Facing Climate Change: The Case of the Arctic Tern (*Sterna paradisaea*) | Finn Mander

Introduction

Scientific evidence supporting the warming of the climate is indisputable. The Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC AR5) shows that greenhouse gases (GHG) are projected to increase global temperatures by up to 4.8°C above pre-industrial levels by 2100 if significant action is not taken to decrease emissions (Overland et al. 2019). These greenhouse gases (primarily CO2) are the dominant cause of observed warming over the past 70 years (USGCRP 2018). Records show that 16 of the warmest years on record have occurred in the last 17 years (USGCRP 2018). Annual near-surface air temperatures across Alaska and the Arctic over the last 50 years have increased at over double the rate of the global average, highlighting the extra sensitivity of the Arctic to climate changes (USGCRP 2018). Alongside increased greenhouse gas emissions (GHG), the ocean has absorbed 93% of excess heat beginning in the mid-20th century in addition to more than a quarter of global CO2 emissions annually produced by humans (USGCRP 2018). These changes to ocean biogeochemistry result in acidification and the reduction of sea ice, both of which have potential implications for marine wildlife (USGCRP 2018; Lannuzel et al. 2020). Since the early 1980s, annual Arctic sea ice has, on average, decreased in extent from 3.5-4.1% per decade, becoming thinner by 4.3-7.5 ft and melting 15 days earlier every year (USGCRP 2018). This results in a September sea ice extent that has decreased between 10.7% and 15.9% per decade (USGCRP 2018). Being a significant cold reservoir for the global climate, the loss of snow, sea ice, land ice, and frozen ground as a result of climate change could result in positive feedback loops that increase temperatures even faster (Overland et al. 2019).

To address this problem, the IPCC AR5 models an aggressive, but realistic approach for limiting GHG emissions, RCP 4.5 (Overland et al. 2019). This model projects temperature increases of 2°C globally and 7.1°C for the Arctic by 2100 (Overland et al. 2019). Despite these improvements, the Arctic Ocean will still be free of sea ice by late summer every year in addition to the eventual total loss of the Greenland ice sheet (Overland et al. 2019). As such, by taking actions in RCP 4.5, effects will not be reversed but will slow down (Overland et al. 2019). This could potentially give humans more time to find ways for reversing the negative outcomes (Overland et al. 2019).

If RCP 4.5 is successful and mechanisms for reversal of climate change are created, perhaps climate change will cease to be a problem in the future. However, in the near future, climate change has potentially grave consequences for ice-associated Arctic marine organisms, especially those in the high Arctic (Cooley et al. 2020). These dramatic changes beg the question of how climate change will affect individual species. In determining the future success for a given species, their adaptability, vulnerability, and sensitivity to a changing environment should be evaluated.

In light of this, the Arctic tern (*Sterna paradisaea*) is a species that has adapted to a diverse Arctic environment (Alerstam et al. 2019), resides in a region of higher vulnerability (Cooley et al. 2020) and is sensitive to aspects of climate change (Mallory et al. 2017). The Arctic tern is a truly unique bird, having the longest annual migration of any animal on the planet (Alerstam et al. 2019). Arctic terns travel an average of 50,000 km round-trip from the Arctic to the Antarctic every year (Alerstam et al. 2019). These small 105-115 g seabirds (Bond et al. 2010) live 11-19 years on average, peaking at 34 years (Petersen et al. 2020). They spend 2/3 of their life in the Arctic and 1/3 in the Antarctic (Redfern and Bevan, 2020) and have a global population of over 2,000,000 individuals (Birdlife International 2018). The International Union for Conservation of Nature (IUCN) Red List has classified them as being "Least Concern" since 1988, reflecting their extremely large range and extremely large population (with a less than 10% decline in 10 years or three generations) (Birdlife International 2018).

In recent decades, alongside climate related changes in the Arctic, populations of seabirds in the high Arctic have been declining, primarily in Greenland and Iceland (Gaston et al. 2012). The Inuit people of the northern Canadian Arctic have observed localized population declines of Arctic terns (Henri et al. 2020), and models of Arctic tern survival predict a 4.6% population decrease per year (Mallory et al. 2018). Despite this, there is no clear explanation for the observed and predicted decline of Arctic terns (Egevang and Frederiksen 2011). In recognition of these points and because Arctic terns serve as an indicator species in the high Arctic (Furness and Camphuysen 1997; Møller et al. 2006; Scopel and Diamond 2018), it is important to comprehensively study the risks associated with the Arctic tern with regards to climate change in order to determine whether it plays a significant part in determining the future survival of the Arctic tern and the surrounding arctic.

This paper discusses the implications of climate change as they relate to five predominant but overlapping areas of the life history of Arctic terns: habitat, migration, diet, reproduction, and predation. Using trends across these areas, a conclusion is made on the overall outlook for the bird.

Discussion

Habitat

Arctic terns have an extremely wide distribution, being natively found in 67 territories and an additional 39 more during migration (Birdlife International 2018). This distribution is spread across the entire range of northernmost latitudes in the Arctic as well as the entire range of southernmost latitudes in the Antarctic where they, respectively, breed and molt (Figure 1) (Birdlife International 2018). When stationary, the birds produce ground nests in shallow cutouts along coastlines or close to water on a large variety of substrates (del Hoyo et al. 1996; Redfern and Bevan 2020). This suggests potential for adaptation regarding ground nesting site choice. Nesting sites are closely associated with fragmented ice and polynyas, areas of high productivity in the Arctic and Antarctic (Redfern and Bevan 2020). A primary component of latent heat polynyas is the formation and breaking off of fast ice, which prevents coastal erosion (Cooley et al. 2020). In their research, Cooley et al. (2020), found that over a 19-year period, Arctic communities with colder mean annual spring air temperatures experienced the largest reductions in fast ice relative to increasing global temperatures. These communities, which Arctic terns inhabit, were the northernmost communities in the study (Cooley et al. 2020). This made them the most sensitive of the study areas to the immediate implications of climate change (Cooley et al. 2020), potentially making Arctic terns vulnerable. With the loss of fast ice, the polynyas may become areas of open water, increasing coastal erosion (Cooley et al. 2020). Extreme weather is predicted to increase due to climate change (Overland et al. 2019), which may magnify the effects of erosion (Cooley et al. 2020). This could pose a risk to Arctic terns nesting along the coastline; however, because the birds can live in many different low-land environments (del Hoyo et al. 1996; Birdlife International 2018), it is unlikely that this change will significantly affect the larger population unless erosion events become widespread.

In the Antarctic, global warming is associated with decreases of sea ice on the western coast and increases of sea ice in the Ross Sea on the eastern coast (Atkinson et al. 2004; Redfern and Bevan 2020). The West Antarctic Ice Sheet (WAIS) has the potential for rapid melting over the course of decades to centuries as a result of latent heat change and changes in ocean circulation (Pattyn and Morlighem 2020). This sheet is situated on the continental shelf deep beneath sea level and has the potential to raise global sea levels by 5.3 m if fully melted (Pattyn and Morlighem 2020). Because Arctic terns predominantly overwinter in Weddell Sea on the west coast of Antarctica (Egevang et al. 2010), the potential for increased erosion (Cooley et al. 2020) as well as WAIS (Pattyn and Morlighem 2020) and sea ice loss (Cooley et al. 2020) could cause disruptions for Arctic terns. The eastern Antarctic may be a suitable alternative site, especially because Arctic terns are found throughout the entire continent (Birdlife International 2018), including the poorly studied south eastern Antarctic (Woehler et al. 2010).

The lessening of sea ice and increased sea surface temperatures associated with climate change (USGCRP 2018) may be cause for concern in the Antarctic (Pattyn and Morlighem 2020), but there could be hope for the Arctic. In their research, Amélineau et al. (2019) found that little auks (*Alle alle*) in east Greenland experienced better environmental conditions during breeding as a result of less sea ice and higher sea surface temperatures. This was likely because the higher temperatures reduced the energy requirements for thermoregulation, allowing for the repurposing of energy towards chick rearing and body maintenance (Amélineau et al. 2019). Because over 50% of Arctic terns breed in Iceland and Greenland (Egevang et al. 2010), this could also be the case for Arctic terns. Additionally, it may be that these conditions also reduce the energy costs associated with molting while in the Antarctic, an energetically taxing process (Dietz et al. 1992; Schieltz & Murphy 1995; Portugal et al. 2007). Regardless, these benefits may be short-lived because of possible phenological mismatch forming between trophic levels due to earlier sea ice loss as well as direct human impacts on habitat (Amélineau et al. 2019).

Human presence in the Arctic may offset the survival benefits that could come with a milder Arctic climate (Amélineau et al. 2019). Increased pollution in the Arctic has been found to increase mortality in little auks, primarily through toxins such as mercury (Amélineau et al. 2019). For example, between 2011 and 2012, 22,000 seabirds were killed by hydrocarbon contamination in Newfoundland (Amélineau et al. 2019). Industrial sites being built in the Arctic pose an additional risk due to a milder climate increasing accessibility (Gaston et al. 2012). For example, land-based mining operations could result in year-round ice-breaking, and offshore oilfields could be built in areas used by seabirds such as the Davis Strait, Newfoundland, and Labrador (Gaston et al. 2012). More research is needed in this area, though, because Liebezeit et al. (2009) found that human infrastructure in proximities of 100 m to 80 km did not have an effect on nest survival for shorebirds in the Arctic coastal plain of Alaska (Liebezeit et al. 2009).

Migration

Arctic terns migrate over incredible distances, with their southbound migration spanning approximately 93 days over 34,600 km, and their northbound migration spanning approximately 40 days over 25,700 km (Egevang et al. 2010). They likely use internal clocks and photoperiods to initiate different stages of migration, but the exact mechanism is still unknown (Gordo 2007; Redfern and Bevan 2020). The migration cycle begins within 1-3 months of birth in the Arctic (Henri et al. 2020) when clusters of 15 birds or less (Egevang et al. 2010) fly south between August and November (Egevang et al. 2010). During this flight, the birds utilize prevailing winds to reduce energy costs (Egevang et al. 2010). Individual populations of Arctic terns travel along varying routes (Figure 2), but most migrate over the Atlantic Ocean (Alerstam et al. 2019; Redfern and Bevan 2020). These populations will travel at slightly offset timeframes in relation to one another to limit competition, indicating potential adaptability to variations in migration timing (Alerstam et al. 2019). Arctic terns maintain a lightweight (Bond et al. 2010) and lean body (Gordo 2007), likely to aid in increased agility for avoiding predation and less energetically taxing (albeit shorter) flights (Gordo 2007). Consequently, they rely on exogenous food sources utilizing concurrent intake while flying (Bond and Diamond 2010; Pratte et al. 2018) and must replenish more frequently than if they maintained heavier fuel reserves (Bairlein 1985; Biebach 1985; Biebach et al. 1986; Yosef et al. 2006; Gordo 2007). This is an energetically taxing form of foraging (Österblom et al. 2008). The Arctic tern is found flying over the open ocean during migration but is also found inland or along coastlines (Higgins and Davies 1996). During the trip, the bird will have a series of steppingstones in areas of high productivity (Egevang et al. 2010; Alerstam et al. 2019).

Upon arrival in the Antarctic in September-October, Arctic terns tend to fly east along the Antarctic coast towards the Indian Ocean and Tasman Sea, which are full of rich and available food sources, before finally settling down in the Antarctic (Alerstam et al. 2019). This could indicate adaptability to fluctuations in optimal spring arrival, which is typically in early

November (Alerstam et al. 2019). Arctic terns will stay in the Antarctic region from December to March (Redfern et al. 2019), molting from January to March (Redfern and Bevan 2020).

Before heading back north in April (Møller et al. 2006; Egevang et al. 2010), the birds will fly to the western coast of Antarctica if they are not already there (Egevang et al. 2010; Alerstam et al. 2019). This travel is aided by longitudinal cyclonic air flows (Redfern and Bevan 2020). The concentration of Arctic terns on the western coast is likely a result of the region containing the highest Antarctic krill (*Euphausia superba*) densities of the continent (Egevang et al. 2010), which Arctic tern assemblage is highly correlated with (Woehler et al. 2010). Overwintering habitats are a limiting factor for breeding success because of energy needs for, and possible delays of, migration, especially in the case of leaner birds (Gordo 2007). This could explain the potential importance of visiting a high productivity site (Egevang et al. 2010) prior to migration north. Documented changes since the 1970s of decreases in Antarctic krill density in the southwest Atlantic (Atkinson et al. 2004) and loss of sea ice on the western Antarctic coastline (Atkinson et al. 2004; Redfern and Bevan 2020) may cause changes to this behavior.

When the Arctic tern returns north in between April and May, it has been found that their arrival date, specifically in Norway, has consistently been within a 13-day window in mid-to-late May (Barrett 2016). Since 1993, this arrival date has advanced by four days, without a clear relationship to the North Atlantic Oscillation (NAO), weather, or sea temperatures (Barrett 2016). Regardless, positive trends in the NAO result in westerly and southerly tailwinds in western Europe, increased temperatures, and increased precipitation (Gordo 2007), which could potentially favor northern flight for the Arctic tern, especially with increased favorable conditions in temperate regions (Gordo 2007). The NAO has seen a positive trend since the 1960s, lying significantly outside of the natural variability found in models, indicating a potential, albeit evidence lacking, connection to climate change (Visbeck et al. 2001; Kuzmina et al. 2005). Spring is starting earlier due to climate change (Menzel et al. 2006), which often coincides with increased southerly tailwinds (Gunnarsson and Tómasson 2011). Arctic terns prefer southwesterly crosswinds and arrive earlier when tailwinds are advancing them (Barret 2016). If southerly or southwesterly tailwinds are increasing, it could explain an earlier spring arrival (Barret 2016) because of the potential for an energetically conservative and faster flight (Gordo 2007; Barrett 2016). In considering the advancement of spring, 1988-2009 research from

Gunnarsson and Tómasson (2011) on 17 species of Icelandic migratory birds (including the Arctic tern) found that only those that fly less than 2,300 km during their northern migration adjusted their arrival dates to arrive earlier in reflection of milder winters, likely because they are close enough to assess conditions prior to arrival. This could explain the early arrival times and movement east seen in the Antarctic before molting (Alerstam et al. 2019), as it would allow the Arctic terns to survey the continent for ideal conditions. Arctic terns have high survival rates even if they experience poor flight performance (Alerstam et al. 2019), which could cause early initiation of the northward return due to a lack of food (Barrett 2016).

Changes in behaviors as a result of climate change may be significant. For example, Clairbaux et al. (2019) suggest that global climate change could result in species or populations changing from being migratory to residential, omitting the need to migrate entirely. If the Arctic tern's migration behavior is similar to that of the whooping crane (*Grus americana*), it may be adaptable to environmental changes. Whooping cranes can learn new migration routes (Cheng et al. 2020) and navigate using familiar landmarks to stay on track during migration, supporting the notion that genetics are not related to migratory performance (Mueller et al 2013). Despite a potential for behavioral adaptation, climate change related increases in extreme weather (Overland et al. 2019) or other changes could make seabirds vulnerable during their migrations or interfere in the mechanisms for initiating various stages of migration (Bairlein 2016). This is supported by increased mortality for European and North American migratory birds compared to their non-migratory counterparts (Bairlein 2016).

Diet

Arctic terns have three distinct environments in which they traverse throughout the year: their northern breeding ground (the Arctic), southern overwintering area (the Antarctic), and the space that is traversed between the two during migration (Birdlife International 2018). They are a plunge-diving bird that predominantly feeds at the surface but is capable of diving 50 cm (Hatch 2002). After catching prey, Arctic terns cannot store it, but can carry one or more items at a time in their beaks, depending on the prey (Hatch 2002). This may result in increased energetically expensive foraging behavior, making the bird vulnerable to changes in prey energy content (Litzow et al. 2002; Litzow et al. 2004; Österblom et al. 2008) due to climate change (Robertson et al. 2015).

During the breeding season, Arctic terns forage for food in coastal bays and over wet tundra within 3 km of their nests in the Arctic but have been observed as far as 50 km offshore (del Hoyo et al. 1996). Inuit in Kuujjuaraapik have observed feeding in association with seals and beluga whales (*Delphinapterus leucas*) in the high Arctic (Henri et al. 2020). Arctic terns that are old enough to breed are central place foragers, being restricted in movement due to the requirement of returning to the nest (Pratte et al. 2018). This results in a narrower isotopic niche during breeding season because of their dependence on local prey (Pratte et al. 2018). Female birds may also target specific prey that meets the physiological needs of egg formation (Pratte et al. 2018). When unconstrained and no longer central place foragers during migration and overwintering, Arctic terns have a wider isotopic niche, which could suggest variable sources of prey (Pratte et al. 2018) and an expanded range (Redfern and Bevan 2020). In their southern overwintering area, they forage for food alongside the edges of pack-ice edges, icefloes, leads, and icebergs (Higgins and Davies 1996) and have been observed as far as 24 km offshore feeding in association with Antarctic minke whales (*Balaenoptera bonaerensis*) (Higgins and Davies 1996).

Throughout these areas, their diet consists primarily of ocean-caught organisms including a large variety of fish, mollusks, crustaceans (del Hoyo et al. 1996), and marine worms (Hatch 2002). Other prey include capelin (*Mallotus villosus*), sand lance (Ammodytes sp.) (Henri et al. 2020), Antarctic krill (*Euphausia superba*), and ice krill (*Euphausia crystallorophias*) (Redfern and Bevan 2020). Arctic terns will eat terrestrial organisms, namely insects such as caterpillars, non-biting midges (*Chironomidae*), and earthworms (del Hoyo et al. 1996).

Despite their significant dietary adaptability (Hatch 2002), Arctic terns are reluctant to switch food sources when their preferred source fails (del Hoyo et al. 1996). Additionally, unlike little auks (Amélineau et al. 2019), Arctic terns cannot compensate for a lack of food by diving deeper or increasing their foraging range (Furness and Camphuysen 1997). This could make them vulnerable to climate related trophic changes such as reductions of sand lance (Robertson et al. 2015), their preferred food source in the North Sea (Österblom et al. 2008). Their status as a shallow diving bird makes them a potential indicator species for such trophic changes (Furness and Camphuysen 1997). Abundance of sand lance has been positively correlated with breeding success of Arctic terns in the North Sea between 1983-1993, and foraging effort between 1990-

1993 (Österblom et al. 2008). Iceland, which contains 20-30% of the breeding population of Arctic terns, experienced a sand lance population collapse in 2000 due to warming water temperatures (Petersen et al. 2020). This collapse resulted in a 10% reduction in annual adult Arctic tern survival for the region, with reduced rates of survival documented from 2000-2017 (Petersen et al. 2020). Arctic terns may benefit from an increase in sand lance abundance in other regions, namely the Hudson Bay (Gaston et al. 2012).

Krill density is closely correlated with sea ice extent (Atkinson et al. 2004). The loss of sea ice in the Western Antarctic (Atkinson et al. 2004; Redfern and Bevan 2020), where over 50% of krill in the Southern Atlantic is found (Atkinson et al. 2004), may prove to be problematic for Arctic terns due to the significant role that krill plays in connecting primary production with higher trophic level consumers in an already non-diverse food web (Rau et al. 1992). Krill not only use sea ice for protection (Redfern and Bevan 2020), but also rely on ice-associated summer phytoplankton and winter ice algae blooms (Atkinson et al. 2004). This decrease in phytoplankton may be countered by a growing phytoplankton habitat in increasingly open oceans due to climate change (Lannuzel et al. 2020), but this will have to counter current declines in krill density observed since the 1970s (Atkinson et al. 2004). In addition to forming the foundation of the heterotrophic food web, krill serve as a preferred food source for Arctic terns, with significant correlation between assemblage and krill density (Woehler et al. 2010). If Arctic terns are unable to get adequate nutrition while in the Antarctic, their molt could be affected (Gordo 2007). If they are unable to get adequate nutrition in the Arctic, their reproductive decisions (Kowalczyk et al. 2014) and success during breeding season may be at risk (Mallory et al. 2017). Krill abundance may improve with increased frequency of mild rain, but moderate or high rain levels will contribute to decreasing abundance (Scopel and Diamond 2018). With increased extreme weather events predicted (Overland et al. 2019), krill may be at risk for higher intensity rain, thus decreased abundance.

Reproduction

After returning to the Arctic in the early summer, small, scattered populations (Gaston et al. 2012) of breeding aged Arctic terns, ages two-four and older (Møller et al. 2006), will breed and initiate nests in the early summer (Mallory et al. 2017). Breeding success is dependent on weather, local food availability, and predation pressure (Mallory et al. 2017). In producing an egg, Arctic terns average 2.66 eggs per clutch, with 22.2 days of incubation and 22.5 days from hatching until fledging (Cramp 1983). Regional survival rates for first year chicks are relatively low at 11.9% ± 2.4 (Petersen et al. 2020) compared to adult survival rates ranging between 87.5% (Cramp 1983), 88.3% (Mallory et al. 2018), and 95.2% (Petersen et al. 2020). Strong adult survival rates indicate that population declines are likely related to reduced juvenile survival (Mallory et al. 2018).

Weather can be a significant inhibitor of survival for chicks (Robinson et al. 2002), with low temperatures, snow, and heavy rains causing exposure (Mallory et al. 2017). Additionally, late ice break-up causes delays in productivity, leading to starvation (Mallory et al. 2017). Increased presence of predators, or severe weather may cause birds to abandon the colony, delay onset of laying, or forgo breeding entirely (Mallory et al. 2017). With extreme weather events increasing due to climate change (Overland et al. 2019), chick survival may be at increased risk in the future.

Additionally, Arctic terns benefit from a wide foraging range during most of the year (Pratte et al. 2018), but during breeding season are limited to their nesting site and surrounding area (Bond and Diamond 2010; Pratte et al. 2018). This is partially because of the significant 15% weight relative to body mass that forming an egg constitutes (Bond and Diamond 2010), in addition to the requirement that after foraging the bird must return back to the nest, limiting the distance that can be traveled (Pratte et al. 2018).

In their research, Møller et al. (2006) investigated the changes in breeding for the Arctic tern in Denmark from 1929-1998. They found that mean ringing date (assumed to be a proxy for breeding date) advanced by 18 days over 70 years as a result of increased temperatures and a positive NAO, indicating an increased probability of survival earlier in the season (Møller et al. 2006). With an average end of migration in early April, an earlier breeding date is not constrained by arrival date, indicating flexibility to further changes (Møller et al. 2006). They also found that natal dispersal extended dramatically over 60 years, from 10 km to 100 km, increasing gene flow between populations of Arctic terns, but delaying reproduction timing (Møller et al. 2006), which could be a future threat to reproduction if the distance keeps increasing. Breeding dispersal did not increase, staying relatively constant (Møller et al. 2006). A benefit of the compilation of long-term data sets is that climate changes can be tracked over time as they relate to Arctic terns, making them a good indicator species (Møller et al. 2006).

Predation

Arctic terns benefit from breeding on offshore islands, which are typically inaccessible to terrestrial predators (Gaston et al. 2012). The birds may be quite vulnerable to predation pressure, with pressures resulting in longer incubation periods (Mallory et al. 2017), and a tendency to abandon colonies (Egevang and Frederiksen 2011; Scopel and Diamond 2018). The birds may decide not to nest while predators are present, causing complete breeding failure (Pratte et al. 2016), as seen on Nasaruvaalik Island, Nunavut (Pratte et al. 2016). Significant fluctuations found in colony populations, but not in overall regions, may indicate that localized threats are causing birds to abandon their colonies (Egevang and Frederiksen 2011). Fluctuations have been observed in west Greenland (Egevang and Frederiksen 2011) and Kuujjuaraapik (Henri et al. 2020), with collapse apparent in the Gulf of Maine (Scopel and Diamond 2018), and regularly occurring collapses found in northeastern Greenland (Egevang and Frederiksen 2011). Potential explanations for fluctuations may be colony-wide panic flights poorly correlated to predator presence (Mallory et al. 2017). Explanations for collapse could be increased predation combined with their inability to breed beyond a 25% predation threshold (Scopel and Diamond 2018). Despite this, urban Arctic and remote Arctic terns have similar hatching success rates (Syrová et al. 2020). The level of disturbance from humans did not alter their incubation performance, suggesting that the birds are able to moderate their incubation behavior for optimal clutch survival in the face of disruption (Syrová et al. 2020). However, significant disruptions may be a threat to embryogenesis with too much time spent off of the nest (Syrová et al. 2020). Additionally, increased hunting pressure and pollution from humans may contribute to large scale population declines in Greenland, but not the Canadian Arctic (Gaston et al. 2012).

Being lightweight birds, Arctic terns have an increased agility which aids them in escaping predators (Gordo 2007). The birds also have effective predator defense strategies characterized by high rates of aggression during the breeding season (Robertson et al. 2015). However, their aggressive behavior is not always able to ward off predators from either themselves or their chicks (Henri et al. 2020), especially when the birds have experienced recent breeding failure reducing the size and health of the population (Nordström et al. 2004). Common predators of the Arctic tern include urban cats (*Felis catus*) and dogs (*Canis lupus familiaris*), polar bears (*Ursus maritimus*), Arctic foxes (*Vulpes lagopus*), various gulls and skuas (Syrová et al. 2020), peregrine falcons (*Falco peregrinus*), merlin falcons (*Falco columbarius*), invasive American ravens (*Corvus corax*), gray wolves (*Canis lupus*), humans (*Homo sapiens*) (Henri et al. 2020), and invasive American mink (*Neovison vison*) (Nordström et al. 2004). Invasive species may continue to increase with the fitness of generalists outperforming that of specialists in the Arctic (Lannuzel et al. 2020), putting the Arctic tern at risk for increased predation and competition (Henri et al. 2020).

Declines in sea ice extent as a result of climate change (USGCRP 2018) are resulting in increased predation of ground nesting bird eggs (Divoky et al. 2015; Rode et al. 2015). For example, polar bears are being forced to terrestrial areas and significantly increasing their intake of Arctic tern eggs due to a lack of their preferred food source (Rode et al. 2015). This pattern has also been seen with other seabirds such as Mandt's black guillemot (*Cepphus grille mandtii*) on Cooper Island (Divoky et al. 2015). Because a significant number of bird eggs are required to satiate a polar bear (Rode et al. 2015), mortality could dramatically increase in bird colonies alongside climate change. In the Northern Arctic, where Arctic tern breeding failure is regularly seen on Sand Island, sea ice connecting the island habitat to the mainland is responsible for Arctic fox predation (Egevang and Frederiksen, 2011). Increased warming could result in earlier melting of sea ice (USGCRP 2018) and decreases in arctic fox predation.

Conclusion

In light of these significantly varied challenges for survival, and the limited opportunities thus far for observing the Arctic tern (Maftei et al. 2015), a clear outlook is impossible. The Arctic tern is adaptable in some ways, but vulnerable and sensitive in others. Immediate areas of concern across the five areas include loss of Arctic and Antarctic sea ice and ice sheets, changes to food webs and prey sourcing, and increased extreme weather events.

What can be concluded is that their status as an indicator species (Furness and Camphuysen 1997; Møller et al. 2006), especially when adjusting for predation (Scopel and Diamond 2018), will give an important measure for the health of the Arctic and Antarctic ecosystems as climate change progresses. The Arctic tern should continue to be studied and monitored to not only assess the health of these ecosystems, but also to determine ways to promote the survival of the species and prevent it from moving further down the IUCN Red List.

Figures

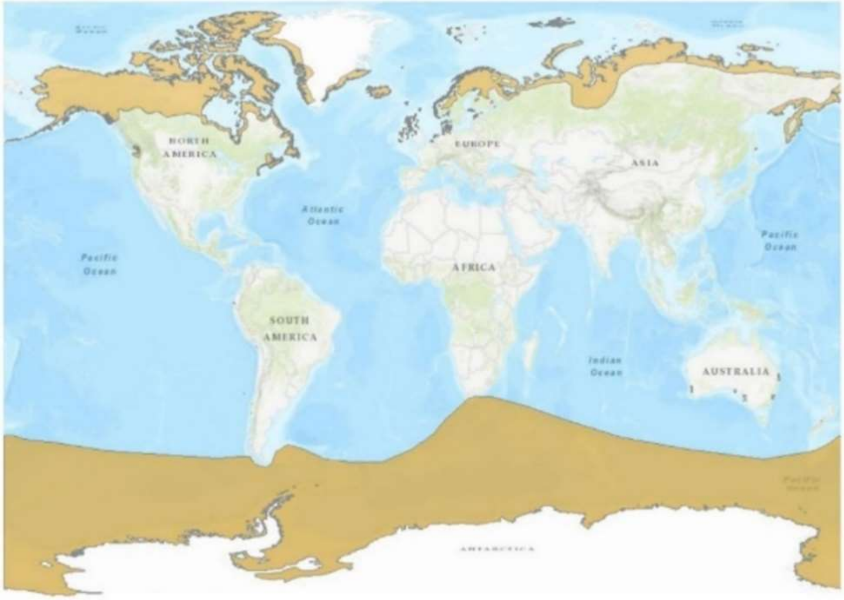

Figure 1: Distribution of the Arctic Tern (*Sterna paradisaea*). Birdlife International 2018

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Kilometer

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Range
▨ Extant (breeding)
▨ Extant (non-breeding)
▨ Extant (passage)

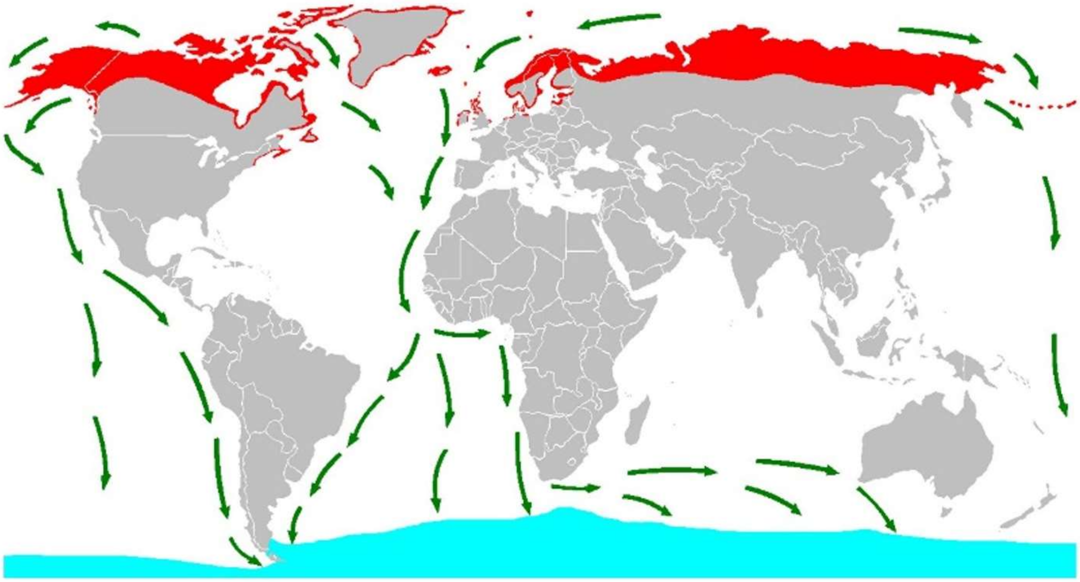

Figure 2: Arctic Tern (*Sterna paradisaea*) Migration Distribution. Trepte 2009.

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