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Colony Connectivity and the Rapid Growth of a Caspian Tern (*Hydroprogne caspia*) Colony on Alaska's Copper River Delta, USA

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Abstract.—North America's northernmost, sizable colony of Caspian Terns (*Hydroprogne caspia*) is located on the Copper River Delta of south-central Alaska, USA. The colony was monitored in June during 2008-2016 and in July during 2009-2013. This 9-year period coincided with reduction of Caspian Tern nesting habitat at East Sand Island in the Columbia River estuary, Oregon, USA, one of the world's largest Caspian Tern breeding colonies. The number of active nests on the Copper River Delta more than doubled during the early study period from 209 in 2008 to 423 in 2013. However, there was a steady decline in the number of nests during 2014 (281) to 2015 (115) and the colony failed in 2016. These declines were likely due to warm sea surface temperature anomalies across the northeastern Pacific Ocean in those years. Based on resightings of banded individuals, colony connectivity was documented between the Copper River Delta and other colonies, ranging from southeast Alaska (215 km) to central California, USA (> 3,000 km). The East Sand Island colony was the most important source of immigrants to the Copper River Delta. While the Copper River Delta now serves as important natural breeding habitat for Caspian Terns, increased flooding and severe storms associated with climate change will likely limit colony size and productivity in the long-term. *Received 16 April 2018, accepted 25 May 2018.*

Key words.—barrier island, breeding colony, breeding dispersal, Caspian Tern, climate change, connectivity, *Hydroprogne caspia*, immigration, marine heat wave, range expansion.

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The Caspian Tern (*Hydroprogne caspia*) breeding population in the Pacific Coast region of North America nearly quadrupled during the last four decades of the 20th century (Gill and Mewaldt 1983; Suryan *et al.* 2004). Concomitant with population growth has been the rapid expansion of the Caspian Tern breeding range northward into Alaska, USA. Currently, North America's northernmost breeding colony of Caspian Terns with more than just a few pairs is located on the Copper River Delta in south-central Alaska. While Caspian Terns and their young have been regularly observed on the Copper River Delta since the late 1980s (Isleib and Kessel 1989), the

existence of a local colony was not confirmed until 2005, when just over 100 nests were found on a barrier island in the Delta (Lohse *et al.* 2008).

One of the world's largest Caspian Tern breeding colonies is located on East Sand Island in the Columbia River estuary, Oregon, USA (Suryan *et al.* 2004). We predicted that management efforts to reduce available nesting habitat for Caspian Terns, which were designed to disperse much of the East Sand Island colony (U.S. Fish and Wildlife Service 2005, 2006), would generate a marked increase in the size of the Copper River Delta colony. Objectives of this study were to document colony size, nesting chro-

nology, and colony connectivity (inter-colony movements) of the Caspian Tern colony in the Copper River Delta.

METHODS

Study Area

Kokinhenik Bar ($60^{\circ} 13' 40.00''$ N, $145^{\circ} 09' 60.00''$ W; Fig. 1) is a low-lying barrier island located at the mouth of the Copper River in Alaska, USA, on the northeastern Pacific Ocean. Kokinhenik Bar is approximately 7 km long x 2.6 km wide and is mostly flat, consisting of sparsely vegetated sand, and littered with driftwood. The Caspian Tern colony is located at the eastern end of the island, next to a major outflow channel of the Copper River. This is also the only area on the island with dunes vegetated with lyme grass (*Elymus arenarius*).

Field Methods and Data Analysis

We conducted 1- to 3-day surveys during 8-14 June 2008-2016 and 6-14 July 2009-2013, coinciding with late incubation/early chick-rearing and late chick-rearing, respectively. During each survey, we recorded the colony location and habitat (open, sandy areas or vegetated

dunes) as well as evidence of recent flooding in or near the colony.

Nest counts were conducted during June surveys. Because predation on Caspian Tern eggs and chicks of this colony was minimal, we walked through the entire colony once to count the number of nests, with walk-through times lasting < 15 min. We defined an active nest as a nest scrape with eggs and/or chicks. We calculated the date when the first egg was laid based on the estimated age of the oldest chick observed during June walk-throughs and assuming a 26-day incubation period. Chick banding was conducted during four survey years: 11 July 2009, 12 July 2010, 7 July 2011, and 14 July 2012. Pre-fledged chicks large enough to receive a set of field-readable leg bands were marked with two plastic color bands and a Federal metal band on one leg, and a tall plastic band with a unique alphanumeric code on the other leg.

During each survey trip, we resighted banded Caspian Terns from portable blinds placed within 50 m of the Copper River Delta colony. Resight effort ranged from 3 person-hr (2008) to 28 person-hr (2015). We used spotting scopes, binoculars, and a SLR digital camera equipped with a telephoto lens to locate and identify banded Caspian Terns. We determined connectivity with other colonies based on banding and resighting records (Bird Research Northwest, pers. commun.).

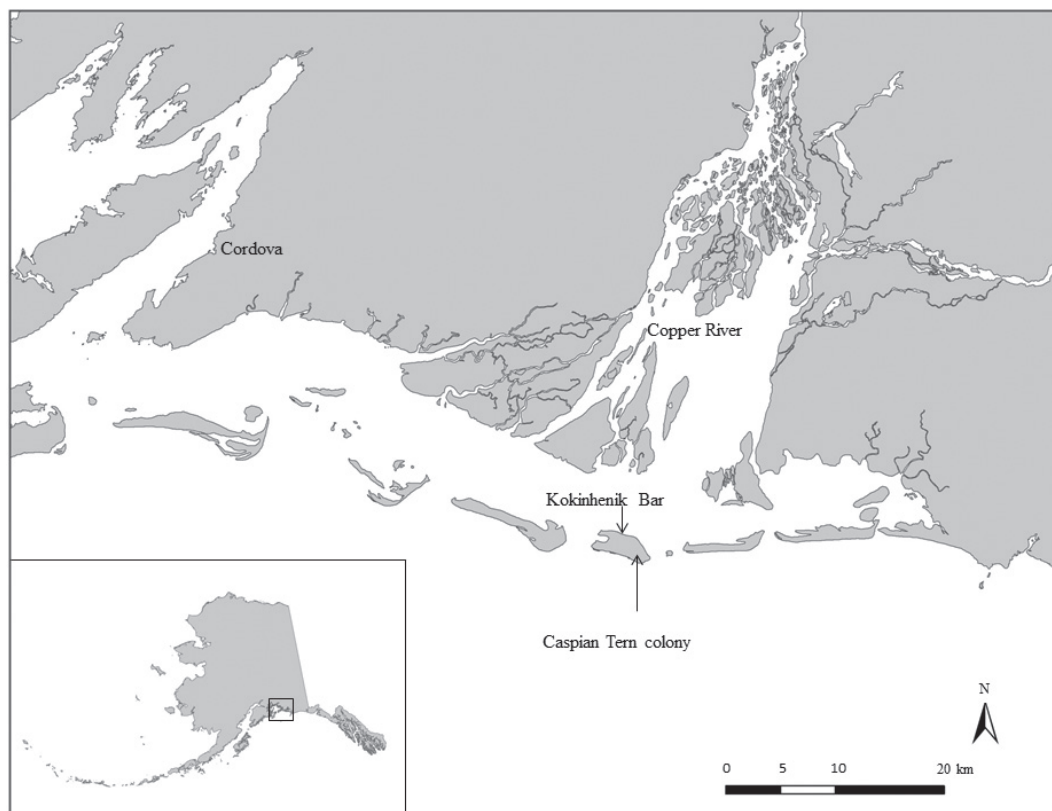


Figure 1. Location of Caspian Tern breeding colony on the Copper River Delta, Alaska, USA.

RESULTS

Nest Counts and Chronology

While the Copper River Delta colony was situated in the same general location on Kokinhenik Bar during all nine survey years, the colony consisted of 1-3 sub-colonies, depending on the year. Caspian Terns nested primarily on slightly raised mounds formed by sand accumulated amongst driftwood. Beginning in 2012, we observed 20% (2012) to 50% (2015) of the breeding pairs nesting in vegetated dunes ranging in height up to 5 m.

Overall, the number of active nests more than doubled during the study period, beginning with 209 nests counted in 2008 and peaking at 423 nests counted in 2013. Despite the overall increasing trend, we observed a single-year decline of 26% in 2010, and a sustained decline during 2014-2016 (Fig. 2). Flooding in and around the Copper River Delta colony due to storm surges was evident in 2010, 2012, 2014, and 2015.

Chronology of nest initiation was similar among years, with the estimated date of first egg laid averaging $9 \text{ May} \pm 1 \text{ day}$ (SE; Range = 4-11 May). July surveys, however, indicated asynchronous nest initiation and/or re-nesting within the colony. During chick-banding in July 2009 and 2011, we recorded 80 and 39 active nests, respectively, each containing 1-4 eggs, while captured chicks ranged in age from < 1-week post-hatching to fledging age (approximately 37 days post-hatching).

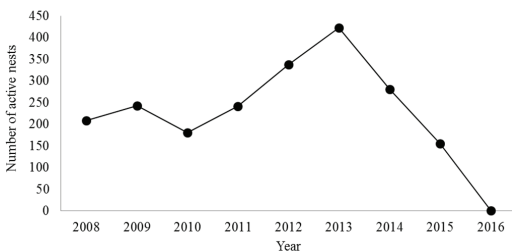


Figure 2. Number of active Caspian Tern nests at the breeding colony on the Copper River Delta, Alaska, 2008-2016.

Natal Philopatry and Connectivity with Other Colonies

At the Copper River Delta colony, we color-banded a total of 71 chicks over 4 years, and subsequently resighted 21% ($n = 15$). Four of these 15 resighted birds were observed during more than one season (maximum = four seasons). The youngest age of first return to the Copper River Delta natal colony as well as the youngest age at first reproduction was 3 years post-hatching. Seven of the chicks banded at the Copper River Delta colony were resighted 2-7 years post-hatching at other Caspian Tern colonies in three USA States: Washington, Oregon, and California (Fig. 3).

Between 2009 and 2016, we resighted 21 Caspian Terns at the Copper River Delta colony that were color-banded as chicks ($n = 18$) or adults ($n = 3$) at other breeding colonies in the Pacific Coast region. While

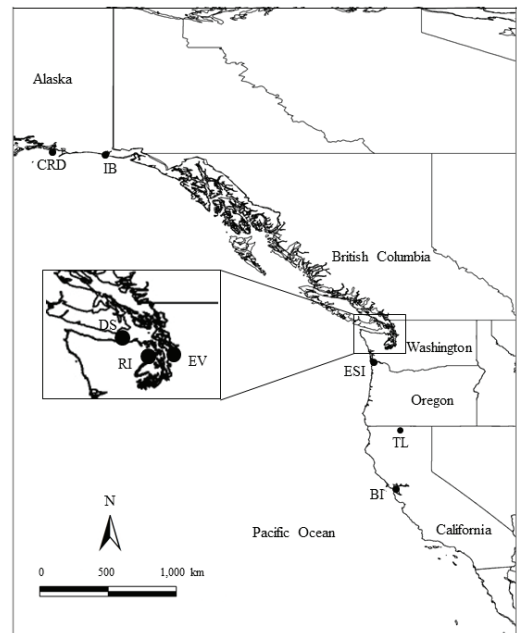


Figure 3. Map of the Pacific Coast of North America showing the location of Caspian Tern breeding colonies where Caspian Terns were color-banded and subsequently observed at the Copper River Delta colony or vice versa. BI = Brooks Island, San Francisco Bay, California; CRD = Copper River Delta, Alaska; DS = Dungeness Spit, Washington; ESI = East Sand Island, Oregon; EV = Everett, Washington; IB = Icy Bay, Alaska; RI = Rat Island, Washington; TL = Tule Lake, California.

the majority had been banded at East Sand Island, Oregon ($n = 19$), we also recorded Caspian Terns banded in northern Washington ($n = 1$) and central California ($n = 1$) (Figs. 3 and 4). Twenty-one percent ($n = 4$) of the individuals previously banded on East Sand Island and subsequently resighted at the Copper River Delta colony were also observed at a Caspian Tern colony in Icy Bay, Alaska, 215 km to the southeast of the Copper River Delta. Resightings at the Icy Bay colony occurred either one ($n = 2$) or two ($n = 2$) seasons prior to the first resighting at the Copper River Delta colony.

When resighted at the Copper River Delta colony, 29% ($n = 6$) of the banded Caspian Terns were confirmed nesting (attending eggs or chicks) during at least one season (maximum = 3 seasons). Two of these six confirmed breeders were banded as breeding adults at East Sand Island, Oregon, and at a colony in central California. Prior to the first resighting of the Caspian Tern from central California at the Copper River Delta,

it had been observed at its originating colony earlier within the same breeding season.

DISCUSSION

While Caspian Tern numbers in Alaska have grown steadily since the early 1980s (Isleib and Kessel 1989; Gibson and Kessel 1992), and small colonies with less than five breeding pairs have been documented at three sites further north (McCaffery *et al.* 1997; Gill 2008; Haynes *et al.* 2017), the Copper River Delta is the largest known colony in Alaska. We suggest that the reason for the formation of a Caspian Tern colony on the Copper River Delta is related to a combination of nesting habitat preference, limited availability of suitable nesting habitat along the Pacific Coast north of Oregon, and high dispersal ability.

Caspian Terns prefer nesting habitat consisting of sandy substrate on islands free of mammalian predators, and their nest-

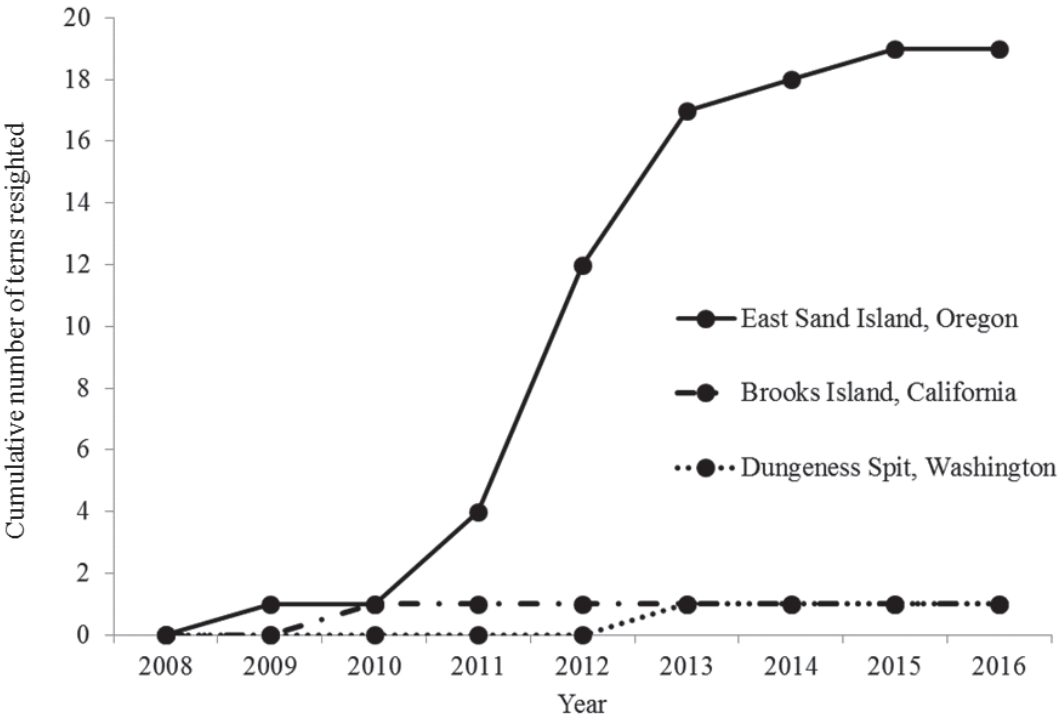


Figure 4. Cumulative number of Caspian Terns color-banded at other colonies and resighted at the Copper River Delta colony, 2008-2016.

ing habitat is generally ephemeral due to flooding, erosion, and human development (Cuthbert and Wires 1999). The series of large barrier islands created by the high sediment loads of the Copper River (Brabets 1997) provide them with breeding habitat that is federally owned, undeveloped, and relatively inaccessible to both humans and mammalian predators. Elsewhere along the coastline of the northeastern Pacific Ocean, however, barrier islands are a rare landform (Boggs 2000) due to the generally steep and rocky shorelines, large tidal ranges, and high wave energy. As a result, Caspian Tern colonies from California north to Alaska tend to occur inland on rivers and lakes and in estuaries.

Caspian Terns demonstrate long-distance movements associated with natal and breeding dispersal (Suzuki 2012). Increased inter-colony movements of breeding Caspian Terns can be associated with low nesting success the previous breeding season (Suzuki 2012) or within the same breeding season.

The largest inter-annual increase in colony size at the Copper River Delta occurred between 2011 and 2012. We suggest this increase may have been due to the combined effects of the 2011 catastrophic colony failure at the East Sand Island colony in Oregon (Collar *et al.* 2017) and the 2012 colony failure at nearby Icy Bay, Alaska, a colony that has supported up to 323 breeding pairs (M. Kissling, unpubl. data).

The dramatic decline in the number of nests at the Copper River Delta Caspian Tern colony observed during June 2014–2016 coincided with the marine heat wave in the northeastern Pacific Ocean that began during the 2013–2014 winter and persisted through 2016 (Bond *et al.* 2015; Di Lorenzo and Mantua 2016). Average monthly sea-surface temperatures recorded near the Copper River Delta Caspian Tern colony ranged from 0.5 to 2.7 °C above average during the 3-year heat wave (Fig. 5). In addition to the Caspian Tern colony, during this time nearby Glaucous-winged Gull (*Larus glauce-*

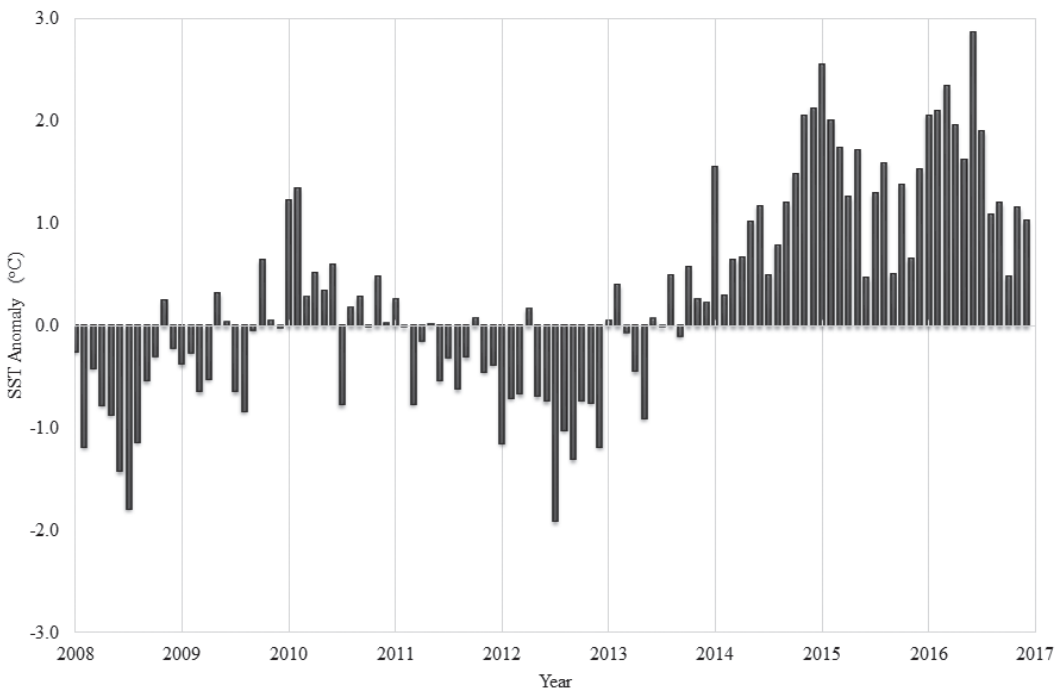


Figure 5. Time series of monthly anomalies of sea-surface temperatures (°C), 2008–2016. Sea-surface temperature data recorded at Cordova, Alaska, USA (60° 33' 26.75" N, 145° 45' 20.95" W); data obtained from the National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products and Services. SST = Sea surface temperature.

scens) colonies either decreased dramatically or failed (M. A. Bishop, unpubl. data), suggesting that the warm ocean conditions negatively affected the availability of marine forage fish.

Our resighting data confirmed both large-scale (> 3,000 km) and relatively small-scale (215 km) connectivity between the Copper River Delta colony and other breeding colony sites to the south. The East Sand Island colony, more than a 2,000-km straight-line distance from the Copper River Delta colony, was the most important source for Caspian Terns immigrating to the Copper River Delta colony. In 2008, management agencies began reducing the availability of Caspian Tern nesting habitat at East Sand Island, while providing new alternative nesting habitat in interior Oregon and northeastern California (Roby *et al.* 2015). The goal is to reduce the colony size from approximately 9,600 breeding pairs prior to management to 3,125 breeding pairs (National Marine Fisheries Service 2008). Since initiation of these management practices, immigration of Caspian Terns from East Sand Island to the new alternative nesting habitats (Suzuki 2012) and colonies in natural and anthropogenic habitats in the Salish Sea, Washington, USA, has been confirmed. Most of those colonies in the Salish Sea, however, have been ephemeral (D. D. Roby, unpubl. data), suggesting limited suitable nesting habitat. In contrast, the influx of Caspian Terns from East Sand Island to the Copper River Delta colony coincided with the growth of this colony.

Gill (2008) suggested that Caspian Tern colonies in Alaska were located on marginal habitat and might not be able to persist under current and projected changes in climate conditions. Kokinhenik Bar is often subjected to flooding when severe storms track across the northeastern Pacific Ocean. During June surveys in three of the years when colony size decreased from the previous year (2010, 2014, and 2015), either high-water lines or large pools of standing water were observed up to the edge of active sub-colonies, suggesting recent flooding events had washed away some nests. In addition,

the observed shift by some Caspian Terns to higher, vegetated dunes also suggests that there had been standing water in the lower-lying habitat where the colony was originally located during nest initiation. Although the Copper River Delta colony may attract more immigrants from East Sand Island and other colonies in the future, the long-term suitability of this barrier island as habitat for a large Caspian Tern colony is questionable given the threat of future sea level rise and increased storm activity.

ACKNOWLEDGMENTS

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