Significant decline observed in Arctic Tern *Sterna paradisaea* population in northwest Greenland

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Abstract
Arctic Terns *Sterna paradisaea* are an understudied species in Greenland. Outside of the largest colonies, little is known about their current population status and no long-term annual monitoring program has been established. Previous surveys outside of key breeding colonies have been limited to a small number of colonies for single-season studies. This limits our understanding of population dynamics as terns have been shown to have a high degree of variation in annual reproduction and readily move between nearby colonies. Here we present results of the first multi-year systematic survey for breeding Arctic Terns in the High Arctic of northwest Greenland. Surveys took place from 2009 to 2017 and identified eight islands where terns currently nest. A total of 426 nests were counted and annual counts ranged from 25 to 92 nests. Complete reproductive failure in at least one year was noted for seven of the eight colonies, and three colonies comprised nearly 90% of the total population. Mean clutch size ranged from 1.4 to 1.7 eggs. When compared with historical data from the late 1960s through late 1990s, the population has declined by over 50%, with the greatest decline occurring over the past two decades. Four previously identified colonies have been extirpated while three colonies have undergone significant reductions in size.

Introduction
The Arctic Tern *Sterna paradisaea* breeds throughout coastal Greenland and nests mostly on islands (Salomonsen 1950). The current population in Greenland is estimated at approximately 65,000 pairs, with the largest colonies located in the Upernavik and Disko Bay regions, the latter having an estimated 20,000 pairs (Kitsissunnguit) (Boertmann *et al*. 1996; Egevang & Frederiksen 2011). Arctic Tern distribution elsewhere is sparse, with hundreds of kilometers often separating breeding areas, and colony sizes that generally range from single to hundreds of pairs (Salomonsen 1950; Boertmann 1994; Boertmann *et al*. 1996). Arctic Terns are currently listed as near threatened in Greenland (Boertmann 2007). While there is no annual monitoring program, limited data strongly suggest that the overall population has declined over the past 50–75 years (Salomonsen 1950; Egevang *et al*. 2004; Burnham *et al*. 2005; Boertmann 2007). However, concern exists that current survey methods are insufficient to provide an accurate appraisal of changes

in population size. To our knowledge, only one multiyear census has been conducted for Arctic Terns in Greenland (Egevang & Frederiksen 2011).

Results from previous Arctic Tern nesting studies have highlighted the difficulties of making accurate assessments of colony size and population trends (Kress 1983; Hatch 2002; Ratcliffe 2004; Egevang & Frederiksen 2011). Significant annual variation in colony size and reproduction has been shown, including total abandonment of the colony and/or complete reproductive failure. Causes of large scale variation include: predation of eggs and/or chicks by mammals (Craik 1995; Levermann & Tøttrup 2007; Egevang & Frederiksen 2011), lack of prey (Monaghan *et al*. 1989; Suddaby & Ratcliffe 1997; Furness 2007), and predation by other bird species (Hatch 1970; Whittam & Leonard 2000). Furthermore, although nest site fidelity in Arctic Terns can be high at a regional scale, movement between neighbouring colonies can be common and often negatively correlated with geographic distance (Drury 1973; Brindley *et al*. 1999; Møller *et al*. 2006a; Devlin *et al*. 2008). To better overcome the above concerns, Egevang & Frederiksen (2011) recommend that Arctic Tern monitoring programs in Greenland should survey colonies in the same season within a large overall geographic area.

The Avanersuaq District in northwest Greenland (Figure 1) is home to the largest remaining seabird and waterfowl colonies in Greenland (Boertmann *et al*. 1996; Burnham *et al*. 2012) and a diverse assemblage of both Nearctic and Western Palearctic bird species (Salomonsen 1950; Boertmann 1994). The Avanersuaq District is also the northern edge of many of those species' breeding range, and in some instances only a few pairs nest in the area each year (Boertmann *et al*. 1996; Burnham *et al*. 2012). Although Arctic Terns do breed in the area, information on colony location and density is limited and no systematic multi-year survey has been conducted there prior to this study.

The aim of our research was to: 1) conduct a multi-year survey identifying the location and size of Arctic Tern colonies in the southern portion of the Avanersuaq District, and 2) determine if Arctic Tern abundance has changed over the past 50 years.

Methods

The Arctic Tern survey area reported here encompasses ~750 km of coastline in northwest Greenland (Figure 1; 76.00–77.25° N). This region is classified as High Arctic in nature with ice-free land primarily existing only along the coastline, bordered by the Greenland Ice Sheet to the east (Figure 1). The nearest known Arctic Tern colonies to our study area are ~450 km to the south (straight line, primarily over ocean) and ~125 km to the northeast (straight line, over portions of the Greenland Ice Sheet; Boertmann *et al*. 2006). The study area has many small coastal islands and islets that are used by nesting waterfowl; Common Eider *Somateria mollissima* and Long-tailed Duck *Clangula hyemalis* frequently nest on the same islands as Arctic Terns. For additional descriptions of the study area, see Burnham *et al*. (2012, 2014).

Arctic Tern survey data collected in the study area prior to 2009 were obtained from two primary sources. The first was the *Greenland Seabird Colony Database*, which compiles anecdotal observations and survey results on seabirds and ducks made by ornithologists throughout Greenland and provides a specific identification code for each location (Boertmann *et al.* 1996). Results obtained from the database for our study area identified ten locations (all islands) where terns were observed either by F. Salomonsen in 1968, K. Kampp in 1987, or A. Mosbech in 1994–95 and 1998. Observations by Salomonsen and Kampp were by boat or on land while surveys by Mosbech were via airplane (Boertmann *et al.* 1996). Results were provided as number of individuals or pairs and no information is provided on locations which were surveyed but where no terns were observed. Based on information in Boertmann *et al.* (1996) previous surveys were not comprehensive of the entire study area and only a limited number of islands were surveyed. We also had access to unpublished tern surveys conducted in 1999 and 2008 (K. Burnham & W. Burnham unpubl. data). These latter surveys provide information on number of adults, and while some data are provided on number of nests and/or young, systematic nest counts were not conducted. Individual colonies are referred to by their *Greenland Seabird Colony Database* identification code throughout the text.

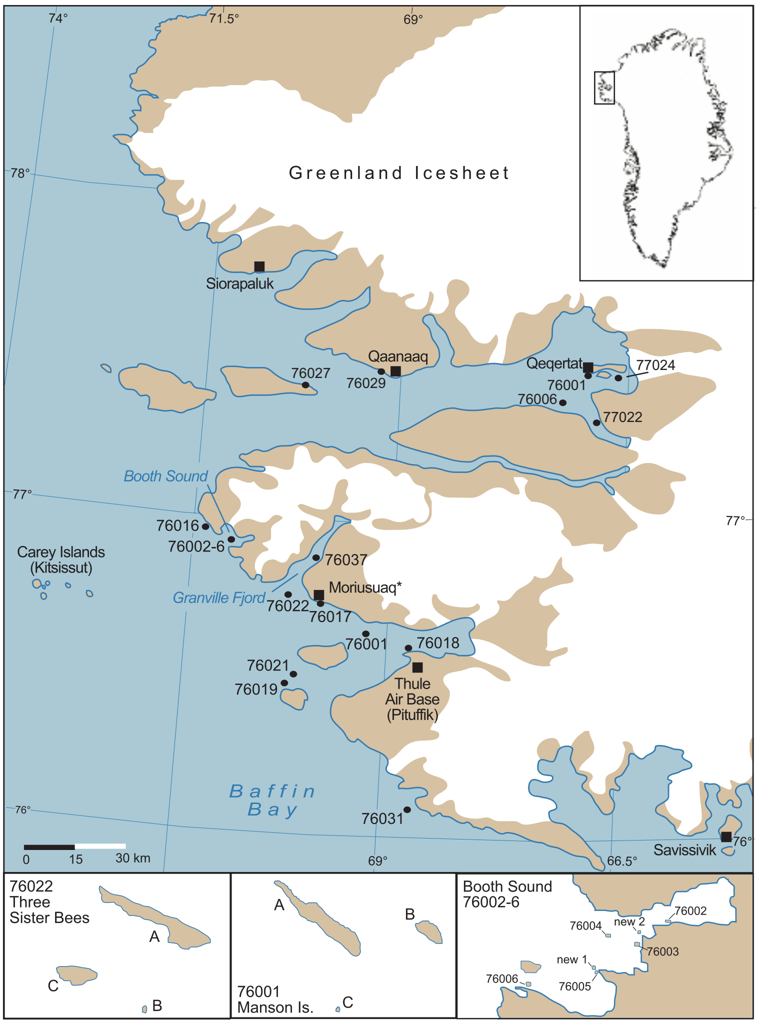

Figure 1. Map of northwest Greenland showing area surveyed for Arctic Terns (dashed box) from 2009 to 2017. Colony numbers from the Greenland Seabird Colony Database (Boertmann *et al.* 1996). Modified from Burnham *et al.* 2014.

Arctic Tern surveys were carried out between 3 and 26 July in 2009–10, 2012, and 2014–17. All coastlines in our study area were surveyed by small boat, and islands with terns were systematically surveyed for nests on foot. Individual nests were marked with a flag and the total number of nests and eggs were recorded. The flags were removed at the conclusion of the nest survey before leaving the colony. Researchers were careful to not disturb chicks when present while conducting nest counts. Direct counts of the total number of adults present were also made, but heavy fog limited visibility and precluded this at some colonies in some years. Furthermore, due to late sea ice breakup and poor weather conditions, it was not possible to reach and survey all islands and coastline every year.

Islands where colonies of Arctic Terns were observed were generally small, and ranged from 0.05 to ~1 ha in size. The exception was island 76001A (77.13 ha); however, the Arctic Tern colony was located on the southeast corner of the island and occupied an area < 1 ha in size. The maximum distance between colonies was 30 km, but closer in Booth Sound (76002–06, New 1, and New 2 islands), where islands were between ~30 m and 5.5 km of each other (Figure 1).

Results from geolocator data (Egevang *et al*. 2010) and nesting chronology from High Arctic tern populations (Egevang & Stenhouse 2007; Egevang *et al*. 2008; Mallory *et al*. 2017; this study) show that some Arctic Terns depart nesting colonies by mid August on outward migration. Thus, population estimates provided by Mosbech on 24 and 26 August in 1994 and 1995, respectively, have been excluded from historical population analysis but are included to compare historical versus current island occupancy. Research by Bullock & Gomersall (1981) demonstrated that number of individuals counted at Arctic Tern colonies could be divided by 1.5 to provide an estimate of nests. Colony counts provided by the *Greenland Seabird Colony Database* (Boertmann *et al*. 1996) and K. Burnham & W. Burnham (unpubl. data) have been converted to nest counts to allow for comparison of results among the three survey datasets and are indicated by a "~" preceding the number of nests.

Results

Arctic Terns were observed nesting on eight islands and a total of 426 nests were documented during the study period between 2009 and 2017 (Table 1). The total number of nests amongst all colonies ranged from 25 in 2017 to 92 in 2014. Colony 76017 had the largest number of nests during any single year of the survey period (51 in 2012, or 88% of the total nests recorded that year). The three largest colonies, 76001A, 76003 and 76017, possessed 88% of the total nests recorded over the duration of the study period (30.0%, 31.9%, and 25.6%, respectively). Four colonies never exceeded three nests each year. Colony 76004 and New 2 both possessed a single nest, which was present in only one or three of the six years surveyed, respectively. At one island (76022A) terns were observed only in 2009, but no breeding was documented.

Complete reproductive failure was observed and no active nests found at seven of the eight tern colonies in at least one of the survey years. The eighth island, colony 76002, had active nests each year surveyed. Causes of failure were not always evident, but in one instance an Arctic Fox *Vulpes lagopus* was present at a colony at the time of the survey, and no tern or waterfowl nests were found with viable eggs. Possible avian predation was suggested in 2012 when colony 76003 was surveyed daily from 8–13 July. During the first four days, between one and three new nests with eggs were documented each day, but depredated on each subsequent day. No nests with eggs were found during the final two days of surveys. The source of the predation was unknown, but observations of predation at other colonies included a Common Eider picking up and crushing a tern egg and a pair of Arctic Skuas *Stercorarius parasiticus* preying upon a partially grown tern

Table 1. Locations surveyed for breeding Arctic Terns in northwest Greenland from 2009 to 2017. First line indicates survey date, second line nests with eggs and number of eggs per nest, third line average clutch size, fourth line number of young, and fifth line number of adults observed. Five-digit location numbers are from the *Greenland Sea Bird Database* (Boertmann *et al*. 1996) and locations with terns noted in the database are indicated by an *. NS = not surveyed, NO = nothing observed, NR = no reproduction, NC = not counted.

Location	2009	2010	2012	2014	2015	2016	2017
76001A*	9 Jul 30 (10/20) 1.67 no yng NC	6 Jul 34 (12/22) 1.7 no yng NC	15 Jul 1 (1/0) 1.0 no yng 14 ad	15 Jul 30 (14/16) 1.5 no yng NC	26 Jul NR - no yng 40–60	16 Jul 32 (9/22) 1.71 w/1 yng 60 ad	15 Jul NR - no yng 30 ad
76002*	14 Jul 15 (7/8[1]/1) 1.7 no yng NC	NS	13 Jul 5 (4/1) 1.2 no yng NC	15 Jul 6 (5/1) 1.7 no yng NC	23 Jul 3 (2/1) 1.3 1 w/1 yng 13 ad	22 Jul 2 (0/2) 2.0 1 w/1 yng 12 ad	13 Jul 2 (1/1) 1.5 no yng 3 ad
76003*	14 Jul 27 (6/20/1) 1.8 no yng NC	18 Jul 42 (10/30/2) 1.8 no yng NC	8–13 Jul predated[2] - no yng 30 ad	15 Jul 11 (2/9) 1.82 no yng NC	23 Jul 16 (12/4) 1.38 w/yng NC	22 Jul 8 (5/3) 1.42 w/yng 40 ad	13 Jul 22 (10/12) 1.6 no yng 20 ad
New 2	12 Jul 1 (1/0) 1.0 no yng NC	NS	9 Jul NR - no yng 10 ad	15 Jul 1 (1/0) 1.0 no yng 2 ad	23 Jul NR - no yng 3 ad	22 Jul NR - no yng 4 ad	13 Jul 1 (1/0) 1.0 no yng 1 ad
76004*	13 Jul NO	NS	9 Jul 1 (?) - no yng 2 ad	15 Jul NO	22 Jul NO	22 Jul NO	13 Jul NO
76005*	12 Jul 3 (1/2) 1.7 no yng NC	NS	7 Jul NO	15 Jul 1 (0/1) 2.0 no yng 4 ad	23 Jul 2 (0/2) 2.0 no yng NC	22 Jul 1 (1/0) 1.0 no yng 7 ad[3]	13 Jul NR - no yng 3 ad
New 1	12 Jul 1 (1/0) 1.0 no yng NC	NS	9 Jul NR - no yng 4 ad	15 Jul 3 (1/2) 1.7 no yng 16 ad	23 Jul 2 (1/1) 1.5 no yng NC	22 Jul 1 (1/0) 1.0 no yng 7 ad[3]	13 Jul NR - no yng 3 ad
76006	12 Jul NO	NS	9 Jul NO	15 Jul NO	23 Jul NO	22 Jul NO	13 Jul NO
76016*	13 Jul NO	NS	30 Jul NO	NS	22 Jul NO	22 Jul NO	11 Jul NO
76017*	NS	NS	14 Jul 51 (25/26) 1.51 no yng 125–175 ad	15 Jul 40 (15/25) 1.63 no yng 100–125 ad	NS	23 Jul 7 (3/4) 1.57 11 w/yng 60–80 ad	14 Jul predated - no yng 25 ad

76018*	13 Jul NO	NS	30 Jul NO	9 Jul NO	26 Jul NO	16 Jul NO	3 Jul NO
76022A*	20 Jul NR - no yng 2 ad	NS	NS	NS	NS	NS	NS
76037*	26 Jul NO	NS	NS	NS	23 Jul NO	22 Jul NO	NS
Total Nests	77	76	58	92	32	66	25
Avg. Clutch	1.69 ± 0.5	1.74 ± 0.5	1.47 ± 0.5	1.59 ± 0.5	1.35 ± 0.5	1.70 ± 0.5	1.52 ± 0.5

[1] includes a single nest with one egg and one just hatched chick. [2] nest counts done daily from 8 to 13 July and all nests predated each day. [3] 14 adults observed between two islands, split equally between them.

chick. In 2017, colony 76001A appeared to have both an Arctic Fox and a Polar Bear *Ursus maritimus* present early in the season, both of which likely depredated a large number of Common Eider nests, and negatively affected tern reproduction that year (C. Sonne pers. comm.).

Mean (± SD) clutch size from 2009 to 2017 was 1.6 ± 0.5 eggs per nest (n = 402) and varied from 1.4 ± 0.5 eggs per clutch in 2014 to 1.7 ± 0.5 in 2010 (Table 1). One- and two-egg clutches were observed among 40.4% and 58.6% of the total nests, respectively, and 1% of the total nests held three eggs (documented only in 2009 and 2010). The percentage of two-egg clutches in any given season ranged from a low of 34.8% in 2015 to a high of 68.4% in 2010. It should be noted that additional eggs may have been laid after surveys were completed and thus, clutch size data should be viewed as minimums.

Using the number of adults observed to estimate the number of nests, ~263 nests were found at the five colonies that Salomonsen noted terns at in in 1968 while ~253 nests were at four colonies Kampp observed terns at in 1987 (Boertmann *et al*. 1996) (Table 2). More recently, ~194 nests were at the six colonies Mosbech (Boertmann *et al*. 1996) observed terns at in 1998 and ~187 terns were at the five colonies K. & W. Burnham (unpubl. data) visited in 1999 (Table 2). Between 2009 and 2017, we recorded a median of 66 nests with a high of 92 nests in 2014. Overall, there was a significant reduction in the number of nests from 1968 to 2017 (r_s = −0.82, P = 0.001, n = 12; Figure 2) with the greatest overall reduction taking place from the late 1990s to this study.

Four colonies that were previously documented with terns did not possess any nesting terns during the entire period of our study between 2009 and 2017. As recently as 1999, colonies 76006 ("terns flying around island") and 76037 ("~100 adults") were documented with terns, while colony 76016 was documented with terns in 1994 (~23 nests) and 76018 in 1987 ("tern observed") (Boertmann *et al*. 2006; K. Burnham & W. Burnham unpubl. data) (Table 2).

Significant reductions in numbers also occurred at three other colonies. Colony 76002, which had an estimated ~33–47 nests in 1999 decreased to a low of two nests in 2017 (Table 2). Similarly, colony 76005 had an estimated ~33–60 nests from 1968 to 1999, but no more than three nests during any year of our survey (Table 2). Additionally, colony 76001A had ~67 nests in 1968 and ~133 nests in 1998, with a maximum of only 34 nests during this study (Table 2).

Colonies 76003 and 76017 appear to be the only stable tern colonies in our study area. While colony 76003 has declined in size by approximately half from 1968 (~100 nests) and 1977 (~133 nests), it appeared relatively stable during our survey period (Table 2). In 1987 and 2008 colony 76017 had ~33 nests and ~52 nests, respectively, compared with a high of 51 nests in 2012 (Table 2).

Two new locations with nesting terns were found in the Booth Sound area during this study, but were close to previously known colonies. Colony New 1 (next to 76005) had a high of three nests and 16 individuals in 2014, while colony New 2 (close to 76003) had a single nest found in three out of six years it was surveyed. In both of these cases, however, it was not possible to determine which colonies were associated with the adults flying above them.

Discussion

Inter-annual movement of adult terns between nearby neighbouring colonies is common and considered an important factor compromising our ability to make accurate population estimates (Drury 1973; Devlin *et al*. 2008; Brindley *et al*. 1999). Previous research with Arctic Terns in Denmark documented a mean breeding dispersal of 1.71 km (range 0–151 km) (Møller *et al*. 2006a). In Booth Sound, 23 nesting terns were colour-ringed at colony 76003 in 2011, and observed in subsequent years flying above colonies 76002, 76005 and New 1, all which are

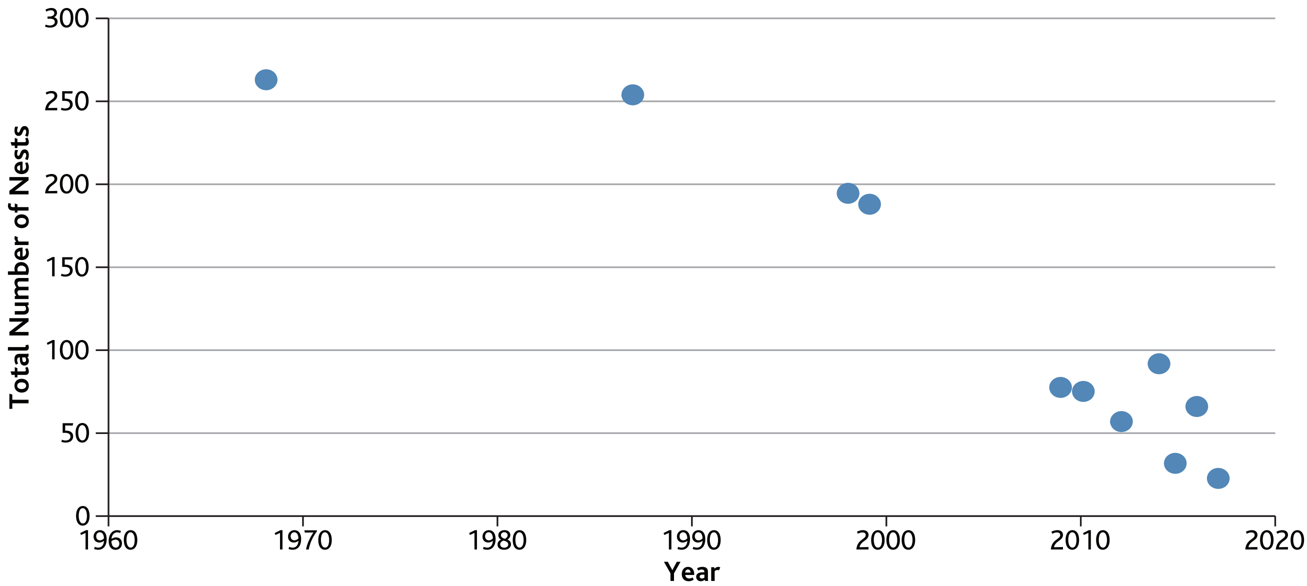

Figure 2. Significant decline (Spearman Rho = −0.82, P = 0.001, n = 12) of Arctic Tern population in northwest Greenland from 1968 to 2017. Data from 1968, 1987, and 1998 (Boertmann *et al*. 1996); 1999 and 2008 (K. Burnham & W. Burnham unpubl. data); and 2009–10, 2012, 2014–17 (this study).

Table 2: Historical observations of Arctic Terns in northwest Greenland from 76.00–77.25°N. Information from the *Greenland Sea Bird Database* (Boertmann *et al*. 1996) and K. Burnham & W. Burnham field notebooks (1999 and 2008). First line indicates survey date, second line estimated number of nests, third line number of adults observed, and fourth line survey method. A "~" preceding the number of nests indicates that number of nests has been estimated from individuals counted (individuals/1.5; Bullock & Gomersall 1981). One pair equals two individuals. NI = no information (see methods), NS = not surveyed.

Location	1968	1987	1994	1995	1998	1999	2008
76001A	1 Aug ~67 100 ad land	NI	NI	26 Aug ~33 50 ad air	17 Jul ~133 200 ad air	31 Jul ~1 1ad boat	7 Aug[1] "12+ yng observed" land
76002	5 Aug ~33 50 ad land	NI	24 Aug ~20 30 ad air	26 Aug ~4 6 ad air	17 Jul ~17 25 ad air	2 Aug[1] ~40 60 ad land	NS
76003	5 Aug ~100 150 ad land	6 Aug ~133 100 pairs land	24 Aug ~33 50 ad air	26 Aug ~3 5 ad air	17 Jul ~1 1 ad air	2 Aug ~40 60 ad boat	NS
76004	5 Aug ~3 4 ad land	NI	NI	26 Aug ~7 10 ad air	NI	NS	NS
76005	5 Aug ~60 90 ad land	6 Aug ~53 40 pairs land	NI	NI	NI	2 Aug ~40 60 ad boat	NS
76006	NI	NI	NI	NI	NI	31 Jul "terns flying around island" boat	NS
76016	NI	NI	24 Aug ~23 35 ad air	NI	NI	NS	NS
76017	NI	7 Aug ~67 50 pairs boat	NI	NI	17 Jul ~3 5 ad air	NS	20 Jul[1] ~52 75–80 ad land
76018	NI	20 Aug tern observed (pair ?) boat	NI	NI	NI	NS	NS
76022A	NI	NI	24 Aug ~3 5 ad air	26 Aug ~4 6 ad air	17 Jul ~7 10 ad air	NS	NS
76037	NI	NI	NI	NI	17 Jul ~33 50 ad air	2 Aug[1] ~67 100 ad land	NS
Total nests estimated	~263	~253	~79	~51	~194	~188	~52

[1] eggs or young observed but no systematic nest survey occurred.

within 1.7 km of 76003 (K. Burnham, unpubl. data). While inter-annual breeding dispersal between colonies seems likely in our study area due to the close proximity of many of the colonies, we feel confident that immigration from surrounding areas is unlikely given the remoteness of our study area from other nesting tern populations to the south and north. However, this assumption deserves further study to determine whether the study area is isolated.

In west Greenland Egevang and Frederiksen (2011) reported annual mean clutch sizes from 1.7–2.0 eggs between 2002 and 2006, while Elkund (1944) reported a mean clutch size of 1.7 in 1943 for south Greenland. The only High Arctic location in Greenland where data is available is Sand Island (east coast), which had a mean clutch size of 1.4 eggs in 2007 and 1.6 in 2008 (Egevang 2010), most similar to our study area (1.4–1.7)

Predation of both tern eggs and young was documented during our survey. An Arctic Fox was observed at a colony in one year when no nesting terns or waterfowl were found (though both were observed nearby); however, a subsequent visit to the colony found the fox no longer present and both terns and waterfowl with eggs. Based on the closeness of the island to the mainland (less than 50 m), it is likely that an ice-bridge had allowed the fox to access the island. Similarly, depredated eggs were found at several other colonies that had either reduced or no reproduction, and it is very likely that their close proximity to the mainland also allowed foxes access via ice-bridge. This appears to be a relatively common cause of complete reproductive failure and has been noted previously (e.g. Levermann & Tøttrup 2007; Egevang & Frederiksen 2011).

The long-term decline of Arctic Terns in Greenland is generally attributed to a number of factors, including predation by foxes and avian predators, egg harvesting by humans, and limited prey availability (see Egevang 2010 for review). In our study area, Arctic Foxes clearly had a significant effect on populations, likely causing complete reproductive failure at multiple colonies. The role of egg harvesting on the decline is less certain. Although large collections of Common Eider eggs were observed in some seasons (K. Burnham, unpubl. data), we did not witness tern eggs ever being collected by local Inuit. It should be noted however, that the majority of tern colonies in our study area are along a section of coast that is travelled by local people moving between Qaanaaq and Thule Air Base, and tern egg harvesting *may* occur. No information on prey availability exists for our area, but based on the small mean clutch size observed during some seasons, it appears productivity may be low when compared with other populations in Greenland and the High Arctic.

Only a few studies exist investigating the effects of recent climate change on Arctic Tern populations (Møller *et al.* 2006a, b). In our study area significant changes have occurred over the past several decades in both temperature (rise) and timing (earlier) of sea-ice breakup (Screen & Simmonds 2010; Serreze & Barry 2011; Stroeve *et al*. 2014), although what direct affect these have had on the local tern population is unknown. Similar changes in other areas of the Arctic have been linked to increased predation by Polar Bears at waterfowl colonies (Smith *et al*. 2010; Iverson *et al*. 2014; Prop *et al*. 2015). While it seems unlikely that bears would directly depredate tern eggs due to their size and crypsis, their presence at tern colonies may discourage nesting. In our study area, we have increasingly observed polar bears at waterfowl colonies since 2012, with no prior sightings from 1993 to 2011 (K. Burnham unpubl. data).

The decline in Arctic Terns documented in this study follows a disturbing trend among several seabird species in both west Greenland and High Arctic Canada. For example, in west Greenland significant declines have been documented in both Brünnich's Guillemot *Uria lomvia* and Kittiwake *Rissa tridactyla* populations (Burnham *et al*. 2005; Labansen *et al*. 2010; Merkel *et al*. 2014). To the west of our study area, in the Queens Channel region of High Arctic Canada, Maftei *et al*. (2015) reported a similar decline in the number of Arctic Terns to that found in this study, including reductions in colony size and colony extirpation. Additionally, the number of nesting Ivory Gull *Pagophila eburnean* in High Arctic Canada has decreased by approximately 80% (Gilchrist & Mallory 2005). These studies all underscore the importance of, and continued need for, long-term data sets, particularly for species which breed in remote, difficult to access areas.

Results from this study provide the first population estimate for Arctic Terns for northwest Greenland and a baseline from which future surveys can be compared. Based on historical information, the population is in decline and multiple colonies have been extirpated in the last 10–30 years. While causes of decline are unknown, nesting colonies should be afforded as much protection as possible from human disturbance, including future mining ventures which are proposed for this area. Although the population of Arctic Terns in northwest Greenland makes up only a very small proportion of the overall population in Greenland, continued monitoring is warranted as several colonies have dramatically reduced in size in just the past 10–15 years. Of specific importance are the remaining three primary colonies, which combined make up almost 90% of the total breeding population in this area.

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