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Indirect Negative Impacts of Double-crested Cormorant (*Phalacrocorax auritus*) Management on Co-nesting Caspian Terns (*Hydroprogne caspia*) in Northern Lake Michigan, USA

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Abstract.—Hat Island, Lake Michigan, Michigan, USA, is an important historical breeding location for Caspian Terns (*Hydroprogne caspia*) and other co-nesting species, including Double-crested Cormorants (*Phalacrocorax auritus*). Although a bird sanctuary of the Michigan Islands National Wildlife Refuge, Double-crested Cormorant management (egg oiling and killing adults) was allowed on Hat Island in 2010; in 2011 and 2012, management actions were restricted to shooting Double-crested Cormorants from at least 500 m offshore. Because the Double-crested Cormorant colony was spread across much of Hat Island, in 2010, a small area of Double-crested Cormorant nests nearest the Caspian Tern colony was left undisturbed to minimize negative impacts on Caspian Terns. Yet, data indicate that management actions had indirect negative impacts on Caspian Terns. Game camera images show that Caspian Terns experienced more frequent disturbances in 2010 as compared to 2011 and 2012. Furthermore, nest inventories and chick banding, in combination with direct chick re-sighting and camera images, show Caspian Tern reproductive success was lower and the colony was abandoned earlier in 2010, as compared to other years. This illustrates that Double-crested Cormorant control actions can cause unintended consequences to co-nesters, even when those conducting management report no impact, and exemplifies that there should be greater consideration of the impacts on co-nesters prior to management. *Received 1 July 2018, accepted 2 August 2018.*

Key words.—Beaver Archipelago, Caspian Tern, co-nesting species, Double-crested Cormorant, *Hydroprogne caspia*, Lake Michigan, management, *Phalacrocorax auritus*.

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Caspian Tern (*Hydroprogne caspia*; hereafter, tern) populations have remained relatively stable between 1997 and 2007 in the U.S. Great Lakes but have declined in Lake Michigan, USA, over the same period (Cuthbert and Wires 2013). In the Beaver Archipelago of northern Lake Michigan, the abandonment of a colony on Gull Island and 42% fewer nesting pairs on Hat Island between 1997 and 2007 exemplify this decline (Cuthbert and Wires 2013). Records indicate that the colony on Hat Island has been active since at least the late 1800s (Reed 1965); such a dramatic reduction in breeding tern numbers could impact the long-term viability of the regional population (Shugart *et al.* 1978). The reasons for the breeding population decline at important historical sites remains unclear, but factors could include unfavorable weather conditions, predators, changes in food supply and human disturbance (Shugart *et al.* 1978; Cuthbert 1988; Cuthbert and Wires 1999). These factors may not act independently but may together cause a synergistic effect reducing tern reproductive success.

Double-crested Cormorants (*Phalacrocorax auritus*; hereafter, cormorants) have nested on Hat Island in recent times since 1984 (Ludwig 1984), and this site has continued to be an important cormorant breeding location through the present (Seefelt 2018). From 2007 to 2015, cormorant management, including egg oiling and killing cormorants, was allowed in the Beaver Archipelago (Seefelt 2018). Because terns are a species listed as threatened in Michigan, cormorant management on Hat Island was restricted to shooting cormorants at least 500 m away from the island, except in 2010. In 2010, eggs were oiled and cormorants were killed on Hat Island (U.S. Department of Agriculture 2010; VanGuilder and Seefelt 2013; Wires 2014; Seefelt 2018). Of a total of 3,751 nests, only a small portion (< 200 nests) of the cormorant colony nearest the tern colony was left un-oiled (VanGuilder and Seefelt 2013); the remainder of the colony was oiled four times during the breeding season (U.S. Department of Agriculture 2010) causing early abandonment of the cormorant colony (VanGuilder and Seefelt 2013; Tucker and Seefelt 2014). Here, we compare the breeding activity and reproductive success of terns on Hat Island during (2010) and after (2011-2012) cormorant management in an effort to understand if management activities had indirect negative impacts on the tern colony.

METHODS

Study Area

The Beaver Archipelago of northern Lake Michigan, Michigan, USA, consists of about 10 main islands and numerous smaller islands, depending on fluctuating water levels (Fig. 1). Hat Island (45° 49′ 00″ N, 85° 18′ 15″ W) is part of the Michigan Islands National Wildlife Refuge overseen by Seney National Wildlife Refuge and is a protected bird sanctuary. The tern colony was located on the southeast end of Hat Island; the cormorant colony was spread over much of the island. Other co-nesting waterbird species in 2010, 2011 and 2012 included Herring Gulls (*Larus argentatus*), Ring-billed Gulls (*L. delawarensis*) and Great Blue Herons (*Ardea herodias*).

Due to ongoing multispecies monitoring activities, our first visits to Hat Island each year were: 22 May 2010, 2 June 2011 and 22 May 2012. During these visits, four game cameras (Moultrie I60 Game Spy 6.0 Megapixel) were deployed each year to record breeding activity at the tern colony. Each camera was mounted on a tripod and situated to minimize the overlap of the areas of view. Cameras were positioned to provide a clear view of six to eight tern nests and a broader view of the colony in the background. The motion sensitive cameras took photos as often as every 5 min; if there was no movement detected after 5 min, a photo was taken when motion was again detected. Images were taken both day and night; night images were obtained using an infrared flash. Furthermore, observations made during camera set up allowed us to determine appropriate dates to census the tern colony each year.

In 2010 and 2011, we visited Hat Island for research five times while the colony was active; in 2012, we visited

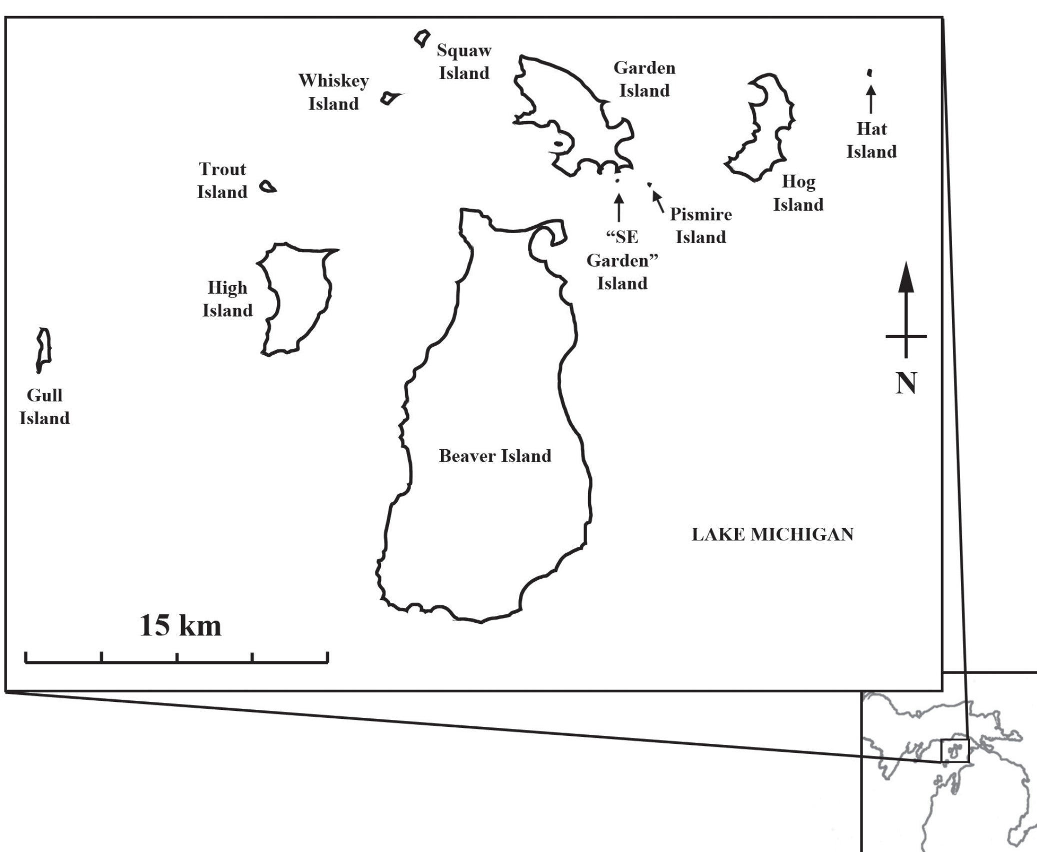

Figure 1. Map of the Beaver Archipelago, northern Lake Michigan, Michigan, USA.

Hat Island three times while the colony was active. In 2010, data collection occurred on 3, 13, and 17 June and 1 and 9 July; the cameras were collected once the colony was abandoned on 14 July. Also, in 2010, the U.S Department of Agriculture Wildlife Services performed cormorant management activities twice on 17 May, once on 18 May, twice on 7 June, and once on 1 July, and also monitored Hat Island by aerial and boat surveys on 28 July and 11 and 31 August, but did not complete any management activities as cormorants were no longer present on Hat Island (U.S. Department of Agriculture 2010). In 2011, our data collection occurred on 7, 17, and 30 June and 8 and 14 July; cameras were removed on 14 July. In 2012, our research visits to Hat Island were on 5 June and 2 and 20 July while the colony was active; the cameras were removed on 15 September.

All active tern nests were counted on Hat Island each year. Our first tern censuses on 3 June 2010, 7 June 2011 and 5 June 2012 were timed to occur during incubation peak when the first eggs were pipping. In 2010 and 2011, nests were labeled with numbered stakes (tongue depressors) so that nests could be identified during later visits and on camera images. In 2012, nests were marked using colored popsicle sticks when censused to avoid double-counting; only focal nests that appeared on camera images were labeled with numbered stakes. Total clutch size (number of eggs) for each nest was recorded during the initial counts each year; mean clutch size for the colony each year was calculated using these data (total number of eggs/total nest count). During subsequent visits in 2010 and 2011, each individual nest was inventoried to determine changes in clutch size and the number of chicks present. These data, in combination with camera images, were used to determine hatching success (number of eggs that hatched per nest). In 2012, only the focal nests visible on camera images were used to observe changes in clutch size, hatching and behavior; there were no additional colony-wide nest inventories, and camera images were not used to extrapolate to the entire colony. In 2010 and 2011, chicks were banded using standard metal bands and blue plastic bands with unique white alpha-numerical codes that could be read from a distance with binoculars and on camera images. The nest number for each chick was also recorded. In 2010 and 2011, camera images and re-sighting of banded chicks (living or dead) during colony visits were used to determine chick survivorship and fledging success (number of offspring capable of flight per nest).

Besides basic nesting phenology and re-sighting of banded chicks (2010 and 2011), camera images were used to record activity at the tern colony each year. The camera images from 2012 provided observations for comparison to a breeding season with cormorant management on Hat Island (2010) and to a season without cormorant management on the island (2011). These same photographs allowed us to determine if research visits in 2010 and 2011 may have impacted terns as research-related disturbance was similar during both years and there were fewer research visits in 2012.

To standardize analysis among years, only camera images beginning on 2 June and ending on 9 July (38 days) were used to document disturbances to the tern colony each year. This end date was chosen as this was the last day terns were recorded on Hat Island in 2010. Photographs were used to document the number of full colony disturbances per day each year; full colony disturbances were defined by the entire colony taking flight as seen on all camera images simultaneously. The direct causes of these flights were not captured on camera. Local disturbances (intraspecific and interspecific interactions) were also noted, but only colony-wide disturbances were used in the analysis. Colony-wide disturbance data were compared using a Kruskal Wallis test to determine differences among years; Dunn's tests were used post hoc to identify which years differed. In addition, photographs were examined to record the number of cormorants in the tern colony per day each year; these data were analyzed with a Kruskal Wallis test and post hoc Dunn's tests. The statistical program R was used in all analysis (R Development Core Team 2016).

Results

The initial tern nest inventories on 3 June 2010, 7 June 2011 and 5 June 2012 documented a total of 351 tern nests in 2010, compared to 320 tern nests in 2011 and 300 tern nests in 2012 (Table 1). Possibly due to a late spring in 2012, an additional 50 newly initiated nests were documented on 2 July 2012 for a peak total of 350 nests during the breeding season (Table 1). Initial nest inventories indicated the mean clutch size was 1.82 in 2010 compared to 1.96 in 2011 and 1.67 in 2012 (Table 1).

Nest inventories, camera images and banding data indicated that hatching success per nest was 0.27 and fledging success per nest was 0.24 in 2010 compared to 1.76 and 1.29, respectively, in 2011 (Table 1). In 2010, 62 chicks were banded; this was the total number of chicks of banding size encountered during all colony visits. In 2011, 100 chicks were banded even though we estimated that several hundred more chicks were present as this was the maximum number allowed by State permit. In 2010, seven chicks (11.3%) were recovered dead on the colony while 55 chicks were observed at fledgling stage on camera and/or during colony visits (Table 1). In 2011, only three chicks (3.0%) were recovered dead while 97 chicks were observed as fledglings on camera and/or during colony visits (Table 1).

Table 1. Hat Island Caspian Tern colony parameters in 2010, 2011 and 2012. Parentheses indicate peak nest count in 2012, as additional nests were documented in July. In 2012, hatching and fledging success, as well as banded chick mortality, were not determined.

Parameter	2010	2011	2012
Nest Count	351	320	300 (350)
Mean Clutch Size/Nest	1.82	1.96	1.67
Mean Hatching Success/Nest	0.27	1.76	—
Mean Fledging Success/Nest	0.24	1.29	—
Banded Chick Mortality	11.3%	3.0%	—

Although no terns were present on Hat Island after 9 July 2010, terns were present after this date in both 2011 and 2012. In 2011, terns were noted on camera through camera removal on 14 July, and nest inventories indicated hatchlings at the colony, as well as larger chicks and fledglings on this date. Terns were observed on Hat Island from offshore through the end of July 2011; no direct observations were made in August. Cameras were left on Hat Island in 2012 to monitor the 50 additional nests that were hatching and had small chicks on 20 July. Images indicate terns remained at the colony through August. Several terns, including fledglings, were observed on Hat Island when the cameras were retrieved on 15 September 2012.

Camera images indicated that there was an average of 2.55 colony-wide disturbances per day (Range = 0-8) in 2010. In 2011, there was an average of 0.18 colony-wide disturbances per day (Range = 0-2), while in 2012, there was an average of 0.47 colony-wide disturbances per day (Range = 0-3) (Fig. 2). A Kruskal Wallis test indicated a significant difference in the number of disturbances per day at the colony among years ($H(2) = 47.0$, $P < 0.001$). Dunn's tests for pairwise comparisons indicated that the number of disturbances per day in 2010 was significantly higher than in 2011 and 2012 (both $P < 0.001$). However, the number of disturbances per day was similar in 2011 and 2012 ($P = 0.438$) (Fig. 2).

Photos also showed that in 2010 an average of 8.24 cormorants (Range = 0-42) roamed through the tern colony each day. In 2011 and 2012, the average was 0.21 and 0.64, respectively (Range = 0-2 during both years). A Kruskal Wallis test indicated a significant difference in the number of cormorants observed in the colony per day among years ($H(2) = 30.5$, $P < 0.001$). Dunn's tests for pairwise comparisons indicated that the number of cormorants in the colony per day in 2010 was significantly higher than in 2011 and 2012 (both $P < 0.001$). However, the number of cormorants observed in the colony per day was similar in 2011 and 2012 ($P = 0.144$).

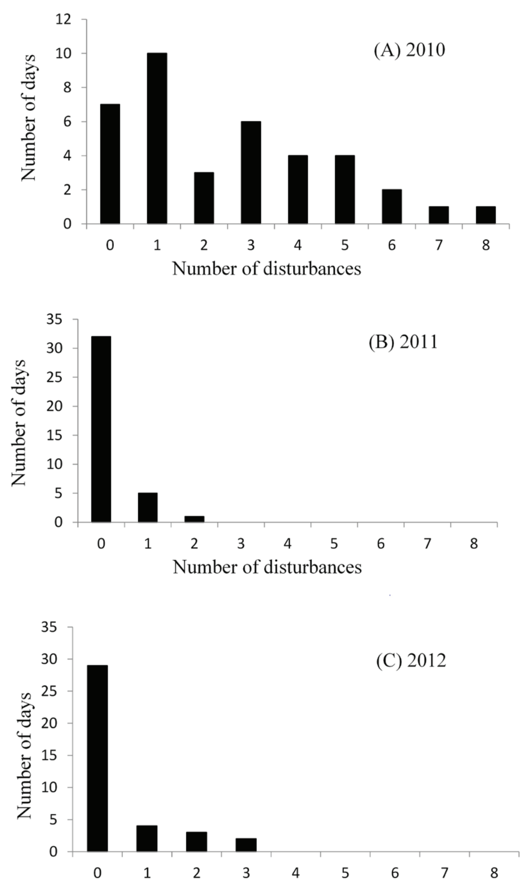

Figure 2. The distribution of the number of disturbances per day at the Hat Island Caspian Tern colony as determined by complete colony flights in (A) 2010, (B) 2011 and (C) 2012.

DISCUSSION

The terns nesting on Hat Island showed differences in reproductive success, disturbance level and colony occupancy among the years. Although each year (2010-2012) showed similar initial clutch sizes, hatching and fledging success were higher in 2011 as compared to 2010. Hatching and fledging success were not documented in 2012. Furthermore, the number of colony-wide disturbances was higher during cormorant management on Hat Island (2010) than in subsequent years when cormorant management was limited to offshore shooting at least 500 m away from the island (2011 and 2012). Also, terns abandoned their colony site early in 2010, as compared to subsequent years. Photographs showed more cormorants spent time in the tern colony in 2010, as compared to 2011 and 2012. Similarities in disturbance level and the number of cormorants in the tern colony in 2011 and 2012 suggest that research visits were not a primary factor influencing observed differences between 2010 and 2011.

During cormorant management activities in 2010, U.S Department of Agriculture Wildlife Services reported that they did not see direct negative impacts (disturbances) on the tern colony (U.S. Department of Agriculture 2010). Wildlife Services provided a buffer zone of cormorant nests around the terns in June as to not approach the terns too closely (U.S. Department of Agriculture 2010; VanGuilder and Seefelt 2013). However, our study suggests that observations made during management activities were not reflective of the actual impact on co-nesting terns. Management activities on Hat Island were successful at disrupting cormorant breeding, changing cormorant behavior and site occupancy as compared to years when management was restricted to offshore (Seefelt and Gillingham 2006; VanGuilder and Seefelt 2013; Tucker and Seefelt 2014); these types of cormorant response behaviors are not limited to Hat Island (Strickland *et al.* 2011; Wires 2014). Our study suggests that these management actions also reduced the reproductive success of co-nesting terns and caused early colony abandonment by terns when compared to other years.

Bald Eagles (*Haliaeetus leucocephalus*; hereafter, eagles) are known predators of waterbirds (Windels *et al.* 2016), they have been documented in the cormorant colony on Hat Island (VanGuilder and Seefelt 2013), and they could have potentially impacted the reproductive success of terns in 2010. However, eagles were present on Hat Island each year of our study (N. E. Seefelt, unpubl. data). Although it is unclear why cormorants were more numerous in the tern colony during management, the larger number of cormorants loafing in the tern colony could have possibly augmented the disturbance level, with or without eagles. High disturbance levels, regardless of cause, are known to lower tern reproductive success (Cuthbert and Wires 1999).

It is important to note that there are other factors that may impact tern behavior and reproductive success. These influences include foraging ecology and fish prey fed to nestlings (Anderson *et al.* 2007; Lyons and Roby 2011). However, important prey fish biomass such as alewife (*Alosa pseudoharengus*) remained relatively low in Lake Michigan consistently over the study period (Madenjian *et al.* 2014), so it is likely that prey availability was similar during each year of our study (2010-2012). Similarly, environmental contaminant levels that can influence tern health and reproductive success (Su *et al.* 2017) were likely similar across all years. Competition and predation pressure from Herring Gulls may also impact terns (Cuthbert and Wires 1999). However, Herring Gulls have been consistent co-nesters on Hat Island since at least 1977 (Cuthbert and Wires 2013) and abandoned their colony on Hat Island in July 2010 (N. E. Seefelt, unpubl. data), making it unlikely that these Herring Gulls are responsible for observed differences in tern reproductive success among years.

Our study suggests that cormorant management caused indirect negative impacts on terns. As the Great Lakes tern population is considered isolated from other regional populations and is maintained primarily through reproduction (Hyde 1996), an unsuccessful breeding season potentially impacts regional population viability (Shugart *et al.* 1978). Any future cormorant control actions must consider how, in synergism with other factors, management can negatively impact co-nesters. Furthermore, our study highlights the inadequacy of on-the-ground cormorant managers in making field assessments regarding the potential impacts of their work on non-target species. Management of one species should not come at a cost to co-nesters.

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