Low recruitment of Common Terns *Sterna hirundo* in the declining Barnegat Bay population

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Abstract

Common Tern *Sterna hirundo* populations have declined in the southern portion of their breeding range along the Atlantic coast of the United States. The Barnegat Bay (New Jersey, USA) population has been declining, with sea-level rise increasing the frequency of flooding of salt marsh islands believed to be a contributory factor. Productivity is typically very poor, relative to studies undertaken elsewhere, and a previous analysis suggested permanent emigration of breeding adults out of Barnegat Bay. At Pettit Island, a long-term study site in the bay, the number of ringed chicks recaptured as adults was extremely low, even when accounting for mortality prior to fledging. Of 1,314 chicks ringed at Pettit Island from 2006 to 2014, only 23 were recaptured as adults at Pettit from 2010 to 2017 (1.8%, or 3.9% of presumed fledglings). Correcting for the proportion of adults captured, recruitment by four years of age was estimated at 8.1 to 9.3% of fledglings, or 3.5 to 4.0% of all chicks. Recruits comprise a small percentage of breeders in the colony. Of 34 adults captured in 2016, 10 were previously ringed and only three of these had been ringed as chicks (8.8% of total, 30% of ringed birds). It is unlikely that the small number of returns at Pettit Island simply reflects natal dispersal within the bay, because no terns ringed as chicks at Pettit Island were recaptured as young breeders at other colonies. Whether poor recruitment reflects low post-fledging or subadult survival, or emigration out of the population is unknown.

Introduction

Concern about biodiversity loss has often focused on rare species in danger of extinction, but many 'species of least concern' (according to International Union for the Conservation of Nature criteria) at a global level have experienced steep declines in numbers, losses of local populations, and range contractions (Ceballos *et al*. 2017). Seabird populations have decreased world-wide, with especially large declines among cosmopolitan long distance migrants in general, and among terns in particular (Paleczny *et al*. 2015). Common Terns *Sterna hirundo*, although widespread and abundant, have experienced notable population declines in several regions, such as the Great Lakes in North America (Morris *et al*. 2012; Nisbet *et al*. 2017) and the Wadden Sea in Europe (Szostek & Becker 2012). Along the Atlantic coast of the United States, Common Tern populations in the northeast appear to be stable (Nisbet *et al*. 2017), but those from about Jamaica Bay, New York, south have declined (Erwin *et al*. 2011; Burger & Gochfeld 2016; Nisbet *et al*. 2017).

In long-lived birds, such as terns, the population growth rate is most sensitive to changes in adult survival, but when adult survival varies little, other demographic parameters may actually be more likely to affect population dynamics (Sæther & Bakke 2000). There is increasing awareness of the importance of variation in juvenile survival and recruitment, immigration, and emigration to the dynamics of seabird populations (Frederiksen & Petersen 2000; Lebreton *et al*. 2003; Coulson & Coulson 2008; Ledwoń *et al*. 2014; García-Quismondo *et al*. 2018), including in the Common Tern (Tims *et al*. 2004; Szostek & Becker 2012; Szostek *et al*. 2014).

In Barnegat Bay, New Jersey, the number of Common Tern individuals has decreased since the mid 1980s and the number of colonies has decreased since the mid 1970s (Burger & Gochfeld 2016). Since about 2007, increased frequency and intensity of flooding presumably due to sea level rise (Sallenger *et al*. 2012; Kopp *et al*., 2016), has caused low productivity at extant colonies and made former colony sites unsuitable (Palestis 2009; Palestis & Hines 2015; Burger & Gochfeld 2016). An analysis of apparent adult survival of Common Terns suggested high rates of emigration out of Barnegat Bay (Palestis & Hines 2015). Here I analyse recruitment of Common Terns at Pettit Island, a long-term study site in the bay. Although apparent adult survival at Pettit Island (0.88, Palestis & Hines 2015) is similar to estimates from stable populations (Nisbet *et al*. 2017), the number of breeding pairs has declined and there may be too few recruits entering the breeding population to sustain this colony.

Methods

Study Area: Barnegat Bay is a shallow estuary separated from the Atlantic Ocean by narrow barrier beaches in New Jersey, USA (Burger & Gochfeld 1991, 2016; U.S. Fish and Wildlife Service 1996). The study took place mainly on Pettit Island (39°40'N, 74°11'W), an 0.3 ha salt marsh island covered mostly by short-form Smooth Cordgrass *Spartina alterniflora*, with the majority of Common Tern nests on mats of dead Eelgrass *Zostera marina* (Burger & Gochfeld 1991; Palestis 2009). From 2006 to 2017 the number of breeding pairs at Pettit Island ranged from about 80 to 300 pairs, with a median of 180 (Table 1). Additional fieldwork was performed at other islands in Barnegat Bay: Little Sedge Island (39°59'N, 74°04'W); Little Mike's Island (39°57'N, 74°05'W); an unnamed island referred to as 'Ortley Cove' (39°57'N, 74°05'W); West Vol Sedge (39°44'N, 74°07'W); and an unnamed island referred to as 'Cedar Bonnet East' (39°39'N, 74°11'W). The farthest island from Pettit is Little Sedge Island, 36 km to the north, and the closest is Cedar Bonnet East, 2 km to the south (Palestis & Hines 2015).

Field Methods: Common Tern chicks have been ringed at Pettit Island since 1996, but not intensively in most years prior to 2006. The data analysed here begin with chicks ringed in 2006 and end with chicks ringed in 2014 (n = 1,314 chicks), because regular trapping of adults did not begin until 2010 and continued through to 2017 (see Analysis, below, for explanation of cut-off years in relation to age at first breeding). All captured chicks were given a stainless steel bird ring, usually within a few days of hatching, and nearly all surviving chicks were ringed. In most

years, searches for chicks and brief checks of ring numbers occurred approximately three days per week. From 2008 to 2012 feather samples were taken from most chicks older than one week, with no chicks sampled more than once and small numbers of samples taken in other years. Chicks rarely ran after feather sampling and survivorship appeared to be unaffected (Palestis & Stanton 2013). Chicks that survived more than two weeks and were never found dead were presumed to have fledged (Palestis & Hines 2015). Because chicks were marked with metal rings only, and therefore could not be re-sighted, the analysis of recruitment is based only on birds that were recaptured as adults.

I captured Common Tern adults throughout the breeding season using walk-in traps placed over nests with eggs. Traps were set at least one week after the appearance of the first egg in a nest and were removed if an adult did not enter within approximately 20 min, which occurred about 60% of the time (Palestis & Hines 2015). Trapping of adults began in 2010 at Pettit Island and in 2011 at the other islands. From 2010 to 2017, 336 adults were captured at Pettit Island (Table 1) and 180 at other colonies (114 at Little Sedge, 48 at Cedar Bonnet East, and 18 at the other three sites combined). Excluding individuals captured more than once across years, 276 and 159 unique individuals were trapped at Pettit and other sites, respectively.

In addition to estimating recruitment via recaptures of birds originally ringed as chicks, data were also collected on the overall proportion of adults in the colony that had rings. If there continue to be many unmarked individuals in the colony after many years of ringing, then the colony could be a sink supported by

Table 1. Summary of the Common Tern *Sterna hirundo* colony and trapping performed at Pettit Island across years. The number of adults trapped in each year is shown, with the number of recruits captured in that year in parentheses. Terns ringed prior to 2006 are not included in the number of recruits; individuals captured more than once are counted only once as recruits. 'Recruits From Cohort' indicates the number of young ringed in one year that were subsequently trapped as adults. The final row shows the median number of breeding pairs (approximate peak count), median productivity (fledglings per breeding pair), total number of adults trapped, and total number of recruits captured.

Year	Breeding Pairs	Productivity	Adults Trapped (Recruits)	Recruits From Cohort
2006	200	0.64	N/A	3
2007	210	0.26	N/A	1
2008	125	0.64	N/A	2
2009	245	0.31	N/A	3
2010	300	0.32	51 (0)	9
2011	210	0.36	60 (0)	2
2012	160	0.08	73 (5)	1
2013	120	0.17	54 (5)	0
2014	80	0.58	27 (4)	2
2015	205	0.10	26 (4)	N/A
2016	115	0.63	34 (3)	N/A
2017	90	0.06	11 (2)	N/A
Median or Total	**180**	**0.31**	**336 (23)**	**23**

immigrants rather than recruits, or there may be a high frequency of natal dispersal among sites within Barnegat Bay. Such data could also indicate trap-shyness if ringed birds are captured at a lower frequency than expected. The proportion of ringed birds was estimated by placing a GoPro® video camera near nests in 2016 and 2017 for about 20 min per nest (one camera in 2016, n = 42 birds at 42 nests; two cameras in 2017, n = 30 birds at 29 nests).

Fieldwork was conducted under a state scientific collecting permit and federal bird ringing permit.

Analysis: The study of recruitment is complicated by variation in age at first breeding and the occurrence of natal dispersal to multiple sites. The typical age at first breeding for Common Terns is three years, but there is variation among individuals (Ludwigs & Becker 2002; Nisbet *et al.*, 2017). By four years of age most surviving individuals should have bred, and recruitment by age four was chosen as the key measure of recruitment probability here (Nisbet 1978; DiCostanzo 1980). Because of the very small number of recaptures, I could not conduct a formal mark-recapture analysis (Lebreton *et al*., 2003). The analysis is simplified by the fact that no four year-old or younger recruits were detected at sites other than the natal site (Pettit Island). Estimates of recruitment rate are based on the number of returns, corrected for the proportion of adults trapped at Pettit Island in a given year (mean across years = 14.0%, or 15.2% if 2017 is excluded - see below).

Recruitment (R) by age four for a given cohort was calculated as the number of individuals captured by age four (n) divided by the expected number if all fledglings had recruited. This expected number is based on the number of fledglings in a cohort (N) multiplied by the probability (p) of a bird being captured at least once by age 4: p = (1 minus the probability of being present but not captured). For a bird to be present but not captured, then that individual must have been missed in both year three and year four (ignoring the possibility of recruitment prior to age three, which was never observed). The probability of being present but not captured (labelled m for 'missed') is therefore calculated as:

$$m = (\text{proportion of adults not trapped in year 3}) \times (\text{proportion not trapped in year 4}).$$

Recruitment probability for a cohort is thus calculated as:

$$R = n/(Np), \text{ where } p = (1-m).$$

To calculate an overall frequency of recruitment for the colony, cohorts were combined:

$$R = (\sum n)/(\sum Np).$$

The analysis was repeated with different years as cut-offs, for the following reasons: 1) Intensive ringing of chicks began in 2006, but trapping of adults did not begin until 2010. Therefore birds that recruited at three years of age in 2009 would be missed if they did not return to breed again. 2) Severe flooding early in the 2017 breeding season caused the near-abandonment of Pettit Island. The number of

nests increased late in the season, but additional flooding soon caused the loss of these late nests. Therefore many fewer birds were trapped at Pettit than in previous years (only 11 adults captured in 2017, mean = 46.4 per year from 2010–2016, Table 1). Analyses first included all years, and then were truncated and repeated in various combinations. Because no birds were captured in 2009, analyses are repeated with the 2006 cohort excluded (birds that would have been three years old in 2009). Analyses were also repeated with the 2014 and/or 2013 cohorts excluded, to account for the low probability of capture in 2017 when the birds would have been three or four years old. Presenting data with different starting and ending years also provides an indication of the sensitivity of the analysis to annual variation, to ensure that the estimates do not vary widely.

Results

Of 1,314 chicks ringed at Pettit Island from 2006 to 2014, only 23 were captured as adults from 2010 to 2017 at Pettit Island (Table 1). These recruits comprise 1.8% of all ringed chicks and 3.9% of 588 chicks presumed to have fledged. The median age that a bird was first recaptured was four years, with a mode of 3; 2.2% of fledglings were recaptured by four years of age. Two additional terns banded at Pettit Island as chicks were captured at nearby Cedar Bonnet East in 2017, when they were seven and 11 years old.

The proportion of fledglings recruiting to the colony by age four is higher than 2.2%, however, because not all adults were captured in a given year (Table 1). After adjusting for the proportion of adults captured (see Methods), it was estimated that 9.3% of fledglings recruited at Pettit Island by age four. The estimate varied little when using different cut-off years, ranging from 8.1% to 9.3% of fledglings (3.5% to 4.0% of all ringed chicks). In the most restricted dataset the estimate was 9.0%. This restricted dataset included only chicks ringed from 2007 to 2012 and trapped from 2010 to 2016, to include only cohorts that experienced trapping at both three and four years of age, and additionally excluding the 2013 cohort because of limited trapping in 2017 (see Methods). Despite this apparent lack of variability, there did appear to be differences among years, as nine of 23 recruits were from the 2010 cohort and no recruits were captured in the first two years of trapping (Table 1, numbers of recruits exclude those ringed prior to 2006, see Methods).

Local recruits comprise a small percentage of breeders in the colony. Based on observations with a video camera placed at nest sites in 2016, I estimated that about 36% of adults in the colony had rings (15 of 42 = 0.357). However, most of these terns had been ringed as adults. Of 34 adults captured in 2016, 10 were previously ringed (29.4%) but only three of these birds had been ringed as chicks. Recruits therefore comprised only 8.8% of captured adults (3/34).

In 2016 the proportion of birds captured with rings (0.294) was not significantly different from the frequency of ringed birds observed at nests (0.357; Fisher's exact test, P = 0.63). Although the sample size is smaller for 2017, and the results not statistically significant, there appeared to be evidence of trap-shyness among

previously ringed adults in this year. Of 11 adults captured in 2017, only two were ringed (18.2%), while videos at nests showed 43.3% with rings (13 of 30; Fisher's exact test, P = 0.17). The two ringed birds were new recruits that had been ringed as chicks (Table 1). Therefore no birds that had been previously caught in a trap were recaptured in 2017. This pattern contrasts with previous years, when 56% of recaptures were of birds ringed as adults (33 of 59 from 2010 to 2016).

Discussion

The Barnegat Bay population of Common Terns has been decreasing (Burger & Gochfeld 2016), and this decline appears to have accelerated in recent years (Palestis & Hines 2015). In addition to poor productivity (Table 1) and emigration of adults out of the bay (Palestis & Hines 2015), poor recruitment may also contribute to the decline. Recruitment was quantified at one colony site in the bay, Pettit Island, which has been occupied since at least 1976 (Burger & Gochfeld 1991). The number of recruits captured at Pettit Island was very small (n = 23), despite ringing nearly all fledglings from 2006 to 2014 and capturing approximately 14% of adults, on average, per year from 2010 to 2017.

In some cases it is difficult to make direct comparisons among studies, because different authors have used different measures, but the values calculated here for recruitment at Pettit Island appear to be very low compared to those in the literature for Common Terns (reviewed in Nisbet *et al*. 2017). At Pettit Island, I recaptured 1.8% of ringed chicks and 3.9% of fledglings (2.2% by age four). After adjusting for proportion of adults captured, probability of recruitment by age four was estimated at 8.1 to 9.3% for fledglings and 3.5 to 4% for all ringed chicks (estimates differ slightly with different cut-off years for analysis). Other than colonies that were abandoned and later recolonized (e.g. Post & Gochfeld 1979), I have found no estimates of recruitment probability in Common Terns clearly lower than the estimates for Pettit Island. Only Nisbet (1978, 1996) reported similar values, in Buzzard's Bay (Massachusetts, USA). During a period of population decline, survival from fledging to age four was estimated at 7–13%, with 5–10% of the population comprising four year old recruits (Nisbet 1978). After the population recovered, Nisbet (1996) recaptured approximately 5% of fledglings from one cohort at Bird Island as adults at the natal site (plus c.1% captured at other sites), despite capturing large numbers of adults over 10 years. Other estimates for recruitment by Common Terns are all higher than those reported here. For example, DiConstanzo (1980) reported that 10–17% (mean = 14%) of fledglings recruited to the natal site (Great Gull Island, New York, USA), with at least 1–2% breeding at other colonies. In the Wadden Sea, Germany, 28–32% of fledglings recruited to the natal site (Ludwigs & Becker 2006), with higher rates of recruitment among males than females (Becker *et al*. 2007). During a period of population decline in the Wadden Sea that was characterized by a decrease in apparent subadult survival and a later recruitment age, recruitment probability decreased to 12% of fledglings (Szostek & Becker 2012), but still remained higher than at Pettit Island. Recruitment probability of Common Terns at Pettit Island also appears low when compared to estimates of recruitment or related demographic

Figure 1. A Common Tern *Sterna hirundo* incubating its eggs at Cedar Bonnet East, Barnegat Bay, New Jersey, USA. © *Brian G. Palestis*

parameters (e.g. juvenile survival) in other species of terns and small gulls (Lebreton *et al*. 2003; Braby *et al*. 2011; Ledwoń *et al*. 2013; Møller *et al*. 2013; Nisbet *et al*. 2016; Acker *et al*. 2017; see Table 1 in Acker *et al*. 2017 for review).

Why recruitment to Pettit Island is poor is unknown. That productivity is low (Palestis & Hines 2015; Table 1) certainly contributes to the small raw number of recruits, but estimates of recruitment probability were based only on chicks presumed to have fledged and are therefore unaffected by mortality prior to fledging. Natal dispersal within Barnegat Bay may contribute to the small number of returns at Pettit Island, but is unlikely to fully explain these results because only two fledglings from Pettit Island were captured breeding at other islands in the bay. These were both older than four years and were captured in 2017, when Pettit Island was nearly abandoned and several other adults moved to Cedar Bonnet East. Although trapping effort was much lower at other sites and the number of adults ringed at Pettit Island much lower than the number of ringed chicks, 14 adults ringed at Pettit Island were recaptured at other sites. This result suggests that local movements of young recruits probably would have been detected if they were frequent. It is also unlikely that the results reflect responses to investigator disturbance, as Common Terns are often subject to more intensive study than performed here and are able to tolerate such disturbance (Nisbet 2000). Adults return to the nest quickly after trapping (Nisbet 1981), and chick growth and survivorship are usually unaffected by handling (Nisbet 2000; Palestis & Stanton 2013). In addition, the declines in the Barnegat Bay population are occurring bay-wide, not just at Pettit Island or other study sites (Burger & Gochfeld 2016; see below). However, subtle effects of researcher disturbance on survival or philopatry cannot be ruled out.

Poor recruitment could result from poor post-fledging survival, poor subadult survival, and/or emigration out of the study system. The main cause of poor productivity in Barnegat Bay is the high number of nests and young lost to frequent flooding (Palestis 2009; Palestis & Hines 2015; Burger & Gochfeld 2016), but flooding of nesting areas would not directly affect terns after fledging. Poor productivity could indirectly affect recruitment, however, if prospecting young adults move on to breed at more productive locations (Dittmann *et al*. 2005; Szostek *et al*. 2014). Evidence is mixed regarding whether juvenile survival in Common Terns is affected by pre-fledging variables such as hatching order and body mass (Nisbet 1996; Dittmann *et al*. 2001; Ludwigs & Becker 2002, 2006). Poor survival among juveniles and pre-breeders may reflect poor foraging conditions near breeding sites during the post-fledging period (Braasch *et al*. 2009), and can also be influenced by conditions at staging and stopover areas or wintering sites (Szostek & Becker 2015).

The situation at Pettit Island is likely to reflect problems affecting Barnegat Bay as a whole, rather than being site-specific. Populations of Common Terns and several other species of colonial waterbirds have declined throughout the bay (Burger & Gochfeld 2016). Pettit Island has been continually occupied and, although produc-

tivity is never high, terns often perform better there than at other colonies in the bay (Palestis & Hines 2015; Palestis, unpubl. data). Extremely poor years at Pettit Island (and other islands) have become more common over more recent years (Table 1). Although salt marsh islands can provide good breeding habitat for Common Terns (Burger & Gochfeld 1991; Buckley & Buckley 2000), the long-term perspective in Barnegat Bay is not encouraging. The population does not appear to be self-sustaining, and the low-lying islands of the bay are unlikely to survive continuing sea level rise (Burger & Gochfeld 2016), which has accelerated along this part of the North American Atlantic coast (Sallenger *et al*. 2012). Two of the colonies included in this study, Little Mike's Island and Ortley Cove, are now too low-lying to provide suitable habitat (Palestis & Hines 2015) and have been abandoned. Poor recruitment may accelerate loss of the breeding population, as even those nests that survive flooding in extant colonies produce very few young that return to breed. The small number of local recruits and large number of unmarked adults suggest that Pettit Island, and perhaps Barnegat Bay as a whole, may be a sink that is being temporarily maintained by immigration from other locations. Creation of new habitat or improvement of existing islands may be needed to prevent population extirpation, but even such conservation action may not be sufficient if the declines reflect long-term regional changes (Palestis & Hines 2015). That Common Terns have declined in the southern part of their breeding range (Erwin *et al*. 2011; Burger & Gochfeld 2016; Nisbet *et al*. 2017) suggests large-scale limiting factors, such as climate change-related shifts in fish populations and increases in the frequency of major storms.

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