalus ridibundus*) and great black-backed gull (*L. marinus*), are in serious decline (Mitchell et al., 2004). The success of gulls in urban areas is largely related to the availability of a reliable food supply. Herring gulls breeding in urban areas in Britain (typically on rooftops) have greater breeding success than those at natural sites, owing largely to predator-free nest sites and an abundant and reliable food supply in the form of domestic and commercial waste (Monaghan 1979, Mitchell *et al*., 2004). In contrast, in the Great Lakes region of North America, where breeding and wintering populations of herring gulls and ring-billed gulls (*L. delawarensis*) have increased dramatically, those nesting at urban sites have been found to have lower breeding success than those at traditional sites (Belant, 1997; Belant *et al.*, 1998).

Urban gulls are generally perceived as a problem by residents, businesses and the tourist industry, and their presence can have significant financial implications for Local Authorities (Wanless *et al.*, 1996). The most commonly reported complaints relate to the removal of litter by gulls from waste bins and bags, fouling, noise production and aggressive behaviour towards the public (Wanless *et al.*, 1996). Additionally, nesting on buildings can cause structural damage and blockage of drainage systems by nest material (Belant, 1993). The basic requirements of gulls and terns are very similar during the breeding season, and they are often found nesting at the same sites. Whereas the subject of gulls nesting in urban and industrial environments has been subject to review (e.g. Belant, 1997; Wanless *et al.*, 1996), this is not true for terns. This could be because terns are generally perceived as less of a problem than gulls. Fisk (1978) reviewed the use of roofs by nesting birds including terns, and the use of other man-made structures by terns has been reported, but as yet the trend has not been reviewed. Unlike gulls, this review of urban and industrial nesting terns stems from a conservation need rather than from a requirement to control their populations.

2.3 Nest site selection in terns: a shift towards nesting on man-made structures?

Examples of tern colonies on man-made structures in remote locations include fairy terns (*Sterna nereis*) on the roofs of military buildings on Midway Island in the Pacific (Fisk, 1978) and common terns nesting on an old fort and the roof of a building on Great Gull

Island, New York (Macfarlane, 1977). Elsewhere, tern colonies can be found at what can be considered truly urban or industrial sites. In Virginia, the car park at the Hampton Roads Bridge Tunnel is home to the state’s largest common tern colony, exceeding 3000 pairs between 1998 and 2001 (Erwin *et al.*, 2001). Currently some of the largest colonies of common terns in the UK and Ireland exist at industrial sites. At the time of the Seabird 2000 survey, the third and fourth largest common tern colonies in the UK were found on at the Imperial Dock Lock Special Protection Area in Leith Docks (Scotland) and on rafts within the Shotton Steel Works complex (Clwyd, North Wales) respectively, and in Ireland the fifth largest colony was at Dublin Port (Co. Dublin) (Ratcliffe, 2004). Various man-made sites have been used for breeding in Scotland, including oil platform construction yards (at Nigg Oil Terminal, Ross and Cromarty and Ardersier, Inverness), gas pipe terminals (St Fergus, Banff and Buchan) and dock yards (former Royal Dockyard, Rosyth and Campbeltown) (Ratcliffe, 2004). Other significant industrial colonies in Europe include those at the ports of Zeebrugge, Belgium (Everaert & Stienen, 2007) and Wilhelmshaven, Germany. The latter has been the subject of a detailed long-term study by Peter Becker and colleagues (Becker & Wendeln, 1997). In Zeebrugge, a purpose built ‘tern-peninsula’ was created to compensate for the loss of breeding sites elsewhere in the port and it is used by common, little and Sandwich terns. It supports a very large colony of common terns, with 1475 breeding pairs recorded in 2005 (Everaert & Stienen, 2007).

In some regions, a pronounced shift in nest site selection has occurred, with great increases in the use of urban and industrial sites by two species in particular, the least tern *Sterna antillarum* and the common tern. The nesting habits of the least tern, which breeds in North America, have changed dramatically in the last century. The species suffered greatly from the millinery trade in the 1880s, reducing the population to only a few colonies in Virginia and Massachusetts by the end of the19th century (Fisk, 1975). Desertion of traditional sites was observed as early as 1890 following further disturbance and habitat loss from the development of coastal resorts (Gochfeld, 1983). As for common terns, colonies were historically found on undisturbed beaches and islands, but following the development and urbanisation of many of these traditional sites, roof-top nesting has been increasingly reported. Colonies tend to be on flat, gravel-covered rooftops, which provide nesting substrate not dissimilar from a natural beach (Forys & Borboen-Abrams, 2006). First reported on the 50 foot high pier roof in Pensacola, Florida (~20 pairs) in 1957 (in Fisk 1975, observed by Goodnight), now up to 80% of the Florida least tern colonies are found on roofs (Burger 1988). Four of the roof-nesting least tern colonies in Florida were associated with nesting black skimmers *Rynchops niger* (Fisk, 1978). In North Carolina, around 30% of least terns now breed on gravel rooftops (Cameron, 2008) and in South Carolina, 61% of all least tern colonies were found on roofs in 1995 (from Murphy and Dodd 1995, in (Krogh & Schweitzer, 1999). Similarly, in Georgia, the proportion of the least tern population nesting on roofs increased from 50% to 73% in only two years (from 1995 to 1997) (Krogh & Schweitzer, 1999). More recently, rooftop nesting has also been reported in the interior subspecies of least tern *Sterna antillarum athalassos* in north-central Texas (Boylan *et al.*, 2004), where much of its natural riverine breeding habitat has been lost due river channelization, irrigation and dam construction (Downing, 1980). It is likely that this trend is replicated across other states that have not yet been surveyed. Forys and Borboen-Abrams (2006) surveyed the occupancy of rooftops by least terns in Pinellas County, Florida, to establish what factors influence rooftop selection. The most important factor was distance to a body of water, either for foraging or cooling purposes (for eggs). Colonies tended to be within 1 km of a body of water deemed suitable for foraging (in the range of 3-7605 m of water bodies greater than 1 ha) and close to smaller bodies of water suitable for cooling (3-284m distance). A range of building heights (from approximately 2m to a twelve storey building of 32m) and rooftop sizes (0.02ha to 2.50ha) were occupied.

The apparent shift toward nesting on man-made structures has also been reported for the common tern at sites in both North America and Europe. In the Lower Great Lakes, a common tern colony was noted as early as 1944 at Donnelly's Pier, Buffalo Harbour (reviewed by Courtney & Blokpoel, 1983), but at 200 pairs when first reported, it is likely that the colony had established earlier than this. By the early 1980s, approximately 70% of common terns on the Lower Great Lakes were found across seven man-made sites (Courtney & Blokpoel., 1983). This switch occurred rapidly; surveys of common tern in Lakes Michigan, Huron and Erie found an 80% increase in the use of man-made structures over a period of only 18 years, with 62% of the total number of pairs surveyed nesting at two man-made sites (Shugart *et al.*, 1978). In the upper St Lawrence River the proportion of common terns nesting on navigation aids increased from 37% of the population in 1982 to almost 69 % in 1990 (Karwowski *et al.*, 1995). Vegetation succession, human recreational and industrial activity and a rapidly increasing ring-billed gull *Larus delawarensis* population (ring-billed gulls establish earlier, outcompeting terns for nesting habitat) have all contributed to the patterns of desertion and relocation observed in the Great Lakes (Courtney *et al.*, 1983; Morris & Hunter, 1976). The first recorded incidence of urban common terns in the Netherlands was of five pairs on a rooftop in Hasselt, Overijssel in 1977, with reports of three more colonies during the 1980's (van Kleunen *et al.*, 2010). A survey in 2009 revealed that 9% of the Netherlands common tern population

(46 colonies totalling 1189 nests) were breeding on man-made structures, mostly rooftops (van Kleunen *et al.*, 2010). Most of the roof-nesting terns were found on gravel-covered roofs, but green roofs (roofs covered in short vegetation) were also used, including those at Schiphol Airport in Amsterdam (van Kleunen *et al.*, 2010).

Summaries of tern colonies at urban or industrial sites, including further examples, are given in Table 2.1 (European colonies) and Table 2.2 (North American colonies).

Table 2.1 Examples of tern colonies at urban or industrial sites in Europe.

Site	Nesting structure	Species	Pairs at time of study (if known)	Reference
Imperial Dock, Leith, Scotland	Port	Common	690 (year)	(Mitchell *et al.*, 2004)
Grangemouth Dock, Scotland	Port	Common		(Mitchell *et al.*, 2004)
Rosyth Dockyard, Scotland	Port	Common		(Mitchell et al., 2004)
Campbeltown Dock, Scotland	Port	Common		(Mitchell et al., 2004)
Nigg, Construction Yard	Industrial	Common		(Mitchell et al., 2004)
Ardersier, Construction Yard	Industrial	Common		(Mitchell et al., 2004)
St Fergus, Gas Pipe Terminal	Industrial	Common		(Mitchell et al., 2004)
Cork Harbour, Cork, Ireland	Port	Common	102 (1995)	(Mitchell et al., 2004)
Dublin Port, Co. Dublin, Ireland	Port	Common	194	(Mitchell et al., 2004)
Wilhelmshaven Harbour, Germany	Rafts in harbour	Common	530	(Becker *et al.*, 2008)
Zeebrugge, Belgium	Port Breakwater	Common	1475 (2005)	(Everaert *et al.*, 2007)
Shotton Steel Works, North Wales	Industrial	Common	~200/ 490	(Henderson, Langston & Clark, 1996) (Mitchell *et al.*, 2004)
Tampere, Finland	Factory roof	Common	9 (in 1971) (present from 1966)	(Hakala & Jokinen, 1971), in Fisk 1978
Tjornin Pond, Reykjavik, Iceland	Island in city lake	Arctic		Gunnar Hallgrimsson, pers. comm.
VBA Flower Auction complex, Aalsmeer, Netherlands	Roof	Common	120-130 (1994)	(Groen, Frieswijk & Bouwmeester, 1995)
South Dublin Bay SPA, Dublin Docks, Ireland	Mooring structure, Docks	Common, Arctic	>400 common tern (2004) (no count for Arctic tern)	Online information: http://www.npws.ie/media/npwsie/content/images/protectedsites/sitesynopsis/SY004024.pdf
Lowestoft, Lake Lothing,	Roof	Common	5+ (2009)	Online information: http://webcache.googleusercontent.com/search?q=cache:QlXMkZj5UQUJ:myweb.tiscali.co.uk/lowestoftbirds/NEWS0609.htm+boat+building+common+tern+lake+lothing&cd=4&hl=en&ct=clnk&gl=uk
Riga, Latvia	Roof	Common, Arctic, little	~500 common tern, ~15 Arctic tern, 26 little tern	(Viksne & Janaus, 2006)

Table 2.2 Examples of tern colonies breeding at urban or industrial sites in North America.

Site	Nesting structure	Species	Pairs at time of study (if known)	Reference
Hampton Roads Bridge Tunnel, Virginia, USA	Road bridge	Common	>3000	(Erwin *et al.*, 2001)
St Lawrence River, NY, USA	Navigation aids	Common		(Karwowski *et al.*, 1995)
Port of Los Angeles, California, USA	Container terminal, Pier 400	California Least	669 (2007)	(Marschalek, 2008)
San Francisco Bay, California, USA	Naval air base	California Least		Elliott et al 2007
Great lakes	Piers, breakwaters, airport, headland	Common		(Courtney *et al.*, 1983)
Great lakes: Lake Erie (Port Colborne), Canada	Port	Common		(Morris, *et al.*, 1992)
Lake Ontario (Eastern Headland), Canada	Industrial	Common		(Morris *et al.*, 1992)
Great Lakes: Duluth Harbour (Port terminal), Lake Superior, Minnesota, USA	Port	Common	146 (1983), 113 (1984)	(McKearnan & Cuthbert, 1989)
Denton County, Texas, USA	Warehouse roof	Interior Least		Boylan *et al.*, 2004
North Carolina, USA	Warehouse roof	Common	(2005)	(Cameron, 2008)
42 sites; in Florida (37), Louisiana (4) and South Carolina (2), USA	Roofs (all but one in urban areas)	Least	-	Fisk 1978
Great Gull Island, New York, USA	Military building rooftop, old fortifications	Common	1	(Macfarlane, 1977)
Patuxent River Naval Air Station, St. Mary's County, Maryland, USA	Harrier Jet Pad	Least	11 (1982)	(Altman & Gano, 1984)
Gibson County, Indiana, USA	Public Power Plant	Interior least		(U.S. Fish and Wildlife Service, 1990)
Georgia	Rooftops	Least		Krogh *et al.*, 1999)

2.4 Challenges at man-made sites

Besides nesting substrate, the main differences for terns nesting in urban or industrial environments rather than at natural sites are likely to be a closer proximity to the human population, the structure of the surrounding environment itself, and the community of potential predators able to access the colony. Predicting the impact of disturbance is not always easy. Although terns are often considered to be sensitive to disturbance, they can also be surprisingly resilient, as demonstrated by the extent to which terns are now breeding in built-up areas. Human disturbance of terns, whether accidental or intended, has long been implicated as a cause of reduced success, but levels of disturbance are not necessarily greater at man-made sites. Some man-made sites, particularly rooftop sites and those within secure sites such as industrial complexes or military bases may offer a higher degree of protection from human disturbance, especially when compared to natural sites which are freely accessible to the public, as well as protection from a range of predators.

Whilst many man-made sites may provide a suitable nesting habitat for terns, urban nesting may be problematic for humans. In Montrose, a small coastal town in east Scotland, colonies of Arctic and common terns nesting in the grounds and on warehouse roofs of industrial compounds caused problems by dive-bombing workers and their parked cars during the breeding season. It was decided that alternative nesting habitat would be provided in the nearby Montrose Basin Local Nature Reserve in the form of a purpose-built tern raft, which was utilised successfully by common terns even in the first season of installation (Lloyd, 2009). A large common tern colony (2000 pairs) was destroyed at Toronto Island Airport in the 1960s due to the danger of collisions between terns and aircraft (from Blokpoel 1977). At a Naval Station in Maryland, a small colony (11 nests) of least terns was found on the perimeter of a Harrier Jet pad which was used once or twice daily by test pilots practicing vertical lift off and landings (Altman & Gano, 1984). Despite the potential for disturbance, the nesting birds were seemingly unaffected by the tests and four chicks fledged successfully, but after the first 4 eggs hatched the remaining 18 eggs were removed, presumably for aircraft safety purposes (Altman & Gano, 1984).

Depending on the location of the nest site, the surrounding built environment could potentially impact foraging efficiency by obscuring flight paths of adult terns and even cause fatalities through collisions. During chick provisioning, terns make use of predictable and consistent routes between the nesting and feeding areas, using the easiest routes possible to minimise energy expenditure. For common terns breeding at Shotton

Steel Works in North Wales, almost all trips to and from the foraging grounds in the nearby Dee Estuary involve passing two sets of power lines (Henderson *et al.*, 1996). Observations found that flight height decreased through the season, as energy demands on the parents increased, with notably lower heights during the nestling and juvenile phases compared to courtship or incubation. Although overall collision mortality was low, vulnerability to collision increased over the season as adults flew lower and closer to the lines to save energy. There is also an increased risk for juveniles, which fly closer to the wires than adults. In the port of Zeebrugge, Belgium, a man-made tern breeding platform is located on the landward side of a port breakwater, which supports 25 wind turbines. Here, terns must cross the breakwater and the wind turbines to access their feeding grounds (Everaert *et al.*, 2007). Although the turbines are not believed to affect the behaviour of the terns, fatalities from collisions with turbines represent a significant cause of mortality for the common, little and Sandwich terns breeding at this site (168 fatalities in 2004, 161 in 2005; Stienen *et al.*, 2008).

2.5 Productivity at man-made sites

Several studies have monitored the breeding success of terns at man-made sites along with colonies at nearby natural sites over the same period. The breeding success values from these studies are summarized in Table 2.3. Given the high annual variability of breeding success in terns, data should be treated with caution, however in many cases breeding success was notably higher at man-made than at natural sites.

Productivity of common terns in particular was much higher at man-made than at natural sites (average 1.17±0.84 fledged chicks/nest at man-made, compared to 0.32 ±0.39 fledged chicks/nest at natural sites, F=12.3, p=0.002, d.f=1, Figure 2.1). At common tern colonies in the Upper St. Lawrence River, New York for example, birds nesting on natural islands experienced complete or near breeding failure over the two study seasons (1984 and 1986) due to direct and indirect effects of avian predation, as well as flooding (Karwowski *et al.*, 1995). Those nesting on man-made navigation aids were protected from flooding as the nests lay about 3m above the water line and were well-drained, and, despite being as close to the mainland as the natural sites, predation by owls - the main suspected predator on the natural islands - was not observed (Karwowski *et al.*, 1995). A small colony of nine pairs of common terns nesting on a factory roof in Finland in 1971 had exceptionally high breeding success, producing 2.8 chicks per pair, double the productivity for terns in that region– the particularly high productivity at this site was attributed to favourable foraging conditions (foraging grounds were about 1km away) and low levels of predation (the only reported predator was hooded crow, *Corvus cornix* (Hakala & Jokinen, 1971).

For least terns, productivity was generally very low at all sites, but man-made nesters produced as many, and in some cases more, chicks as natural sites (0.19±0.25 fledged chicks/nest man-made and 0.1±0.14 natural sites, GLM, $F= 0.8$, $p=0.383$, d.f.=1, Figure 2.1). However, if the difference is real, the man-made sites have twice the reproductive output of the natural sites which would be biologically important. Two studies in Florida, 14 years apart, from 1975 and 1989, both reported higher breeding success for least terns at man-made sites (Fisk, 1978; Gore & Kinnison, 1991). In 1989, least tern colonies at both natural and man-made sites were severely affected by storms; high tides destroyed almost all nests at the Phipps beach colony and heavy rain and wind resulted in losses at the rooftop colonies either by leaving eggs standing in water or physically removing them from the nest (Gore & Kinnison, 1991). Despite losses at all types of sites, breeding success was still lower at natural ground-nesting colonies, and this was largely attributed to mammalian predators which were absent from rooftop sites (Gore & Kinnison, 1991).

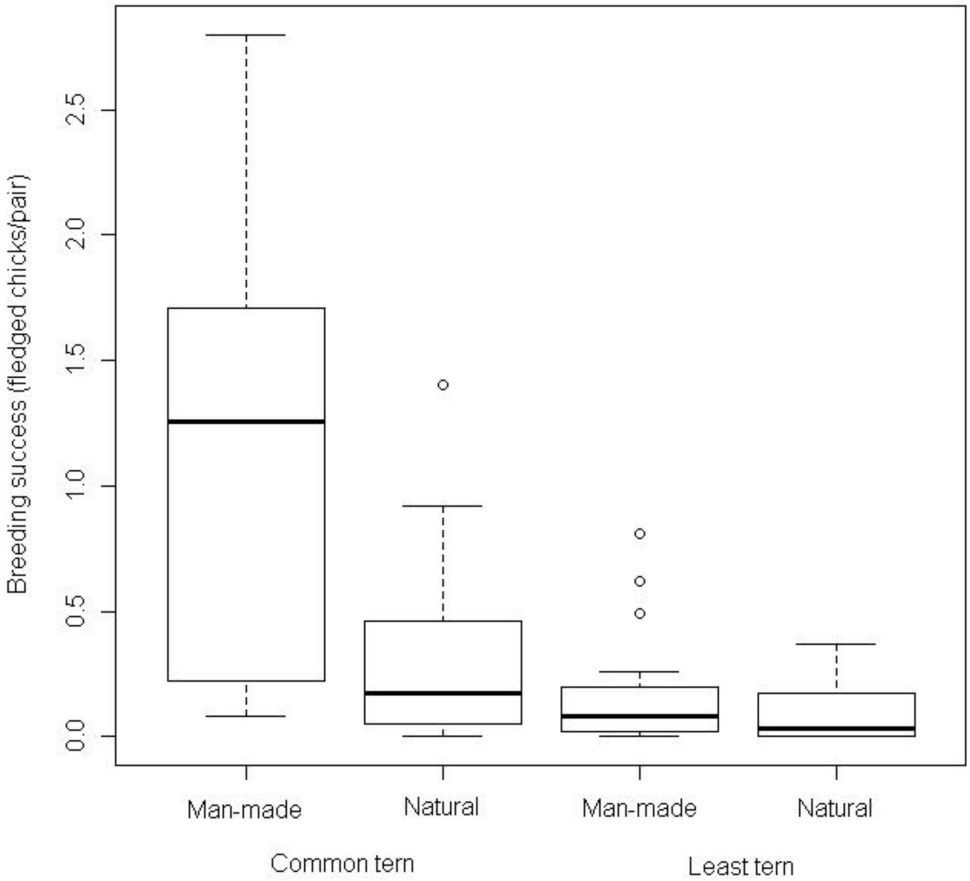

Figure 2.1 Breeding success (number of fledged chicks/pair) of common and least terns nesting at man-made and natural sites, based on values presented in Table 2.3. In this boxplot the bold horizontal bars represent the median, the box shows the 1st and 3rd quartiles of the data and the whiskers indicate the smallest and largest values.

Table 2.3 Breeding success of common and least terns at man-made colonies and nearby natural colonies (in grey). *Breeding success values are shown in the format stated by the author(s) – typically the number of fledged chicks/pair but occasionally 'percentage breeding success'.

Location	Species	Year	Breeding site	Breeding success	Type of habitat	Reference
Northeast Florida, USA	Least	1975	Roofs (unspecified)	77%*	Roof	In Fisk 1978
			Beaches (unspecified)	9%*	Natural beach	
Bay County, northwest Florida, USA	Least	1989	Navy 319	0.13	Roof(mean 0.51)	(Gore & Kinnison, 1991)
			Walmart	0.49	Roof	
			Publix	0.62	Roof	
			Navy 110	0.81	Roof	
			St. Andrews	0.07	Natural (Ground) mainland	
			Highway 98	0.10	Natural (Ground) mainland	
			East Pass	0.25	Natural (Ground) mainland	
			Phipps(mean 0.19)	0.37	Natural (Ground) mainland	
Georgia, USA	Least	1996	Gulfstream roof	0.14	Roof	Krogh & Schweitzer, 1999
			Dixie Crystals roof	0.04	Roof	
			Glynn County Mall roof	Not surveyed	Roof	
			Crab Island	0	Man-made island (dredged material)	
			Andrews Island	0	Man-made island (dredged material)	
			Mainside Spoil	0	Man-made island (dredged material)	
			Ossabaw Island	0	Natural island	
			Sea Island	0	Natural island	
		1997	Gulfstream roof	0.08	Roof	
			Dixie Crystals roof	0.04	Roof	
			Glynn County Mall roof	0.26	Roof	
			Crab Island	0	Man-made island (dredged material)	
			Andrews Island	0.12	Man-made island (dredged material)	
			Mainside Spoil	0.05	Man-made island (dredged material)	
			Ossabaw Island	0	Natural island	
			Sea Island	0	Natural island	
St.Lawrence River, New York, USA	Common	1984	Roofs (unspecified)	77%*	Roof	Karwowski *et al.*, 1995
			Navigation aid N-58	1.69	Man-made structure	
		1986	Navigation aid N-156	2.00	Man-made structure	
		1984	Eagle Wing Islands	0.00	Natural island	
			Gull Island	0.04	Natural island	
		1986	Eagle Wing Islands	0.00	Natural island	
			Gull Island	0.11	Natural island	

Table 2.3 (continued) Breeding success of common and least terns at man-made colonies and nearby natural colonies (in grey).

Location	Species	Year	Breeding site	Breeding success	Type of habitat	Reference
VBA Flower Auction complex, Aalsmeer, Netherlands	Common	1994	VBA Flower Auction complex	0.83	Roof	(Groen *et al.*, 1995)
			polder 'IJdoorn' , Lake IJsselmeer	Not reported	Natural mainland	
Tampere, Finland	Common	1971	Factory roof	2.8	Roof	(Hakala & Jokinen, 1971)
			Finnish archipelago (overall)	1.4	All natural sites studied	
Lower Great Lakes, Canada/USA	Common	1972	Port Colborne Breakwater	0.95	Industrial site	Reviewed by (Courtney & Blokpoel, 1983)
		1976	Port Colborne Breakwater	0.77	Industrial site	
		1973	Eastern Headland	1.56	Industrial site	
		1977	Eastern Headland	1.71	Industrial site	
		1972	Port Colborne Breakwater and Canada Furnace	0.93	Industrial site	
		1974	Port Colborne Breakwater and Canada Furnace	1.56	Industrial site	
		1972	Hamilton Harbour (Neare and Farr Islands)	0.13	Natural island	
		1972	Mugg's Island	0.19	Natural island	
		1973	Mugg's Island	0.34	Natural island	
		1975	Gull Island	0.49	Natural island	
		1976	Gull Island	0.55	Natural island	
		1976	Eagle Wing Island	0.92	Natural island	
Minnesota, USA	Common	1983	Port Terminal (Duluth Harbour)	0.13	Industrial site	McKearnan and Cuthbert, 1989
		1984	Port Terminal (Duluth Harbour)	0.12	Industrial site	
		1983	Sky Harbour (Duluth Harbour)	0.08	Alongside the harbour airport runway	
		1984	Sky Harbour (Duluth Harbour)	0.22	Alongside the harbour airport runway	
		1984	Hennepin Island, Mille Lacs Lake	0.06	Natural Island	
		1984	Spirit Island, Mille Lacs Lake	0.04	Natural Island	
		1984	Gull Island, Leech Lake	0.43	Natural Island	
		1984	Pine and Curry Island, Lake of the Woods	0.17	Natural Island	

2.6 Management considerations for urban and industrial colonies

Some regional populations of common and least terns are now so dependent on man-made nesting sites that the loss of these sites may lead to population decline unless further alternatives are made available. An important consideration for any tern conservation efforts will be whether to focus on the maintenance of man-made sites to enable continued use, or on the restoration of traditional natural sites to increase available nesting habitat. Whilst terns can habituate to living in urban environments, it is unclear how new developments and changes in use may affect them. Urban and industrial environments are likely to be subject to ongoing development, meaning that nesting conditions may be unstable in the long term. Indeed, in the southeastern United States, energy efficiency regulations now require that newly developed materials which give a smooth surface replace gravel for rooftop surfaces (DeVries & Forms, 2004). The benefits of reduced levels of both predation and interspecific competition for nesting space (particularly by gulls) that are provided by some man-made sites may change over time, if predators become aware of such colonies or competing species are forced to find alternative breeding sites. Some man-made sites, particularly rooftop sites and secure sites such as military bases or industrial complexes may have relatively low levels of disturbance compared to natural sites which are often open to the public and are often disturbed by walkers, tourists and water traffic. Where sites are favoured for their low levels of disturbance, the potential impact of any planned changes in use should be considered.

Management choices should be based on a range of colony-specific factors including site location (mainland or island, on the ground or elevated), the types and levels of predation, substrate type, risk of flooding, and the type and frequency of disturbance. A case study of the management of two man-made sites used by common terns in the Canadian Great Lakes (where the population has declined since the early 1970's) highlighted the importance of considering individual colonies when designing management plans (Courtney & Blokpoel, 1983; Morris *et al.*, 1992). The Port Colborne Breakwater colony (Lake Erie) and the Eastern Headland colony (Lake Ontario), despite their many similarities (close proximity to urban areas, similar colony size - both exceed 1000 pairs, both sites have nesting ring billed gulls), responded very differently to similar management programmes, with tern numbers increasing at Port Colborne during the management period but declining significantly at the Eastern Headland. The Eastern Headland, as a mainland colony near Toronto, is thought to have suffered from increased human disturbance, poorer nesting substrate (sandy ground allows vegetation growth) and accessibility for mammalian predators. The Port Colborne site is a breakwater and therefore naturally more isolated, has infrequent human visitation and has little scope for vegetation overgrowth (Morris *et al.*, 1992). Monitoring of both breeding numbers and productivity, along with recording the apparent causes of any losses during the breeding season will benefit management decisions.

2.7 Conclusions

The use of man-made structures as nesting sites is widespread in common and least terns and many of the largest colonies of these species currently exist in urban or industrial environments. Whereas the shift of some gull species to urban sites seems to have been driven by food availability, the shift by terns has been driven by loss of suitable natural nesting habitat in predator-free locations. Despite the potential problems of urban nesting, birds nesting at man-made sites fledge as many, or more chicks than those nesting at remaining traditional sites, further highlighting the extent of habitat degradation and lack of good quality natural habitat. Other than instances where terns have actively been prevented from breeding, there was little evidence of increased disturbance at man-made sites. The ability of terns to find and succeed in these unnatural breeding habitats is a testament to the transient, adaptive nature of the terns. Relocation of nesting sites in response to changing conditions has allowed populations to persist and recover from the heaviest of persecutions, however as natural habitat becomes increasingly limited, the role of man-made sites will become even more critical for these species.

3 Common terns in the Firth of Forth: Population trends and distribution patterns

This chapter reviews the history of the common tern, *Sterna hirundo*, in the Firth of Forth, looking at fluctuations in population size and breeding distribution, with a particular focus on data spanning more than four decades from 1969 to 2010. It considers factors that may have contributed to changes in population size, describes the major colonies that have existed during this period and the factors that may have led to the colonisation of the current stronghold at the Imperial Dock Lock Special Protection Area in Leith Docks.

3.1 Introduction

The population of common terns breeding in the UK and Ireland has been broadly stable over the last few decades but localised impacts at the colony level have resulted in regional variation in population trends (Ratcliffe, 2004). When conditions are favourable, terns generally show fidelity to their breeding sites, returning year after year if reproduction is successful, but if conditions become unfavourable then sites may be abandoned (Ratcliffe, 2004). Within regions, tern populations can be extremely transient, switching between sites in response to predation, disturbance or due to changes in nesting habitat. In the west of Scotland, invasion by the alien American mink *Mustela vison* has had devastating impacts on tern colonies, causing complete breeding failures and subsequent abandonment of many breeding sites (Craik 1995). The breeding distribution of terns is also largely dependent on prey availability. In a study of breeding seabirds on the Farne Islands, Pearson (1968) found that terns (common, Arctic *S.paradisaea* and Sandwich *S.sandvicensis*) were performing close to the limits of their physical ability to collect food, with little leeway in their energy budgets. Compared to larger seabird species, terns spent more time foraging to rear a single chick and both parents would often be away from the nest foraging at the same time (Pearson, 1968). The high energetic demands of breeding, coupled with the small body size and low energy reserves means that terns have relatively small foraging ranges and rely on an abundance of prey close to the breeding site; this makes them particularly vulnerable to food shortage (Frank, 1992; Frank & Becker, 1992; Furness & Tasker, 2000). In the Northern Isles of Orkney and Shetland, population trends and reproductive success of Arctic terns is highly dependent on the availability of sandeel *Ammodytes marinus* (Monaghan *et al.*, 1992; Monaghan *et al.*, 1989; Pennington *et al.*, 2004). Low recruitment into the Shetland sandeel stock in the mid-1980s through to 1990 caused the sandeel stock biomass to fall, resulting in reduced productivity and in some cases, complete breeding failure, for Arctic terns across Shetland. In contrast, Arctic terns breeding in Orkney during this period were able to provide sufficient sandeel to their young and there were no reported breeding failures (Monaghan *et al.*, 1992). In response to failures in Shetland, a high proportion of the Arctic terns abandoned breeding there, only to return in large numbers in 1991 when sandeel recruitment in Shetland suddenly improved due to larval movement from Orkney (Brindley *et al.*, 1999).

The Firth of Forth, an industrialised estuary in the east of Scotland, is an important area for breeding and overwintering seabirds including breeding common terns. The Firth of Forth Site of Special Scientific Interest (SSSI) encompasses a large proportion of the foreshore and a Forth Islands Special Protection Area was designated for islands supporting populations of European importance of common tern, Arctic tern, roseate tern (*S.dougallii*) and Sandwich tern, in addition to populations of other migrant species. Historically, the Isle of May was the most important breeding site in the region for the common tern, with a reported 3400 pairs in 1936 (Southern, 1938). During the 1970s, Inchmickery (an RSPB Island Reserve) became a regional stronghold for the species and the island was designated a SSSI in 1985 for supporting regionally important breeding colonies of common and Arctic terns as well as nationally important colonies of roseate and Sandwich terns. Despite this designation, the number of terns breeding on Inchmickery declined drastically, reportedly as a result of increasing gull populations on the island. Herring gulls (*Larus argentatus*) and lesser black-backed gulls (*Larus fuscus*) were controlled on the island between 1972 and 1989 but with limited success and habitat management programmes in the early 1970s and 1990s failed to increase breeding tern numbers (Corbet, 1997). The greatest numbers of common tern in the region are now found on a man-made site within Leith docks. Here, terns nest on the Imperial Dock Lock, a former lock wall at the entrance to the Imperial Dock, which was classified as an SPA for the common tern in 2004.

Here, the changes in the numbers and distribution of common terns breeding in the Firth of Forth over the past four decades are described and the factors which may be related to such changes are discussed. The relationship between the number of gulls and terns breeding on the Isle of May and Inchmickery is examined. Observations made at the Leith colony in 2009 and 2010 indicated that the diet of terns breeding in the area consists largely of clupeids, of which, most could be identified as sprat *Sprattus sprattus* (see Chapter 4). The impact of prey availability on breeding numbers of terns is investigated, using annual sprat fishery landings as a proxy for the Firth of Forth sprat stock status. Firstly we test the hypothesis that tern numbers vary much more at individual colonies than across the region as a whole, so that individual colony sizes are less suitable indicators of seabird-fish stock relationships than the sum of all colonies within a region. Then we test the hypothesis that breeding numbers of common terns in the Firth of Forth would have decreased when the sprat stock collapsed after 1980, but would recover after sprats increased during the unfished period in recent years.

3.2 Methods

3.2.1 Numbers and distribution

Common tern records pre-1969

Early breeding records of common tern in the Firth of Forth were obtained from a literature search, primarily Rintoul and Baxter's '*A Vertebrate Fauna of the Forth'* (1935) and 'The birds of Scotland: their history, distribution, and migration' (1953) and Eggeling's '*The Isle of May: a Scottish Nature Reserve*' (1960). Whilst providing a useful baseline, such early counts tended to be performed non-systematically and the methods are often unclear so are simply included in the results for background information.

Common tern records 1969-2010

Seabird surveys have been performed annually in the Firth of Forth since 1969, providing an unusually large dataset on a regional breeding population of common terns. Data were obtained from the Forth Seabird Group database and the Joint Nature Conservation Committee's (JNCC) Seabird Monitoring Programme database for twelve sites in the Firth of Forth, listed from west to east: Grangemouth, Rosyth Dockyard, Port Edgar, Forth Rail Bridge (the nest site is a natural island under the bridge), Inchmickery, Granton Harbour, Leith Docks (Imperial Dock Lock SPA), Long Craig Island, Aberlady Bay, Fidra, St Baldred's Boat and the Isle of May (see Figure 3.1 for locations). There were several years with missing data for some sites, but in most cases it is likely that the site was not counted because breeding terns were absent or numbers were negligible. The standard count unit is apparently occupied nests (AON), which equates closely to breeding pairs (Walsh et al., 1995).

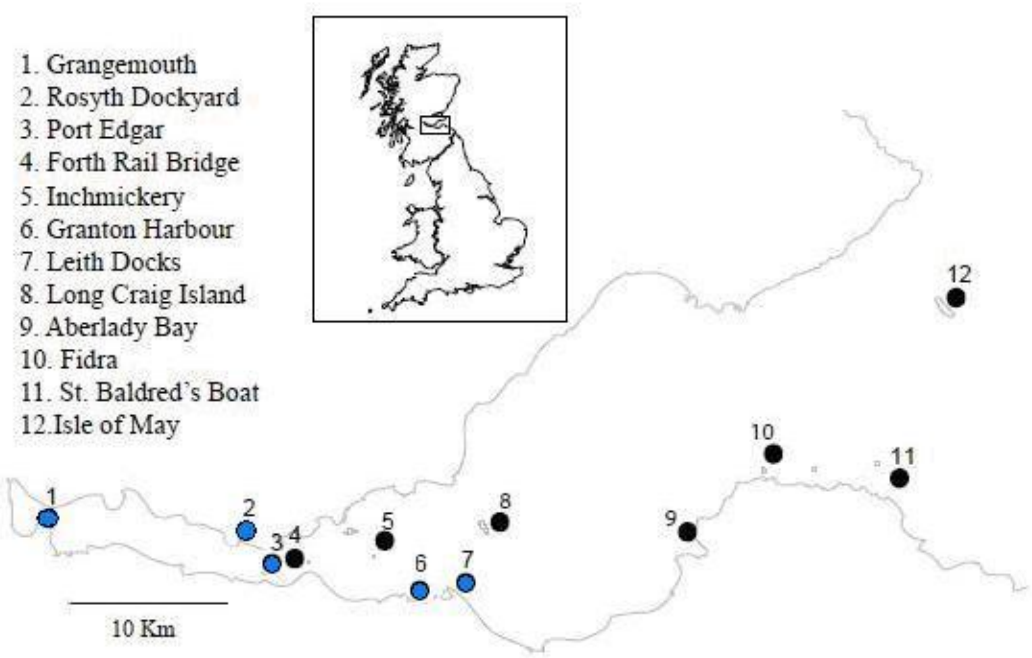

Figure 3.1 Map of the Firth of Forth showing the location of 12 common tern colonies, numbered 1-12 from west to east. Blue circles indicate colonies at man-made sites.

3.2.2 Productivity

In order to understand the conservation status of a population, a measure of productivity, as well as population size, is important. Unfortunately few productivity data are available for the area; the seabird counts in the Firth of Forth are labour intensive, requiring visits to many sites over a short time period, all constrained by weather suitability. Such counts are performed early in the season and it is normally not possible to also record productivity. Estimates were available for Leith Docks for 1992 and 1996 on the SMP database. In response to this lack of productivity data, minimum estimates of breeding success for common terns breeding in Leith were obtained during field work in 2009 and 2010. When most chicks were close to fledging, a count of all visible chicks was performed from the dockside using a telescope. Minimum productivity was calculated by dividing the number of chicks by the number of breeding pairs recorded during the nest count earlier in the season. Predation attempts at the colony during incubation and chick rearing were recorded, as were any other notable causes of reduced breeding success (see Chapter 6 for details).

3.2.3 Relationship with gull numbers

Declines in the number of terns breeding on the Isle of May and Inchmickery have been largely attributed to increasing numbers of herring gull and lesser black-backed gull on these islands (Corbet, 1997; Wanless, 1988). Gull numbers were taken from the Forth Seabird Group records and the SMP database. The relationship between the number of breeding gulls and common terns was examined for the Isle of May from 1969-2008 and for Inchmickery from 1960-2008.

In some cases, 'mixed' counts consisting of both species were provided so the total number of gulls (herring gull plus lesser black-backed gull) was chosen as the unit of analysis. Where numbers were recorded as a range (for example 100-150 pairs), the lower value was taken for analysis. In years where counts were missing, the number of gulls was estimated by imputation by taking the average of counts from the surrounding available years. Raw gull data is included in the Appendix.

For the Isle of May, lesser black-backed gull numbers were estimated for 1970, 1971 and 1973 and herring gulls were estimated for 2006. For Inchmickery, lesser black-backed gull numbers were estimated for 1959, 1970, 1973-1975, 1979-86, 1988-93 and 1998 and herring gulls were estimated for 1959, 1979-85, 1989-91 and 1998. Since 2008, the Isle of May gull counts have been performed biennially, so no data were available for 2009.

Gull populations on both islands have been subject to control since the early 1970s. On the Isle of May this involved 'intense culling' from 1972-76, 'culling' from 1977-87 and subsequent 'variable levels of control' from 1989 onwards. Data available for culls on Inchmickery are shown in Table 3.1.

Table 3.1 Estimated gull culls in Inchmickery, 1965-1975 and 1990-1993. Data compiled by SNH (* = no data)

Year	Total pairs of gulls	Confirmed cull	Probable total cull	Total tern pairs (all species)
1965	8	0	0	1000+
1966	45	0	0	1000+
1967	15+	0	0	1000+
1968	30	0	0	1000+
1969	20+	0	0	~300
1970	130	0	0	155
1971	120	0	0	11
1972	206	0	135	820
1973	90	0	*	1200
1974	110	102	*	*
1975	90	105	100	1450
1990	150	*	*	515
1991	135	*	43	475
1992	108	*	40	122
1993	194	*	0	10

3.2.4 Relationship with sprat abundance

3.2.4.1 Firth of Forth fishery background

Historically, the Firth of Forth has supported various important fisheries; by 1900, pelagic fisheries, mostly for sprat and herring *Clupea harengus*, constituted around 58% of all commercial landings in the Forth (Howard *et al*., 1987). This fishery was steady until the 1950s when herring stocks began to decline, but sprat continued to be abundant. The herring fishery was subject to seasonal closures in 1971, total allowable catch (TAC) regulations in 1974 and a total ban from February 1977 to October 1981 in the southern North Sea and to 1983 in the northern North Sea (Greenstreet *et al.*, 1999). A major winter sprat fishery persisted in the Firth of Forth and Moray Firth throughout the 1960s and 1970s, accounting for almost all small pelagic fishing by UK vessels landing in Scotland. The sprat fishery of the Firth of Forth harvested 88,000 tonnes between 1966 and 1980 (Fernandez *et al*., 2005), a large harvest from a relatively small sea area (93km long with a 4655km^2 drainage basin; Elliott and Neill, 2007). After 1980, catches fell to extremely low levels as the stock collapsed, and the fishery was progressively abandoned by local fishermen in the early 1980s due to the lack of a profitable catch rate. It ceased completely in 1985. It has never reopened, although it is known that sprat abundance in the Firth of

Forth has subsequently recovered (Fernandez *et al*., 2005). There have been numerous attempts since the late 1990s by local fishermen to argue that sprat fishing in the Firth of Forth should be allowed to resume, but, to date these have been rejected by the Scottish Executive (http://www.theyworkforyou.com/sp/?id=2005-10-27.20112.2), and so the Firth of Forth sprat stock has been unfished for the last 27 years.

3.2.4.2 Use of tern breeding numbers as indicators

To test the hypothesis that tern numbers at individual colonies (Figure 3.1) will vary more than numbers across the Firth of Forth region as a whole, the mean, variance and coefficient of variation (CV) were calculated for numbers of breeding terns at each of the twelve colonies and for the whole region, for the period 1969-2010. We predicted that the CV would be lower for the whole Firth of Forth than for individual colonies, thus providing a better indicator of seabird-fish stock relationships. We then correlated breeding numbers at the four largest colonies (Leith Docks, Inchmickery, Aberlady Bay and the Isle of May) across years to test whether numbers at different colonies followed similar patterns responding to changes in food abundance (i.e., were positively correlated), showed independent dynamics (uncorrelated), or showed inverse relationships (negatively correlated) indicating local redistribution within the region in response to changes in colony habitat quality of a total regional population that was likely to be food limited. Only years for which birds bred at a given site were used in the analysis.

3.2.4.3 Relationship between common tern breeding numbers and the status of the sprat fishery

Annual landing data (tonnes of sprat) dating back to 1960 were obtained from the Marine Scotland database for the Firth of Forth (ICES rectangles 41E6 and 41E7). Data were for all vessels landing in Scotland, and for all types of gear. These data were assessed in relation to trends in the number of breeding common terns. As the exact location of catches within the Firth of Forth is unknown, and as it is likely that a complicated relationship exists between fishery catch and local sprat abundance, these data were analysed at the regional tern population level (i.e. Firth of Forth) rather than colony level. Sprat stock biomass is difficult to measure, and ICES recently concluded that even at the scale of the North Sea, there were no reliable data on annual variations in sprat stock biomass (ICES 2009). There are no analytical data on sprat stock biomass in the Firth of Forth (ICES 2009) and annual sprat catch data cannot be directly used as a proxy for sprat stock biomass, as catch varies in part as a function of effort. However, we can categorize years into periods of differing sprat stock status. Numbers of breeding common terns in the Firth of Forth were compared across four periods between 1969 and 2010; these periods were based on the perceived state of the sprat stock during this time, which was inferred from landings data and general information on the activity of the fishery. When the fishery started, the sprat abundance was high, leading to large catches during the period 1969-1980, which was labelled "harvest period". Between 1981 and 1990, landings were greatly reduced and the fishery was eventually abandoned by local fishers due to the collapse of the sprat stock. This period was thus labelled "collapse". The ten-year period 1991-2000 was labelled "initial no-take period"; it is likely that the reduced sprat stock was in a state of recovery during this time, but there are no data to confirm this. However, after 2001, the stock had clearly recovered and fishers were lobbying to reopen the fishery, so we define this fourth period as "recent" and infer that sprat stock biomass was relatively high during this period. In summary, these periods, based on the inferred status of the sprat stock of the Firth of Forth, were defined as follows. 1) 1969-1980: "harvest period", 2) 1981-1990 "collapse"; 3) 1991-2000 "initial no-take period" and 4) 2001-2010 "recent". The response variable (numbers of breeding common terns) was overdispersed, so a generalised linear model with a quasipoisson distribution was applied to the data.

3.3 Results

3.3.1 Numbers and distribution

Common tern numbers pre-1969

Historically, the Isle of May was the most important breeding site in the region for the common tern. A few pairs were recorded as early as 1825 and they continued to breed there in fluctuating numbers but by the middle of the 19th century they ceased to do so (Baxter & Rintoul, 1953). They returned in 1921 when about 50 pairs bred (Baxter *et al.*, 1953). Three pairs bred in 1922 and none in 1923 but in 1925 there were 'hundreds of nests'; this was the start of a large breeding colony (Baxter *et al.*, 1953). In 1936, 3400 pairs were reported (Southern, 1938), although this appears to be an unsound estimate as it was not cited by Baxter and Rintoul. For example, an entry in the Bird Observatory Log on 12 June 1946 describes a count of nests, of which only around half contained eggs; this calls into question the reliability of such records and indicates a likely overestimate of nests.

Observations ceased during the Second World War when the Island was under Navy occupation until 1946. Only 300 pairs were noted on the Isle of May in 1949. Some reports for the Isle of May seem unusually large and, due to a lack of information regarding the methods by which counts were performed, it seems plausible that in some counts, true breeding numbers were seriously overestimated. The common tern was reportedly a faithful breeder on Inchmickery, breeding there 'very numerously' as long ago as 1845, although numbers are not available (Rintoul and Baxter 1953).

Common tern numbers and distribution 1969-2010

The number of common terns breeding in the Firth of Forth fluctuated considerably between 1969 and 2010 (Table 3.2). On average 823 pairs (± 256 SD) bred in the Firth of Forth each year from 1969-2010. The population increased from 587 in 1969 to 1100 in 1972. This was followed by a general decline during the late 1970s and 1980s and a subsequent recovery during the 1990s. Numbers of breeding pairs declined to a low of 364 pairs in 1981 and peaked in 2007 with 1254 pairs. The sites that have supported the largest colonies during this period are the Isle of May, Aberlady Bay, Inchmickery and the Imperial Dock Lock SPA in Leith Docks (see

Table 3.3.

In addition to fluctuations in population size between 1969 and 2010, the distribution of common terns in the Firth of Forth also varied over this period, with several major changes in nest site use. From 1969-71, Aberlady Bay Nature Reserve supported the greatest number of pairs. By 1972, Aberlady Bay and Inchmickery supported equal numbers (500 pairs) and from 1973 to 1985, Inchmickery supported more pairs than any other site. Despite holding the greatest number of pairs over this period, there was a general decline in numbers from 1973 onward and common terns last bred on Inchmickery in 1998 (when only 9 nests were recorded). Records from Aberlady Bay Nature Reserve attribute breeding failure of common and arctic (recorded as "comic") and little terns during 1978-1995 to a combination of nest site flooding, significant predation by fox and possible predation by hedgehog (John Harrison, *pers. comm.*). From 1986-2010, the Imperial Dock Lock SPA in Leith docks has been the most used nest site by common terns in the region, holding the majority of the local population. From initial colonisation by only 50 pairs in

1971, colony has grown steadily, reaching 818 pairs in 2010. This distributional shift is presented in figure 3-2. In addition to major distribution shifts, several sites were abandoned and later re-colonised during this period; for example Fidra held a colony from 1969-1973, 1981-1986 and then was used again in 1994 (see Table 3.2).

Since 1969, the common tern has occupied a variety of habitats in the region, including the natural Forth islands (Inchmickery, Long Craig Island, Fidra, St. Baldred’s Boat and the Isle of May, Forth Rail Bridge (the nest site is an island beneath the bridge)), a mainland nature reserve (Aberlady Bay Nature Reserve) and several man-made sites (Leith Docks, Port Edgar, Grangemouth, Granton Harbour, Rosyth Dockyard). The distribution of breeding terns across these habitat types is summarised in Table 3.4.

Table 3.2 Numbers of common tern breeding pairs recorded at 12 sites in the Firth of Forth during the period 1969-2010. GRM = Grangemouth, ROS = Rosyth Dockyard, PED = Port Edgar, FRB = Forth Rail Bridge, INCH = Inchmickery, GHB = Granton Harbour, LEI = Leith Docks (Imperial Dock Lock SPA), LCI = Long Craig Island, ABE = Aberlady Bay, FID = Fidra, SBB = St. Baldred's Boat, MAY = Isle of May.
* No counts made.

	GRM	ROS	PED	FRB	INCH	GHB	LEI	LCI	ABE	FID	SBB	MAY	Total
1969	*	*	*	*	100	0	*	*	220	175	92	0	587
1970	*	*	*	*	150	0	*	*	260	250	*	0	660
1971	*	*	*	*	0	0	50	*	450	310	20	0	830
1972	*	*	*	*	500	0	*	*	500	100	*	0	1100
1973	*	*	*	*	777	0	*	*	175	20	20	0	992
1974	*	*	*	*	750	0	60	27	72	0	55	0	964
1975	*	*	*	*	727	0	75	30	217	0	*	0	1049
1976	*	*	*	*	635	0	*	30	253	0	*	0	918
1977	25	*	*	*	548	0	35	*	318	0	*	0	926
1978	*	*	*	*	429	0	69	15	221	0	*	0	734
1979	*	*	*	*	500	0	55	*	216	0	*	1	772
1980	56	*	*	*	533	0	65	60	*	0	*	1	715
1981	*	*	*	*	175	0	75	60	*	50	*	4	364
1982	55	*	*	*	415	0	155	45	*	22	*	14	706
1983	*	*	*	*	357	0	170	40	*	30	*	29	626
1984	22	*	*	*	216	0	120	40	11	30	*	36	475
1985	30	*	*	*	247	0	200	60	1	20	45	80	683
1986	*	*	*	*	202	0	315	*	*	26	75	22	640
1987	*	*	*	*	210	0	382	60	0	0	55	68	775
1988	70	*	*	*	146	0	183	45	0	*	*	50	494
1989	62	*	*	*	182	0	334	*	23	*	*	60	661
1990	*	20	*	*	172	0	*	70	*	0	*	190	452
1991	4	13	*	*	126	0	*	145	*	0	*	195	483
1992	73	20	*	*	98	0	185	110	0	0	*	94	580
1993	139	32	20	0	91	*	694	80	0	0	*	143	1199
1994	95	*	10	5	92	*	499	48	0	13	*	148	910
1995	104	*	12	0	11	15	416	76	0	0	*	181	815
1996	106	1	1	4	15	18	488	80	1	0	*	248	962
1997	125	51	2	5	0	4	520	69	0	*	*	338	1114
1998	102	*	0	10	9	0	554	63	0	*	*	127	865
1999	109	40	*	10	0	*	518	118	0	*	*	415	1210
2000	114	60	*	*	0	0	690	75	0	*	0	303	1242
2001	86	37	*	7	0	*	507	14	0	*	*	132	783
2002	106	*	*	6	0	*	*	55	*	*	*	2	169
2003	139	75	1	4	0	*	795	126	*	*	*	60	1200
2004	106	0	0	5	0	*	639	171	*	*	*	62	983
2005	*	40	*	10	0	*	764	120	*	*	*	65	999
2006	*	*	*	*	0	*	900	92	*	*	*	99	1091
2007	*	*	10	0	0	*	989	172	*	*	*	83	1254
2008	*	*	*	*	0	*	789	90	*	0	4	101	984
2009	*	*	*	*	0	*	732	*	*	0	*	40	772
2010	*	*	*	*	0	*	818	*	*	*	*	*	818
Mean	82	32	6	5	200	1	407	74	113	37	41	83	823
StDv	39	23	7	4	240	4	296	42	152	79	32	101	256

Table 3.3 Summary of the number of breeding pairs of common terns at colonies in the Firth of Forth during the period 1969-2010.

Colony	Mean no. pairs	Standard deviation	Minimum no. pairs	Maximum no. pairs	Years surveyed	Years present
Grangemouth	82.3	39.1	4	139	23	23
Rosyth Dockyard	32.4	22.9	1	75	14	13
Port Edgar	6.2	7.1	1	20	11	9
Forth Rail Bridge	5.1	3.6	4	10	15	12
Inchmickery	200.3	240.1	9	777	44	30
Granton Harbour	1.3	4.3	1	18	31	9
Leith Docks	407.1	295.9	35	989	36	36
Long Craig Island	73.7	41.6	14	172	33	33
Aberlady Bay	113	152.4	1	500	28	17
Fidra	37.4	78.6	13	310	30	14
St. Baldred's Boat	40.7	31.8	4	92	11	10
Isle of May	82.7	101.4	1	415	43	33

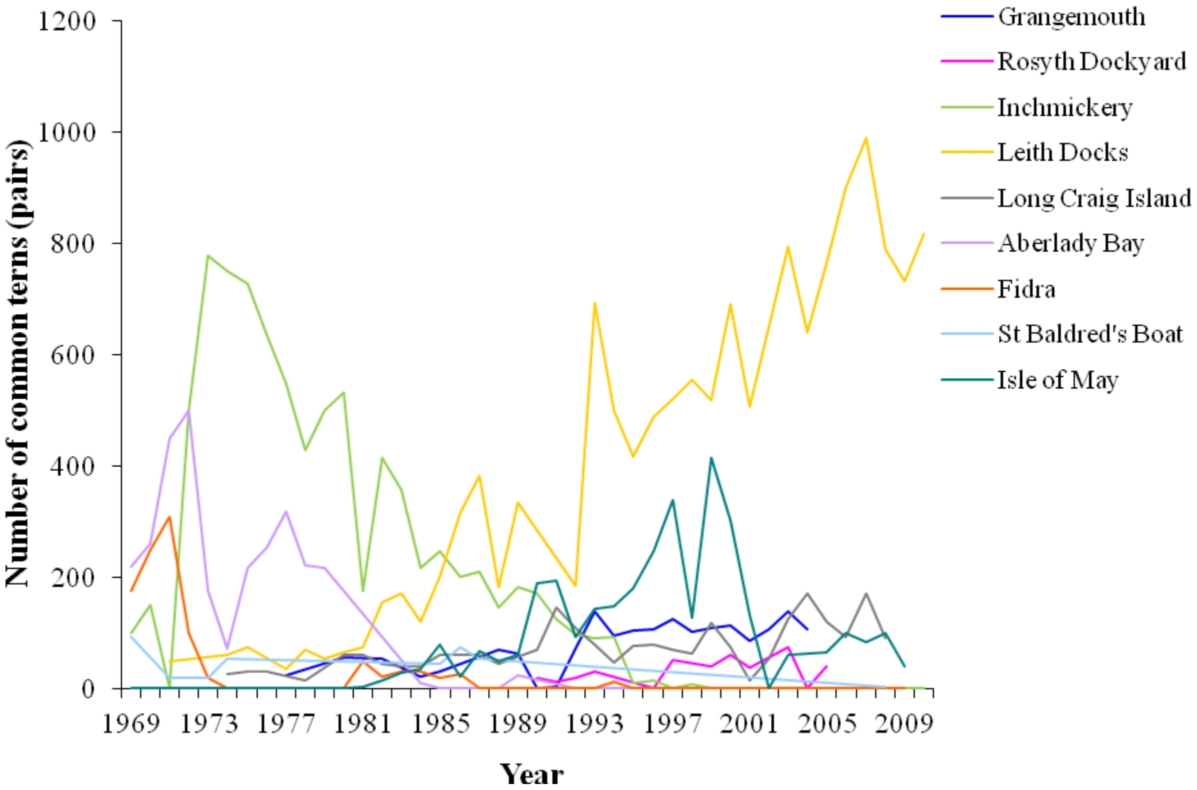

Figure 3.2 Numbers of breeding pairs of common terns each year from 1969-2010 at the nine largest colonies in the Firth of Forth [three further colonies (Granton, Port Edgar and Forth Rail Bridge) that held on average fewer than ten pairs are not shown].

Table 3.4 Distribution of common tern colonies in the Firth of Forth in 1969-2010 across different types of nesting sites.

Type of nest site	Number of colonies	Mean colony size (% total Firth of Forth population)
Forth Islands	6	440 (41)
Natural mainland site	1	113 (10)
Man-made sites	5	529 (49)

3.3.2 Productivity

Productivity data for common terns breeding at the Imperial Dock Lock SPA in Leith Docks were available for only 4 seasons (Table 3.5). The colony experienced complete breeding failure in 1996 but produced more than 0.5 chicks per pair in 1992, 2009 and 2010. In both 2009 and 2010 breeding success was impacted by predation by herring gull and lesser black-backed gull, although overall rates of predation were low (see chapter 8 Predation).

Table 3.5 Productivity summary for common terns nesting at the Imperial Dock Lock SPA in Leith docks (* estimates from SMP database).

Year	Number of nests	Minimum productivity
1992	185	0.54*
1996	488	0.00*
2009	732	0.61
2010	818	0.53

3.3.3 Relationship with gull numbers

The number of gulls and common terns on the Isle of May between 1969 and 2008 are shown in Figure 3.3. Between 1969 and 1972 the island supported very high numbers of gulls, the majority of which were herring gulls. After the introduction of a control programme in 1972, gull numbers declined rapidly from 16950 pairs in 1972 to 3717 pairs in 1976. Since then, gull numbers remained at below 5000 pairs. Between 1969 and 1978 no common terns bred on the island. One pair was recorded in 1979, increasing to 14 pairs by 1982, marking the recolonisation of the Isle of May by common terns. Numbers reached a high of 415 pairs in 1999. The population then crashed to only 2 pairs in 2002 but started to recover during the 2000's.

Figure 3.4 shows the number of gulls and common terns on Inchmickery from 1959 to 2008. Between 1959 and 1969 gulls numbered 35 pairs or fewer. In 1959, 500 pairs of common terns nested and several hundred pairs were recorded during the 1960's. In 1970 gull numbers increased to 134 pairs and in the following year only 1 pair of common terns nested. Tern numbers then increased rapidly, peaking at 780 pairs in 1973, followed by a steady decline, as terns shifted to breeding in Leith Docks. Common terns last bred on Inchmickery in 1998 (only 9 pairs). Following the abandonment of the island by terns, gull management was less intensive and numbers increased greatly throughout the 1990's.

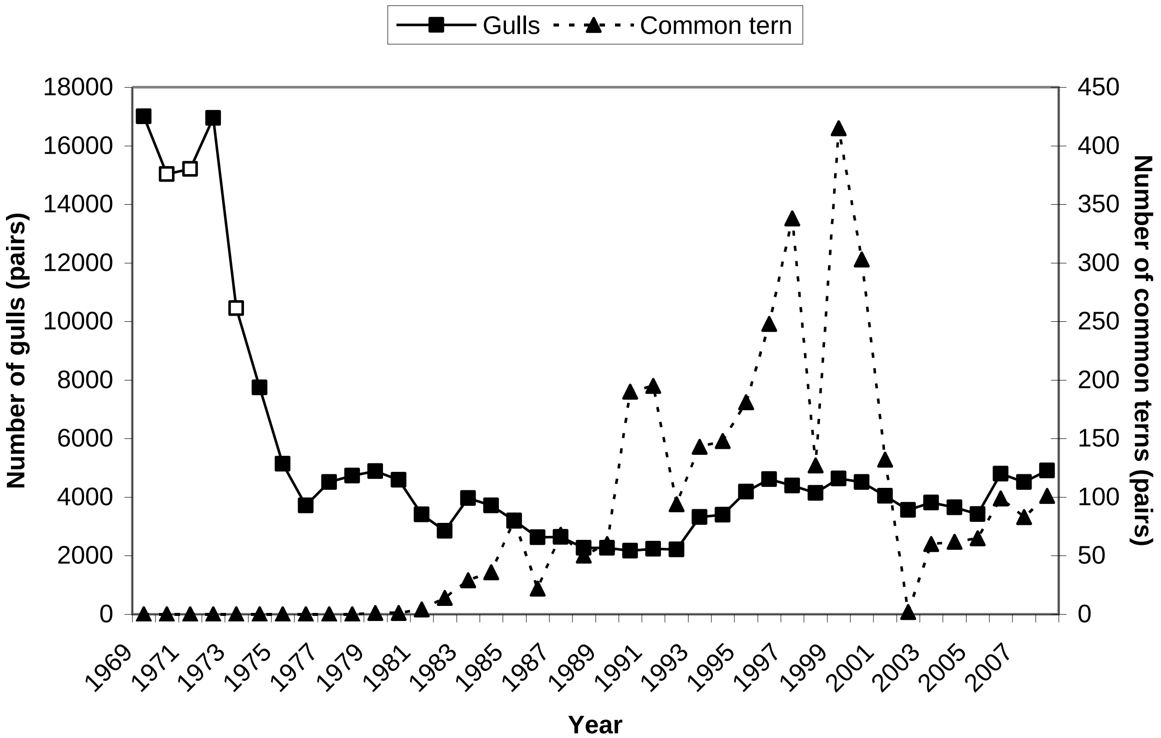

Figure 3.3 Number of gulls (herring gull plus lesser black-backed gull) and common terns on the Isle of May from 1969-2008. Open squares indicate years in which gulls were present but data are missing (for herring gull, lesser black-backed gull, or both species) for which total counts have been estimated.

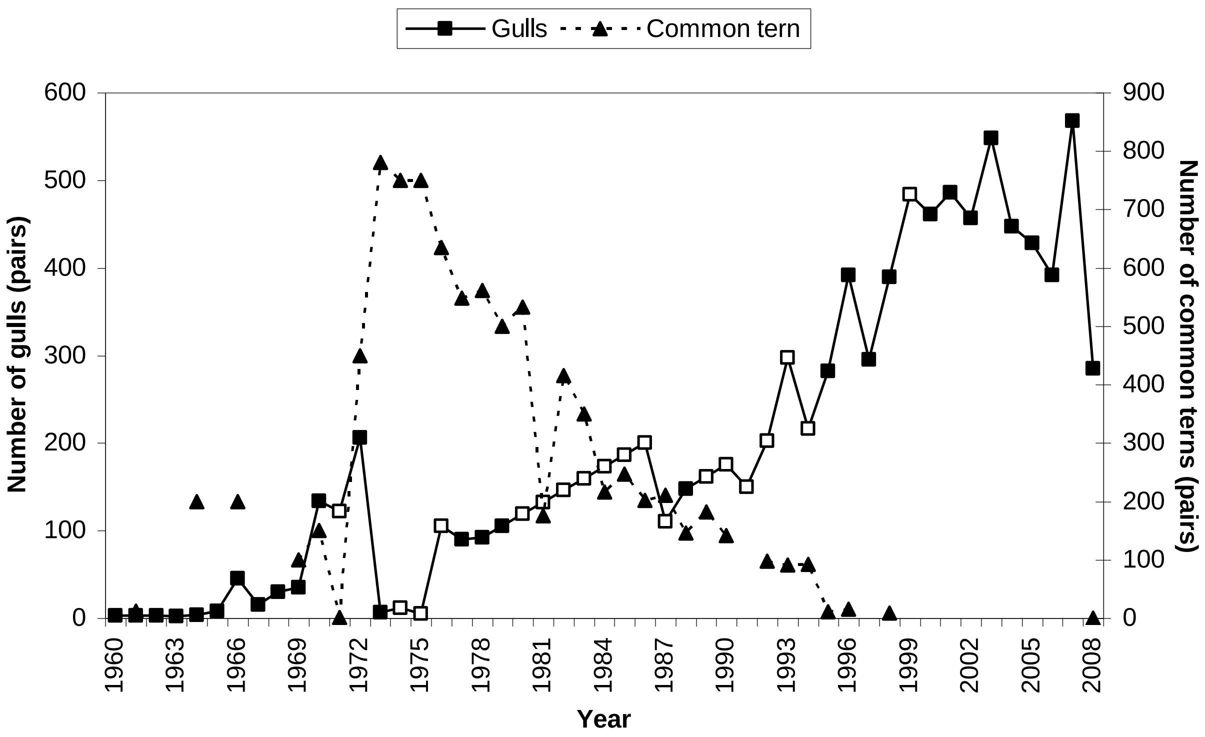

Figure 3.4 Number of gulls (herring gull plus lesser black-backed gull) and common terns on Inchmickery from 1959-2008. Open squares indicate years in which gulls were present but data are missing (for herring gull, lesser black-backed gull, or both species) for which total counts have been estimated.

3.3.4 Use of tern breeding numbers as indicators

There was considerable interannual variation in numbers of breeding pairs at individual colonies, with some colonies being abandoned during the study period and other new colonies being formed. The CV in common tern breeding numbers at the twelve colonies in the Firth of Forth varied from 0.48 at Grangemouth to 3.37 at Granton Harbour (Table 3.6) with half of the colonies having a CV above 1. The CV for the entire Firth of Forth was much lower, at 0.31. Clearly the breeding population of the Firth of Forth has been relatively more stable over the period 1969 to 2010 than have numbers at any single colony within the region.

Breeding numbers at individual colonies showed strong changes across years and it is clear from the data in Figure 3.2 that numbers showed strongly differing trends at certain colonies. Spearman's correlations between numbers at the five largest colonies (Table 3.7) show strong negative correlations between numbers breeding at Leith Docks and Inchmickery, the two largest colonies, and between numbers at Leith Docks and Aberlady Bay, the third largest colony. In contrast, numbers at Inchmickery and Aberlady Bay show a strong positive correlation over the 42 year period. Numbers at Leith Docks and the Isle of May show a positive correlation over this period.

Table 3.6 Mean and Coefficient of Variation of breeding numbers of common terns in the Firth of Forth at individual colonies (listed individually below from west to east, see Figure 3.1), and for the whole area, from 1969-2010.

Colony	**Mean**	**Coefficient of variation**
Grangemouth	82.3	0.48
Rosyth	32.4	0.71
Port Edgar	6.2	1.14
Forth Rail Bridge	5.1	0.71
Inchmickery	200.3	1.20
Granton Harbour	1.3	3.37
Leith Docks	407.1	0.73
Long Craig Island	73.7	0.56
Aberlady Bay	113.0	1.35
Fidra	37.4	2.10
St Baldred's Boat	40.7	0.78
Isle of May	82.7	1.23
Firth of Forth region	822.8	0.31

Table 3.7 Spearman Correlations between numbers of common terns nesting at the four largest colonies in the Firth of Forth from 1969 to 2010. Significant correlations are denoted by an asterisk ($p<0.05$).

Colony	Inchmickery	Aberlady Bay	Isle of May	Fidra
Leith Docks	-0.81*	-0.83*	0.72*	-0.24
Inchmickery		0.59*	-0.62*	0.03
Aberlady Bay			-0.87*	0.42
Isle of May				-0.38*

3.3.5 Relationship between common tern breeding numbers and the status of the sprat fishery

The most recent Firth of Forth sprat fishery was in operation from 1963-1982. Tonnes of sprat landed, along with numbers of common terns, are shown in Figure 3.5. Landings increased sharply in the late 1960s, peaking at 20,314 tonnes in 1970. After 1970, landings decreased and generally did not exceed 6000 tonnes except for a second peak in 1978 when 10300 tonnes of sprat was landed. Across the region as a whole, there was a significant difference between numbers of breeding pairs of common terns present during the "harvest period" (1969-1980), "initial no-take period" (1991-2000) and "recent" (2001-2010) periods compared with the "collapse" period (1981-1990), with lower numbers of breeding pairs of common terns during the "collapse" (Figure 3.6; ANOVA, F=9.6, d.f.=3, p<0.001). During the early presence of the fishery, common tern breeding numbers initially showed an increase from 587 pairs in 1969 to 1110 in 1972. After this, landings declined (apparently due to a sprat stock collapse within the region) and the sprat fishery was closed by 1985. This collapse was followed by a period of reduced common tern numbers throughout the 1980s. Eight years after the closure of the sprat fishery, in 1993, the common tern population increased and has remained at high numbers ever since.

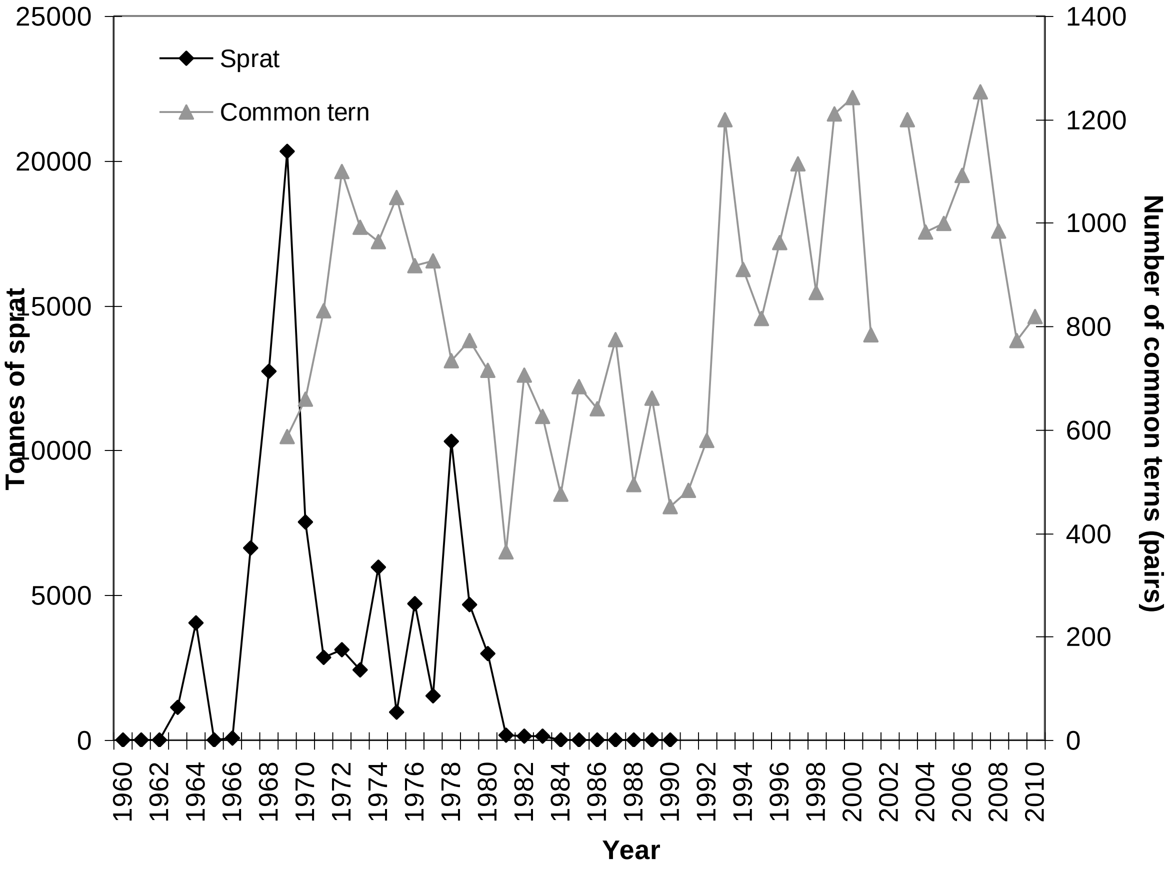

Figure 3.5 Sprat landings from 1960-1990 and pairs of breeding common terns from 1969-2010 in the Firth of Forth. Sprat data are tonnes of sprat landed in ICES rectangles 41E6 and 41E7. The sprat fishery closed in 1982.

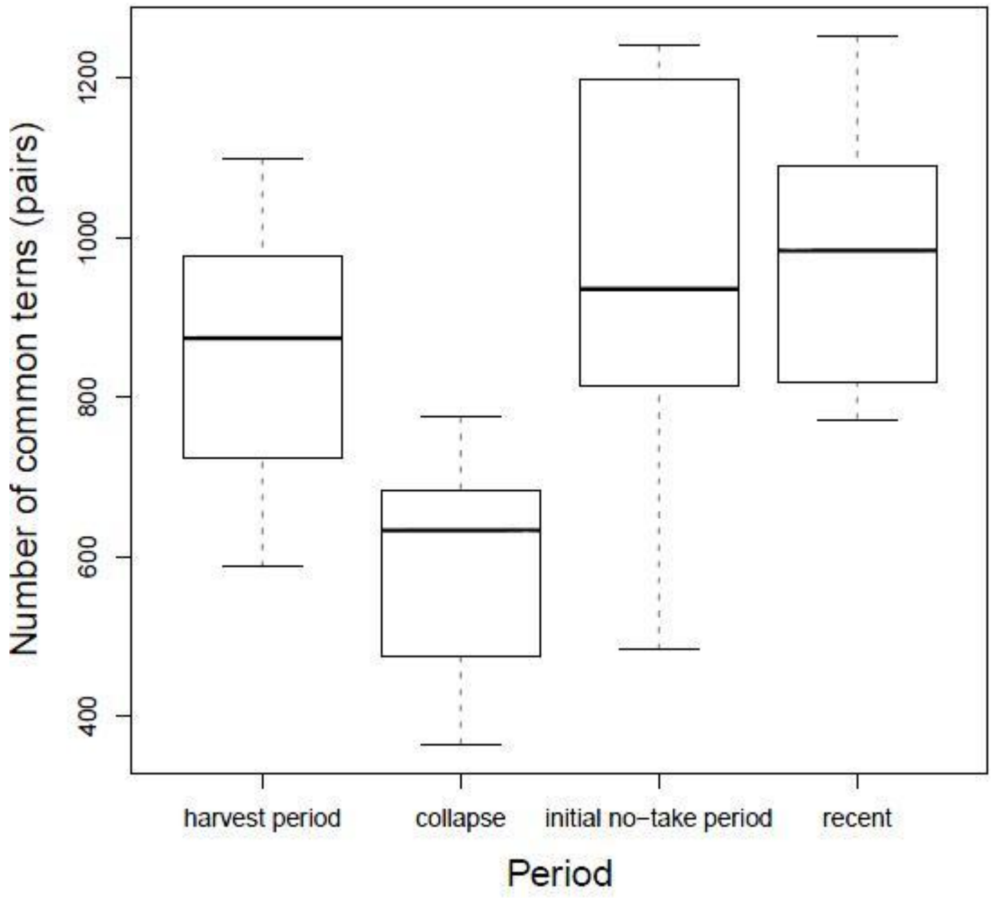

Figure 3.6 Numbers of common terns in the Firth of Forth over four periods 1) 1969-1980: “harvest period”, 2) 1981-1990 “collapse”, 3) 1991-2000 “initial no-take period” and 4) 2001-2010 “recent”. In this boxplot the bold horizontal bars represent the median, the box shows the 1st and 3rd quartiles of the data and the whiskers indicate the smallest and largest values.

3.4 Discussion

3.4.1 Numbers and distribution

Long-term data for common terns breeding at sites in the Firth of Forth show that overall numbers have fluctuated considerably since 1969. During this time, some sites were abandoned and later re-colonised, which is typical of the transient nature of tern colonies. Several major distributional shifts also occurred within this period, involving a significant increase in common terns at Inchmickery and, later, colonisation of the Imperial Dock Lock SPA at Leith Docks. At the beginning of the period, the largest concentration of common terns in the area was at Aberlady Bay, with several reasonably sized colonies existing elsewhere. A seemingly rapid shift towards Inchmickery occurred during the early 1970s, where a large common tern colony established alongside large numbers of roseate and Sandwich terns, making Inchmickery by far the most used site by common terns from the period 1973-1985 and an important island for tern species generally. The establishment of a large colony at Inchmickery was followed by a second major shift during the 1980s to the current regional stronghold at the Imperial Dock Lock SPA in Leith docks. The Leith colony has grown from only 50 pairs in 1971 to 818 pairs in 2010 and the data indicate that the colonisation of Leith docks occurred as a result of relocation from other sites in the Firth of Forth, especially Inchmickery, rather than from a population expansion and associated overspill effect. The colonisation of Leith docks by the common tern not only represents a distributional shift but also a notable shift in the main type of nesting habitat used for breeding, from natural to artificial substrate, a pattern which has been seen in other regions across Europe and North America (see Chapter 2). As the Imperial Dock Lock SPA is largest common tern colony in Scotland, this shift is significant at the national level.

3.4.2 Productivity

The productivity of common terns breeding at the Imperial Dock Lock SPA in 2009 and 2010 was relatively high compared to other colonies across Scotland – with minimum estimates of 0.61 and 0.53 chicks per pair. In most years between 1986 and 2009, the productivity of common terns across all Scottish colonies was less than 0.6 chicks per pair (SMP database). Chapter 6 investigates predation at the colony and discusses ways of improving productivity.

3.4.3 Relationship with gull numbers

Terns are known to be particularly sensitive to impacts of gulls, which predate eggs and chicks as well as displacing terns from nesting habitat (Eggeling, 1974; Forrester *et al*., 2007). Numbers of herring gull and lesser black-backed gull were examined in relation to the number of common terns at two major tern colonies in the Firth of Forth - the Isle of May and Inchmickery. On both islands, large common tern colonies existed when gull numbers were relatively low. Terns started to abandon The Isle of May during the 1950s as gull numbers increased (Eggeling, 1974). Following the introduction of a gull control program in 1972, gull numbers declined and terns began to nest on the island again in 1979. The colony has never regained its status of the 1940s, as the largest common tern colony in the region (Wanless, 1988) and after reaching 415 pairs in 1999, numbers have declined since then. The number of common terns breeding on Inchmickery declined drastically during the 1970s, during which time the terns colonised Leith Docks. The abandonment of Inchmickery may be attributed, in part, to increasing gull numbers on the island seen at this time; indeed, the tern colony was at its highest 1973-1975 following the introduction of gull control in 1972. The potential anti-predator benefits of large colony size on Inchmickery were seemingly insufficient to outweigh the negative impacts of such high gull numbers. However, the relationship between gull numbers and tern site fidelity is probably influenced by other factors, such as quality of nesting habitat and availability of alternative suitable nesting sites. At Inchmickery it seems likely that lack of suitable nesting habitat due to overgrown vegetation may have also been a contributing factor to the abandonment of this site.

3.4.4 Use of tern breeding numbers as indicators

There was a considerably lower CV in numbers of common tern pairs in the whole Firth of Forth compared to numbers at individual colonies (whether large or small), indicating that numbers at individual colonies varied much more than the total population of the region. Based on the strong negative correlations between breeding numbers at the largest colonies, we refute the hypothesis that numbers vary independently among colonies and that numbers at each colony respond similarly across years to changes in abundance of their main food, the Firth of Forth sprat stock. We propose that the strong negative correlations between the largest colonies indicate a redistribution of the Firth of Forth breeding population of common terns from one colony to another, either as a result of large differences in recruitment or as a result of the movement of adults between sites. Numbers fluctuate at individual colonies for a wide variety of reasons, which include local effects of predators, food shortage, human disturbance, exposure to weather extremes, and local environmental change (Becker and Specht, 1991; Craik, 1992, 1997; Becker and Ludwigs, 2004; Forrester *et al*., 2007).

3.4.5 Relationship between common tern breeding numbers and the status of the sprat fishery

Long-term data for common terns breeding at all sites in the Firth of Forth show that overall numbers fluctuated considerably between 1969 and 2010. A comparison of tern breeding numbers across four fishery periods supports the hypothesis that breeding numbers would decrease when the sprat stock collapsed after 1980 but would recover after sprats increased during the recent unfished period. During the initial presence of the sprat fishery, common tern numbers showed an increase, but when the sprat stock collapsed in the 1980s, tern numbers declined. Following the collapse and subsequent fishery closure, the number of common terns in the Firth of Forth remained considerably reduced for a ten-year period. The state of the sprat stock during this post-fishery period is unknown, but it is likely that the sprat population would have required a number of years to recover to unfished levels of abundance (Hutchings, 2000; Worm *et al*., 2009; Hammer *et al*., 2010; Murawski 2010). In 1993, the tern population increased and since then, has been higher than it was during the fishery or during the ten-year period that followed the collapse of the sprat stock. The data clearly show that tern numbers were reduced in the region when sprat abundance was too low to sustain a fishery, and that numbers subsequently recovered to be similar to numbers before the sprat stock collapse. These data indicate that while breeding numbers at individual colonies fluctuated considerably and showed evidence of the fortunes of particular colonies rising and falling over the years, the total population of the region changed in relation to the inferred variations in sprat abundance. Although sprat catch data do not act as a proxy for annual stock biomass, the change from an abundant stock supporting a fishery in 1969-80 ("harvest period") to a collapsed stock in 1981-90 with very low catch represents a large qualitative change in status with consequences for terns. Such major changes in key food fish stocks, with consequent impacts on seabirds, are not uncommon and have been described in the North Sea (sandeels *Ammodytes marinus*; Furness and Tasker, 2000; Frederiksen *et al*., 2004), the Barents Sea (capelin *Mallotus villosus*; Barrett and Krasnov, 1996; Gjøsæter *et al*., 2009) and the Benguela ecosystem in southern Africa (anchovy *Engraulis encrasicolus*; Crawford *et al*., 2007).

3.4.6 Conclusions

In summary, common terns in the Firth of Forth have occupied several breeding sites during the period 1969-2010, with the two largest colonies at Inchmickery and the Imperial Dock Lock SPA. The abandonment of Inchmickery and before that, the Isle of May, can be attributed largely to increasing gull numbers on the island. The Imperial Dock Lock SPA is now the major breeding site for common terns in the area and it supports Scotland's largest common tern colony. The high concentration of common terns at Leith Docks in recent years is an interesting move by the birds to nest in an industrial site where both predation risk and human disturbance exist, but currently at low levels (see Chapters 6 and 7). Changes in common tern distribution in the Firth of Forth since 1969 indicate that the population has the ability to colonise a variety of sites in response to environmental conditions. Predatory gulls breeding on islands in the Firth of Forth may cause reduced breeding success leading to changes in colony choice and shifts in tern distribution. Whilst gulls may directly affect the suitability of a nest site for breeding terns, resulting in distributional shifts, the extent of the impact on the overall population size will depend upon the number of gulls present, the availability of alternative nest sites for terns and on other limiting factors such as food availability. A site visit to Inchmickery in 2010 found no evidence of nesting attempts by common terns; high numbers of gulls continue to breed there and it is highly unlikely that a tern colony will re-establish without significant habitat management and gull control. The availability of the Imperial Dock Lock SPA as a nest site is therefore critically important for the long-term success of the common tern in the Firth of Forth. Further information on prey availability and abundance along with continued monitoring of breeding success, including monitoring of predators, would enable the integrity of the SPA to be maintained, thus benefiting the long term conservation of the colony and regional population.

The results suggest that numbers at individual colonies are strongly affected particularly by local influences of predation, whereas numbers in the region as a whole are more strongly influenced by food supply. Dänhardt *et al.* (2011) showed that breeding success of common terns at colonies in the Wadden Sea correlated with annual estimates of North Sea herring recruitment and Wadden Sea sprat abundance. However, at some common tern colonies impacts of predation can be so severe that any relationship with food supply is completely obscured by catastrophic breeding failures caused by predators (e.g. Eggeling, 1974; Craik, 1997; Forrester *et al*., 2007). We suggest that, in regions where food supply is good but some colonies are affected by predators, common terns will readily relocate or will recruit predominantly into colonies where predation impacts are absent or small (see Dittmann *et al*., 2005). Such behaviour will result in regional breeding numbers showing closer relationships with forage fish abundance and individual colony sizes being driven more by local predation impacts. This has important implications for seabird monitoring studies and conservation. With the implementation of policies such as the EU Marine Strategy Framework Directive, there is now an increased need to establish appropriate indicators, and consideration of regional seabird breeding numbers is of particular relevance to ecosystem-management of shared fish stocks. Future research should carefully consider the dynamics of individual colonies when evaluating how generally applicable conclusion drawn from a single or small number of seabird colonies may be for management on a broader scale.

Currently there is no sprat fishery in the Firth of Forth but the sprat stock is now considered to be at a high level (Fernandes *et al.*, 2004). Any assessments considering the re-opening of the Firth of Forth sprat fishery should consider the potential impact that changes in sprat abundance may have on dependent predators in the region, in particular the population of common terns since the largest colony, at Leith Docks (now holding about 90% of the Firth of Forth population), is protected under European Law as a Special Protection Area (SPA) for the species.

4 Foraging ecology of common terns breeding at the Imperial Dock Lock Special Protection Area in Leith Docks

4.1 Introduction

The annual reproductive success of long-lived seabirds such as terns can show great variation, often in response to changes in prey availability (Monaghan et al 1989; Regehr & Rodaway, 1999; Furness and Tasker, 2000). Particularly good evidence for this comes from studies where both fisheries data and seabird population data are available (for example Furness and Tasker, 2000). Seabird diet can provide information about prey availability and thus the quality of breeding conditions. The Imperial Dock Lock Special Protection Area (SPA) in Leith Docks holds one of the largest common tern colonies in the UK and since 2005 has been the largest in Scotland, exceeding the numbers at Scotland's former largest colony at Glas Eileanan SPA, Mull. Such a large concentration of terns breeding at the one site would seem to indicate an abundant and reliable food source nearby, however very little is known about the foraging ecology of the terns at Leith.

Early in the breeding season, common terns participate in courtship feeding at the colony (Nisbet, 1973). Initially males carry fish around the colony, displaying to prospective mates. Then, once a pair bond is formed, the male frequently feeds the female and it is during this stage in which copulation occurs. The pair often spends time on the feeding grounds where the female continues to feed herself as well as receive feeds from her mate. In the final stages of courtship feeding, the female remains in the nest territory and is fed exclusively by the male in the few days prior to egg laying (Nisbet, 1973). Traditionally considered as a behaviour serving to primarily strengthen the pair bond (Lack 1940), courtship feeding has since been recognised as an important source of nutrition for the female (for example, Nisbet, 1973). Rates of courtship feeding have been found to correlate positively with clutch size, egg size and hatching and fledging success (Nisbet, 1973, 1977). Furthermore, a positive correlation exists between courtship feeding rate and chick feeding rate by the male, suggesting that a males' performance during courtship is indicative of parental quality (Nisbet, 1973; Wiggins & Morris, 1987). Once hatched, both sexes share provisioning duties although Wiggins & Morris (1986) found that males fed chicks at a higher rate than females, with the difference being particularly pronounced in the early stages of provisioning. A recent study showed that common terns preferentially select the highest quality of prey for provisioning their mate or chicks even if they feed themselves on lower quality items that are abundant (Daenhardt *et al*,. 2011).

During courtship feeding and chick provisioning, terns exhibit ‘central place foraging’ (Orians & Pearson, 1979) meaning that individuals travel to the foraging grounds and return to a central place, the nest site, with prey items. Central place foragers are predicted to provide large, energy rich prey items to their mates or chicks but are energetically constrained by how far to travel for food. Terns are generally single prey-loaders, delivering a single prey item to their partner or chicks at the colony, making them particularly good indicators of even short-term changes in feeding conditions (Frank, 1992). As visual foragers that feed during daylight only, any weather conditions affecting visibility and flight conditions can affect the feeding efficiency and locations of terns (Frank & Becker, 1992). The common tern is a generalist predator and an opportunist, and can feed both in saltwater and freshwater, so survival and productivity tends to be less sensitive to changes in food supply than for those tern species which specialise on particular prey types (Ratcliffe, 2004). Breeding failures due to changes in food supply have been reported however, although these were short term and localised events (Norman Ratcliffe, 2008; Ratcliffe, 2004). A reduction in surface feeding larval herring has been suggested as the cause of a decline in terns in the Firth of Clyde (Monaghan & Zonfrillo, 1986). Whilst common terns are more able to adapt to changing feeding conditions, reductions in certain prey can have indirect consequences; between 1984 and 1990, sandeel (*Ammodytes* sp.) availability around the Shetland Isles was extremely low and resulted in complete breeding failure for Arctic terns, which specialise on sandeels, through nest abandonment and chick starvation (Monaghan *et al.*, 1992). Although common terns avoided starvation by switching from sandeels to gadoids, they were more heavily predated by gulls and Great skuas in the absence of Arctic terns (Uttley *et al.*, 1989).

The aims of this chapter were to:

1) Describe the diets of adults during courtship.

2) Describe the diet of chicks and record food provisioning rates.

3) Locate the feeding areas of common terns breeding at the Imperial Dock Lock SPA.

4.2 Methods

4.2.1 Diet studies

The diet of common terns at the Leith colony was studied during the breeding seasons of 2009 and 2010. Observations were made from the dockside adjacent to the colony using 10x40 binoculars during courtship and incubation, and a 30x telescope during chick provisioning. Observations were performed during daylight between 0600 and 2100 and throughout a range of weather conditions, provided visibility was satisfactory for identification purposes. Prey deliveries to adults during courtship and incubation were observed between May and June in each season (14 May 2009 to 11 June 2009 and 13 May 2010 to 11 June 2010). Scan sampling was used to detect adults arriving at the colony with prey items in their bills.

During chick rearing, several nests were selected for focal observations of provisioning (twenty nests in 2009 and seventeen in 2010). Only nests that were easily visible from the dockside were selected. Nests were observed from June to July, up until the point where chicks were too mobile to be reliably assigned to a particular nest (between June 12th to July 15th 2009 and June 14th to July 2nd 2010). Nests were observed using a telescope, with up to six nests observed at a time.

For both adult and chick feeds, prey were identified to family level where possible, using the fish identification guide from the book '*Fishes of the sea'* by John and Gillian Lythgoe (1971). In addition to the use of binoculars and a telescope, photography was also used to aid the identity of some prey. In cases where identification was not possible, prey items were recorded as 'unidentified' or, if identifiable as fish, as 'unidentified fish'. Prey size was estimated by relation to adult bill length, to the nearest 0.5 bill lengths. To allow comparison of the size of prey delivered, data were subsequently grouped into four categories (0-1, >1-2, >2-3 and >3 bill lengths). The frequency of prey types and sizes were compared between courtship and chick rearing phases, and between years, using a Chi-squared contingency table (using counts). Focal nests for which ten or more feeds were recorded were included in an analysis of chick provisioning rate (some nests failed after the start of observations). These data were used to calculate the average number of feeds/chick/hour over each season. Feeding rate was analysed using a generalised linear model with a quasipoisson distribution; with year (2009/2010), brood size (1, 2 or 3 chicks) and chick age (either 1, 2 or 3 weeks old) included as explanatory variables.

In 2009 a sample of 243 otoliths were collected from the colony at the end of the season in August. By this stage all of the terns had left the docks and the pellets had broken down, such that only loose otoliths remained on the breeding site. These were identified to the lowest possible taxon using an identification guide (Härkönen, 1986) and a light microscope.

4.2.2 Foraging areas

Preliminary observations were performed within the docks during the breeding season of 2009 to establish the direction in which foraging terns left the colony. Terns were followed visually using the naked eye, binoculars or a telescope as appropriate. Additionally, any instances of feeding that were observed within or around the docks were recorded ad hoc in 2009 and 2010. In many cases it was possible to observe terns foraging near the shore either from vantage points along the sea wall or from the harbour entrance.

In 2009 the JNCC began research to identify important marine areas for terns in the UK – the project sought to recommend suitable areas as Marine Special Protection Areas for Arctic, common, little, roseate and Sandwich terns (Wilson et al., 2009). Part of the project involved creating habitat suitability models that could be used to explain in part the at-sea distributions of these species, using a combination of existing marine habitat data and new data on the at-sea distribution of terns at selected colonies. Leith was selected as a study site for the common tern in partnership with my studies at the colony. The methods were based on those developed by Perrow et al (2009) and are described fully in Wilson et al. (2009). During 16 June-10 July 2009, foraging terns were followed as they left the docks in a rigid inflatable boat (RIB). The RIB was stationed offshore, but as close to the docks as safely possible to maximise the possibility of successfully following terns as they left the colony to forage. Only one bird was tracked at a time and the tracks were recorded using an on-board GPS, following terns from the starting point to their foraging grounds and back. The boat traced the flight path of the birds as closely as possible, maintaining a distance of 50-100m to minimise any impact on the behaviour of the birds (there appeared to be no influence of the vessel on behaviour at this distance). Boat surveys were restricted by weather conditions, as this method of tracking requires good visibility, little or no rain and a sea state of 3 or less (Beaufort scale).

4.3 Results

4.3.1 Diet composition

A total of 3834 adult feeds (Table 4.1) and 525 chick feeds (Table 4.2) were observed over the two seasons. Apart from a very small number of squid and crustaceans, all prey recorded were fish. Clupeids, most of which were identified as sprat (*Sprattus sprattus*), formed the greatest part of the diet for adults and chicks in both seasons. Sprat and juvenile herring look alike but can be distinguished by fin position; in sprat the dorsal fin begins midway between the hind edge of the eye and base of the tail fin, and in herring the dorsal fin begins halfway between the snout and base of the anal fin. The positive identification of sprat was verified from photographs by Dr Peter Wright of the Fisheries Research Service (FRS). Some clupeids could not be identified to species due to the speed in which they brought in or angle in which they were held by the bird, and were recorded only to family level. No clupeids were positively identified as herring. The dominance of sprat is further supported by the very low bycatches of juvenile herring in the Firth of Forth sprat fishery (see Fernandes *et al.*, 2004). The remaining diet comprised mainly sandeel (*Ammodytes* species) and also gadoids. Diet data collected by the JNCC in 2009 during visual tracking of terns leaving the colony also showed a higher proportion of clupeid than sandeel (Wilson et al., 2009). More unusual prey items included juvenile flatfish (2009), squid (2009/10), boxfish and pipefish (one of each collected on the colony during the nest count in 2009). Images of the range of otoliths identified are presented in Figure 4.1.

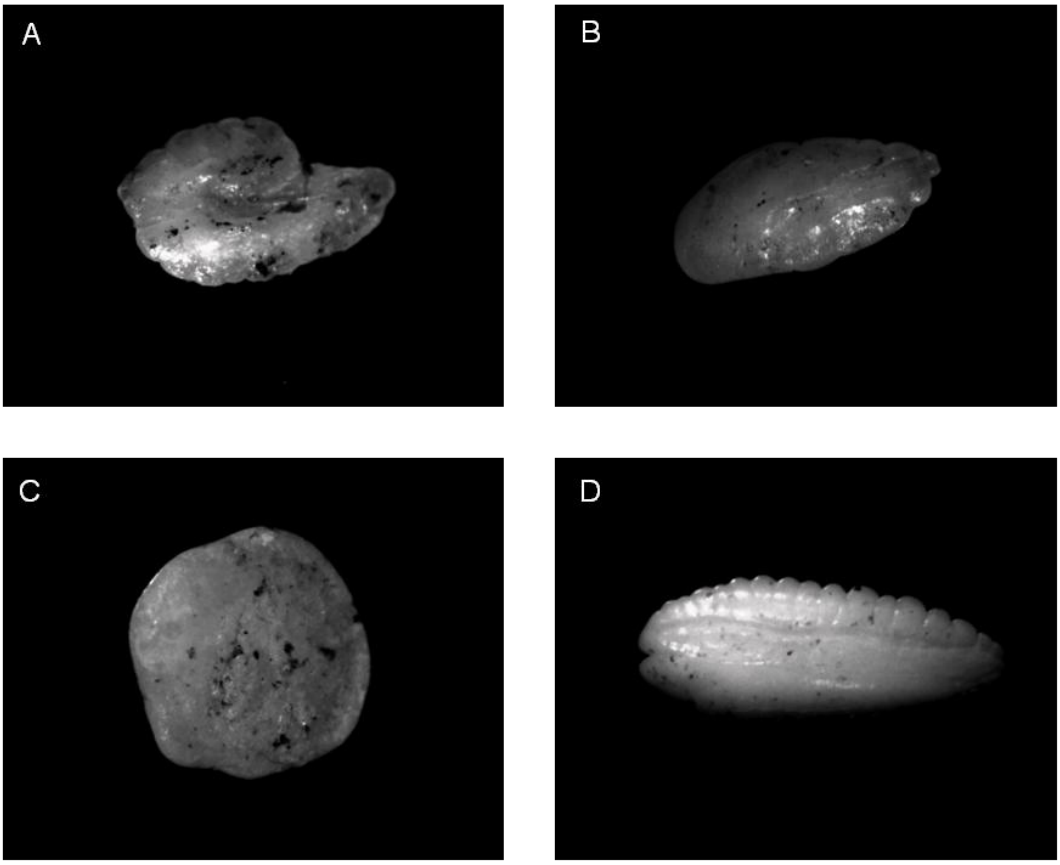

Figure 4.1. Magnified images of fish otoliths collected from the Imperial Dock Lock SPA common tern colony at the end of the breeding season in 2009. A) Clupeid – identified as sprat, B) Sandeel, C) Gobidae, D) Gadid.

Adult diet

For adult feeds during courtship and incubation 2661 prey items were recorded over 48 hours of observation in 2009 (0.9 feeds. min^{-1}) and 1173 prey items were recorded over 35 hours of observation in 2010 (0.6 feeds. min^{-1}). Whilst most feeds consisted of a single prey item, on a number of occasions terns were observed carrying 2, 3 or even 4 fish to the colony for their partner (n=9 in 2009, n = 31 in 2010). Of all prey items identified during courtship in 2009, 55.4% were clupeid, 32.5% were sandeel and 12.1% were gadoid (table 1-1). Of courtship feeds in 2010, 79.4% were clupeid, 14.2% were sandeel and 6.4% were gadoid (Table 4.1).

Table 4.1. Adult diet. Diet composition of common terns breeding in Leith docks based on observations of courtship feeding in 2009 and 2010. 48 hours of observation were performed in 2009 and 35 hours in 2010. Number = number of prey items observed, % = percent of identified prey items.

	2009 *(n = 2661)*		**2010** *(n = 1173)*	
Prey type	**Number**	**%**	**Number**	**%**
Clupeid	1451	55.4	913	79.4
Sandeel	852	32.5	163	14.2
Gadoid	317	12.1	74	6.4
Unidentified fish	41	-	23	-
Total	**2661**	**-**	**1173**	**-**
Total identified	**2620**	**-**	**1150**	**-**

Chick diet

In 2009, 20 nests were observed over the season but this summary only includes data from 12 of them – those with 10 or more recorded feeds (plus several failed). The 2009 analysis is based on 328 feeds recorded over 82 hours (0.6 feeds. h^{-1}). Similarly, seventeen nests were observed in 2010 but this summary only includes data from 7 (those with 10 or more recorded feeds); the 2010 analysis is based on 197 feeds recorded over 89 hours (3 feeds. h^{-1}). In most instances chick feeds consisted of a single prey item, although adults at one nest were observed providing two sprats on two occasions during the 2010 season. Of all prey items identified during chick provisioning in 2009, 68.7% were clupeid, 24.2% were sandeel and 5.3% were gadoid (Table 4-2). Of chick feeds in 2010, 93.2% were clupeid, 5.5% were sandeel and less than 1% were gadoid (Table 4.2). The proportion of clupeids was greater during chick rearing than courtship in both seasons (2009: $\chi^2 = 22.8$, d.f. = 2, $p<0.001$ and 2010: $\chi^2 = 17.9$, d.f. = 2, $p<0.001$).

Table 4.2. Chick diet. Diet composition of common terns breeding in Leith docks based on prey deliveries to nests during chick rearing in 2009 and 2010. 82 hours of observation were performed in 2009 and 89 in 2010. Number = number of prey items observed, % = percent of identified prey items.

	2009 *(n = 328)*		**2010** *(n = 197)*	
Prey type	**Number**	**%**	**Number**	**%**
Clupeid	182	68.7	136	93.2
Sandeel	64	24.2	8	5.5
Gadoid	14	5.3	1	0.7
Other	5	1.9	1	0.7
Unidentified fish	63	-	51	-
Total	**328**	**-**	**197**	**-**
Total identified	**265**	**-**	**146**	**-**

In addition to differences between adult courtship and chick diets, an inter-annual difference was observed, with a greater occurrence of clupeids in 2010 than 2009 ($\chi^2 = 231$, d.f. = 2, $p<0.001$).

4.3.2 Prey size

The most common prey size was >1-2 bill lengths (BL), which equates to 3.8-7.5cm for both adults and chicks in both years. Mean length of prey brought to adults was approximately 7.9cm (2.11 BL) in 2009 and 8.6cm (2.3 BL) in 2010. For chicks the mean prey length was approximately 6cm (1.61 BL) in both 2009 and 2010.

Prey size for adults

The size of prey provided during courtship and incubation was greater in 2010 than 2009. The proportion of >2-3 BL and >3 BL sized prey items varied only slightly between 2009 and 2010, however there was a greater proportion of 0-1 BL in 2009 than 2010 (22% compared to 3%) and a greater proportion of >1-2 BL in 2010 than 2009 (49% in 2009 compared to 64% in 2010) (χ^2 = 216.2, d.f. = 3, p<0.001; Figure 4.2).

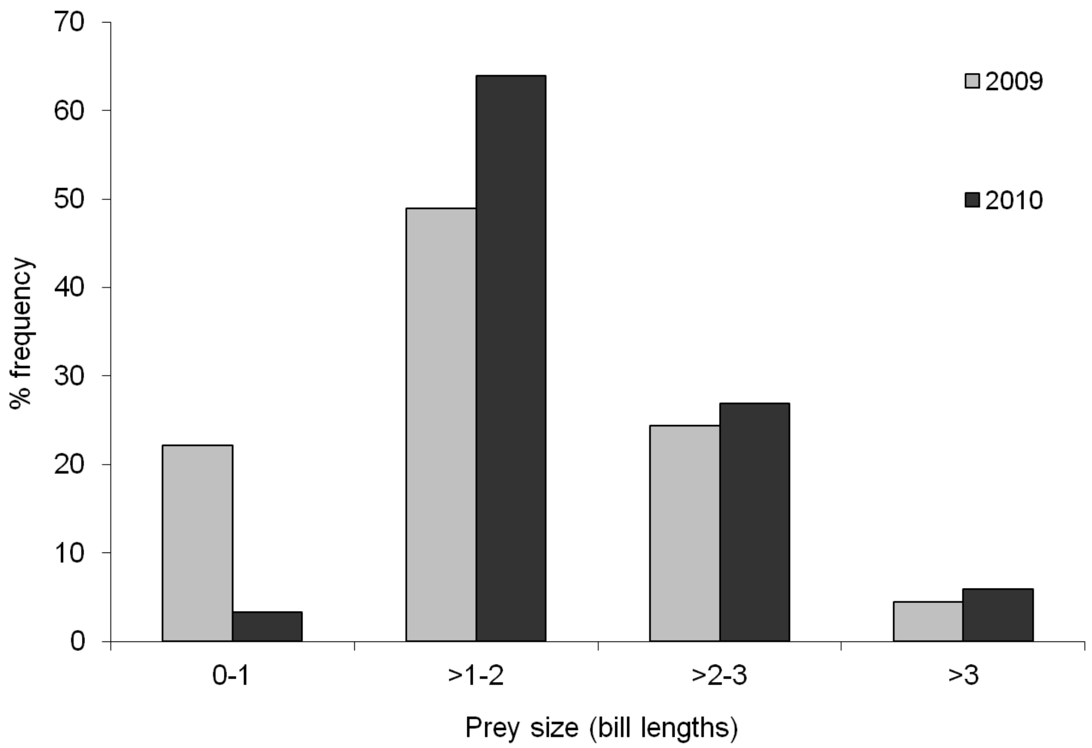

Figure 4.2 Frequency distribution of prey sizes during courtship and incubation feeding in adult common terns at the Imperial Dock Lock SPA in 2009 and 2010.

Prey size for chicks

The frequency of different prey sizes delivered to chicks did not vary between 2009 and 2010 (χ^2 = 3.5, d.f. = 3, p=0.315; Figure 4.3). However the frequencies of prey between size categories varied significantly (χ^2 = 563.8, d.f. = 3, p<0.001; Figure 4.3). In chicks by far the most common prey size was >1-2 BL (69% of prey in 2009 and 76% of prey in 2010), followed by 0-1 BL (21% in 2009, 19% in 2010), >2-3 BL (9% in 2009, 5% in 2010) and >3 BL (<1% in 2009 and 2010).

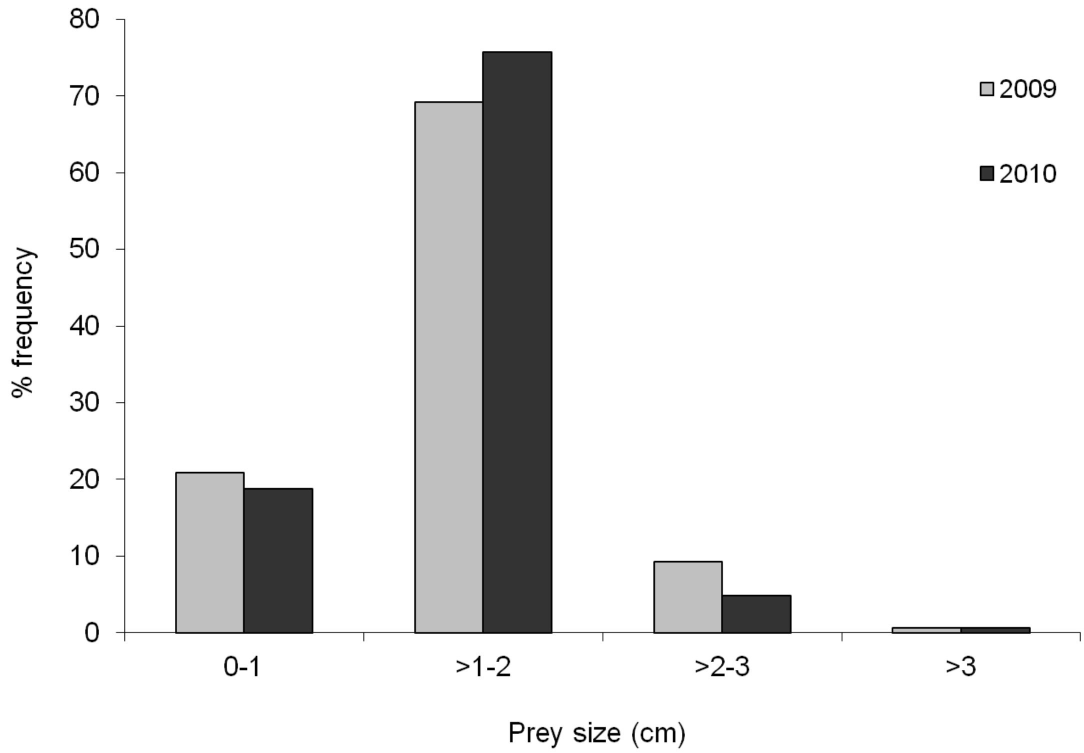

Figure 4.3 Frequency distribution of prey sizes provided by common terns during chick feeding at the Imperial Dock Lock SPA in 2009 and 2010.

Comparison of prey sizes for adults and chicks

The proportions of prey sizes delivered to adults and chicks differed significantly (χ^2 = 97.4, d.f. = 3, p<0.001; Figure 4.4). Both received more prey items in the >1-2 BL category than other sizes, but this constituted a higher proportion of the total for chicks than adults.

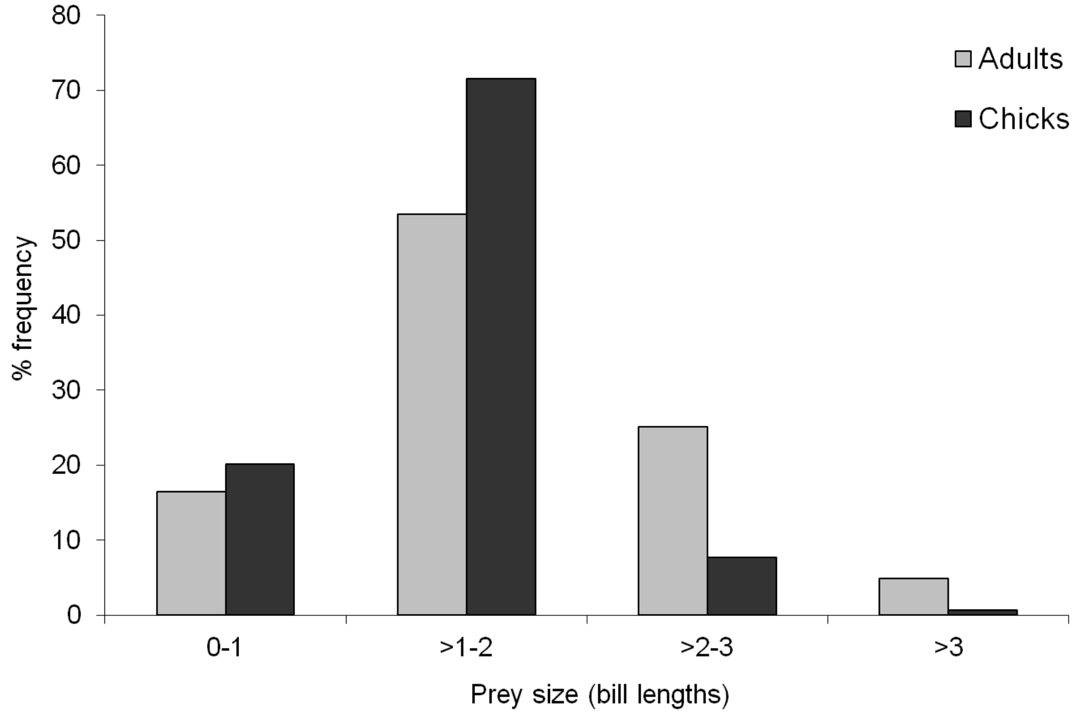

Figure 4.4 Frequency distribution of prey sizes provided to common tern adults (during courtship and incubation) and chicks at the Imperial Dock Lock SPA in 2009 and 2010.

4.3.3 Chick provisioning rate

Chick provisioning rate (feeds/chick/hour) was greater 2009 than 2010 (average of 0.62±0.47 feeds.chick^{-1}.h^{-1} in 2009 and 0.42±0.30 feeds.chick^{-1}.h^{-1} in 2010; F = 10.98, d.f. =1, p<0.01) and decreased with increasing brood size (F = 3.1, d.f. = 2, p = 0.048). There was no relationship between feeding rate and age of chick in weeks (F = 0.2, d.f. = 2, p>0.05).

Prey energy content

Energy values of the two main prey types, sprat and sandeel were estimated for each size category using calculations outlined by Hislop, Harris and Smith (1991) as shown below. The estimates are presented in Table 4.3.

Sprat (kJ) = 0.0096 length (cm) $^{3.845}$

Sandeel (kJ) = 0.0081 length (cm) $^{3.427}$

Table 4.3. Energy value estimates of the two main prey types fed to common tern chicks at the Imperial Dock Lock SPA in 2009 and 2010.

Prey Size (bill lengths)	Sandeel energy value (kJ per fish)	Sprat energy value (kJ per fish)
0-1	0.0081	0.0096
>1-2	0.0871	0.1380
>2-3	0.3496	0.6558
>3	0.9370	1.9824

The most common prey item fed to chicks was sprat in the >1-2 BL size category. This translates to 0.1380 kJ per fish, which for the average provisioning rates, is 0.86kJ.h^{-1} in 2009 and 0.06kJ.h^{-1} in 2010.

4.3.4 Foraging locations

Some foraging was recorded within Leith Docks but this was infrequent and constituted a minor part of overall foraging activity. Terns were observed feeding in the wake of vessels in the Imperial Dock and the Western Harbour, and at the entrance lock in the Western Harbour during controlled water level changes to allow vessel movement. Terns were also observed foraging in the Victoria Dock and in the Water of Leith, and these feeds were not associated with vessels. Where feeds in the dock were observed, the fish taken were very small (less than 1 bill length in size), unidentifiable and were not commonly seen during observations of prey deliveries to chicks and adults at the colony. Late in the season, juvenile terns were also observed fishing in the docks, again taking very small unidentifiable fish. During periods of poor visibility, some feeding was also observed further inland, in the water of Leith. This too however was very infrequent and only one or two birds were observed feeding in this area at any one time. Most foraging activity occurred outside of the docks in the Firth of Forth. The JNCC recorded 114 tern foraging tracks, 48 of which were complete tracks; Figure 4.5 shows the tracks produced from following individual terns that were leaving the docks to forage and indicates the general feeding distribution of terns breeding in Leith docks (taken from Wilson et al., 2009). Most recorded trips were in close proximity to the colony (within 10km), stretching from Cramond Island to the west of the colony, across to Kirkcaldy Bay in the north-east, and also eastwards from the colony to Portobello and Musselburgh in the south of the Forth. Based on these foraging tracks, neither foraging range nor foraging trip duration changed throughout the season (Wilson et al., 2009).

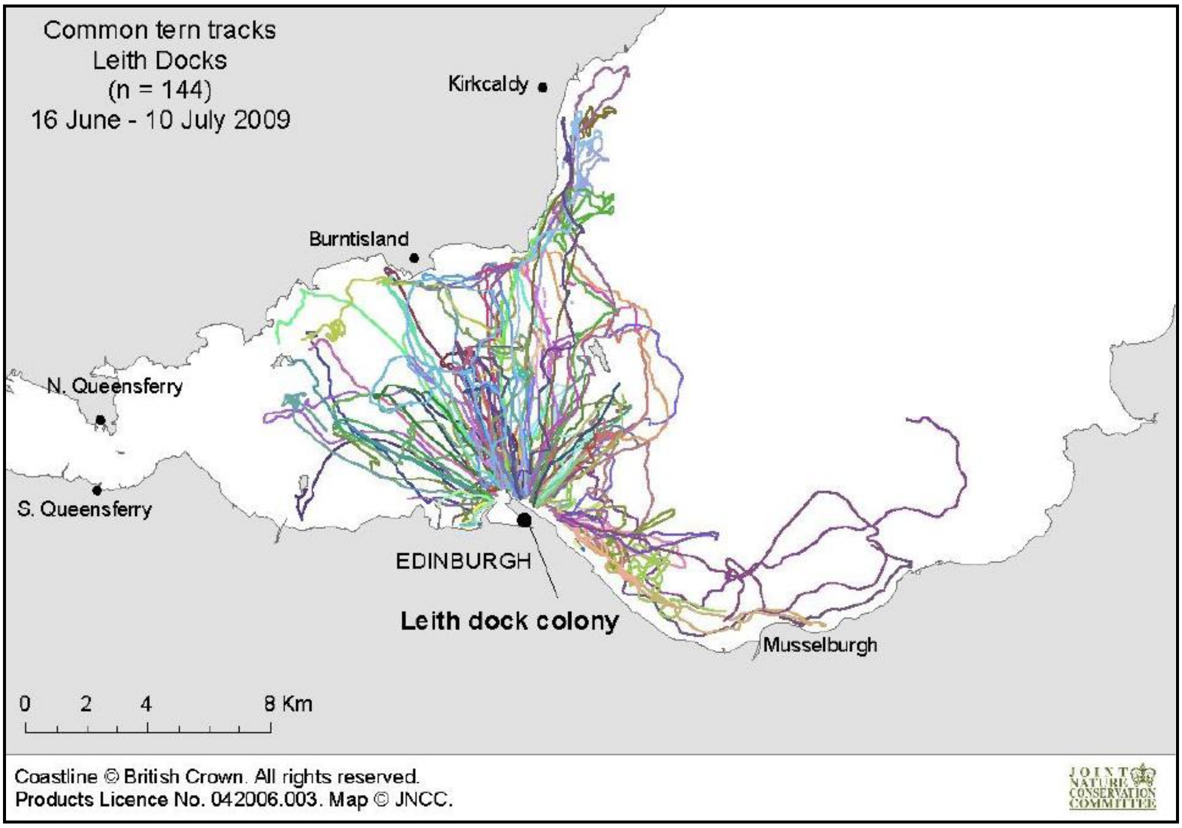

Figure 4.5 Foraging tracks of common terns breeding at the Imperial Dock Lock SPA in Leith Docks in 2009. Each line represents the path of a single bird. Image used by permission of JNCC.

4.4 Discussion

4.4.1 Diet

The diet of common terns breeding at the Imperial Dock Lock SPA included a range of prey items, but consisted predominantly of marine fish. Clupeids, mostly identifiable as sprat, formed the greatest part of the diet during courtship and chick provisioning in both seasons. A study of common terns in the Farne Islands (northeast England) found a high proportion of clupeids (sprat and herring) in the diet (Pearson, 1968), whereas in Coquet Island (also northeast England) common tern diet included some sprat and herring but consisted predominantly of sandeel (Robinson, 1999). Clupeids were presumably the most abundant suitable prey type available in the Firth of Forth, with some terns observed carrying several back to the colony at once on numerous occasions. The proportion of clupeids was greater during chick rearing than courtship in both seasons. Clupeids have a greater calorific content than sandeel (Harris and Hislop 1978) so this increase during chick rearing may represent selection of more calorific prey for provisioning young. Whilst the nutritional value of prey offered to mates is important, the visual appearance of fish also acts as a cue in mate choice, which may explain the significant sandeel component of the diet during courtship feeding (Taylor 1979**).**

Both adults and chicks received prey of >1-2 bill lengths more than any other size of prey, but this was more pronounced in chick provisioning than courtship feeds, again reflecting the terns' ability to provide the most appropriate prey to their young. It has been suggested that the fate of each prey item caught (i.e. whether to deliver to a mate, a chick, or to self-feed) is decided post-catch, such that adults could sample the prey base several times before an appropriately sized prey item is selected to be taken back to the nest (for example Taylor, 1979).

Knowledge of foraging ecology could benefit from further sampling over more breeding seasons, including continued feeding observations at the colony, as well as direct fish sampling from the Firth of Forth, to help further understand the relative importance of prey availability and prey choice in diet composition. The recent finding by Daenhardt (2011) that common terns may feed themselves very different prey at-sea compared to what they bring back to the colony for chicks (in this case lower quality items) indicates that colony-based studies of diet may be further complemented by at-sea studies of adult feeding during provisioning.

4.4.2 Chick provisioning rate

Chick provisioning rates were comparable with those recorded at other large common tern colonies such as Coquet Island, Northumberland (Robinson & Hamer 2000) and Port Colbourne, Ontario (Morris and Burness 1992). However, there was great annual variation, with much higher provisioning rates observed in 2009 than 2010. It is possible that the greater occurrence of clupeids in the diet in 2010 allowed feeding frequency to be reduced without any observable effect on fledging success (productivity was actually estimated to be higher in 2009 than 2010, see 3.3.2), although there is no data for long-term survival or recruitment for chicks fledged from this colony. Provisioning rate decreased with increasing brood size, meaning that broods of one chick were fed more frequently than chicks in broods of two or three. This relationship between brood size and feeding rate has been observed in several avian species, including wheatear *Oenanthe oenanthe* (Moreno, 1987) and tree swallow *Tachycineta bicolor* (Leonard et al. 1999), as well as common tern (Robinson and Hamer 2000).

4.4.3 Foraging locations

While some foraging occurs within Leith docks, it is largely opportunistic, with the majority of foraging trips extending out of the docks into the Firth of Forth. During periods of poor visibility, some feeding was observed further inland, in the water of Leith, but only one or two individuals were ever observed at a time. It was sometimes possible to observe terns foraging very close the shore surrounding the docks, but many birds spread out further across the Firth of Forth during foraging trips. Due to the infrequent nature of feeding within the docks and the small size of prey taken, it is likely such foraging was for self-feeding rather than provisioning of partners or chicks. Juveniles were also observed practising fishing within the docks; it could be that the sheltered environment close to the colony provides a safe haven for this activity. Tracking of foraging terns in 2009 showed that terns breeding in Leith docks feed mostly within 10km of the colony (Wilson *et al*., 2009) and this was supported by observations around the shore in both 2009 and 2010. This foraging range is consistent with common terns breeding in the Wadden Sea (which had a mean foraging radius of 6.3 ± 2.4 km from the colony; Becker *et al*., 1993), as well as common terns at other sites in the JNCC study (foraging ranges at Leith did not differ significantly than those for common terns at Cemlyn Bay (Anglesey), Coquet Island or Larne Lough/Copeland Island/Cockle Island (Northern Ireland); Wilson *et al*., 2009). The close proximity of the main foraging distribution to the colony indicates that the terns are breeding in an area of good food availability. At less than 1km away from the former breeding site of Inchmickery, it is likely that terns presently breeding at Leith are exploiting the same foraging areas as those breeding at Inchmickery during the 1970s and 1980s.

5 Flight lines of common terns at the Imperial Dock Lock SPA

5.1 Introduction

During the breeding season, terns make frequent foraging trips between nesting and feeding areas, often forming predictable flight lines, the use of which are particularly pronounced during chick rearing. Terns exhibit biparental care, whereby both parents contribute to incubation of eggs and chick provisioning. Energy requirements are relatively low during incubation but during the chick rearing stage, adult terns must meet the energy demands of both themselves and their chicks. In a study of breeding seabird species on the Farne Islands, Northumberland, Pearson (1968) found that terns (common tern *Sterna hirundo*, Arctic tern *S. paradisaea* and Sandwich tern *S. sandvicensis*) were performing at close to the limits of their physical ability to collect food, with little leeway in their energy budgets. Both parents were often away from the nest at the same time and, compared to larger seabird species, spent more time foraging to rear a single chick (Pearson, 1968). With their small body size and low energy reserves, terns have a shorter foraging range than many other seabird species and little scope to increase foraging time, which makes them particularly vulnerable to food shortage (Frank, 1992; Frank *et al.*, 1992). Foraging activities can be affected by environmental conditions such as wind speed (Becker & Specht, 1991; Dunn, 1973; Frank, 1992; Taylor, 1983) and tidal conditions (Becker, Frank & Sudmann, 1993; Becker, Frank & Wagener, 1997; Becker *et al.*, 1991; Frank, 1992; Frick & Becker, 1995). The relationship between feeding patterns and tide has been found to be more pronounced during incubation than chick rearing (Frank & Becker, 1992) which probably relates to heightened energy demands during chick rearing such that adults must forage continually during daylight hours, even when conditions are unfavourable (Frank, 1992).

Obstruction of favoured flight routes can present a barrier to movement, resulting in displacement or avoidance, and potentially cause injury or mortality through collisions. Displacement can result in increased energy expenditure, a reduction in foraging efficiency and thus a reduction in breeding performance and survival (Drewitt & Langston, 2008). The impact of any structure on birds is influenced by its location, size and height and by factors such as the use of lighting. Susceptibility to collisions is species-specific and within species, risk may vary with the time of the season, behaviour and age of bird (see review by Drewitt *et al.*, 2008). For common terns breeding at Shotton Steel Works in North Wales, most trips to and from the foraging grounds in the nearby Dee Estuary involve passing two sets of power lines (Henderson et al., 1996). Although overall mortality was found to be low, vulnerability to collision was elevated during the chick stages due to increased energy demands. Trip frequency was over three times greater in the nestling phase than during courtship, reflecting the need for increased journeys when provisioning chicks. Flight height decreased through the season, as the energy demands on the parents increase, with notably lower heights during the nestling and juvenile phases compared to courtship or incubation. Flight style also varied with age, with juveniles flying closer to the wires than adults. In 1989, 172 common and Sandwich terns were killed by a collision with a power cable in Cape Town docks (Cochrane *et al*,. 1991). It was speculated that these terns had not roosted in this area in previous years and were unfamiliar with the cable. The cable was subsequently modified by lowering by it 1m and by attaching streamers and in the following year only two mortalities were recorded (Cochrane et al., 1991). In the port of Zeebrugge, Belgium, a purpose built 'tern-peninsula' was created to compensate for the loss of breeding sites elsewhere in the port. The peninsula is directly adjacent to a breakwater supporting 25 wind turbines, which the terns have to cross to access their feeding grounds (Everaert *et al.*, 2007). It is used by common, little and Sandwich terns, with 1475 breeding pairs of common terns recorded in 2005 (Everaert *et al.*, 2007). Inevitably, the proximity to the colony and direct interception of flight lines by turbines has caused considerable mortality through collision. Mortality was sex biased toward males, possibly due to sex differences in flight behaviour (Stienen et al., 2008).

The literature suggests that, although terns are vulnerable to injury and death from collisions with moving obstacles such as turbines or obstacles which may be difficult to see such as power cables, with careful planning and an understanding of flight routes, such consequences could be avoidable. This chapter investigates flight lines of common terns between their nest site at the Imperial Dock Lock SPA and their main feeding grounds in the Firth of Forth. The aims were to:

1) Investigate temporal influences on foraging flight activity.

2) Investigate the effect of environmental factors on foraging flight activity.

3) Record spatial use of flight routes.

4) Quantify the height of foraging flight lines.

5.2 Methods

Fieldwork took place from 22 May to 28 July 2009 and 15 May to 7 July 2010 at the Imperial Dock Lock SPA in Leith Docks, Edinburgh (55^o 59’ 00s N, 03^o 10’ 15s W). Surveys were performed throughout daylight hours from early morning to dusk. Although an attempt was made to cover a full range of weather conditions, survey days were restricted by periods of fog and strong winds. In order to be consistent with previous work, the flight survey protocol was based on the surveys performed by Environ (by Adam Fitchet and Dr Peter Reynolds). Surveys were performed in four sectors covering the sea wall in the port, (see description and Figure 5.1 on page 69). In each sector the number of inbound terns (flying into the port) and outbound terns (flying out of the port, towards the Firth of Forth) was recorded for 20 minutes. Heights of birds were estimated using buildings and other structures within the docks as references, and each bird recorded was assigned to a height category (0-5 m, >5-10 m, >10-20 m or >20 m). Table 5.1 shows the number of surveys performed each year and the total number of flights recorded over each season.

Table 5.1 Summary of flight surveys performed in each season. *2008 surveys by Environ.

Year	**Survey period**	**Number of surveys**	**Number of flights**
2008*	16 May to 8 August	15	3671
2009	22 May to 28 July	18	3819
2010	15 May to 7 July	12	2548

Environmental data

Tidal data were obtained from the Forth Ports 2009 and 2010 tide tables for Leith Docks. Periods of four tidal states (high, low, ebb and flood) were calculated for each survey day from the high and low water times, and each observation was assigned a tidal state. Wind records were obtained from a wind anemometer positioned at the Lock gates of the harbour entrance which records wind conditions every minute. Mean wind speed (knots) was calculated for each 20 minute period. Wind direction (degrees) was found to vary over the season and was removed from the analysis due to colinearity with survey week.

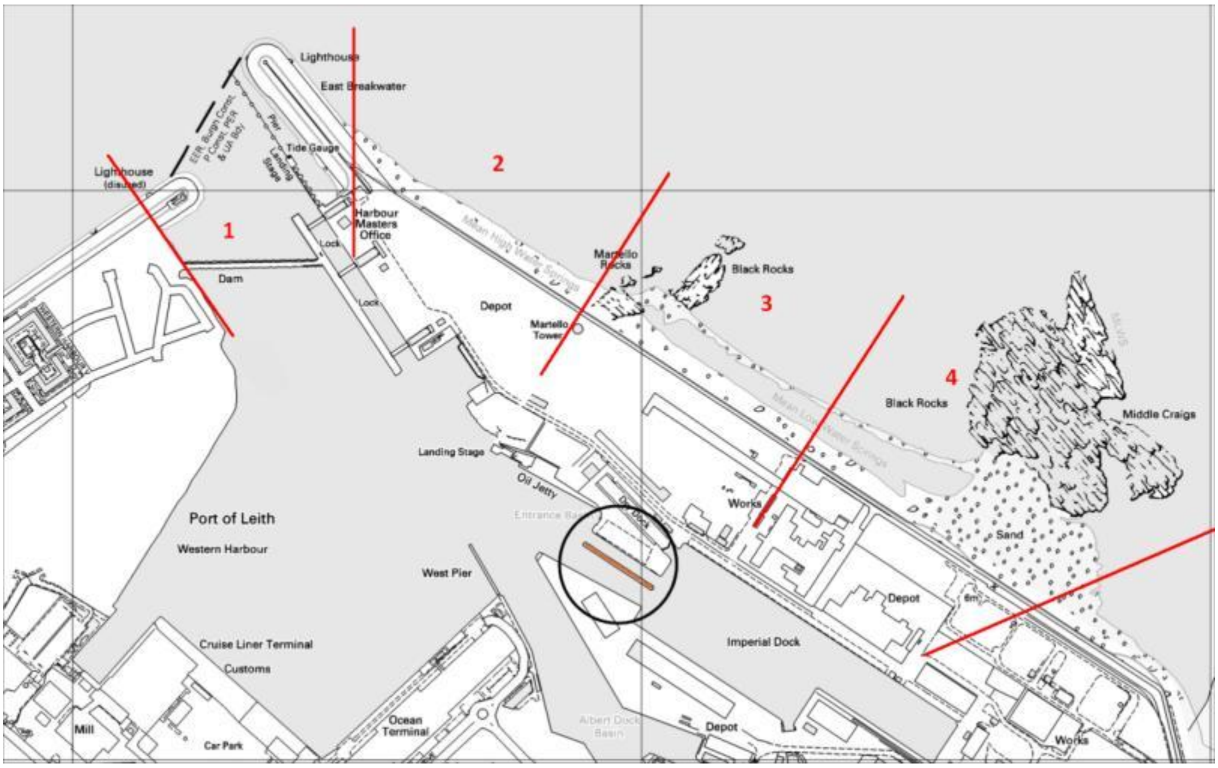

Figure 5.1 Map of Leith docks indicating the boundaries of the four survey sectors used in the flight surveys. The Imperial Dock Lock SPA is circled.

Sector 1: Western Harbour development to Harbour Office

This area is mostly open water with few structures which could obstruct flight. It covers the entrance to the western harbour and so vessels frequently move through this area.

Sector 2: Harbour Office to Martello Tower

This is a relatively flat area used for storage of pipes. It is mostly free of buildings but includes a few single story buildings and some large mobile structures. Pipes can be stacked to at least 5m above ground level.

Sector 3: Martello Tower to western edge of blue shed

This area is also used for pipe storage. It has piles of raw materials used in pipe coating and contains large industrial sheds ranging in height above ground from equivalent to approximately one to three storeys.

Sector 4: Western edge of blue shed to the east of the Bredero Shaw main building.

This area is the most built up of all the survey sectors, with industrial sheds up to four storeys high. It has a flat area to the east which is used for pipe storage.

5.2.1 Data analysis

For continuity with the Tern Survey Report by Environ (2008), the number of terns is expressed as the number of terns per hour in the figures below (extrapolated from the 20 minute observation periods). All statistical analysis was performed on counts for each 20 minute survey period.

Total flights

Total count data were analysed using a generalised linear model (GLM). The total number of birds recorded in a survey was modelled against breeding phase (incubation or chick rearing), week, time of day (dawn, morning, midday, afternoon or evening), tidal state (high, low, ebb and flood), wind speed and survey sector (sectors 1 to 4). As the data consisted of over-dispersed counts a GLM with a quasipoisson distribution was fitted. Model simplification was performed by stepwise deletion of non-significant terms to produce the minimum adequate model. The significance of terms in the model was analysed using the F statistic.

Sector use by outbound and inbound birds

To test for a relationship between the proportion of inbound and outbound birds with survey sector a chi-square contingency test was applied to the data on numbers of inbound and outbound birds in each survey. The chi-square found a relationship between flight direction and sector so z-tests were then applied to determine the nature of these relationships.

Proportion of inbound birds with fish

The proportion of inbound birds that were carrying fish was calculated for each sector. A chi squared test was used to compare the number of inbound birds with and without fish in each sector, with a null hypothesis of no differences between sectors.

Flight heights

The overall numbers of birds in each height band were compared using a chi square test to determine whether some bands were used more than others. A chi-square contingency test was then applied to test for an association between flight heights within survey sector; the nature of any associations were tested with a z-test.

5.3 Results

The number of commuting terns recorded in each observation did not vary between 2009 and 2010 ($p>0.05$), so data were pooled for any statistical analyses. A total of 6367 flights were recorded in 2009 and 2010. The number of terns recorded in each twenty minute flight survey ranged from 2 to 204, with an average of 53.5±47.21/survey**.**

Temporal patterns of foraging activity

Over the season, greater numbers were recorded during the chick rearing period than during incubation (GLM, d.f. = 1, F = 21.4, $p<0.001$, Figure 5.2). Greater numbers of terns were recorded during dawn and morning surveys than any other survey period during the day (GLM, d.f. = 4, F = 3.7, $p<0.01$, Figure 5.3).

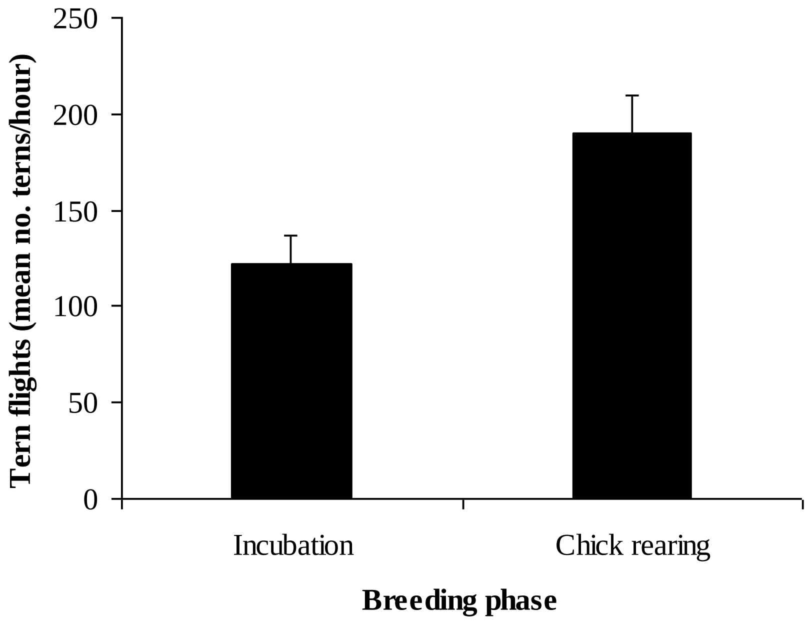

Figure 5.2 Mean number of tern flights recorded per hour during incubation and chick rearing. Columns are mean+SE for the number of terns per hour for 2009 and 2010 combined ($p<0.001$).

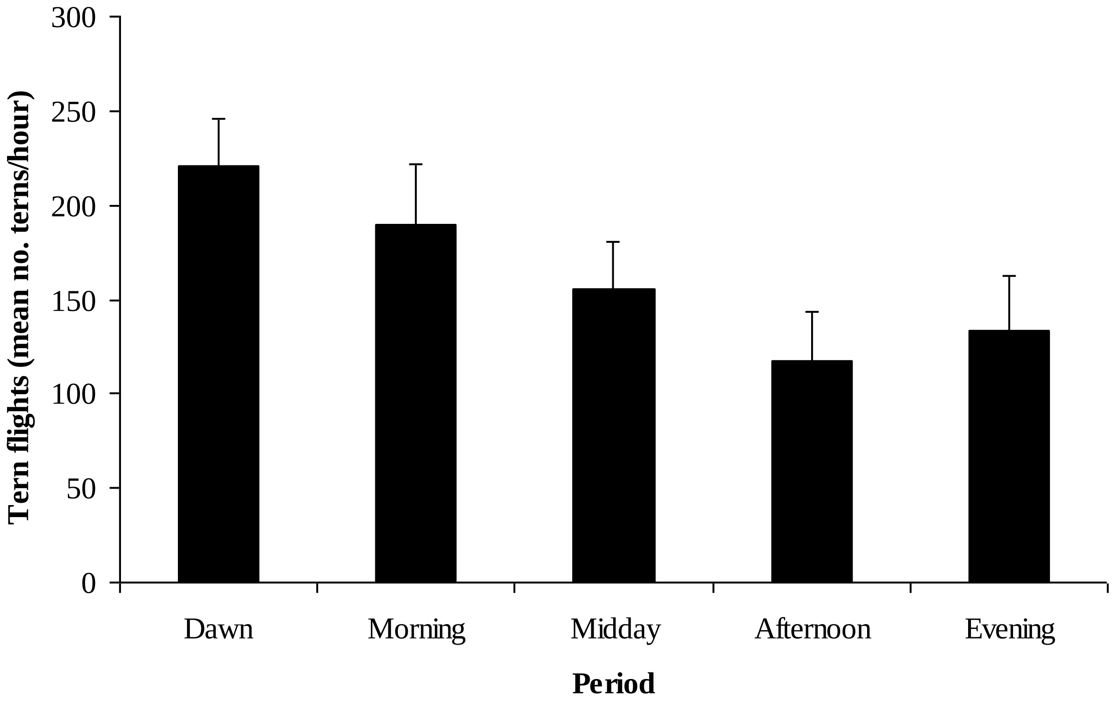

Figure 5.3 Daily activity patterns. Tern movements during different periods throughout the day. Columns are mean+SE for the number of terns per hour for the whole season in 2009 and 2010 ($p<0.01$).

Environmental conditions

There was no effect of tidal state on the number of terns recorded in each survey ($p>0.05$) but numbers decreased with increasing wind speed (GLM, d.f. = 1, $F = 10.5$, $p<0.01$, Figure 5.4).

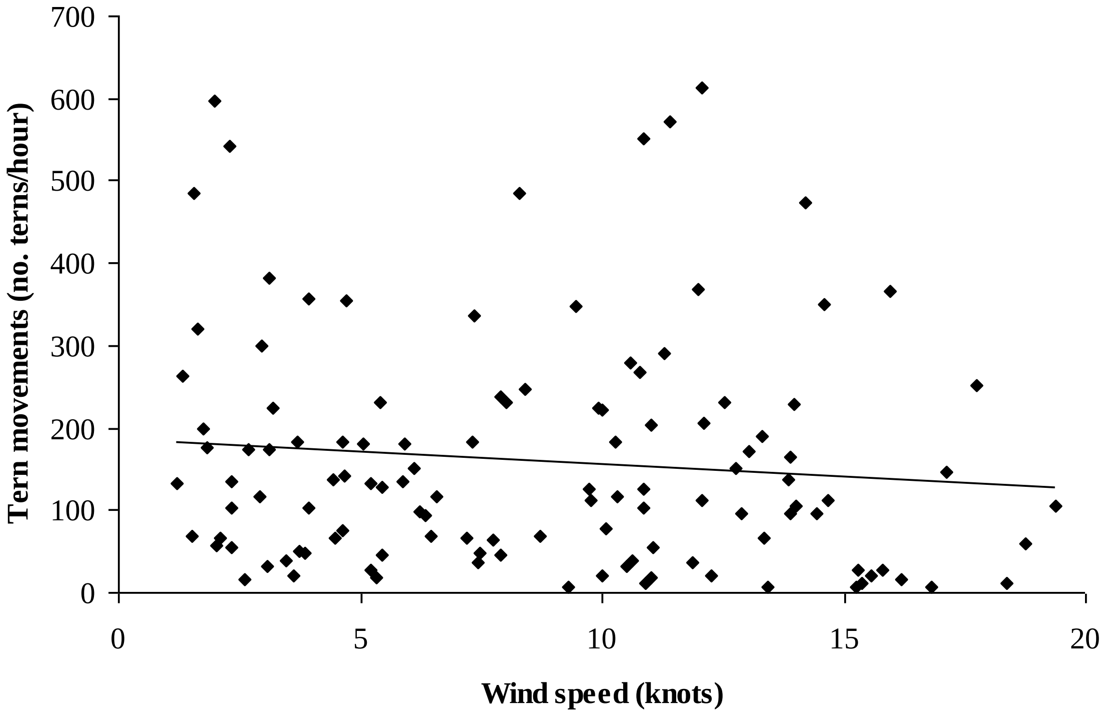

Figure 5.4 Effect of wind speed on the rate of tern foraging flights (p<0.01) (20 knots = 23mph).

Spatial trends

Flight lines between the colony and the Firth of Forth were widespread along the sea wall, with flight lines recorded in all 4 survey sectors. The total numbers and rates of terns recorded flying through each sector are shown in Table 5.2 and Figure 5.5 respectively for the year 2008-2009. The 2008 data are from the Enivron report, all subsequent analysis focuses on collected by the author in 2009 and 2010.

Table 5.2 Summary of flight lines use from 2008-2010, showing the total number of tern flights recorded in each sector. Data for 2008 are taken from the 'Leith Docks Tern Survey Report' by Environ.

	Total number of flights recorded		
Sector	**2008**	**2009**	**2010**
1	1467	816	483
2	549	418	368
3	1221	1935	1445
4	434	650	252
Total	3671	3819	2548

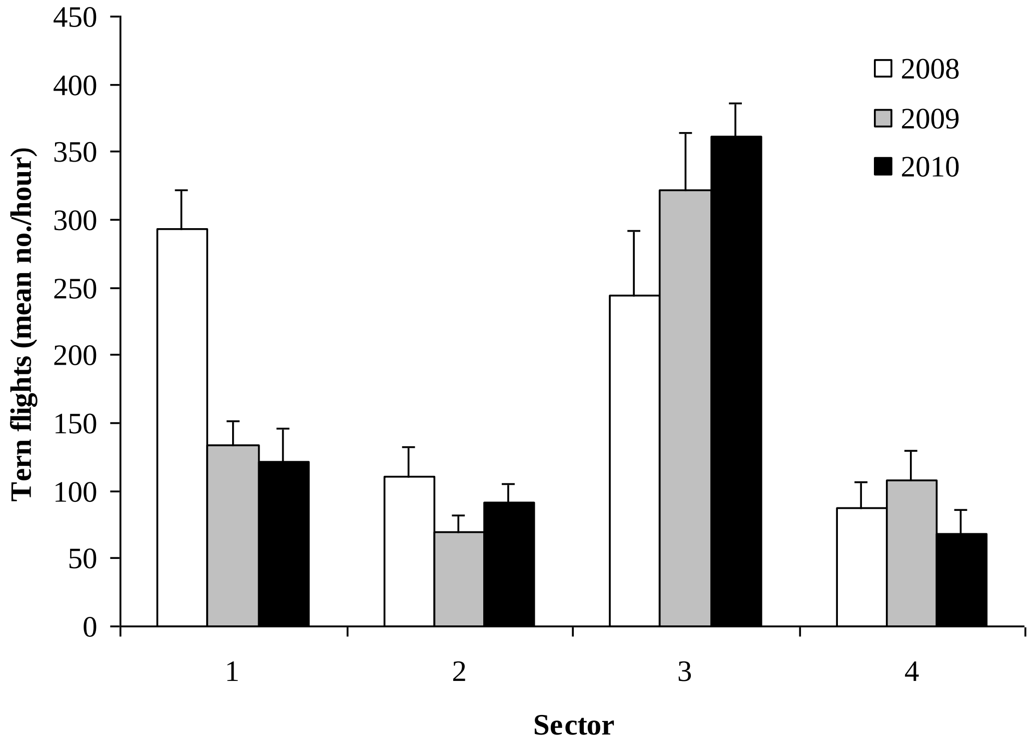

Figure 5.5 Tern movements through each survey sector in 2008-2010. Values indicate the mean number of terns per hour +SE (inbound and outbound flights combined). Data for 2008 are taken from the 'Leith Docks Tern Survey Report' by Environ.

The number of terns recorded varied significantly between survey sectors. Sector 3 was by far the most frequently used route (53.09% of all recorded flights); followed by sector 1 (20.4% of all recorded flights). Sectors 2 and 4 were each used to a similar extent (12.34% and 14.17% of all recorded flights respectively).

The proportion of inbound and outbound birds was not equal in each sector (Chi-square test, $\chi^2 = 521.0$, d.f. = 3, p<0.001, Table 5.3). Sector 3 had a higher proportion of outbound birds than inbound; the opposite was true for sectors 1, 2 and 4 (see Figure 5.7). Sector 3 had a higher proportion of outbound birds than any other sector (61.12%), accounting for 66.8% of all outbound flights. Sector 4 had a higher proportion of inbound birds than any other sector (76.83%).

There was a relationship between sector and the number of the inbound birds which were carrying fish (Chi-square test, $\chi^2 = 70.4$, d.f. = 3, p<0.001, Figure 5.8). The z-test showed that the proportion of inbound birds with fish was higher in sectors 1, 2 and 4 than in sector

3. 58.8% of inbound birds carried fish through sector 3 compared to 70.6%, 73.5% and 74% in sectors 1, 2 and 4 respectively.

Table 5.3 Use of each sector. Summary of the use of four flight routes between the colony and the Firth of Forth by common terns breeding in Leith Docks in 2009 and 2010.

Sector	Total **outbound** flights recorded	% of flights in sector	% of all outbound flights	Total **inbound** flights recorded	% of flights in sector	% of all inbound flights	Total number of flights recorded	% of all flights
1	516	39.72	16.69	783	60.28	23.90	1299	20.40
2	300	38.17	9.71	486	61.83	14.84	786	12.34
3	2066	61.12	66.84	1314	38.88	40.11	3380	53.09
4	209	23.17	6.76	693	76.83	21.15	902	14.17

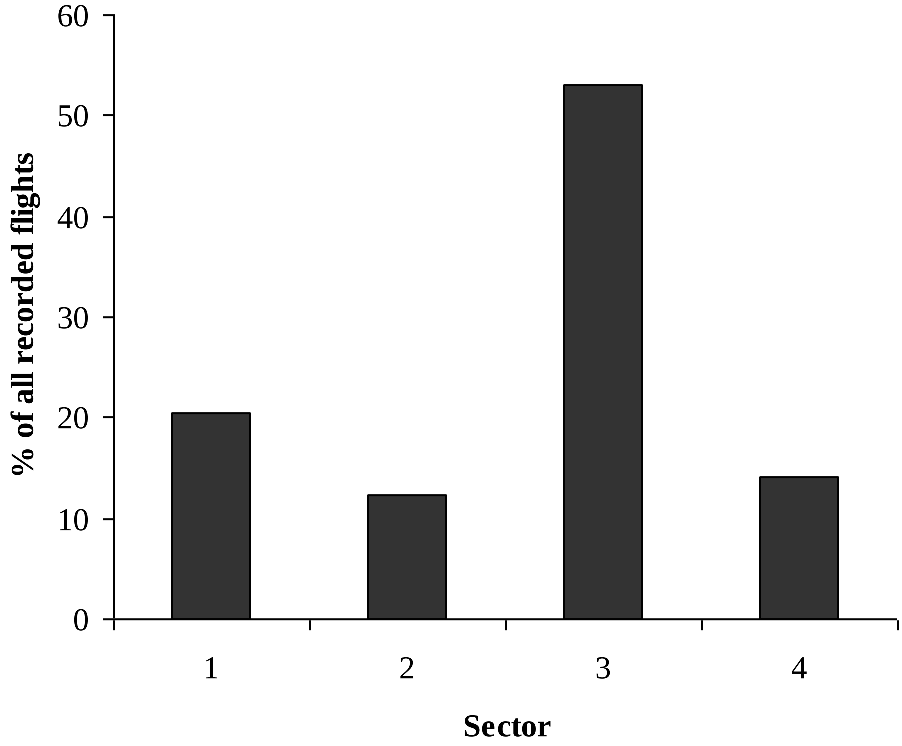

Figure 5.6 Spatial distribution of common tern foraging trips at the Imperial Dock Lock SPA. Data combined from 2009 and 2010.

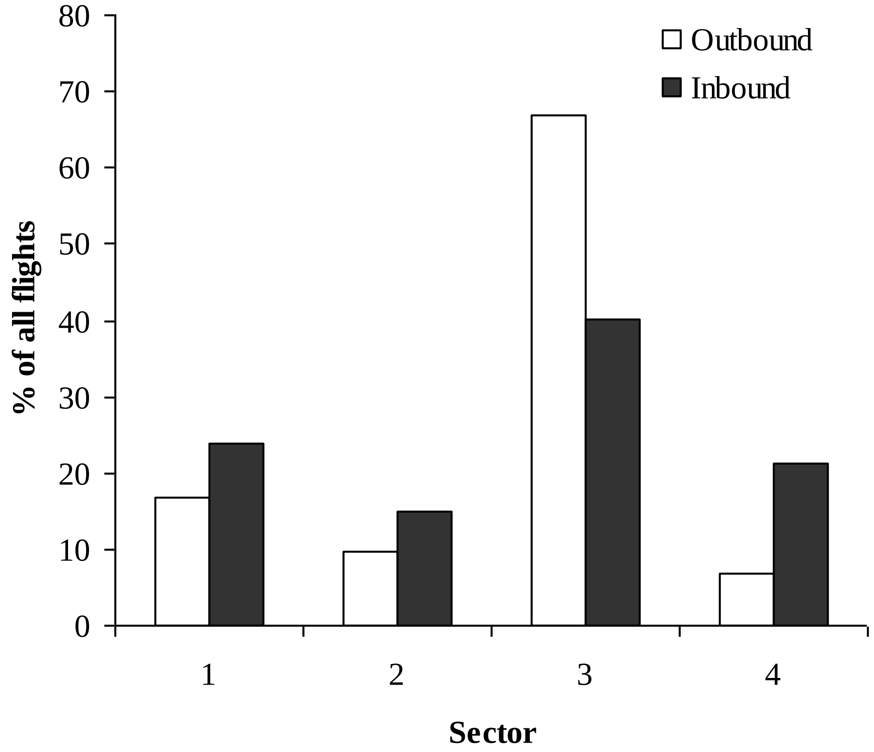

Figure 5.7 Spatial distribution of the outbound and inbound legs of common tern foraging trips at the Imperial Dock Lock SPA. Data combined from 2009 and 2010.

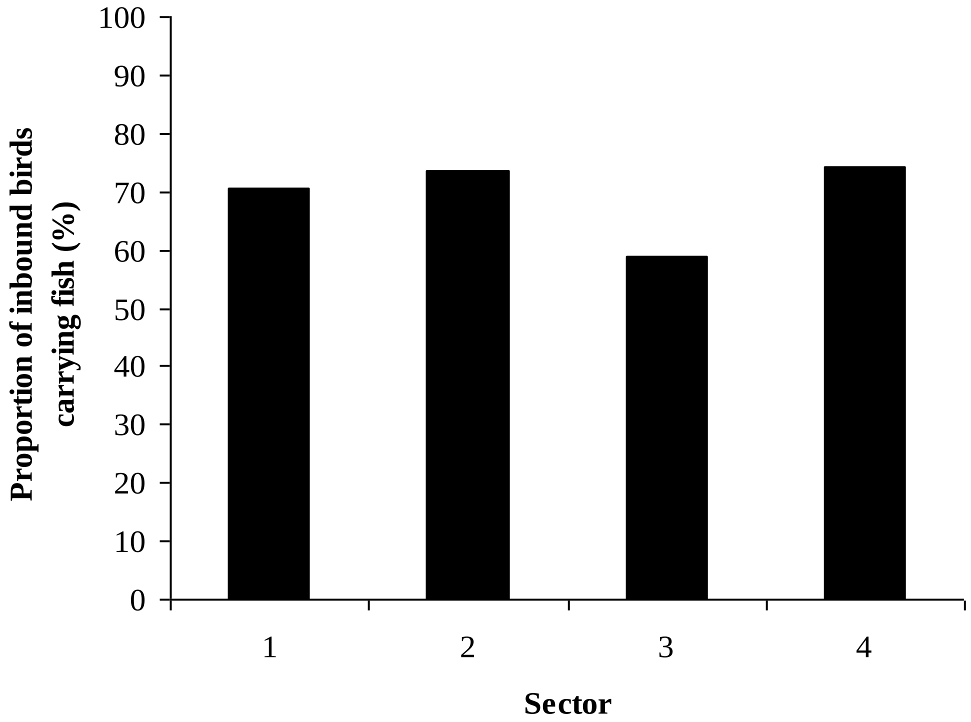

Figure 5.8 Proportion of inbound common terns with fish in each survey sector. Sector 3 had a significantly lower proportion than the other sectors ($p<0.05$). Data combined from 2009 and 2010.

Table 5.4 shows the results of the final GLM for the total number of terns recorded in each survey.

Table 5.4 Results of GLM for total numbers of terns counted in each flight survey. Parameter levels lacking a coefficient are included in the intercept coefficient. Significance values are ***: p<0.001, **: p<0.01, *: p<0.05.

Parameter	Coefficients	Degrees of freedom (d.f.)	Deviance	F value	Significance
Intercept	3.80727	-	-	-	***
Breeding phase		1	287.29	21.4	***
Incubation	-0.48546				
Chick-rearing	-				
Period		4	200.86	3.7	**
Dawn	0.56851***				
Morning	0.46196**				
Midday	0.22781				
Afternoon	-				
Evening	0.14432				
Wind speed	-0.01604	1	140.57	10.5	**
Sector		3	2361.78	58.6	***
Sector 1	-				
Sector 2	-0.4993**				
Sector 3	0.95207***				
Sector 4	-0.3305*				

Flight heights

The number of birds recorded varied significantly between height bands (Chi-square test, χ^2 = 1259, d.f = 3, p<0.001, Figure 5.9). Most birds (82%) were recorded flying at 20 m or less above ground level. Overall, 10.6% of birds were recorded flying between 0-5 m, 27.2% were at >5-10 m, 44.2% were at >10-20 m and 18% were at >20 m. The distribution of flight heights used varied between the four survey sectors (Chi-square test, χ^2 = 727.1, d.f = 9, p<0.001, Figure 5.10). Sectors 1 and 2 had the greatest proportion of birds at 0-5 m and sector 4 had the lowest (z-test, p<0.05). Sector 4 also had a lower proportion of birds at >5-10 m than the other sectors (z-test, p<0.05). Sectors 3 and 4 had higher proportions of birds at >10-20 m than sectors 1 and 2 (z-test, p<0.05). Sector 4 had a greater proportion of birds flying >20 m than the other sectors (z-test, p<0.05). Counts are broken down further to illustrate inbound and outbound flight heights in each sector in Figure 5.11.

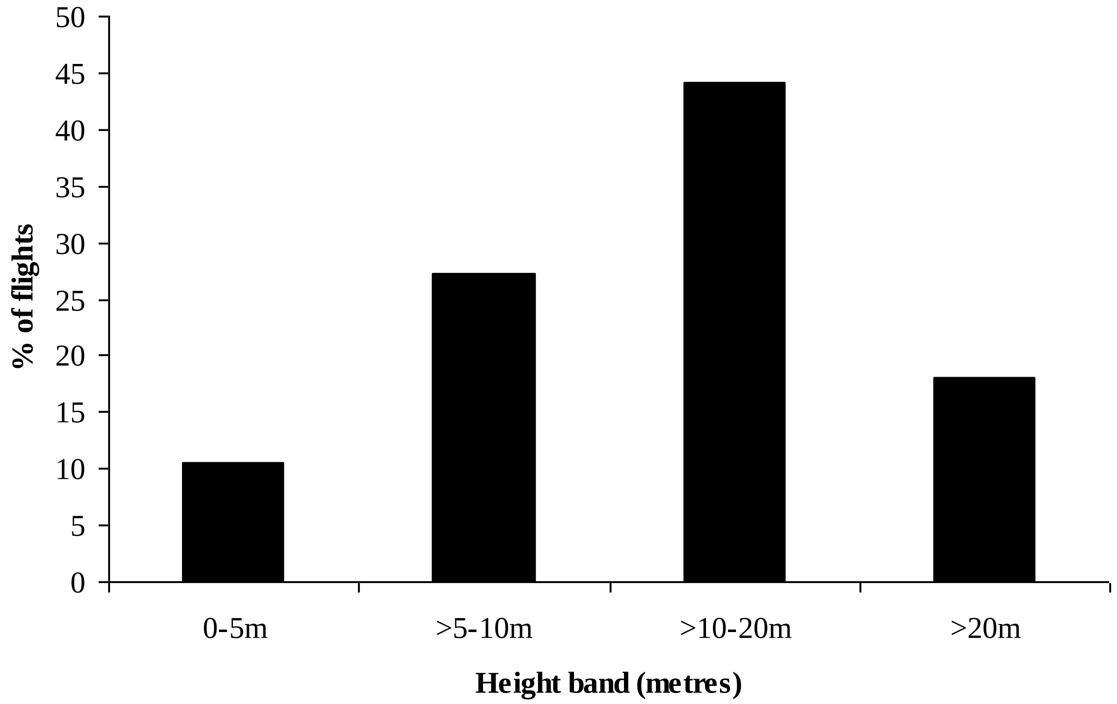

Figure 5.9 Distribution of flight heights of common terns as they passed survey points between the nest site and the Firth of Forth. Heights are metres about ground level. Data combined from 2009 and 2010.

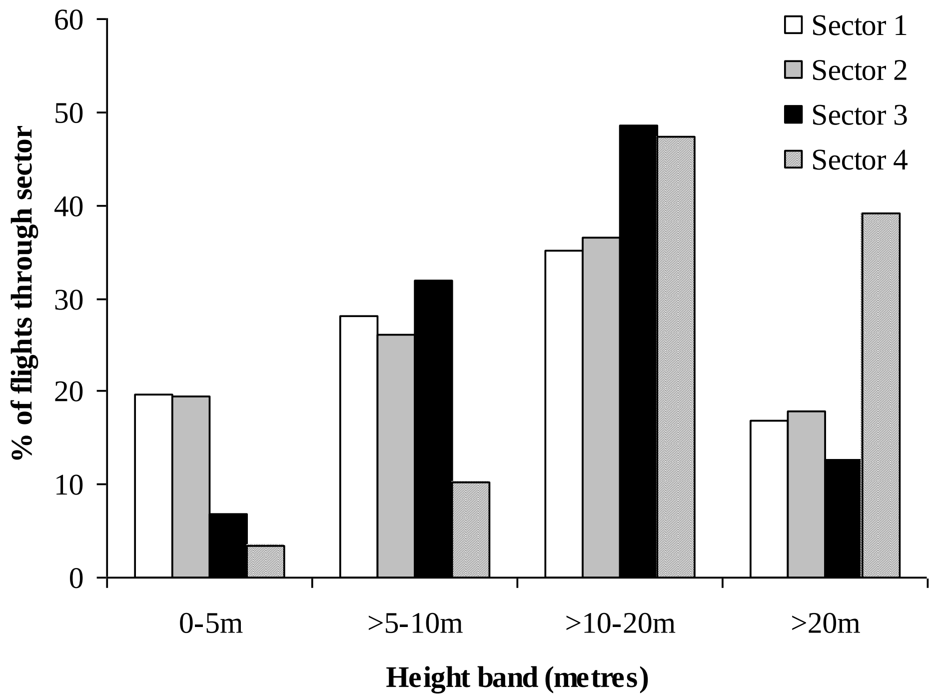

Figure 5.10 Distribution of flight heights in each survey sector. Values are percentage of the total birds counted in each sector. Heights are metres about ground level. Data combined from 2009 and 2010.

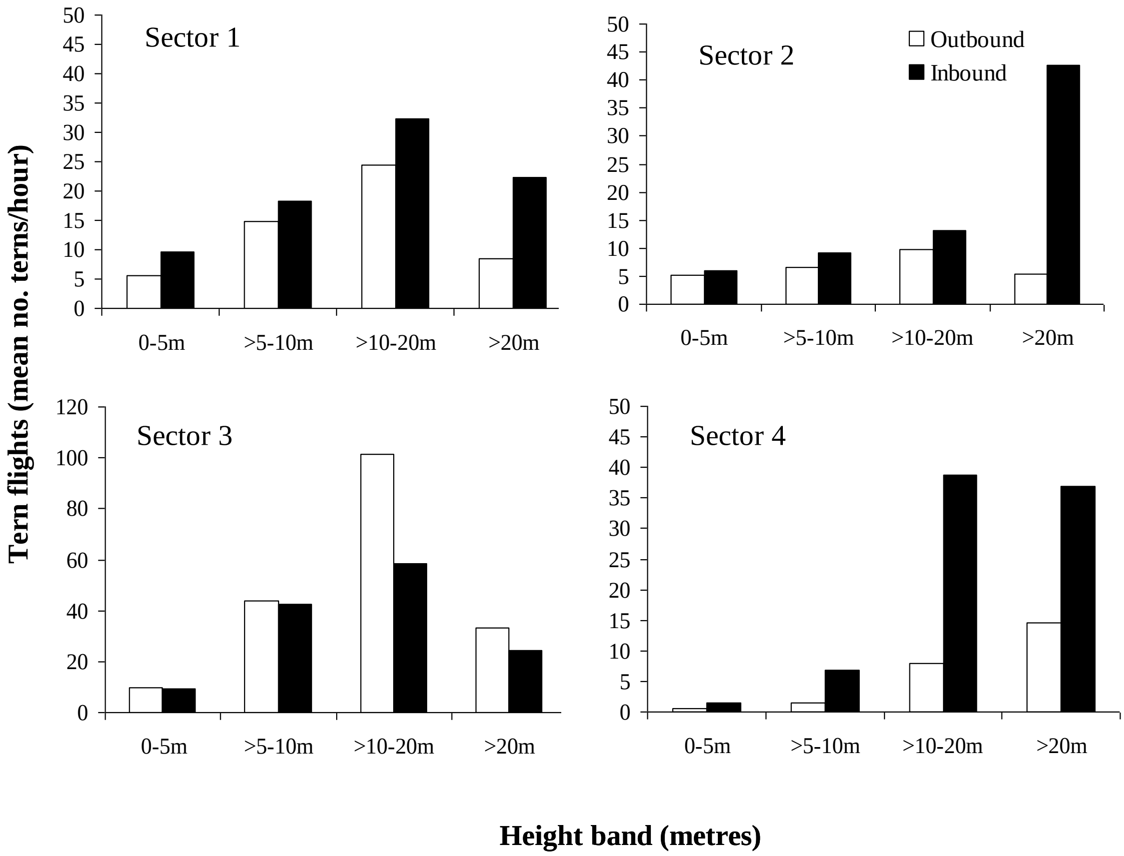

Figure 5.11 Flight heights of outbound and inbound terns passing through each survey sector. Heights are metres about ground level for each sector (note the different scale for sector 3). Data combined from 2009 and 2010.

5.4 Discussion

Flight lines surveys of common terns breeding at the Imperial Dock Lock SPA found that numbers of commuting birds showed high variability which could be explained by a combination of temporal, environmental and spatial factors. No evidence of collisions with buildings or other port structures was found.

5.4.1 Temporal patterns of foraging activity

The number of terns recorded during flight line surveys had a strong temporal influence. Greater rates of commuting birds were observed during chick-rearing than incubation, reflecting the need for adults to provision chicks as well as self-feed (Burger & Gochfield, 1991). Greater foraging flight activity was also recorded at the start of the day (from dawn and throughout the morning), a pattern observed in other studies of common tern foraging behaviour (for example Frank & Becker, 1992, Morris, 1986, Frank, 1992 and Bugoni & Vooren, 2004). This diurnal pattern is explained by the fact that, as visual foragers, common terns feed only during daylight and so compensate for overnight fasting with high foraging activity early in the day (Frank & Becker, 1992).

5.4.2 Environmental conditions

Numbers of terns passing between the nest site and foraging grounds decreased with increasing wind speeds. Wave amplitude increases with wind speed, making prey capture more difficult, so the lower rate of commuting birds likely reflects increased trip duration due to more difficult fishing conditions in higher winds. At very high wind speeds, flight ability may also be reduced, further reducing foraging rate (Taylor, 1983). In contrast with previous tidal studies (Frank & Becker 1992, Becker *et al.*, 1993), tidal state did not influence the number of terns foraging (based on the number of birds recorded passing between the colony and the Firth of Forth), but this is not to say that foraging is not influenced by tidal state in a spatial sense. Becker *et al.* (1993) found that common terns foraging in the Wadden Sea showed site-specific tidal preferences and targeted different foraging areas during different parts of the tidal cycle. Nevertheless, no such pattern was detected at Leith Docks since the flight line surveys focussed on the passage of terns over the docks between the colony and the Firth of Forth, rather than tracking them once at sea.

5.4.3 Spatial trends

Flight lines between the colony and the Firth of Forth were widespread along the sea wall, with commuting terns being recorded in all four survey sectors. Sector 3 was by far the most used of all routes, accounting for more than half of all recorded flight lines. The route in sector 3 is the shortest distance to the Firth of Forth, providing the quickest means of reaching the Firth of Forth. Sector 1 was the next most-used route, possibly because it provides clear, open route out of the docks. Sectors 2 and 4 were used by similar numbers of birds. The direction of birds flying through each sector was examined to determine whether birds returned via the same route by which they left the docks. Sector 3 had more outbound birds than inbound birds, the opposite being true for the other three routes. The difference between the number of outbound and inbound birds in a single sector indicates that birds did not necessarily follow the same route on the outbound and inbound leg of the foraging trip. The choice of inbound route for each trip is probably determined by the location of where food is found, with terns returning to the colony via the closest sector.

On average, almost 70% of all inbound birds were seen to be carrying fish back to the colony, but this varied between survey sectors with sector 3 having a lower proportion

(58.8%) of inbound birds carrying fish than the other sectors. There are a number or reasons why birds may return to the colony without fish. Firstly, that they were only self-feeding, consuming prey once caught. These could be breeding or non-breeding individuals (it was not possible to distinguish breeders from not breeders). Secondly, foraging trips might not always be successful and birds may return to the colony without prey for their partner or chick, for example in periods of adverse weather. Finally, some birds observed returning without fish might not have been returning from a foraging trip but could actually be returning from bathing. Very few birds were seen bathing near the colony and it therefore seems likely that most would go out into the Firth of Forth to bathe. As the quickest route to the colony, the greater number of inbound birds without fish in sector 3 would further support the possibility that this route is used by birds going out to the Firth of Forth to bathe.

5.4.4 Flight heights

Commuting terns occupied a range of flight heights from just above ground level to over 20 m, but most (82%) flight lines were below 20m. Flight lines are not currently obstructed by buildings (both sectors 3 and 4 require terns to cross over buildings) but terns did appear to use the lowest route available. In sector three for example, inbound birds approaching the sea wall in line with buildings were seen to increase their flight height as they crossed the sea wall to allow them to skim over the rooftop. This suggests that birds are already increasing the height of their flight lines from sea to over land to accommodate the built environment and that a further increase in building height could cause increased energy expenditure.

5.4.5 Conclusions

This study identified the major flight lines of foraging terns between the nest site at the Imperial Dock Lock SPA and their feeding grounds in the Firth of Forth. Although flight routes were widespread, sector 3 is particularly important and provides the quickest route between the nest site and the Firth of Forth. No structures in the port such as buildings, cranes or cables were found to pose a risk in terms of collision, and the wide distribution of flight paths along the seawall indicates that flight routes are not currently constrained by the built environment. Terns occupied a core flight height range of below 20m. The impact of any structural changes between the colony and the feeding grounds will depend on the location, height and size of the development as well as the availability of spaces between buildings.

6 Predators of common terns at the Imperial Dock Lock SPA

6.1 Introduction

6.1.1 Coloniality and predation

Increased protection from predators is one the main proposed factors in the evolution of colonial nesting in seabirds (Gaston, 2004). Earlier detection of predators and increased ability to deter predators through increased numbers may result in lower rates of predation at colonies. Colonial nesting may also facilitate predator avoidance through the Selfish Herd effect, in which individuals group to seek cover from a predator (Hamilton, 1971). At the same time however, colonies can be conspicuous and attract predators, making the evolution of coloniality a subject of debate (Danchin & Wagner, 1997). It is likely that other potential benefits of group-living, in particular those relating to increased foraging success, are also important in the evolution of coloniality. Due to the potential of colonies to attract predators, nest sites in areas where predators are scarce or absent are preferred, but nest site selection is also governed by the availability of suitable nesting habitat and close proximity to a reliable food supply (Gaston, 2004).

Protection from predation has been considered with relation to colony size, spatial position of nests and synchronicity of egg-laying. Predation rates should be lower in larger colonies due to more effective antipredator behaviour. In the Selfish Herd model, an individual's survival depends on the number of immediate neighbours such that those at the edge are at greater risk than those at the centre (Hamilton, 1971). In seabird colonies, this model predicts that the centre of the colony is the optimal nest location and that predators acting on the outer nests will be subject to less severe antipredator behaviour, resulting in reduced breeding success around the periphery (Brunton, 1997; Tenaza, 1971). However, Coulson (1968) attributed differences in productivity between edge- and central-nesting black-legged kittiwakes (*Rissa tridactyla*) at a colony in North Shields, England, to differences in male quality at different areas of the colony, rather than any differential effect of predation. Terns may nest as single pairs or colonially, and colony size can range from a few pairs to several thousand. Several studies have investigated the relationship between centrality and predation in terns, although findings varied between colonies; some found evidence of increased predation around the colony edge (Becker, 1995), some found no effect

(Sorokaite & Budrys, 2000) and others reported increased predation at the centre of the colony (Brunton, 1997). Becker (1995) found that under strong predation pressure from herring gulls (*Larus argentatus*), common terns (*Sterna hirundo*) at Mellum Island (Wadden Sea, Germany) benefited from increased nest density and centrality, but centrality was also associated with earlier nesting and presumably therefore higher quality and/or more experienced pairs. With synchronous laying, chicks hatching during the peak period may gain further protection from predation than young hatched much earlier or later in the season (Becker, 1995).

6.1.2 Predators of terns

Terns are found across a range of habitats including freshwater and saltwater, island and mainland and natural and man-made sites and consequently are targeted by a wide range of predators. Given that breeding colonies of terns persist for only a few months each year, predators acting on such colonies must be flexible in their feeding preferences. For some, terns may serve to supplement a varied diet, for others, the arrival of terns may mean a major shift in predatory behaviour, even to the point of exclusivity. Long term monitoring of common, roseate (*S. dougallii*) and Arctic tern (*S. paradisaea*) colonies in Cape Cod, Massachusetts found predation by the brown rat (*Rattus norvegicus*) to be the greatest threat to breeding success over a 19 year period (Austin, 1948). Austin described in detail the pattern of predation by rats at a tern colony; rats switch from their former source of food as soon as the terns arrive to breed, killing adult terns by night. The method of predation is very wasteful, with one individual killing several adults in a night (reported in the range of 3-20 in the Cape Cod colonies) but only eating a small fraction of the prey and never returning to feed on a previous catch. Once laid, rats switch to feeding on eggs, and then to chicks, again only feeding on a small portion of each kill.

Mammalian predators at tern colonies include both native and non-native invasive species, including rats, foxes, dogs, cats, skunks, hedgehogs, otters and mink. On the island of Foula in Shetland, Arctic tern chicks were found to be predated by a usually non-predatory species, the domesticated sheep (*Ovis aries*); sheep were selectively eating the bone-rich parts of the chick (legs, wings and heads), a behaviour believed to be a response to calcium deficiency in sheep diet (Furness, 1988). Introduced American mink (*Mustela vison*) is an important predator of many seabird species, including terns, throughout Europe. Brought to Europe in the 1920’s and 1930’s for the fur-farming industry, feral mink populations established throughout many parts of Europe following escape or release from farms

(Cuthbert, 1973). In western Scotland, mink became established on the mainland and on the islands of Lewis and Arran (the latter of which had no recorded fur farm, suggesting illegal keeping of mink) during the 1950's and 1960's (Cuthbert, 1973). In this region, mink caused widespread breeding failures of entire colonies between 1989-1995, resulting in reduced productivity in areas where mink was present, a decline in regional numbers of common tern and a redistribution of terns into fewer, but sometimes larger, colonies on mink-free islands (Craik, 1997; Craik, 1995; Ratcliffe *et al.*, 2008). Mink control around tern colonies in Argyll has been shown to dramatically increase tern breeding success; in a 20-year study common tern breeding success was reduced by food shortage in only one year, whereas mink affected breeding success in every year at those colonies they could reach and where they were not trapped out (ap Rheinallt *et al.* 2007). Feral mink populations have been long-established elsewhere in northern Europe (Cuthbert, 1973), and in Finland a mink removal experiment resulted in increased productivity for Arctic terns at colonies at which mink were active (Nordström *et al.*, 2004).

Avian predators of terns include birds of prey, corvids, herons and larger scavenging and predatory seabirds such as gulls and skuas. Gulls are one of the most important diurnal predators of tern eggs and chicks throughout their range – including herring gull and lesser black-backed gull (*L. fuscus*) in Europe and herring gull, great black-backed gull (*Larus marinus*) laughing gull (*L. atricilla*) and ring-billed gull (*L. delawarensis*) in North America. Nocera and Kress (1996) also observed nocturnal predation of common terns by great black-backed gulls at a colony on Stratton Island, Maine. Black-headed gulls (*Chroicocephalus ridibundus*) often nest among terns and may take eggs, but usually not chicks, as found at mixed tern colonies at the Sands of Forvie, northeast Scotland (Fuchs, 1977) and Coquet Island, northeast England (Langham, 1974). Although gulls as species are generalist predators, it is often the case that individual gulls acting at tern colonies are specialists, focusing their foraging efforts on a colony during the breeding season. Guillemette and Brousseau (2001) state that gull specialists on tern eggs and chicks represent a small proportion of a nesting colony (~1%), defend feeding territories that are distinct from their breeding territory, and are mostly males. While gulls are important predators of terns but they may also impact breeding terns by usurping nesting habitat. Gulls start breeding earlier in the season and will usually be incubating eggs by the time terns arrive to breed. This can lead to competition with gulls and even displacement of terns from a site entirely. In areas where good quality nesting habitat is limited, displacement from a favoured site may cause delayed breeding and result in the use of less suitable habitat by terns (Kress, 1983), further adding to the impacts of gulls. In North

America, nocturnal predation by great horned owl *Bubo virginianus*, short-eared owl *Asio flammeus*, long-eared owl *A.otus* and black-crowned night heron *Nycticorax nycticorax* is known to impact tern productivity (summarised by Nocera & Kress, 1996). Common tern colonies may also be attacked by peregrine falcons (ap Rheinallt *et al*., 2007). A somewhat unusual predator of common tern (and roseate tern) eggs is the starling *Sturnus vulgaris*, which has been reported to take quite large numbers of eggs at the Farne Islands and at a colony in the Azores (Neves *et al*., 2006).

6.1.3 Predators in urban and industrial environments

There are relatively few studies of predators at urban or industrial common tern nesting sites, but the long-term work of Professor Peter Becker and colleagues at the Banter See colony in Wilhelmshaven provides a detailed insight into many aspects of ecology including predators. Here long-eared owls and short-eared owls have taken chicks in many years (Sudmann *et al.*,1994) and predation by brown rats was a problem at the colony in 1993 (Ludwig & Becker, 2008).

While there is little information on predation of common terns in Leith Docks, analysis of long-term data on the distribution of the Firth of Forth common tern population in relation to numbers of gulls (herring and lesser black-backed combined; see Chapter 3) indicated that numbers of predators were an important factor in distributional shifts that eventually resulted in colonisation of the docks. On both the Isle of May and Inchmickery, large common tern colonies existed only when gull numbers were relatively low. Similarly, at Aberlady Bay Nature Reserve, records for the period 1978-1995, attribute breeding failure of common and Arctic (recorded as “comic”) and little terns to a combination of nest site flooding, significant predation by fox and possible predation by hedgehog (John Harrison, pers. comm. 2011). An understanding of breeding success is fundamental for conservation plans, and predation is often a major determinant of seabird productivity.

This aims of this chapter were to:

1) Describe the types of predators active at the colony and the reactions of terns to them

2) Measure predation rates and patterns.

3) Consider the potential impact of site development or change in use in relation to possible effects on predator populations.

6.2 Methods

Observations of predation were made at the Leith colony during the breeding seasons of 2009 and 2010, and to a lesser extent in 2011. Any visible predation activity was recorded, noting the species, time of day, the outcome of the predation attempt and the response of the terns to the predator (such as the number or proportion of terns mobbing the predator). Predators were identified and they were often tracked visually to gather further information such as whether they resided within the docks (and if so, where) and whether they were breeding. In the case of gulls in particular, an attempt was made to determine if a small number of 'specialists' – gulls that specialise on feeding on tern chicks - were acting on the colony, or if the attacks were purely opportunistic and undertaken by any gulls. 194 hours of observation were performed over the three seasons (139 hours in 2009, 44 hours in 2010 and 11 hours in 2011). A survey of nesting gulls was performed in 2010 by counting all visible gull nests on rooftops in the docks (within the docks no gull nests were found on sites other than rooftops).

Observations were made from the dockside to the south of the colony, using 10x40 binoculars to confirm the identity of the predator or whether an egg or chick had been taken. Observations were performed between 0500 and 2100, although very little activity occurred in the evening, so observations of predation events were more concentrated between early morning and late afternoon. Periods of observation varied from 1.5 hours to 4 hours, and were dictated somewhat by port activity, but periods of at least 2 hours were preferred to give a representative picture of predator activity at the colony, as activity can be sporadic. Although very little activity was recorded in the evenings, a night survey was performed in 2009 to confirm that predators were not acting on the colony after nightfall.

People working in the docks occasionally provided information on the colony, including sightings of predation events. Anecdotal reports were not included in any quantitative analysis but were a useful source of additional information.

6.2.1 Predation rates

Due to variation in the duration of observation periods, rates of predation attempts and of chicks taken (per hour) rather than absolute numbers were subject to statistical analysis. Rates of both the total number of attacks and the number of successful attacks (i.e. those in which a chick was taken) were analysed to allow comparison between weeks and years. Total attack rate and success rate were calculated for each species of gull for each day of observation. A Mann-Whitney U test (also known as the Wilcoxon rank-sum test) was used to compare rates between years and between gull species. A Kruskal-Wallis test was used to test for differences in predation rates over the breeding season by comparing rates between the first four weeks after the date of first hatching (11/06/2009 and 08/06/2010). Hatching was largely synchronous within the tern colony, so these four weeks roughly correspond to 1-4 week old chicks.

6.2.2 Location of predation attempts

In 2010 the location within the colony of each predation attempt was noted to determine whether particular parts of the colony were being targeted, and if predation rates varied between chicks taken from the island and chicks taken from the surrounding water. The number of chicks taken by gulls in each week from the SPA and the surrounding water was compared using a chi-squared contingency test. To investigate differences in attacks on the island itself, the island was divided into sectors A-J based on the position of fixed bollards on the former lock wall (Figure 6.1 and Figure 6.2). This method of dividing the colony is used by the Forth Seabird Group for nest counts (performed on June 11th in 2010), and it was also used to count the number of chicks and fledglings on July 6th 2010, allowing a comparison between locations of predation attempts and nest density. Figures 6.2 and 6.3 show the type of nesting substrate used at the site. As the chick count was performed from the dockside rather than on the island itself, the values will undoubtedly underestimate the number of fledglings, as some chicks will have been hidden by vegetation and stones. A Pearson correlation was used to test for association between the number of nests and productivity (chicks/pair), the number of nests and number of predation attempts, and number of predation attempts and productivity at each sector.

Figure 6.1 Aerial view of the Imperial Dock Lock SPA indicating the position of each sector (A-K). The two cranes visible overhang the colony but are not attached to it. Map source: Google Maps.

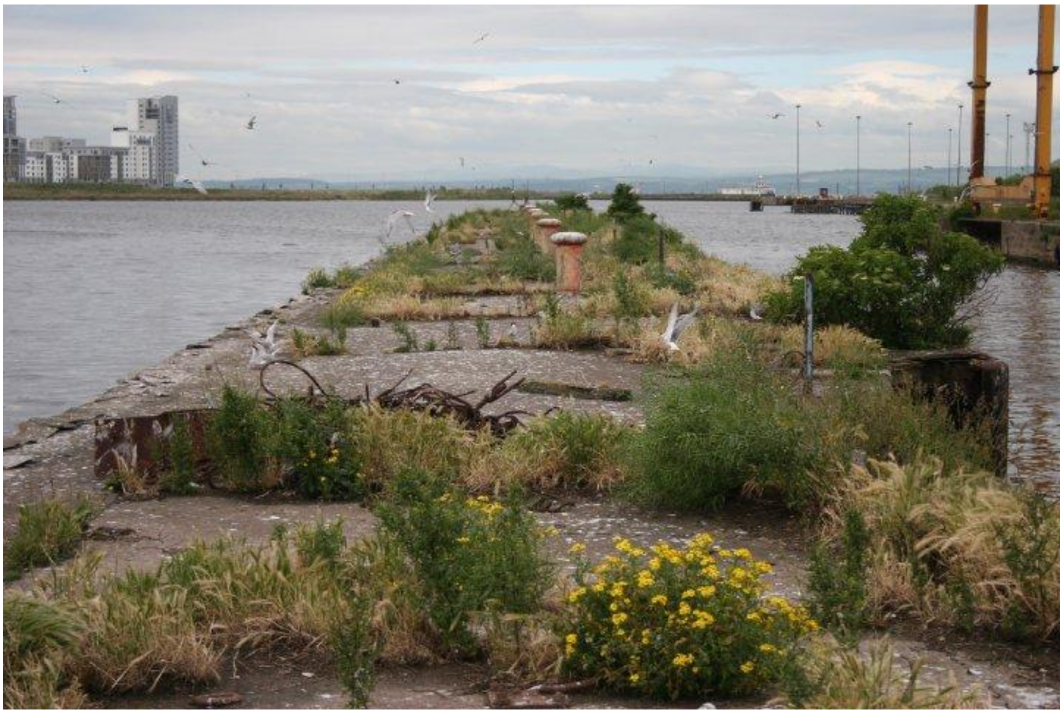

Figure 6.2 View of the Imperial Dock Lock SPA, looking westward. © Gemma Jennings.

Figure 6.3 Common tern nests at the Imperial Dock Lock SPA. Most nests were alongside patches of vegetation. © Gemma Jennings.

6.3 Results

6.3.1 Types of predators and responses of terns

Terns were highly successful at differentiating between predatory and non-predatory species and also between types of predators. Eiders were frequently present in the water surrounding the SPA and starlings (which at Leith were not predatory on tern eggs) and pigeons occasionally landed on the SPA but received little attention from the terns.

The following predators were active at the common tern colony during the study:

Gulls

During the egg stage, gulls rarely approached the colony other than in passing, and no egg predation events were observed. Terns showed little response to gulls during the egg stages. However, lesser black-backed gulls and herring gulls were the most important predators of tern chicks during the study (see 6.3.2 on predation rates). Although many immature gulls were observed in the docks, only adult gulls targeted the colony. Gulls flying past the colony without scanning for chicks or making any predation attempt tended to elicit little or no response from the terns. However adult terns always responded strongly to predation attempts by gulls by chasing and mobbing; if the gull was detected early enough, the mobbing response was often sufficient to deter the gull, but for those which managed to reach the colony, the predation attempt was almost always successful. When targeting the colony, a large proportion of adults in the surrounding area would lift off the nests and attack the gull as a group (see Figure 6.4). Gulls would swoop down and pick up a chick mid-flight or land on the colony, pick up a chick and then fly off. Tern chicks tended to move towards vegetation patches for cover during predation attempts and on a number of occasions gulls were seen to land on the SPA and walk to the nearest patch of vegetation to pick off a chick. Chicks were sometimes swallowed instantly but, if too large, they were carried off by the gull (see Figure 6.5 and Figure 6.6) either to the gull's nest or to an area where the gull could take time to consume the chick (see Figure 6.7). Gulls were active during daylight hours but were not seen around the colony at night and it is believed that nocturnal predation by gulls did not occur.

A total of 6 lesser black-backed gull nests, 1 herring gull nest and 2 unidentified large gull nests were counted in June 2010. Lesser black-backed gulls were tracked visually back to nests on one rooftop (the Subsea 7 Internal Plant building) and on one occasion, one was seen to make 3 successive successful predation attempts, returning to its nest each time. Table 6.1 shows the use of buildings around the Imperial Dock by nesting gulls.

Table 6.1. Gulls nesting on rooftops of buildings around the Imperial Dock in Leith Docks in 2010.

Building	**Lesser black-backed gull nests**	**Herring gull nests**	**Unidentified gull nests**	**Total**
Subsea 7 Internal Plant	4	1	0	5
Grain Shed 2	2	0	0	2
Enamel Plant	0	0	1	1
Imperial Dock southeast warehouse	0	0	1	1
Total	6	1	2	9

Figure 6.4 Typical reaction of common terns to a gull attack, in this case a herring gull. © Gemma Jennings.

Figure 6.5 Lesser black-backed gull flying off with a chick from the colony. © Gemma Jennings.

Figure 6.6 Five common terns chasing a herring gull after taking a large chick. © Gemma Jennings.

Figure 6.7 Herring gull consuming a chick taken from the colony on the roof of Shed 1. © Gemma Jennings.

Crows

A single pair of carrion crows *Corvus corone* nested on the gantry crane adjacent to the colony in each year of study, in the same location as had been used in previous years (John Davies, *pers. comm.* 2009). Crows took eggs only on a few occasions and did not appear to be a direct threat to productivity. However the crows crossed the tern colony several times a day when leaving and returning to their nest, and this almost always resulted in a behavioural response from the terns. This response typically consisted of terns lifting off the colony and chasing and mobbing the crow if it came close to the colony (see Chapter 7 for more information). When crows returned to the nest and then perched on the crane, a strong reaction was observed, with a large proportion of the colony lifting off, gathering around the crane and mobbing the crow (see Figure 6.8). When a crow fledgling was seen on June 15th 2010 it remained in the area just below the cranes and was mobbed heavily and defecated on by terns to the point where it was difficult for the crow to fly.

At one point was hoped that some adult terns could be caught and marked to aid identification of individuals in a foraging study. Based on the strong reaction of terns to crows, a stuffed crow was used to attract terns to a mist net. When placed on the dockside beneath the cranes a strong mobbing response was observed, similar to that for a live crow and the stuffed crow very quickly became heavily soiled with tern faeces. While the attempt to catch terns proved largely unsuccessful (only one tern was caught), it provided an interesting opportunity for observation.

Figure 6.8 Common terns reacting to a crow on the gantry crane by the colony. © Gemma Jennings.

Mink

In 2009, port staff working around the colony reported the presence of mink in recent years; this was validated by John Davies who was previously involved in a mink trapping effort at the colony in response to observations of mink attempting to access the colony. No mink were seen during observations in 2009. However during a night observation, 15 terns were observed aggressively mobbing something in the water by the SPA. Closer inspection revealed the recipient of this attack to be a piece of floating debris which closely resembled a mink, a strong indication of prior experience of this predator. Employees reported sightings of mink regularly from at least the 1970s (Derek McGlashan, *pers. comm.*) but since no mink were observed or reported in 2009, it is possible that they were not active in the dock in this particular year. However, mink were observed at the colony in both 2010 and 2011. The first sighting of mink during observations was on the morning of June 4th 2010 (4 days before the first tern chicks were observed). A large group of terns were hovering over and mobbing something in the channel of water on the south side of the SPA, which was found to be a mink swimming directly towards the colony. When the mink reached the south edge it climbed onto the bottom rung of the easternmost ladder on the wall of the island. The terns continued to attack the mink and it then swam around to the north side of the colony. The terns followed and continued to respond with mobbing behaviour. On the north side of the island the mink attempted to access the colony via the old lock gate mechanism built into the side of the lock wall. On this occasion the terns successfully prevented the mink from accessing the colony. Subsequent conversations with dock workers indicated that a mink had been seen around the docks in the days before this incident and that one was often seen by an embankment in the Imperial Dock and came close to workers in this area of the docks. The mink was observed subsequently during daylight near the colony, as shown in Figures 6.10 and 6.11. It seemed well habituated to the environment, coming very close to both observers and dock workers on the dockside. On June 10th 2011, I received further reports mink activity around the colony in the previous two weeks and of a mink on the island one evening. Predation by mink in 2011 therefore seems likely but was not quantified, and was apparently not extensive.

Figure 6.9 Reaction of common terns to a mink on the dockside to the south of the Imperial Dock Lock SPA. © Gemma Jennings.

Figure 6.10 Mink on the dockside near the observation area (the Imperial Dock Lock SPA is visible in the background. © Gemma Jennings.

Other potential predators

Peregrines were present in the port and have nested there in recent years. Although nesting was not confirmed during the study, single peregrines were observed flying over and around the Imperial Dock. Peregrines targeted pigeons but were never seen to approach or attempt to predate the terns. Despite this, the adult terns responded very strongly to the passing of a peregrine over the colony, with all adults becoming completely silent and leaving the nest site in a coordinated dread. Starlings were frequently observed on the colony, normally in the few bushes that are present on the island and occasionally on the ground, although they did not appear to be feeding on eggs, and terns showed no visible response. Black-headed gulls were occasionally seen around the SPA and were possibly nesting on wasteland on the dockside to the north of the SPA, but again, no predation attempts were observed.

The colony is surrounded entirely by water, offering protection during the incubation and chick rearing phases from truly terrestrial predators. Once fledged, many juvenile birds left the colony and gathered on the dockside adjacent to the SPA, presumably to minimise conflict with remaining nesting birds. This could make juveniles vulnerable to attack from land-based predators. Foxes were observed in the docks, but never near the colony. Feral cats are present in the docks and paw prints were recorded on a couple of occasions on the dockside north of the colony; it seems possible that cats could target juvenile terns resting in this area, but no incidences were observed. On one occasion terns were observed mobbing a heron over the western harbour, although predation was not observed.

6.3.2 Predation rates

Although mink may have predated some terns in 2011, this was not quantified so this analysis focuses on data from 2009 and 2010, when gulls were the only significant predator at the site (egg losses to crows being trivial). Gulls took chicks but did not appear to take eggs. Table 6.2 summarises predatory activity of gulls at the colony in 2009 and 2010.

Total gull predation rates

During the tern chick-rearing period, there were no significant differences in the rates of total gull attacks between 2009 and 2010 (2.06±0.72 attempts.h^{-1} in 2009 compared to 1.75±0.53 attempts.h^{-1} in 2010, Mann-Whitney U test, $W = 259.5$, $p = 0.104$), nor was there any significant difference in the rates of successful attacks (i.e. the number of chicks taken; 0.51±0.23 chicks.h^{-1} in 2009 and 0.81±0.41 chicks.h^{-1} in 2010, Mann-Whitney U test, $W = 141.5$, $p = 0.115$). Success rates for 2009 and 2010 equate to approximately an average predation rate of 7 and 11 chicks/day respectively.

Predation rates by lesser black-backed gulls and herring gulls

There was a greater number of attacks by herring gulls in 2009 than 2010 (0.73±0.48 attacks.h^{-1} in 2009 and 0.3±0.29 attacks.h^{-1} in 2010, Mann-Whitney U test, $W = 313.5$, $p=0.002$), but the overall success rate did not vary significantly (0.21±0.27 chicks.h^{-1} in 2009 and 0.18±0.23 chicks.h^{-1} in 2010, Mann-Whitney U test, $W = 212.5$, $p = 0.712$). Conversely, the total number of attacks by lesser black-backed gulls did not vary between 2009 and 2010 (1.17±0.8 attacks.h^{-1} in 2009 and 1.21±0.73 attacks.h^{-1} in 2010, Mann-Whitney U test, $W = 183.5$, $p = 0.664$) but success rate was higher in 2010 than 2009 (0.26±0.29 chicks.h^{-1} in 2009 and 0.56±0.42 chicks.h^{-1} in 2010, Mann-Whitney U test, $W = 112.5$, $p = 0.016$).

In 2009, approximately 39% of all predation attempts were by herring gulls and 56% were by lesser black-backed gulls, although this difference was not statistically significant (0.73±0.48 attacks.h^{-1} by herring gulls and 1.17±0.8 attacks.h^{-1} by lesser black-backed gulls, Mann-Whitney U test, $W = 127$, $p = 0.117$). In 2010, 18% of predation attempts were by herring gulls and 82% by lesser black-backed gulls (0.3±0.29 attacks.h^{-1} by herring gulls, 1.21±0.73 attacks.h^{-1} by lesser black-backed gulls, Mann-Whitney U test, W = 61.5, p<0.001; Table 6.2).

There was no difference in the rates of successful predation attempts between gull species in 2009; herring gulls accounted for 44% of chicks taken and lesser black-backed gulls 56% (herring gulls took 0.21±0.27 chicks.h^{-1}, lesser black-backed took 0.26±0.29 chicks.h^{-1}, Mann-Whitney U test, W = 162.5, p = 0.581). In 2010 lesser black-backed gulls took significantly more chicks than did herring gulls, accounting for 76% of chicks taken (herring gulls took 0.18±0.23 chicks.h^{-1}, lesser black-backed took 0.56±0.42 chicks.h^{-1}, Mann-Whitney U test, W = 109, p = 0.004).

Table 6.2 Predatory activity of gulls on common terns at the Imperial Dock Lock SPA in 2009 and 2010. (*Gull not identified but likely to be herring gull or lesser black-backed gull)

Gull		**2009**	**2010**
Lesser black-backed gull	Predation attempts	92	159
	Chicks taken	23	74
Herring gull	Predation attempts	63	35
	Chicks taken	17	23
Unidentified gull*	Predation attempts	10	1
	Chicks taken	0	0
Total	Predation attempts	165	195
	Chicks taken	40	95
	Hours of observation	78	115
	Diurnal predation rate (chicks/hour)	0.51	0.83

Weekly predation rates

The overall attack rate varied significantly between weeks in 2009 (Kruskal-Wallis, χ^2 = 8.24, d.f = 3, p = 0.041; Figure 6.11) and in 2010 (Kruskal-Wallis, χ^2= 10.7, d.f = 3, p = 0.014; Figure 6.11). Rates of attack were lowest in the first and fourth week of chick rearing. Success rate did not vary significantly between weeks in 2009 (Kruskal-Wallis, χ^2 = 4.8, d.f = 3, p = 0.188; Figure 6.11) but did in 2010, increasing each week after hatching until week four, when rates declined (Kruskal-Wallis, χ^2= 10.7, d.f = 3, p = 0.014; Figure 6.11).

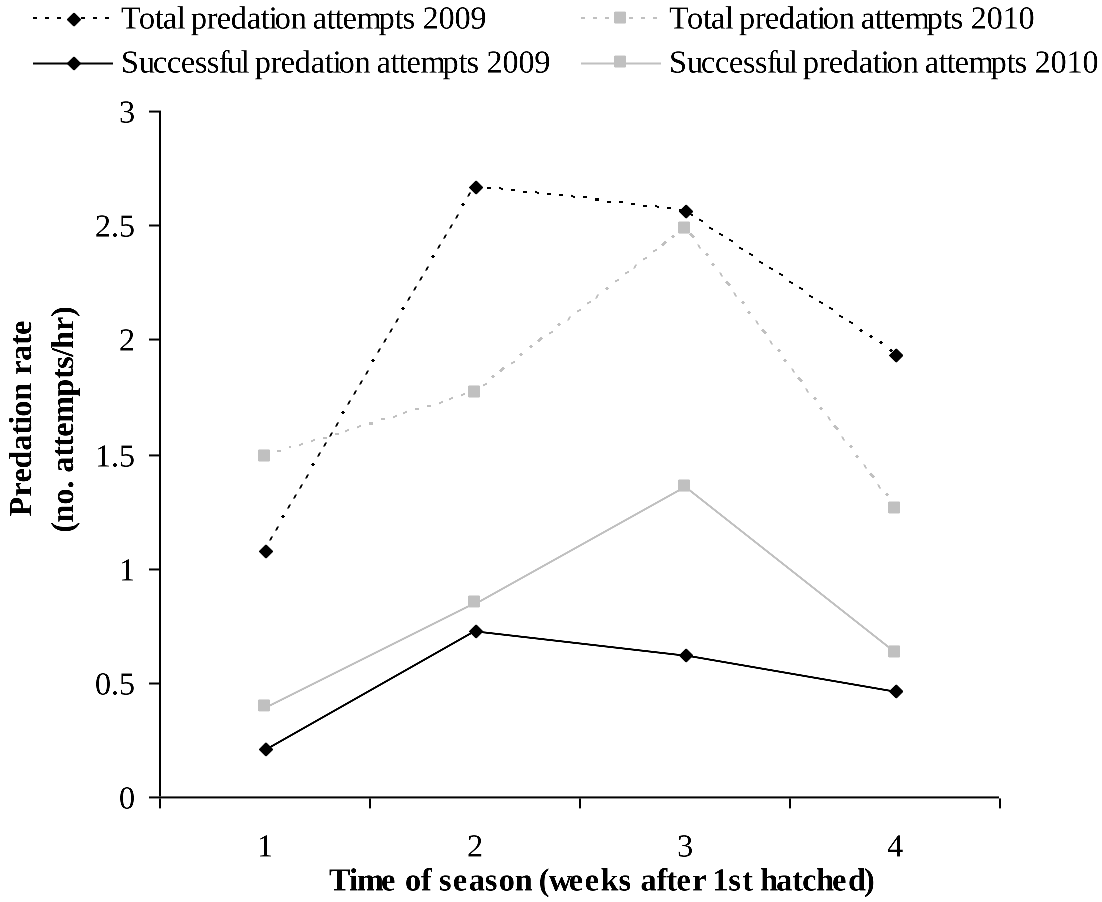

Figure 6.11 Predation rates of gulls on common terns at the Imperial Dock Lock SPA during chick-rearing in 2009 and 2010. Rates are shown for the total number of predation attempts and for successful predation attempts

Location of predation attempts

In 2010 the majority of predation attempts were directed at chicks on the island, but more chicks were taken from the surrounding water than the island; of 95 chicks that were seen to be taken by gulls, 76 were from the water. Chicks sometimes fell or flapped off the island into the surrounding water, especially when more mobile or close to fledging. Once in the water it was not possible to get back onto the island and these chicks would typically remain in the water around the island, sometimes resting on the ladders or tyres used as fenders around its edge. Only on one occasion was a chick seen to fly back onto the island after seemingly fledging too soon, and this followed much encouragement from its parent. Not only were chicks in the water more conspicuous than chicks on the island (due to lack of cover), gulls attacking such individuals received a weaker antipredator response from adult terns, meaning that chicks in the water were an easy target for gulls and that predation attempts in the water were more successful than those on the island. Both the total number of predation attempts and the number of successful predation attempts varied between the colony and surrounding water in each of the four weeks (total attacks: χ^2 = 20.5, d.f. = 3, p<0.001 and successful attempts: χ^2 = 30.0, d.f. = 3, p<0.001)

Of predation attempts on the island, most were directed at the east end of the colony. Taking sector F as the centre of the colony, 25 attempts were to the west of this sector and 55 to the east of it. Most gulls approached the colony from the east, from the Imperial Dock, which is close to where gulls were nesting. The greatest number of predation attempts were on sector J (20) which was both close to the easternmost point and had the highest nest density of any sector on the colony (see Table 6.3).

There was a significant positive correlation between nest count and number of chicks fledged for each sector (Pearson's product-moment correlation, r = 0.71, d.f. = 7, p = 0.032). Productivity (fledged chicks/pair) was slightly lower in sectors with more nests, but not significantly so (Pearson's product-moment correlation, r = -0.18, d.f. = 7, p = 0.633). Gulls made a greater number of predation attempts at sectors with more nests but again this difference was not statistically significant (Pearson's product-moment correlation, r = 0.58 d.f. = 7, p = 0.104).

Table 6.3. Nest counts, numbers of fledged chicks, and gull predation attempts for common terns at the Imperial Dock Lock SPA in 2010, defined by colony sector A-K, running west to east. Nests were counted on 11/06/10 and chicks on 06/07/2010. (*B/C and H/I were grouped together during the nest counts and so were left combined)

Colony sector	**A**	**B/C***	**D**	**E**	**F**	**G**	**H/I***	**J**	**K**	**Total**
Number of nests	3	159	102	102	95	75	111	164	7	818
Chicks fledged	0	72	50	45	72	52	91	40	8	430
Chicks/pair	0	0.45	0.49	0.44	0.78	0.69	0.82	0.24	1.14	0.53
Gull predation attempts	4	8	5	8	9	8	21	20	6	89
Gull predation attempts per 100 nests	133.3	5.03	4.9	7.84	9.47	10.67	18.91	12.19	85.71	10.88

6.4 Discussion

6.4.1 Types of predators and responses of terns

Common terns responded to a variety of animal species in the vicinity of the Imperial Dock Lock SPA and the nature of the response varied distinctly between species. We would expect different reactions based on the severity of the risk posed and whether adults, chicks or eggs were targeted. As long lived species, adult terns should favour their own survival above their chicks to maximize lifetime reproductive success. The reaction of terns to predation attempts by their main predators at this site - lesser black-backed gulls and herring gulls - generally consisted of mobbing and chasing, with the severity of the response increasing as the gulls came closer to the colony. Whilst gulls did not attempt to take eggs, predation of chicks was observed within a day of the first hatched tern chick, showing that gulls are able to detect the presence of chicks almost immediately and change their feeding behaviour accordingly. Terns removed egg shells from the nest upon hatching, depositing them in the water around the SPA. The white interior of eggshells stands out against the darker nesting substrate so it is thought that this removal behaviour may help to reduce conspicuousness of the nest to predators (Stienen *et al.*, 1997). Terns rarely reacted to gulls during incubation, showing that terns are able to modify antipredator behaviour in response to risk. Even at colonies where egg predation by gulls has been observed, terns have shown a greater defensive response during the chick stage than incubation (Whittam & Leonard, 2000). This can be attributed to both increased vulnerability of chicks to predation (chicks can move away from the nest, leaving them more open to attack) and to the greater reproductive value of offspring after hatching (Montgomerie & Weatherhead, 1988).

The reaction of terns to crows seemed disproportionate to the risk posed. A strong mobbing reaction was observed throughout each breeding season, despite the low impact of crows as predators. Although they did not nest on the SPA itself, the crows can be considered to be nesting on the periphery of the colony due to the close proximity of the gantry crane. McNicholl (1973) found evidence of habituation by terns to predators nesting on the periphery of a colony; in one case Arctic terns at 10 colonies in Churchill, Manitoba, attacked herring gulls on every approach, apart from at one colony where two pairs of herring gulls nested on the periphery. Forster's terns nesting at Delta, Manitoba, also attacked all predators as soon as they approached the colony, except for black-crowned night herons which nested on the periphery, which were attacked only when beginning to land (McNicholl, 1973). This habituation to peripheral-breeding predators has also been recorded in black-headed gulls, which attacked those predators nesting on the periphery of a colony only when landing or when exhibiting predatory behaviour (Kruuk, 1964). Selection should favour behaviours that strike a balance between habituation and aggression (McNicholl, 1973). A juvenile crow was attacked by the terns soon after fledging. It was mobbed and defecated on, a behaviour that was also reported by Fuchs at a colony of black-headed gulls and terns - here a juvenile crow was found dead and covered in faeces the day after an attack by terns (Fuchs, 1977). Given that crows rarely made predation attempts, this reaction of terns seemed to relate more to territoriality than any form of antipredator behaviour.

Although mink and peregrines are both potential predators of adult terns, the response of terns to each was vastly different. A peregrine flyover caused all adults to fall silent, flush and leave the area entirely, whereas when a mink was near or on the colony, the birds would flock around it, hovering in a dense group over the animal. In the case of the peregrine, fleeing serves to place the birds out of reach of a highly agile aerial predator from which they could not defend themselves. When responding to mink, a land-based predator, it is in the interest of the birds to lift of the ground to avoid attack, but there would be little benefit in leaving the site completely once the mink has already located the colony. Furthermore, this type of response can be an effective deterrent to mink, as observed at the Imperial Dock Lock SPA, making it a technique that aids in both the survival of adults and protection of eggs or chicks. Clode *et al*. (2000) suggest that the dense hovering of terns over mink may also serve to highlight the location of mink within a colony, acting as an “early warning system” for other adults in the colony.

Strong responses to low-risk species such as crows could potentially have indirect impacts on breeding success of terns. As terns typically fly off the nest during disturbance events these impacts could be mediated through nest attendance by interrupting incubation or brooding, resulting in cooling of eggs or increased thermodynamic stress for chicks (Burness & Morris, 1993). Disturbances also may create opportunities for other predators to move in undetected and non-attendance of parents also allows chicks to stray from the nest, thus further increasing their vulnerability to predation (Burness & Morris, 1993). If numbers of active predators, and therefore frequency of predation attempts were to increase then such disturbances could have even greater impacts.

6.4.2 Predation rates of gulls

Lesser black-backed gulls and herring gulls were the only significant predators of common terns at the Imperial Dock Lock SPA during the study. Predation attempts were made throughout the chick rearing phase in all years, but no attempts were observed during incubation. Analysis of predation rates from 2009 and 2010 showed that lesser black-backed gulls attacked the colony more frequently than herring gulls, although this difference was only statistically significant in 2010. In 2009 the total number of chicks taken by each species was equal, but in 2010 predation by lesser black-backed gulls accounted for approximately three quarters of the chicks taken. Although lesser black-backed gulls took a greater number of chicks in 2010 than did herring gulls, they also made a greater number of unsuccessful attempts, such that herring gulls had a higher proportion of successful attacks. Whilst both species have important impacts on productivity at this site, lesser black-backed gulls may have an additional negative impact on the colony through disturbance effects relating to the larger number of unsuccessful predation attempts. At least one lesser black-backed gull appeared to be specialising on feeding on tern chicks, as it was observed making repeated successful attacks on the colony. This ‘specialist’ phenomenon has been observed in other studies of gull predation on terns (Hatch, 1970, Guillemette & Brousseau, 2001). On the Isle of May in 1998, two lesser black-backed gulls and one herring gull accounted for 73% of tern chicks lost to predation and a single gull was found to be responsible for 85% of all successful predation attempts at a tern colony in Québec (Guillemette and Brousseau, 2001)

Gulls took chicks from the first day of hatching up to near-fledging but the frequency of attacks changed over the season, being lowest in the first and last weeks. Gulls seemed to focus their attacks on the most profitable period of chick rearing when chicks were numerous and of manageable size. In the first week of hatching, chicks would be small and less numerous and in the fourth week, their large size and mobility would make them less manageable prey.

Location of predation attempts was studied in 2010 to determine whether gulls were targeting chicks in certain areas. The majority of predation attempts were directed at chicks on the island, but more chicks were taken from the surrounding water than the island; not only were chicks in the water more conspicuous but attacks on such chicks also received a weaker antipredator response from adult terns, presumably because there was no way for these chicks to rejoin the colony. Most predation attempts on the island were directed at the east end of the colony, that is, the end closet to the Imperial Dock (from which most gulls approached the colony) and the end of the colony with the most nests. This indicates that, despite the potentially greater antipredator response from attacking a part of the colony with a higher density of nesting terns, gulls target the areas with the most chicks. For gulls approaching from the east, it makes sense to attack the part of the colony closest to them to minimise the time in which terns could react during the approach.

Breeding gulls

Other than one unsuccessful predation attempt by a juvenile gull, all observed attacks were by adult gulls, some of which were breeding in the docks. Several lesser black-backed gulls that were targeting the colony nested on the roof of the Subsea 7 Internal Plant building. There were fewer gulls breeding within Leith Docks than would be expected given the availability of suitable nesting habitat combined with the location of the Docks between the Firth of Forth and Leith itself, which provides easy access to both the marine and urban environments (only 9 nests were recorded in June 2010). Furthermore, no gulls currently nest on the Imperial Dock lock SPA itself. Gulls, whether breeding or non-breeding, were seen to feed opportunistically in the area on anthropogenic food sources in Leith (at waste bins and at a restaurant at the Ocean Terminal shopping centre) and on one occasion large numbers of gulls were observed feeding on starfish washed up along the sea wall following a storm. It is possible that such alternative food sources provide sufficient foraging opportunities to keep numbers of gulls feeding on the colony relatively low. Since gulls fed on tern chicks only over a period of a few weeks, by which time the gulls were already well advanced in their breeding season, it is clear that the gulls require other feeding opportunities to sustain them, and therefore they cannot be dependent on the terns. However, the availability of a variety of feeding opportunities for gulls, and the availability of large areas of apparently suitable nesting habitat on roofs of buildings, suggests that gull numbers breeding within the docks might increase, and such an increase could affect breeding success of the tern colony.

6.4.3 Conservation implications

High predator abundance at historical nesting sites for common terns in the Firth of Forth is largely responsible for the colonisation of Leith Docks. Terns attempted to nest at three sites on the Isle of May in 2011 but were targeted by gulls at all three colonies, resulting in the abandonment of breeding attempts (David Pickett, pers. comm., observations by the author). Leith Docks has a much lower abundance of predators than previous tern strongholds within the Firth of Forth, and although it can be considered somewhat of a 'safe haven' for terns, the fact that the majority of the Firth of Forth population breeds here (forming the largest common tern colony in Scotland) means that any heavy predation events at this one site could result in breeding failure for a significant proportion of the national breeding population.

At current predation levels, and with the low numbers of breeding gulls in the Docks, gull control does not seem necessary. Gull abundance here is vastly smaller than at previous strongholds of the common tern in the Firth of Forth (Inchmickery, Isle of May). However, monitoring of gull numbers and of predation rates would be recommended as part of any management plan for terns nesting at the Imperial Dock Lock SPA. Implemented carefully, gull control can be successful in improving breeding success of terns and any control measures should be targeted at specialist gulls (if appropriate), but would need to be carried out over consecutive years to continue to be effective (Guillemette & Brousseau, 2001). Gulls only made predation attempts during daylight; predation attempts involved visual scanning of the colony and it can be assumed that at night it was simply too dark for gulls to act as predators. Maintenance of current night light levels may therefore be one key to maintaining sustainable levels of predation and should be considered in future developments of the site.

The impact of predation may be minimised by improving the nesting conditions at the SPA; the site consists of bare concrete with sparse vegetation growing through adjoining concrete blocks, providing very little shelter from predators for chicks. Any modifications to the island would need to be carefully implemented and structurally secure so as not to pose any risk to dock operations. The addition of gravel to the site may improve conditions both though camouflage for eggs and chicks and by making it easier for parents to control egg movement (eggs were seen to roll away from some parents during incubation switches). Chick shelters may provide protection from predators, and have been successful at reducing rates of gull predation at common tern colonies (e.g. Burness & Morris, 1992), but would need to be secured to the site so as not to pose any risk to dock operations. Placement of shelters could be based on records of the distribution of nests, taken from annual nest counts. A small barrier around the colony edge would reduce chick losses to the water, but again would need to be very stable. Whilst this wouldn't stop gulls attacking chicks on the island, it may be a worthwhile to reduce the number of chick losses to the water given the opportunistic nature of the many water-based predation attempts. Although the majority of tern chicks eaten by gulls were picked up out of the water having fallen off the colony, some of these chicks may have fallen into the water as a result of attacks by gulls landing on the colony surface, so it is unclear how much of this mortality would have occurred in the absence of gulls.

Mink control

In the west of Scotland, overall fledging success of common and Arctic terns is greater in mink-free than mink-inhabited areas, but great variation exists between colonies, such that some colonies in mink-free areas may perform worse than some in mink-inhabited areas (Clode *et al.*, 2000; Clode & MacDonald, 2002). This in part can be attributed to differences in antipredator behaviour. For example, common terns at Finsbay (Isle of Harris), where mink are present, were found to react very aggressively to models of mink and had high fledging success (Clode *et al.*, 2000). Similarly, at the Imperial Dock Lock SPA, terns were seen to successfully deter mink from the colony on several occasions.

Mink reportedly gained access onto the island in 2011 but to date the impact of mink on the productivity has been apparently low. The potentially devastating effects of mink predation should not be underestimated however and continued monitoring of mink activity at the Imperial Dock Lock SPA is important, especially given that the majority of the Firth of Forth common tern population currently breeds at this one site. Presently, there is no protocol in place for the control of mink within the Docks, and this should be addressed to enable appropriate management should it be required. It is possible that mink could be prevented from gaining access to the island by filling any gaps in the wall, such as the lock gate mechanism, which can be used to climb up onto the island. The ability of mink to spread should be considered in any management plans; on the west coast of Scotland, for example, mink have reached all islands within 2km of the mainland (Craik, 1997). Given this dispersal ability, it is likely that, if mink were removed from the site, they could be replaced by new individuals from the surrounding area.

Predator populations and site development

Plans for any future developments in the area should consider potential impacts on predator populations, in addition to direct effects on the tern colony. Development may cause a local re-distribution of predators, through disturbance or destruction of their favoured habitat. At a tern colony on Tern Island, Cape Cod (Massachusetts) parts of the site that were not normally subject to rat predation were impacted heavily by rats following the burning of a rubbish dump nearby (Austin, 1948). Increased industrial activity around the colony could disturb birds, causing them to leave their nests, leaving eggs and chicks unprotected and vulnerable to predators. Structural changes to the surrounding built environment could potentially aid predators by providing vantage points or improved lighting conditions which would facilitate nocturnal predation. In terms of building design, rooftops of new buildings could be designed to reduce suitability for nesting gulls. Gulls are thought to prefer to nest on light-coloured rooftops rather than dark ones, presumably to avoid heat stress, and also prefer to nest on relatively flat roofs, and near rooftop structures such as vents or chimneys (Belant, 1993).

Many urban gulls rely greatly on landfill sites for food, but they also make use of other anthropogenic food sources found in waste bins, in streets and by being fed by people (Belant, 1997). Currently there is little food waste in the Docks but gulls regularly steal food from the outdoor restaurant area at the nearby Ocean Terminal shopping centre. If the site was to be developed for public use then an increase in anthropogenic food would be likely, which could result in an increase in gull numbers in the area. This could potentially lead to an increase in the number of gulls preying on the colony.

Large numbers of pigeons reside within the Docks and feed on grain stores. Removal of grain stores could lead to a reduction in the number of pigeons in the area, which could have impacts on their predators, which could have implications for terns. Peregrines were seen to actively predate pigeons, but not terns, and gulls were seen feeding on pigeons, although it is uncertain whether these were scavenging or true predation events.

6.4.4 Conclusions

Common terns at the Imperial Dock Lock SPA encounter several potential predator species, but during this study only herring gulls and lesser black-backed gulls caused significant losses. Predator abundance is relatively low compared to previously-used natural breeding sites in the region, but if predation levels were to become unsustainable, breeding attempts would be constrained by availability of suitable alternative nesting habitat in the region. Given that the majority of the Firth of Forth common tern population now breeds at the Imperial Dock Lock SPA, any large-scale predation events would have a significant effect on the regional productivity. Continued monitoring of predators, in particular gulls and mink, would therefore be very useful and would enable implementation of conservation measures. Finally, plans for any developments and change in site use should consider the potential impacts on predators in addition to direct impacts on the tern colony.

7 Disturbance and habituation of common terns at the Imperial Dock Lock SPA, Leith Docks

7.1 Introduction

The development of coastal areas for industrial, residential or recreational use can result in the increased exposure of seabirds to human disturbance (Burger, 1998). The potential for disturbance to adversely affect seabird fitness in terms of survival and reproductive success, thus leading to population declines, is of great conservation concern (Gill *et al.*, 2001). Fitness costs can arise from direct disturbance such as habitat destruction, egg collection, and killing of adults or chicks, and from disturbance associated with recreational activities, the mechanism of which may be less clear (Beale & Monaghan, 2004). Types of human disturbance can range from researchers actively entering a nest site to perform research procedures, to pedestrian and vehicular activity nearby. Although humans may not pose any real threat, it is widely believed that birds may perceive humans as potential predators and so spend more time in a vigilant state to reduce ‘predation’ risk and in some cases desert their nests, resulting in temporary abandonment of nests, eggs and chicks (Beale & Monaghan, 2004; Burger & Gochfeld, 1983), which can increase exposure of clutches or chicks to weather and predation risk.

The degree of sensitivity to human disturbance varies with the level of previous exposure to human activity (Burger & Gochfeld, 1983). Approach distance - the distance between the bird(s) and an approaching human at which point the bird(s) exhibits a response to the approach, is often used as a measure of tolerance to disturbance and can be used to guide the implementation of buffer-zones around colonies. It can be expected that, as a consequence of habituation, approach distances will be smaller at sites with more human activity (Erwin, 1989). In a study of bridled terns, approach distance was smaller for those breeding on an island with frequent human activity than those breeding on a remote island (Dunlop, 1996). It can be argued that frequent exposure to non-threatening human disturbance is less stressful to birds than infrequent exposure, as a result of habituation. In an experimental study, bridled terns from sites exposed to higher levels of disturbance had a greater hatching success and higher chick weights than those with a lower level of disturbance (Gyuris, 2004). Subtle behavioural responses such as vocalisation often occur before more obvious ones such as dreads and in some species, it has been found that there may be a physiological response to disturbance (e.g. heart rate) even in the absence of a visible behavioural response (Nimon *et al.*, 1994). Nisbet (2000) describes the types of effects reported in disturbance literature, ranging from physiological effects without a visible behavioural change, to abandonment, sometimes leading to reduction in local, regional or total populations, but argues that responses such as increased heart rate or flying off the nest should not be classed as “adverse” unless it can be shown that these result in reduced fitness either through survival or reproductive effects. It is worth noting that in cases where disturbance has been reported to cause an adverse effect on terns, the potentially confounding effects of other environmental factors such as predation and weather have not been considered and that fitness depends on a complex array of interacting factors (Nisbet, 2000).

Common terns typically react to disturbance with alarm calls and by lifting off the nest, unless there is a risk of adult predation, in which case they will fall silent and dread, leaving the site completely. Alarm calls warn other adults of the threat, allowing the colony to respond accordingly, and signal to chicks to be still and remain by the nest (Cavanagh & Griffin, 1993). Responses of common terns to disturbance have been studied at several colonies in the USA (e.g. Burger, 1998; Burger & Gochfeld, 1988; Erwin, 1989). The colonies in these studies varied greatly from the colony at Leith Docks in terms of habitat (typically ‘natural’ sites on marsh land and sandy beaches), isolation and exposure to activity, and therefore the results are unlikely to provide a useful indicator of the impact of disturbance at more urban or industrial sites. Although the lock wall on which the terns breed is disused, the immediate areas surrounding the wall are still very much operational; waterways are frequently used by ships which pass to within inches of the colony and two large gantry cranes operate in the vicinity of the SPA, on the northern dockside. Other port activities include movements of lorries, vans and cars and workers on foot on the surrounding dockside. Given that the colony has been long-established in a fully operational port, it is expected that the birds will be largely habituated to general port activity. Identifying the current levels and types of disturbances and the reactions of birds to disturbance will allow predictions to be made regarding the potential disturbance impact of changes in site use. An understanding of the sensitivity of this colony to human disturbance and the establishment of appropriate minimum approach distances will be very valuable for maintaining the integrity of the SPA.

Observations of disturbance from general port activity were described in the Leith Tern Survey Report (ENVIRON; Fitchet, 2008). Weekly observations at the colony in 2008 found evidence of habituation to most normal port operations. Attempted predation by gulls, rather than any human disturbance, was found to be the primary source of disturbance during these initial observations. This project extended the research started by Environ to include a further three breeding seasons and longer observation periods. In addition to the general disturbance observations, anecdotal reports that the terns at the Imperial Dock Lock SPA have habituated to, or are tolerant of, people working in the docks provided they are wearing work uniform were tested experimentally. All people on site are required for safety reasons to wear Personal Protective Equipment (PPE), and so terns experience large numbers of people dressed in a similar way with hard hats and high visibility jackets. In addition to regular port activities, the colony is visited once per season by members of the Lothian Ringing Group to allow nest counts and chick banding, providing an opportunity to study the impact of humans accessing the colony.

The aims of the disturbance study were:

1) To record any events or activities that could potentially cause disturbance of terns at the Imperial Dock Lock SPA and to record the behavioural reaction of the birds to these factors. Of particular interest was the potential impact of anthropogenic factors such as people on the dockside, vehicles moving along the dockside, vessels passing through the cut between the Western Harbour and the Imperial Dock and industrial noise. Disturbance from other species including predatory/threatening species and non-predatory species was also quantified to place any anthropogenic disturbance into context.

2) To test experimentally the anecdotal reports that birds are habituated to dock workers provided they are wearing PPE.

7.2 Methods

7.2.1 Disturbance observations

Observations were made at the colony during the breeding seasons of 2009 and 2010, and to a lesser extent in 2011. Disturbance observations were made in conjunction with predation observations (see Chapter 6). Observations were made from the dockside adjacent to and south of the colony between 0500 and 2100, but were more concentrated between early morning and late afternoon. Periods of observation varied from 30 minutes to 4 hours, and were dictated somewhat by port activity, but periods of at least 2 hours were preferred to give a representative picture of activity at the colony. 194 hours of observation were performed over the three seasons (139 hours in 2009, 44 hours in 2010 and 11 hours in 2011).

For every instance of a disturbance, or potential disturbance (an event that was considered to have the potential to cause disturbance - terns didn't always display a visible reaction), the following was recorded: type of disturbance (see Table 7.1), date, time and reaction (if any) of the terns. Anthropogenic disturbance was split into four categories: bystanders, dockside work, noise and vessels passing (see Table 7.1). A range of predators caused disturbance including lesser black-backed gulls, herring gulls, peregrine and mink. Although crows were rarely seen predating the colony (some egg predation occurred early in the season) terns exhibited a strong response, possibly relating to territorially or perceived predation risk. Due to low observed incidences, data on peregrine and mink disturbance could not be included in the statistical analysis. Activities of predatory/threatening species were grouped into four categories: gull flyovers, gull predation, crow flyovers and crow at crane (see Table 7.1). There were many occasions when birds displayed behaviour characteristic of a reaction to disturbance but the cause was unapparent, in which case the cause of the reaction was recorded as 'unknown'. It seemed that in most of these cases terns were not responding to a specific stimulus that they had detected but a human observer could not see, but were responding to activities of their neighbours and raising a 'false alarm' with no specific stimulus as a trigger. Such behaviour is widely described for terns, and in particular, dreads are known to occur for no obvious reason and often to be particularly frequent early in the breeding season before the birds have fully 'settled' (Snow & Perrins, 1998).

For each reaction to a disturbance, the proportion of birds reacting and duration of reaction was recorded. The duration of the reaction was the time it took for birds to resume "normal" activity following the disturbance event. Change in flight behaviour was used to measure the reaction of the birds as it was visually clear and easy to determine when flight behaviour had returned to normal. Change in vocalisation forms a large part of behavioural responses to disturbance but was not deemed an appropriate variable as it would be difficult to measure accurately. In addition to the proportion of birds reacting and the duration of the reaction, the type of flight behaviour was also noted by classifying reaction into one of three categories: 1) fly-up', 2) 'attack' and 3) 'dread'. A 'fly-up' was recorded when the birds lifted off the colony but remained in the vicinity, and it normally included alarm calling. An 'attack' was recorded when the birds displayed defensive aggression toward the cause of disturbance, specifically humans or other animals. Like a 'fly-up', an 'attack' response involved birds lifting off the colony and alarm calling but with the addition of an aerial attack such as chasing off or mobbing approaching predators and flying toward and mobbing bystanders. 'Dreads' involve silent flight by large numbers of terns, often followed by high levels of calling as the birds begin to settle. Sometimes birds at just one end of the colony would dread, flowing out into either the Western Harbour or the Imperial Dock. During a dread, birds tended to move back and forth between the colony and the Western Harbour or Imperial Dock before finally settling. The distinction between 'attacks' and 'dreads' is usually clear from the noise made by the birds as well as from whether or not they show a clear focus on a specific target.

When (rarely) number rather than proportion of birds reacting was recorded, it was later converted to a proportion based on the nest count for that season. Most of the time one parent would be present at a nest, so nest count was considered a reasonable estimate of the total number of birds present at any given point during the day.

Table 7.1. Types of disturbance recorded during the study

Anthropogenic Factors	
Bystanders	People present on the dockside to the north and south of the SPA, either working outside or standing, not associated with vehicular or other types of mechanical activity.
Dockside work	Vehicles including lorries, cars and vans on the north and south dockside, loading of grain/coal ships from the Imperial Dock, forklift truck activity, crane operations. Low-level background noise.
Noise	Loud noises - typically infrequent, short bursts, including sounding of ship horns, tannoy announcements, helicopters flying over Leith and other one-off events such as loud noises made by moving of industrial equipment.
Vessels passing	Movement of ships between the Imperial Dock and Western Harbour past the Imperial Dock Lock SPA. Vessels observed (length in m) Normand Mariner – Anchor Handling Tug Supply vessel (82.1m) Forth Sentinel Leith – tanker/grain (28m) Arklow Sand – Cargo (90m) Polsteam – coal ship (190m) Union Saturn - Cargo (100m) Toisa Intrepid – support vessel (82.8m) Normand Pioneer – tug/supply (95m) Cherry Sand – hopper dredger (62m) Sea Kestrel – cargo/grain ship (78m) Boa Fortune – tug/supply vessel (69m) Tugs: Fidra (30x11m), Oxcar (28x9m)
Predatory/threatening species	
Gull flyovers	Gulls flying over or nearby the colony without making any obvious predation attempt.
Gull predation	All predation attempts by gulls, whether successful or not.
Crow flyovers	Crows flying over the colony, normally between their nest at the crane on the north of the colony and the area of the docks to the south of the colony.
Crow at crane	Crow sitting exposed on the crane.
Non-predatory species	
Eiders, swans, starlings, pigeons, black-headed gulls, juvenile gulls.	Any non-threatening species flying over or past the colony, on the water in the cut or on the island.

7.2.2 Habituation experiment

An experiment was conducted in 2009 to test the hypothesis that terns are habituated to port workers wearing PPE but not people in plain clothes and therefore respond at greater distances to people not wearing PPE. The experiment was performed on the north dockside (birds were more sensitive to people on the north dockside than the south as the north dockside is closer to the colony) and consisted of an individual walking slowly and directly toward the colony until a visible response was observed, which generally involved between one and a few birds flying up off the colony. As soon as a response was elicited, the individual stopped and retreated directly away from the colony to allow the birds to settle, minimising the response period to a matter of seconds. The walk-up was repeated in both plain clothes and PPE (high visibility jacket and hard hat). Repetitions were performed once the birds were settled and showing normal activity, and always at least five minutes after a previous test. Trials were only carried out when there were negligible risks of adverse consequences to the birds. No trials were performed during very sunny, damp, windy or cold weather, to ensure that nest contents (if any) weren't exposed to adverse environmental conditions. No trials were carried out if there was any evident risk of predators or scavengers accessing nests as a result of the trial. This experiment was performed following the approval of an Appropriate Assessment of potential impacts of the research by Scottish Natural Heritage.

7.2.3 Data analysis

Disturbance observations

'Unknown' disturbances are mentioned in the discussion but were excluded from statistical analyses. To test whether the likelihood of a reaction was related to type of disturbance, the number of occasions on which birds responded and the number on which they didn't were compared using a chi-squared contingency test. Disturbance types were grouped into three broad categories: anthropogenic, predatory/threatening species and non-predatory species.

For all cases where a response was recorded, the duration of the reaction was modelled using a linear model with log of duration as the response variable (durations were skewed toward short times). Log duration provided a better fitting model than a model of duration with a negative binomial error structure to account for this overdispersion. Disturbance type, nesting phase, time of day and year were included in the maximal model as explanatory variables, with an interaction term for disturbance type and nesting phase. Model simplification was performed by stepwise deletion, such that time of day was removed, producing a minimum adequate model with an interaction term for type of disturbance and nesting phase and a separate explanatory variable for year.

A linear model with a square root transformation of proportion of birds responding as the response was applied to the data. A generalised linear model with a binomial function (quasibinomial) was also fitted but was not as good a fit. As with the model for duration of response, the terms disturbance type, nesting phase, time of day and year were initially all included as explanatory variables and the model was then simplified to only include significant terms. Significance of each model was tested using ANOVA.

Habituation experiment

Approach distances of walk-ups with and without PPE were compared by Analysis of Variance, controlling for trial (daily and seasonal variations were expected).

7.3 Results

7.3.1 Disturbance observations

Causes of disturbance

Other species (non-human) were by far the most frequent cause of disturbance (n=454 for predatory/threatening and non-predatory species combined), followed by unknown causes (n=242) and then anthropogenic causes (n=61). For all known causes of disturbance, the number of times in which birds responded depended on the type of disturbance, such that terns were more likely to respond to predators than any of the anthropogenic disturbances or other non-predatory species (χ^2=177.3, d.f. =2, p<0.001). Terns reacted to 96% of incidences involving predatory/threatening species, 58% of all anthropogenic disturbances and 33% of incidences involving non-predatory species. Table 7.2 summarises all known disturbance events.

Table 7.2 Summary of known disturbance events observed at the Imperial Dock Lock SPA common tern colony. The data is from 194 hours of observation during the breeding seasons of 2009-2011.

Disturbance type	**Total number of events**	**Number of events terns reacted to (%)**	**Total duration of reactions**
Dockside work	25	4 (16)	38s
Bystanders	23	9 (39)	10min 43s
Noise	29	20 (69)	13min 45s
Vessels passing	29	28 (97)	1h 36min
Crow at crane	40	39 (98)	1h 32min
Crow flyover	123	117 (95)	1h 37min
Gull flyover	153	145 (95)	39min 36s
Gull predation	154	153 (99)	1h
Other species	37	17 (46)	6min 53s

Table 7.1 shows the frequency of each type of response to anthropogenic disturbances, disturbance caused by other species (all non-human) and to unknown factors. Figure 7.2 show responses to the four categories of anthropogenic disturbance and Figure 7.3 shows responses to gulls and crows, the main cause of disturbance in the current environment. Reactions to gulls, crows, and mink are described in Chapter 6.

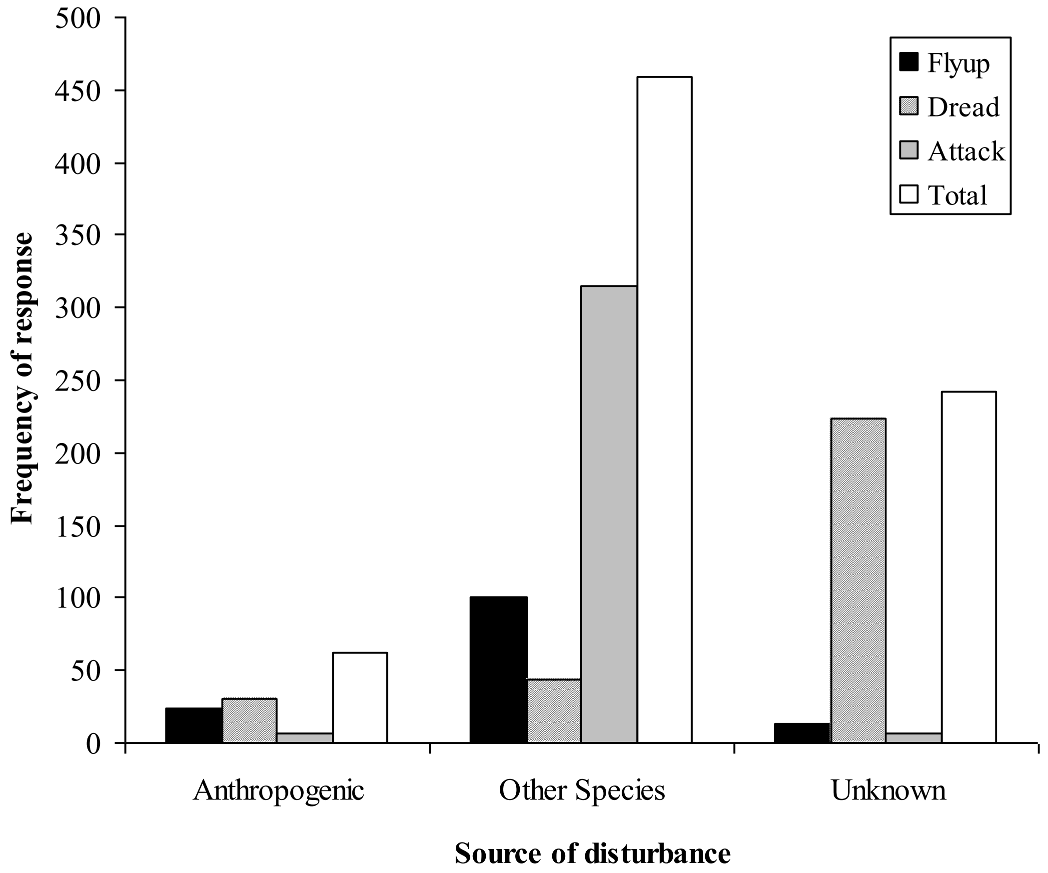

Figure 7.1. Frequency of responses of common terns to different sources of disturbance observed at the Imperial Dock Lock SPA during 2009-2011. Frequencies shown are based on the raw data.

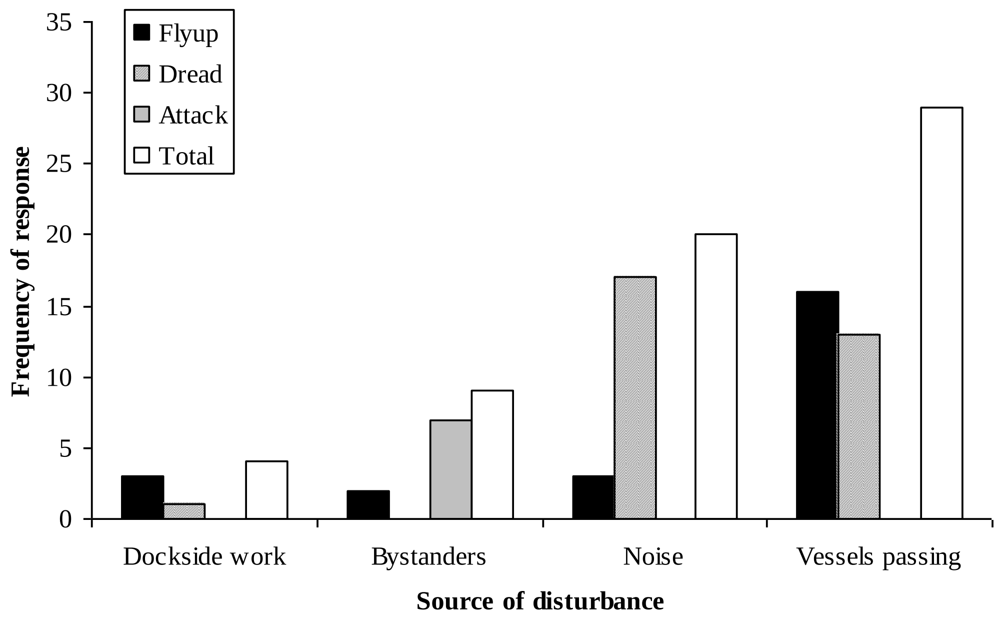

Figure 7.2. Anthropogenic disturbance: Frequency of responses of common terns to different types of anthropogenic disturbance observed at the Imperial Dock Lock SPA during 2009-2011. Frequencies shown are based on the raw data.

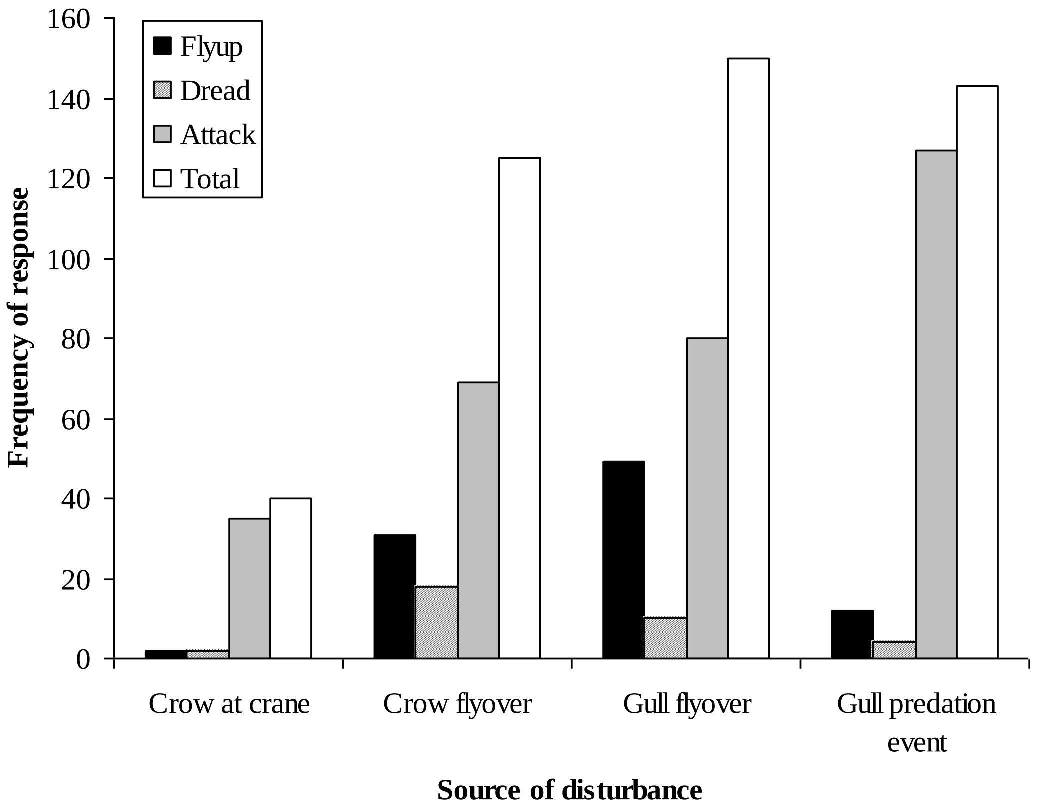

Figure 7.3. Frequency of responses of common terns to the actions of crows and gulls (lesser black-backed gulls and herring gulls) observed at the Imperial Dock Lock SPA during 2009-2011. Frequencies shown are based on the raw data.

Responses to anthropogenic disturbance

Terns were largely habituated to general work occurring on the dockside. On the occasions that reactions were observed, either a dread or fly-up response was recorded. In 2009 observations were initially performed from the dockside to the north and the south of the colony, but when the first eggs were present, the terns no longer tolerated observer presence on the north dockside and all subsequent observations were performed from the south dockside. Not only is the north dock closer to the colony, it is likely that observer presence was more noticeable here because it lies in the flight path between the colony and the Firth of Forth. Greater vigilance here may also relate to the presence of crows on the crane at the north dock. When birds did react to bystanders, they either exhibited a fly-up or attack response. If people stood prominently on the dockside for a prolonged duration, in particular on the north dockside, which is closer to the island and in the feeding flight lines of the birds, then the reaction could escalate resulting in the birds forming a cloud above the bystander. This was uncommon, however, as people normally retreated once attacked by a bird.

Reactions to noise disturbance involved a fly-up or more commonly, a dread. Birds tolerated background noise from general dock activity but reacted strongly to sudden, loud bursts of noise. On one occasion a ship in the Imperial Dock sounded its horn three times in close succession. The first sound caused most of the colony to dread but the severity of the reaction reduced with the second and there was no visible response with the third. Terns were disturbed by the sound of helicopters and by a Red Arrows display over the western harbour. On 24th June 2011, the Red Arrows were displaying over the western harbour. Around 50 individual terns (possibly non-breeders) on the old pier flocked around the western harbour during the display, only settling once it had finished. Most of the display was performed high above the harbour and the birds remained at the colony, but at one point the planes flew low over the docks, causing the entire colony to dread. Terns on the SPA were mostly settled within 2 minutes of the low flyover.

Vessels passing through the cut between the western harbour and the Imperial Dock could cause a fly-up or dread, but it was not unusual for birds to stay around the colony during passage, even if birds lifted off their nests (see Figure 7.4). Terns bringing in fish during vessel passage would hold onto their fish rather than drop them, which would be expected if threatened. Often, terns would begin to settle at one end of the colony once the ship had moved further through the cut.

Figure 7.4 Terns displaying a ‘fly-up’ reaction as a large vessel is manoeuvred through the cut from the Imperial Dock by tug boats. © Gemma Jennings.

Size of response

The proportion of the colony responding to a disturbance was significantly related to the type of disturbance and the nesting phase, and there was a significant interaction between disturbance type and nesting phase (Linear model, d.f. = 24, F = 8.9, $p<0.001$). Proportion also varied with year (Linear model, d.f. =2, F=3.5, $p<0.03$). Anthropogenic noise, vessels passing and predators caused the greatest proportions of birds to react. Bystanders and dockside work caused the lowest proportions to react. Reactions to vessels and noise decreased through the season as terns became more settled but showed greater sensitivity to bystanders once chicks hatched, presumably as people were then considered an increased threat. Figure 7.5 shows the proportion of birds responding to different disturbance types.

Similarly, for the duration of a response, there was a significant interaction between disturbance type and nesting phase (Linear model, d.f. = 22, F = 11.1, $p<0.001$) and a significant effect of year (Linear model, d.f. = 2, F = 5.1, $p<0.01$). Vessels passing and crows on the crane caused the most prolonged reactions, probably because these incidences were more prolonged than many of the other disturbances. Figure 7.6 shows the duration of responses to different disturbance types.

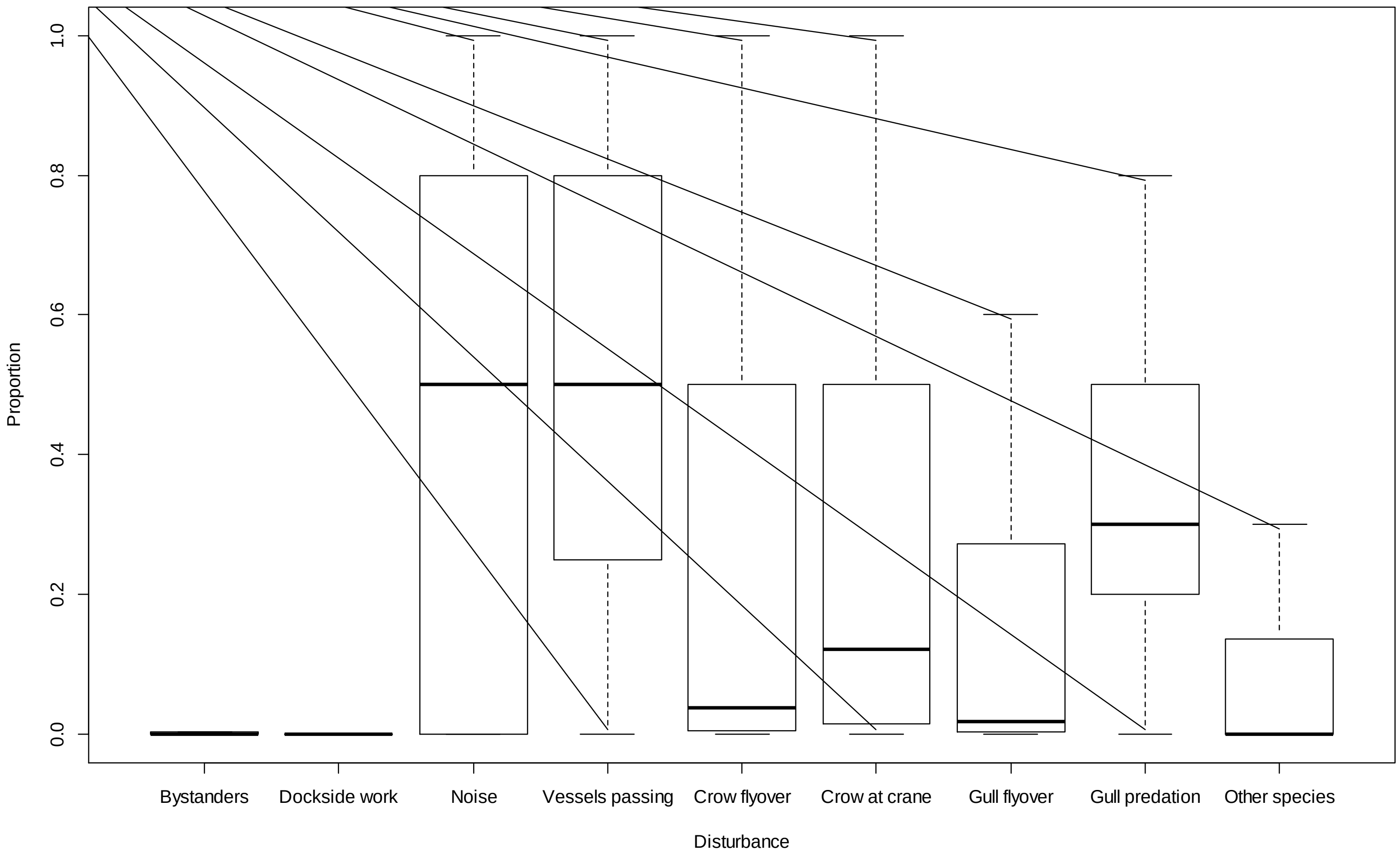

Figure 7.5 Box plot of the proportion of the Imperial Dock Lock SPA common tern colony showing flight reactions to different types of disturbance. In this boxplot the bold horizontal bars represent the median, the box shows the 1st and 3rd quartiles of the data and the whiskers indicate the smallest and largest values.

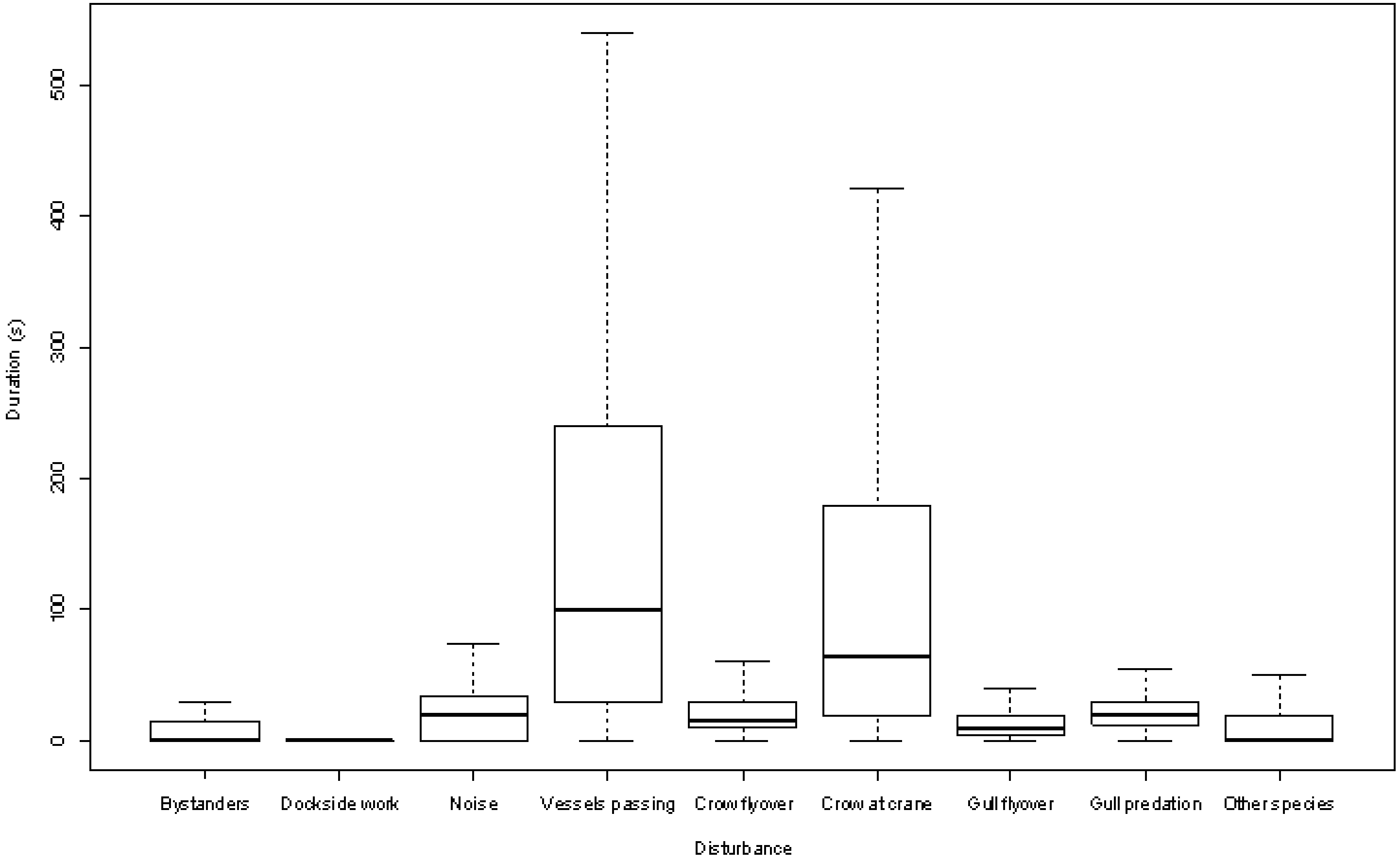

Figure 7.6 Box plot of the duration of flight reactions by common terns to different types of disturbance at the Imperial Dock Lock SPA, Leith Docks. In this boxplot the bold horizontal bars represent the median, the box shows the 1st and 3rd quartiles of the data and the whiskers indicate the smallest and largest values.

Additional notes on disturbance

Annual nest count

Members of the Forth Seabird Group perform a nest count each year soon after the first hatched chick has been observed. This is the only time during the season that people access the island. The colony is approached by a small boat and accessed by the fixed ladders on the side of the lock wall. On the approach, a small number of birds tend to alarm call and come towards the boat. Normally three people are involved in the count. When people reach the island, all of the adult terns lift off their nests and circle like a cloud several metres above the island (Figure 7.7). The nest counters work their way from one end of the colony to the other as promptly and carefully as possible. Dive-bombing is infrequent and although most of the terns remain flying above the island for the duration of the count, some start to settle before the humans have left the island (especially at the end where the count is begun once the people have moved away further down the island).

Figure 7.7 Terns circle above the island during a nest count on June 11th 2010. © Gemma Jennings.

Pipe-loading activity

In 2011, for the first time during the study, pipe loading (the loading of pipes from the dock to a vessel using lorries and cranes) was performed directly alongside the colony. Each vessel takes approximately 3 hours to load but may be stationed there longer, depending on when is convenient to leave. Large numbers of common terns arrived in the Firth of Forth on April 21st (Iain Muir, *pers. comm*.) but a site visit on April 29th found no terns on the SPA and only four birds in the vicinity, flying high above the cranes adjacent to the colony. On May 6th around 150 terns were on the colony at 11:34am. No vessel was present and birds were exhibiting "normal" behaviour (based on previous observations), despite lorries offloading pipes on the northern dockside. At 12:10pm, a vessel, the Toisa Intrepid, entered the cut from the Imperial Dock. The terns initially showed a typical fly-up response but when the vessel docked in the cut all birds left the island. In the following three hours, the vessel remained and the birds did not return to settle (Figure 7.8). At one point a crow landed on the colony for a minute before three terns attacked it. On May 13th, at which point terns would be expected to be nesting, pipe-loading was ongoing; no terns were on the island, only ten were seen overhead and about 30 were present on the old oil jetty. It was reported that after the vessel sailed, the birds returned sometime between the night of the 13th and the morning of the 14th. A break in work then provided an opportunity for birds to settle and commence mating and egg-laying, with many on eggs by May 28th.

Figure 7.8 Pipe-loading beside the Imperial Dock Lock SPA caused terns to leave the nest site on May 6th 2011. © Gemma Jennings

Important areas for terns around the Imperial Dock Lock SPA

Figure 7.9 highlights areas around the Imperial Dock Lock SPA which were commonly used by common terns. The edges of the dockside to the north and south of the SPA are used by courting birds early in the season, by adults throughout and by juveniles after fledging. In both 2009 and 2010 several hundred juveniles were seen using a larger expanse of the north dockside (underneath the gantry cranes) after fledging.

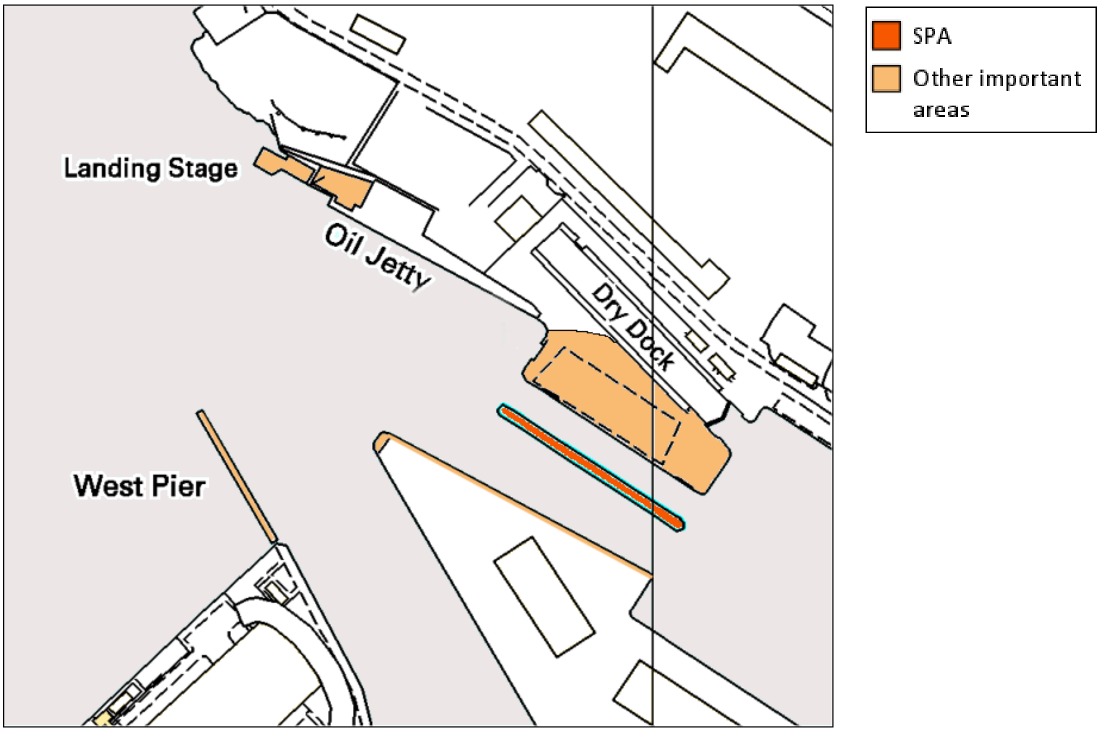

Figure 7.9 Areas used by adult and juvenile common terns nearby the Imperial Dock Lock SPA

7.3.2Habituation experiment

Approach distances in each trial were the same for an individual wearing plain clothes or PPE, indicating no evidence of greater habituation to people in PEE (7.7m±4.6 to the dock edge (so 28.7m to the island edge) in plain clothes, 7.7m±4.1 in PPE; Analysis of Variance, d.f.=1, p>0.05).

7.4 Discussion

Current sources of disturbance

Observations of common terns at the Imperial Dock Lock SPA in Leith Docks between 2009 and 2011 showed that the most frequent causes of disturbance were natural events, related to predation (gulls) and territoriality (crows), rather than anthropogenic activity within the docks. Gull predation attempts, fly-overs by gulls and crows, and crows sitting on a crane to the north of the colony all caused disturbance. Next in frequency after reactions to gulls and crows, terns mostly displayed changes in flight behaviour for ‘unknown’ reasons. Sometimes terns appeared to be mobbing something in the water or on the opposite dockside and although it was not possible to see what it was, these ‘unknowns’ were most likely perceived predators. In other instances when the terns displayed a dread for an unknown reason, it is likely that they were either reacting to a perceived threat not detected by the observer, such as a peregrine (when detected they were often flying at great heights above the colony) or that the behaviour was purely social.

The colony established when Leith Docks was more active and has grown to be the largest in Scotland, so a tolerance of general dock activities was expected. Relatively little human activity occurred in the vicinity of the colony, but out of the anthropogenic factors recognised, vessels passing and loud noises were the most frequent causes of disturbance. Terns were largely habituated to general dockside work and to bystanders on the dockside, but would react more strongly to people that stood close and in a conspicuous position on the edge of the dock. No evidence of greater habituation to people wearing PPE was found. If anecdotal reports of different responses to people in plain clothes are true, it seems probable that the responses related to some difference in human behaviour or to close proximity to the colony rather than to differences in appearance.

Work in the dry dock of the Imperial Dock caused no visible disturbance but vessels passing the colony did. Vessels passing the colony caused the birds to be off the nest for a longer period than most other disturbance events due to the time it took for them to pass, but birds settled soon after, or even during passing. Noise disturbance (loud, unpredictable noises) generally elicited a large response with most of the colony showing a fly-up response. Evidence of habituation to noise disturbance was observed when a ship in the Imperial Dock sounded its horn several times in succession, with a reduction in the severity of the reaction each time. The fact that the lock wall is essentially an island, and is therefore separated from the surrounding dockside, has undoubtedly aided the habituation of terns to human activity on the dockside.

The potential for industrial activity occurring close to the colony to have a serious disturbance impact was made clear in 2011 when pipe-loading was performed in the cut to the north of the island. The presence of a ship in the cut caused the birds to delay settling on the island to breed. When the ship sailed on May 13th, the birds settled promptly indicating that the terns had not found an alternative nest site during the disturbance and that prospecting birds had continued to monitor the site. A break in work which followed the departure of this vessel provided an opportunity for the colony to become fully settled and commence mating and egg-laying.

Humans only access the island once a year during nest counts. Adult terns reacted by lifting off their nests and hovering above the island for most of the count, perhaps indicating that humans were considered a threat to adults but not an aerial one. Dive-bombing was infrequent which contrasts with the high rates of dive-bombing reported by Burger and Gochfield (1988) during a study of common terns responses to human intruders at natural sites on Long Island (New York) and Buster Island (New Jersey). It is recommended that such counts are continued to be carried out by experienced birders under the protocol devised by the Forth Seabird Group to minimise disturbance and avoid negative impacts on fitness.

7.4.1 Impact of disturbance and recommendations

The colony is habituated to most human activity around the colony and current levels of anthropogenic disturbance do not appear to have a significant negative impact on the colony, as supported by continued high breeding numbers at the site. Predators have the greatest impact on breeding success both directly through reproductive losses and indirectly by causing disturbance. During incubation, time off the nest can increase incubation period and, if prolonged, can result in cooling of eggs and leave eggs and chicks more vulnerable to predation (Burness & Morris, 1993). Most disturbance events were short in duration and it normally took less than a minute for birds to resume normal behaviour. However, an increase in high-level disturbance could have significant negative effects, especially if close to the colony. As demonstrated during pipe-loading in 2011, industrial work next to the colony could adversely affect birds arriving to breed at the sites, resulting in delays to breeding and even complete failure to settle and site abandonment if the disturbance is ongoing. The impact of industrial disturbance can be exacerbated by the opportunistic actions of predators; when a ship arrived in the cut to commence pipe loading during an observation, terns left the area and a crow, which would not normally be tolerated near the island, was able to access the colony for a minute before any terns responded.

Several areas outwith the SPA boundary were identified as important for courtship displaying, and for loafing by adults and juveniles (Figure 7.9). The edges of the dockside are often used by loafing birds so if there is an increase in traffic or work then caution should be taken not to disturb these areas. Juveniles moved to the northern dockside after fledging; this area provides more space for the birds which probably reduces aggressive interactions but, importantly, it is close enough to the main colony to offer the protection of adults. Care should be taken to avoid disturbance in this area late in the season.

Since the start of this project the plans for the immediate future of Leith Docks have changed focus from urban regeneration to increased investment in industrial activity, namely marine renewables. In terms of disturbance, this is likely to involve a greater frequency of shipping traffic and increased human activity around the docks generally. The impact of increased industrial activity ultimately depends on the timing and location of the work. If potentially disturbing activities become more common, but are not directly threatening, then there is a greater chance that habituation will occur and that the terns will adjust their response accordingly. If, at some point in the future, urban regeneration was to proceed, the two most obvious causes of disturbance would arise from construction work and subsequent increase in the number of humans. The potential effects of development on predator populations are addressed in Chapter 4. The largest disturbance from construction work, provided it is not performed close to the colony, is likely to be noise-related. Flight distance decreases in response to increased human exposure, so it is expected that although numbers of humans are currently low, over time more humans could be tolerated, provided they are not seen as a threat. Behaviour such as standing conspicuously on the dockside could be considered threatening and could be minimised by the introduction of a buffer zone or barrier to create cover for the birds. The enforcement of clear pathways allows birds to learn that human on these paths are not a threat (Ikuta & Blumstein 2003).

Colonies of terns, guillemots, puffins and gulls on islands along the southern coast of Norway suffered declines due to disturbance caused by pleasure crafts (Barrett & Vader, 1984). Burger (1998) studied the effects personal watercraft on common terns by recording numbers of birds in flight above the colony and found that personal watercrafts (PWCs) caused a greater response than motorboats and that responses increased significantly with speed and decreasing distance to the colony. Such examples arise from relatively isolated colonies, whereas terns at Leith already experience some water traffic. Currently, shipping vessels in the port are slow moving and produce relatively quiet, steady noise, to which terns seem habituated, but if proposals to allow access to PWCs were made then the issues of speed and noise should be considered further.

7.4.2 Conclusions

Terns nesting in Leith Docks are largely habituated to human activities that more isolated colonies would not be expected to tolerate. Although nesting in a man-made environment, terns at the Imperial Dock Lock SPA experience far lower numbers of humans than at some nature reserves (for example the Isle of May or Inner Farne) or at mainland sites where peaks in public access coincide with the breeding season. Natural sources of disturbance, primarily gulls and crows, are the greatest source of disturbance in the current environment. Any future developments should therefore consider the impact on natural processes in addition to anthropogenic factors. Based on the observed levels of tolerance of terns to general human activity, it is probable that the terns will habituate to increasing activity around the colony, care should be taken to allow a sufficient period of adjustment. The timing of high-disturbance operations or construction activities should be controlled carefully to avoid sensitive periods.

8 General Discussion

This chapter reviews the key findings of the thesis and discusses management implications for the colony at the Imperial Dock Lock SPA, as well as outlining potential areas for ongoing monitoring and research.

8.1 Key findings

The use of man-made structures for nesting sites by common terns has become increasingly widespread in Europe and North America and is probably evident in other areas, albeit undocumented. Within many regions, large changes in nesting distribution have been associated with a major shift towards man-made sites, some largely urbanised or industrial. This shift, an adaptive response to loss or degradation of suitable natural nesting grounds, highlights the flexibility of this species. Long-term breeding records for the population of common terns in the Firth of Forth provide a prime example of this trend, where the Imperial Dock Lock SPA in Leith Docks now not only supports the vast majority of common terns in the region but also constitutes the largest colony in Scotland. Here, movement away from traditional nesting sites on natural islands in the Firth of Forth was driven by unsustainable levels of predation (mostly by herring gulls and lesser black-backed gulls) at these sites. Gulls are active predators on common terns in Leith Docks but are present in far fewer numbers than experienced at other sites in the region and nesting areas do not overlap. Predation attempts by mink could present a serious threat, however, and if successful, could be highly detrimental to the colony. This research has highlighted the value of urban environments in maintaining biodiversity, which will become increasingly important in wildlife management and conservation.

Foraging studies revealed that terns are feeding mostly on sprat taken from the Firth of Forth, with a small amount of opportunistic foraging also occurring within the docks. The large proportion of sprat - a high-quality prey item for terns - in the diet of adults and chicks underpins the success of this population. When the sprat stock of the Firth of Forth collapsed in the 1980s, the regional breeding population of common terns declined, but has since recovered following closure of the fishery and subsequent recovery of the sprat stock (Jennings *et al.* 2012). Terns make use of several flight paths between the colony and the Firth of Forth; these paths are spread across the sea wall to the north of the colony and the harbour entrance to the west. Although flight routes were widespread, sector 3 is particularly important and provides the quickest route between the nest site and Firth of Forth. Currently, flight paths are not obstructed by the built environment within the docks and no collisions with any dock structures such as cranes or power lines were evident.

Terns are traditionally considered to be highly sensitive to disturbance, but this has largely been based on studies at more natural, undisturbed sites. This study compliments the existing literature, providing an insight into disturbance at an urban seabird colony. Common terns nesting at the Imperial Dock Lock SPA were found to be well-habituated to regular human activity, which may be attributed in part to the low-levels of human activity close to the colony, and the predictable, benign, and routine nature of those human activities that do take place, as well as the protection from approach by humans offered by the island-like nature of the nesting structure. Gulls and crows, rather than humans, were the greatest disturbance factors for nesting birds. Despite tolerance of regular human activity, the stationing of a pipe-loading vessel near the colony in 2011 caused the settling of the terns at the start of the season to be delayed, showing that sensitivity to novel, close-proximity industrial activity does exist. Several areas outwith the boundary of the SPA, including the nearby dockside and the old pier and oil jetty, were identified as important for courtship displaying early in the season and for loafing by adults and juveniles later in the season.

8.2 Management considerations and future recommendations

As a migrant species which faces a variety of threats across its range, the common tern is Amber-listed in the Birds of Conservation Concern (BOCC3, 2009) and listed in Annex I of the EU Birds Directive. The dynamics of the Firth of Forth breeding population of common terns was linked both to local influences of predators and the regional status of their main food source, the Firth of Forth sprat stock. Increasing numbers of gulls forced common terns to abandon natural sites and colonise a man-made environment. Currently the Imperial Dock Lock SPA is the only site in the region that could support common terns breeding in considerable numbers, but despite its designation as an SPA, there is no management plan in place for the colony. Although predation risk and human disturbance exist at this site, they are at low levels and the site can be seen as a ‘safe-haven’ for the species. The presence of mink in the area however, could present a serious risk to the continued success of the colony. Given that the majority of the Firth of Forth common tern population now breeds here, along with the lack of availability of suitable alternative nest sites, predation by mink at this site could be devastating at the regional level and mink control would be strongly advised. Within the docks, several measures could be taken to reduce the impact of predation by gulls including the provision of chick shelters and a barrier to prevent chick losses over the colony edge.

On a regional scale, improvement of breeding conditions elsewhere would require long-term management of gull numbers at former sites as well as improvement of nesting substrate (for example, vegetation on Inchmickery is too overgrown for terns), but this could be seen as an important objective to reduce the dependence of the population on a single major breeding site.

After fledging, juvenile terns congregated by the gantry cranes to the north of the Imperial Dock Lock SPA. Newly fledged terns are vulnerable and dependent on their parents as they learn to feed themselves, so care should be taken to avoid disturbance in this area late in the season. It seems likely that over time the terns will habituate to changes in activity around the colony, but care should be taken to allow a sufficient period of adjustment. The timing of high-disturbance operations or construction activities should be controlled carefully to avoid sensitive periods and, if very close to the colony, should avoid the breeding season entirely if possible, and particularly the early breeding season before birds have fully settled in the colony.

The impact of any structural changes between the colony and the feeding grounds will depend on the location, height and size of the development as well as the availability of spaces between buildings. If a change in site use occurs which results in a significantly greater human presence around the colony (public access, for example) then the implementation of an exclusion zone during the breeding season, combined with the provision of educational information about the colony would be recommended. Terns, due to their vocal and territorial behaviour during breeding, can sometimes be considered a nuisance by the public. Following conversations with people around the port about the history of the population and the biology of the species, I found that they were not only more accepting but took an active interest in the wellbeing of the colony, demonstrating the value of education in conservation.

This study highlights the importance of the collection of long-term seabird data, which enabled the findings of the field research performed at the Imperial Dock Lock SPA to be placed in the broader context of the history of the Firth of Forth population. This historical perspective further enabled the study to be placed within the context of the nesting distribution shifts reported across much of the breeding range of the common tern. Currently, there is no sprat fishery in the Firth of Forth but any assessments considering the re-opening of the Firth of Forth sprat fishery should consider the potential impact that changes in sprat abundance may have on the common tern population. Further information on prey availability, such as a direct assessment of the sprat stock, along with continued monitoring of tern breeding success and levels of predation would enable the integrity of the Imperial Dock Lock SPA to be maintained, thus benefiting the long-term conservation of the colony and securing the future of common terns in the Firth of Forth.

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Appendix

Raw data for gull counts on the Isle of May and Inchmickery between 1969 and 2011. Data was taken from the Forth Seabird group records and the Seabird Monitoring Program database. Years with missing data indicate no count was made, although gulls may have been present.

Year	Isle of May		Inchmickery	
	Herring gull	Lesser black-backed gull	Herring gull	Lesser black-backed gull
1960	-	-	3	-
1961	-	-	3	-
1962	-	-	3	-
1963	-	-	2	-
1964	-	-	4	-
1965	-	-	8	-
1966	-	-	45	-
1967	-	-	15	-
1968	-	-	30	-
1969	15000	2000	30	5
1970	13000	-	130	-
1971	13140	-	120	2
1972	14850	2100	200	6
1973	9000	-	1	-
1974	6955	795	6	-
1975	4485	651	-	-
1976	2975	742	100	5
1977	3670	841	85	5
1978	3880	855	82	10
1979	3950	935	-	-
1980	4105	490	-	-
1981	2936	470	-	-
1982	2300	550	-	-
1983	2578	1385	-	-
1984	2230	1488	-	-
1985	2165	1033	-	-
1986	1943	682	140	-
1987	2117	520	50	60
1988	1710	563	81	-
1989	1629	643	-	-
1990	1551	618	95	-
1991	1447	788	-	-
1992	1462	751	108	-
1993	2059	1259	196	-
1994	2122	1270	108	108
1995	2554	1635	141	141
1996	2969	1641	196	196
1997	2856	1540	148	147

1998	2607	1533	-	-
1999	3115	1519	242	242
2000	3067	1442	231	230
2001	2845	1203	395	91
2002	2367	1198	371	86
2003	2559	1253	413	135
2004	2428	1221	313	134
2005	2094	1320	319	109
2006	-	1884	257	135
2007	2854	1665	341	227
2008	2962	1944	120	165
2009	-	-	205	289
2010	-	-	-	-
2011	3215	2348	-	-