Living with Double-Crested Cormorants *(Phalacrocorax auritus)*: A Spatial Approach for Non-Lethal Management in Toronto, Canada

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Living with Double-crested Cormorants (*Phalacrocorax auritus*): a Spatial Approach for Non-lethal Management in Toronto, Canada

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Abstract.—Tree mortality incurred through the nesting habits of Double-crested Cormorants (*Phalacrocorax auritus*) can cause human-wildlife conflicts, often resulting in the lethal control of cormorants to reduce local population numbers in North America. In a protected area in Toronto, Ontario, Canada, that supports the largest colony of Double-crested Cormorants in North America, a non-lethal management approach to mitigate cormorant-induced tree mortality was adopted by the site managers in 2008. Double-crested Cormorants were managed for space occupancy rather than population size, with the main objective of minimizing tree mortality while supporting the cormorant population. Targeted non-lethal deterrence of tree-nesting Double-crested Cormorants was labor intensive, but effective in protecting trees. Between 2008 and 2016, the tree-nesting colony was prevented from expanding. Accessing ground-nesting Double-crested Cormorants only at night to avoid *Larus* sp. predation of Double-crested Cormorant nests appeared to be highly effective in minimizing disturbance; the ground-nesting colony expanded 899% over an 8-year period, with a 44% decrease in tree nesting. Ground-nesting Double-crested Cormorants had less impact on trees than tree-nesting individuals, and this spatially focused approach allowed for the sustained existence of a thriving colony. *Received 13 January 2018, accepted 22 January 2018.*

Key words.—Double-crested Cormorant, management, monitoring, nesting, non-lethal deterrence, *Phalacrocorax auritus*, Tommy Thompson Park, Toronto, tree health, tree nesting.

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Double-crested Cormorant (*Phalacrocorax auritus*; hereafter, cormorant) populations in North America experienced a rapid recovery after decades of low abundance (Weseloh *et al.* 1995; Wires and Cuthbert 2006). This recovery is attributed to the prohibition of DDT (dichloro-diphenyl-trichloroethane) and legislative protection (Weseloh *et al.* 1995; Dorr *et al.* 2014). Further, increased food availability may have also contributed to increases in survival (Price and Weseloh 1986; Duffy 1995; King *et al.* 2010). Weseloh and Ewins (1994) and Weseloh *et al.* (1995) proposed that rapid population growth of nesting cormorants on the Great Lakes was largely supported by an invasive forage fish, alewife (*Alosa pseudoharengus*), from the late 1970s to 1990s. As populations recovered, a variety of human-wildlife conflicts arose over use of resources by cormorants. One of these conflicts involved vegetation use because cormorant nesting behavior often results in tree mortality and can dramatically change landscapes (Jones *et al.* 1994). High nest density, guano-covered leaves and soil acidification result in tree death (Herbert *et al.* 2005; Craig *et al.* 2012; McGrath and Murphy 2012) over a relatively short period of time (3-10 years; Weseloh *et al.* 2002).

In response to this conflict, cormorants are managed at numerous locations in North America. Management strategies are often chosen based on consultation with limited groups of stakeholders (Wires *et al.* 2001) and typically include lethal intervention. In the USA, until 2016, cormorants were primarily managed through culling (1998-2011: > 500,000 cormorants killed) and egg oiling (of ground nests) under Federal depredation orders and permits issued by the U.S. Fish and Wildlife Service (Trapp *et al.* 1995; U.S. Fish and Wildlife Service 2014; Wires 2014). In Canada, cormorants are regulated provincially (Keith 1995; Weseloh *et al.* 2002), and in the Canadian lower Great Lakes, impacts to habitats in protected areas resulted in culls of over 32,000 nesting cormorants between the 1970s and 2012 (Bédard *et al.* 1999; Ontario Parks 2008; Dobbie and Kehoe 2012; Wires 2014). The culls came with public controversy (Bédard *et al.* 1999; Erwin 2006; Harries 2007), illustrating a need for new non-lethal management techniques.

This study focused on non-lethal management approaches taken to mitigate impacts of the largest known cormorant colony in North America (≥ 13,000 pairs in 2016; L. Wires, pers. commun.), which occurs within the municipal boundaries of Toronto, Ontario, the largest city in Canada. The conflict was over tree use by cormorants at a popular urban park (Tommy Thompson Park) where 24% of the trees were experiencing impacts due to cormorant nesting in 2010 (Taylor *et al.* 2011). Colony management is the responsibility of the Toronto and Region Conservation Authority (TRCA), which continues to recognize and value the cormorant's important roles in aquatic and terrestrial ecosystems in the Great Lakes. The TRCA chose non-lethal, adaptive management as its core approach to achieve a balance between the continued existence of a healthy, thriving cormorant colony and the other ecological, educational, scientific and recreational values of the park. Here, the term "adaptive" refers to modification of approaches over time in response to what is or is not working (Rist *et al.* 2013). The management objectives and final management options (Table 1) were informed by the scientific community, a wide variety of stakeholders and the park's master plan (Metropolitan Toronto and Region Conservation Authority 1992).

The TRCA's non-lethal management approach was unique in that it focused on how cormorants were distributed in the park rather than on reducing their numbers. The emphasis was on encouraging birds to nest on the ground rather than in trees and to prevent tree-nesting expansion (Taylor *et al.* 2011). A key feature was the use of a spatial strategy to identify areas where cormorant nesting should be allowed and encouraged, and areas where cormorant nesting and roosting should be discouraged. Here, we describe and evaluate the techniques used to protect trees and spatially manage nesting cormorants, and consider the applicability of these techniques to other cormorant colonies.

Methods

Study Area

Tommy Thompson Park is located on the Leslie Street Spit (the Spit), a 471-ha, 5-km long man-made peninsula extending into Lake Ontario, and is immediately adjacent to downtown Toronto, Ontario, Canada. Construction of the Spit began in 1959 through the dumping of dry rubble (e.g., bricks and concrete) from construction sites and sand and silt materials dredged from Toronto's inner harbor (Ports Toronto 2015). The final configuration of the Spit is a linear landform with four peninsulas extending perpendicular from the west side, referred to as Peninsulas A, B, C and D, and three confined disposal facilities on the east side. In the early 1970s, gulls and terns (Laridae) began to nest on the leveled rubble, vegetation began to grow, and limited public access was allowed. In 1982, after continued nesting by colonial waterbirds (Laridae and Ardeidae), Tommy Thompson Park was designated as an Environmentally Significant Area (Metropolitan Toronto and Region Conservation Authority 1982); in 2015, this designation extended to the entire Spit due to rare species and/or rare communities, and significant ecological functions (City of Toronto 2015). In 2000, Birdlife International designated the Spit as an Important Bird Area due to globally significant populations of breeding colonial waterbirds, continentally significant num-

Table 1. Goals, objectives and management options for Double-crested Cormorants as discussed by the Tommy Thompson Park Cormorant Advisory Group.

Goal	To achieve a balance between the continued existence of a healthy, thriving cormorant colony and the other ecological, educational, scientific and recreational values of Tommy Thompson Park.
Objectives	a) increase public knowledge, awareness and appreciation of colonial waterbirds; b) deter cormorants from nesting on Peninsula D; c) limit further loss of tree canopy on Peninsulas A, B and C beyond the existing colonies; and d) continue research on colonial waterbirds in an urban wilderness context.
Final management options (2016)	Pre-nesting and active-nesting deterrents Enhanced ground nesting

bers of overwintering waterfowl and nationally significant numbers of migratory birds (Wilson and Cheskey 2001). Seven colonial waterbird species regularly nest at Tommy Thompson Park: cormorants, Great Egret (*Ardea alba*), Black-crowned Night-Heron (*Nycticorax nycticorax*), Ring-billed Gull (*Larus delawarensis*), Herring Gull (*L. argentatus*), Common Tern (*Sterna hirundo*) and Caspian Tern (*Hydroprogne caspia*).

In addition to its significance for bird populations, Tommy Thompson Park is the largest natural park on the central Toronto waterfront, providing an important contribution to regional biodiversity (City of Toronto 2015). The park is also very popular for birdwatching and other nature-based activities, and it is highly regarded by cyclists and fitness enthusiasts who seek a quiet refuge from the urban environment.

Cormorants started nesting at the site in 1990 with six nests on Peninsula B. Over time, the local population expanded to Peninsulas A and C, and included tree- and ground-nesting birds (Taylor *et al.* 2011; Toronto and Region Conservation Authority, unpubl. data; Fig. 1). As of 2016, cormorants nested on three of the four Peninsulas (Fig. 1), with ground nesting on Peninsulas A and B.

Annual Data Collection on Cormorant Nest Numbers, Location and Tree Health

An annual monitoring program, launched in 1991, categorized the number and location of cormorant nests during the nesting season (Jarvie *et al.* 1999; Rosenberger 2015). Tree nests were counted once annually, and occupied trees were tagged and geo-referenced at peak colony breeding (from 27 May to 22 June; Table 2).

Ground nests were also counted and mapped. Prior to 2008, one on-the-ground crew counted ground nests during daylight hours. From 2008 to 2013, ground-nest counting was completed by an on-the-ground crew one night during peak nesting (from 27 May to 16 June; Table 2) to minimize disturbance and depredation (Duerr *et al.* 2007). The crew systematically walked through the colony and counted each nest. Since 2014, the on-the-ground count effort has surpassed available labor resources. Also, in 2014, Caspian Terns nested near

Figure 1. Double-crested Cormorant nesting at Tommy Thompson Park, Toronto, Ontario. Tree nesting occurred on Peninsulas B and C and ground nesting occurred on Peninsulas A (initiated in 2014) and B. Peninsulas A and B were identified as the "Cormorant Conservation Zones" where nesting was allowed. On these peninsulas, various enhancement efforts/attraction experiments were undertaken using: 1) nest substrate, decoys and vocal playbacks (top left inset, Area 1, Peninsula A); 2) nest substrate and decoys (top right inset, Areas 1 and 2, Peninsula B); and 3) landscaping to increase elevation (Area 1, Peninsula A).

Table 2. A summary of annual effort for data collection and maintenance activities for Double-crested Cormorant monitoring and management at Tommy Thompson Park, Toronto, Ontario.

Activity	Human Resources	Time	Frequency
Tree-nest count	2-5	4-7 days	Annual
Ground-nest count (nighttime)	4-6	2-3 hr	Annual 2009-2013
Aerial ground nest survey			Annual
Helicopter	1	1 day (1.0-1.2-hr flight)	2014, 2016
Drone	1	0.5 days	2015
Full tree health survey	2-5	3-5 days	Annual 2009-2011
Tunnel/blind construction	6	2 hr	Once
Tunnel/blind maintenance	3	2 hr	Annual
Active deterrence	2-8	9-39 days	Annual
Night deterrence	2	2-19 days	Annual except 2012-2013

the ground-nesting cormorants (Peninsula B), which increased the necessity to limit disturbance. To reduce labor and circumvent disturbance, photographs taken from a drone or helicopter were used to count cormorant nests from 13 to 18 June in 2014-2016 (Table 2). The colony area was mapped from 2008 to 2013 by the on-the-ground crew using a handheld GPS during the post-breeding season. Since 2014, nests in the photographs were geo-referenced and stitched together using GIS software based on natural landmarks in the colony. In 2015, a series of ground markers (large alphabetic letters) created from 5-cm x 10-cm wood planks were placed on the ground between nests to facilitate geo-referencing and photo stitching. Each letter on the ground was geo-referenced using a handheld device.

From 25 August to 8 September, 2008-2011, the health of every tree used by nesting cormorants, Black-crowned Night-Herons and Great Egrets was assessed. Trees were qualitatively ranked from 1 to 5 based on their canopy and epicormic branching: 1) < 90% of the canopy intact with no epicormic branching; 2) 60-90% of the canopy intact with no epicormic branching; 3) 40-60% of the canopy intact with mild epicormic branching; 4) 10-40% of the canopy intact with substantial epicormic branching; and 5) less than 10% of the canopy was intact with severe epicormic branching. However, the collection of these data was labor intensive, human resources were limited and the main areas surveyed were mostly dead trees with scores that were not going to change. Between 2012 and 2016 (25 August-8 September), a subsample of trees was assessed on Peninsula C only. An initial starting point was selected and a coin tossed to determine whether a sample of five trees was taken left or right of the starting position. This process was repeated from the end point of the previous location and guided the direction through the colony.

Spatial Management Strategy: Cormorant Conservation Zones and Deterrence Areas

Areas where cormorant nesting was allowed/encouraged (Cormorant Conservation Zones) were identified and included those composed of ground-nesting cormorants (Peninsula B) or that were previously deforested by cormorant nesting activities (Peninsula A). Areas where cormorant nesting and roosting were discouraged (Cormorant Deterrent Areas) included those with healthy trees that were near existing nest areas and likely to attract tree-nesting cormorants (Peninsulas B, C and D) (Fig. 1).

Deterrence Activities

Cormorants in Cormorant Deterrent Areas were discouraged from nesting using non-lethal deterrence techniques to: 1) encourage ground nesting; and/or 2) minimize or prevent cormorants from nesting in healthier trees outside the Cormorant Conservation Zones (Fig. 2), particularly focusing on colony expansion boundaries. Deterrence occurred in two phases: 1) winter nest removal (no cormorants present); and 2) pre-nesting and active nest removal (individual cormorants scouting or building nests, pre-incubation, and during the first 10 days of incubation). The winter nest removal phase involved knocking down existing cormorant nests from trees in Cormorant Deterrent Areas using 4.3-m to 25.9-m fiberglass forestry poles from 15 January to 1 March. Removing nests forced cormorants to begin nest building in these areas from scratch; nests that were knocked down were placed on the ground within the Cormorant Conservation Zones to encourage nesting.

The pre-nesting phase began 1 April when cormorants returned to the colony and started nest building. Implementation of pre-nesting deterrence was in response to nesting attempts, using an escalating scale of deterrence techniques, where a technique was deemed ineffective before escalating to the next, more aggressive technique (Fig. 3). Deterrence occurred primarily during daylight hours, with up to five annual nighttime deterrence events from 2009 to 2016.

Enhancement of Ground-nesting Locations within Cormorant Conservation Zones

Peninsula A. Two areas were identified for ground-nest enhancement efforts on Peninsula A (Areas 1 and 2; Fig. 1). From 2009 to 2010, a conspecific attraction experiment was conducted in Area 1 (Table 2). The experiment used a randomized block, treatment-control design for decoy density. There were four adjacent

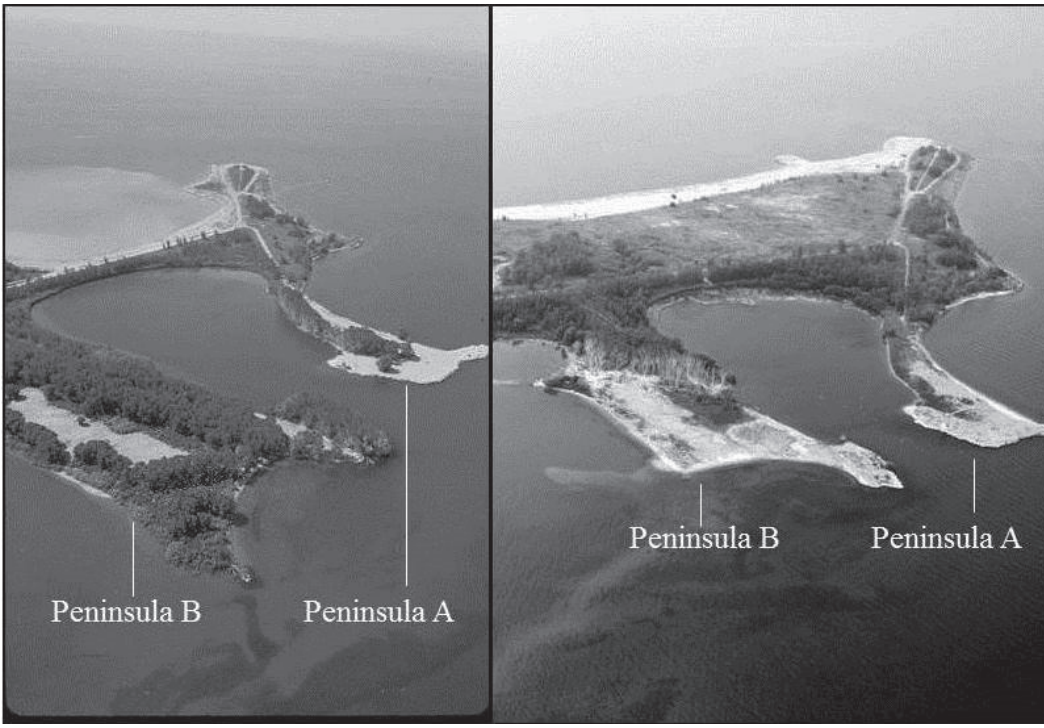

Figure 2. Photographs showing changes in tree health at Tommy Thompson Park, Toronto, Ontario, Peninsulas A and B. Early 1990s (left) compared to 2011 (right).

blocks. Each block contained three plots (5 x 8 m^2): a control (no decoys) and two treatments (low density = 3 decoys and high density = 12 decoys). Each plot had 36 nest sites where half were used automobile tires (n = 18; Suzuki *et al.* 2015) and half were 0.75-m high 5-cm x 10-cm wooden stakes (n = 18). All nest sites were given a straw base. Cormorant decoys (sitting pose; Mad River Decoy) were placed randomly at the nest sites within each plot and within each substrate (tires and wooden stakes). Vocalizations were centrally broadcast (iPod speaker or FOXPRO system) continuously from 10 April to 30 July 2009 and 8 April to 14 July 2010. To minimize disturbance and facilitate access, a viewing blind and access tunnel (approximately 20 m in length with wooden frame, plywood roof and burlap cover) were installed parallel to the attraction area (2009); then perpendicular (2010) (Table 2; Fig. 4). The primary metric for these enhancement efforts was whether cormorants initiated nesting in attraction Area 1. The second metric was whether deterrence efforts on Peninsula C increased cormorant visit rates to attraction plots. Two additional questions assisted with subsequent enhancement design: 1) was there a preference for nesting substrate of stakes or tires; and 2) did the presence of decoys or decoy density influence cormorant visitation rates. From 10 April to 30 July 2009 and 8 April to 14 July 2010, cormorant visits were quantified using instantaneous scans (Altmann 1974) every 5 min. Cormorant presence, location within each block and plot, and associated nesting substrate was recorded (see Feldmann 2011 for further details). The rate of cormorant visits to attraction Area 1 in 2010 was compared on days with deterrence to days without deterrence using a t-test with unequal variance. A three-way contingency table was used to test if the rate of cormorant visits changed with respect to nest substrate and decoy density and a log-linear model (Tabachnick and Fidell 1996) was used to determine if there were any interactions among the factors (nest substrate and decoy density).

From 2011 to 2016, following the conspecific attraction experiment, various components of attraction were maintained in Area 1. In 2012, all wooden stakes and tires were removed and replaced with 36 knocked-down nests, containing 18 decoys arranged in a circle formation directly below the one nesting tree. Vocalization broadcast continued each breeding season from 25 April to 25 May from 2011 to 2013. Unbound straw bales were available as nesting material from 2012 to 2016.

In Area 2, a variety of ground-nest enhancements was implemented in 2009 and remained active until 2012; these included grids of vertical wooden stakes that were installed with knocked-down nests or straw at the base; fallen trees placed to replicate a naturally disturbed area; and additional straw bales provided for nesting material. Decoys were added to the enhanced areas and opportunistically placed in varying densities, but the numbers of decoys were not recorded. The wooden stakes and tires were removed prior to the 2012 breeding season.

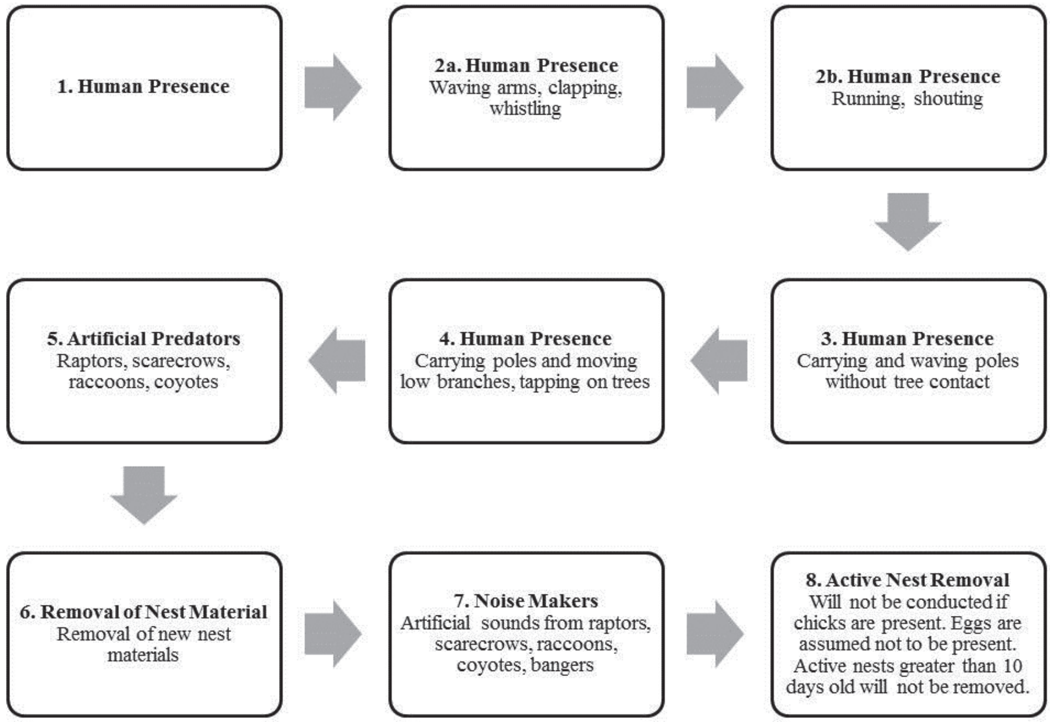

Figure 3. Deterrence escalation scale used in management of Double-crested Cormorants at Tommy Thompson Park, Toronto, Ontario. Each deterrent technique escalated only after it was determined that the technique employed was no longer effective. Techniques typically escalate quickly once nesting begins.

Additional ground-nest enhancements were undertaken on Peninsula A (Area 1). In 2013, a large black tarp was placed on the ground for 2 weeks (11 to 22 April) to prevent early nesting Ring-billed Gulls from establishing territories. Two enhancements were implemented to improve sightlines and achieve a more uniform topography: 1) herbaceous vegetation was mowed adjacent to Area 1; and 2) in autumn 2013, the ground elevation was raised (increased by approximately 0.75 m) using approximately 1,000 m^3 of silty sand over a 2,550 m^2 area.

Peninsula B. Starting in 2009, enhancement efforts were applied on Peninsula B to attract cormorants to nest in areas adjacent to the existing ground-nesting colony. A 3- x 6 m^2 grid of used automobile tires, spaced approximately 1 m apart and filled with a straw base, was placed between the two ground sub-colonies, and additional tires were placed around a tunnel blind system in hope of gaining access to nesting adults (Suzuki *et al.* 2015). The tires remained in 2010 and 2011, and annual enhancements were undertaken on the east side of Peninsula B with the addition of: 1) fallen trees replicating a naturally disturbed area; 2) nests collected during winter nest removal (in accordance with best nest density measurements from the existing ground colony); and 3) decoys (standing pose; Sports Plast Decoy Company). In 2011, a buffer area of herbaceous vegetation was cleared to improve sightlines and flushing areas to the water. In 2012, the tires were removed and 40 knocked-down nests were placed between the two sub-colonies. In 2013, fallen trees and naturally downed nests were placed in the remaining gap between the two sub-colonies. Enhancements were not undertaken from 2014 to 2016.

Results

Annual Data Collection on Cormorant Nest Numbers, Location and Tree Health

Between 2008 and 2016, the total cormorant population at Tommy Thompson Park grew an average of 7.7% annually to > 13,000 pairs (Table 3). The number of cormorants nesting on the ground increased an average of 29.5% annually (on Peninsulas A and B combined; Table 3). Conversely, the number of tree nests peaked in 2011 and then became proportionally smaller each year (Table 3). In 2009, the tree-nest density at Tommy Thompson Park was 0.2 nests/m^2, while ground nesting was 1.3 nests/m^2. Since 2013, there were more cormorant nests on the ground (6,986) than in trees (5,004)

Figure 4. The ground-nesting attraction area with tunnel blind system used on Peninsula A at Tommy Thompson Park, Toronto, Ontario.

(Table 3), and ground nesting represented 70% of the nesting population in 2016.

Nighttime ground-nest counts flushed cormorants from their nest sites for 1.5 to 2.5 hr. No cormorants were observed being flushed from nest sites using a helicopter or drone. The helicopter provided high-resolution photos; however, the images captured were not at a perfect 180º angle, and the camera required stabilization to compensate for the aircraft shake. The drone had good camera stability and a direct overhead angle, but the photos did not have high enough resolution to confirm nesting with 100% confidence, and camera lens and settings were pre-determined prior to flight. Helicopter flights were determined to be more suitable and were resumed in 2016 after using the drone in 2015.

From 2008 to 2011 between 1,816 and 2,081 trees on Peninsulas B and C were assessed annually for tree health. On both Peninsulas, the majority of trees assessed were categorized as 3 or higher with a mode of category 5 (Peninsula C: 2008 = 83.0%; 2009 = 80.8%; 2010 = 81.0%; 2011 = 73%; Peninsula B: 2008 = 76.4%; 2009 = 57.1%; 2010 = 75.4%; 2011 = 83%; Table 3).

Deterrence

Winter nest removal. The number of nests removed from trees in the winter ranged from 32 to 236 per year (Table 4). This range was based on the degree of cormorant expansion into Cormorant Deterrent Areas in the previous year. The nests removed were used in ground-nesting attraction efforts.

Pre-nesting and active-nest phases. The majority of deterrence efforts focused on the pre-nesting and active-nest phases. From 2010 to 2013, cormorant nesting in Cormorant Deterrent Areas was successfully limited with low effort and resource requirements

Table 3. Annual Double-crested Cormorant nest monitoring results at Tommy Thompson Park, Toronto, Ontario, 2008-2016.

Results	Year 2008	2009	2010	2011	2012	2013	2014	2015	2016
Total nest #	6,717	7,564	9,434	11,374	11,741	11,990	12,409	11,908	13,275
# tree nest	5,708	5,607	6,124	6,827	5,929	5,004	4,600	3,759	3,195
# ground nest	1,009	1,957	3,310	4,547	5,812	6,986	7,809	8,149	10,080
% total change	-4.84	12.61	24.72	20.56	3.23	2.12	3.49	-4.04	11.48
% tree-nest change	-0.85	-1.77	9.22	11.48	-13.15	-15.60	-8.07	-18.28	-15.00
% ground-nest change	-23.00	94.00	69.00	37.00	28.00	20.00	12.00	4.00	24.00
# active cormorant nest trees	1,064	1,045	1,047	1,076	961	762	703	574	460
# new cormorant nest trees (% of total active cormorant nest trees)	—	—	44 (4)	48 (4)	36 (4)	24 (3)	88 (13)	156 (27)	47 (10)
# trees monitored for tree health	2,046	1,996	1,816	2,081	106	471	172	40	42
Mode tree health Peninsula B	5	5	5	5	—	—	—	—	—
Mode tree health Peninsula C	3	5	5	5	5	5	5	5	5

(Table 4). During this period, 69-172 nests containing 93-147 eggs annually were removed (Table 4), and 24-48 new trees were used for nesting (3-4% of total nest trees; Table 3). Effort and resource requirements, including the number of nighttime deterrence visits, increased from 2014 to 2016 as cormorants were observed to persistently attempt nesting in the Cormorant Deterrent Areas. Over these three years, 565-1,082 nests containing 154-547 eggs were removed (Table 4), and 47-156 new trees were nested in annually (10-27% of total nest trees; Table 3). Dawn to dusk deterrence efforts started on a daily basis (5 days/week) on 16 May 2016. While it was an effective approach, the ideal start date of 30 April was missed because nest building was well underway in the Cormorant Deterrent Areas, and removal of all nests required additional effort.

Throughout the breeding season, the public served as a deterrent for cormorant nesting and loafing on Peninsula D. This Peninsula, closest to the park entrance, was an access point for a sailing club and a migratory bird monitoring station, and was the only Peninsula without a history of cormorant nesting. Cormorants flushed easily from Peninsula D simply by the volume and consistency of human activity.

Enhancement of Ground-nesting Locations within Cormorant Conservation Zones

Peninsula A. Despite the various attraction efforts used, ground nesting did not occur from 2009 to 2013 on Peninsula A. In 2014, ground nesting (10 nests) in Area 1 started following the ground elevation modifications in autumn 2013 and the simple addition of one unbound straw bale. Ground nesting continued and increased in 2015 and 2016 (Table 3).

There was no observed difference between the rate of cormorant visits to attraction Area 1 on days with ($n = 17$) deterrent activities (mean ± SD, 1.2 ± 1.0 cormorants per hr,) and days without ($n = 19$ days) deterrent activities (0.9 ± 0.6 cormorants per hr; T_{25} = 0.8, $P = 0.4$). Based upon the goodness-of-fit test, the model [nest*plot][nest*treatment][treatment*plot] most accurately reflected observations (2009, $\chi^2_6 = 7.3$, $P = 0.3$; 2010,

Table 4. A timeline summary of Double-crested Cormorant related management actions at Tommy Thompson Park, Toronto, Ontario, 2008-2016.

	Year								
Action	2008	2009	2010	2011	2012	2013	2014	2015	2016
Winter nest removal (# of nests)	No	No	Yes (32)	Yes (236)	Yes (183)	Yes (115)	Yes (101)	Yes (67)	Yes (57)
Deterrence with active nest removal (# of days)	No	No[a]	Yes (34)	Yes (32)	Yes (9)	Yes (13)	Yes (20)	Yes (35)	Yes (39)
# of nests			72	69	145[b]	172	565	1,082	936
# of eggs			94	93	124	147	154	481	547
Deterrence at night (# of nights)	No	Yes (3)	Yes (3)	Yes (3)	No	Yes (3)	Yes (5)	Yes (10)	Yes (19)
Ground nest enhancements: Peninsula A							*Nesting started		
Decoys		Yes[be]	Yes[be]	Yes[e]	Yes[c]				
Vocal playbacks		Yes[bc]	Yes[bc]	Yes[c]	Yes[c]	Yes[c]			
Straw		Yes[bc]	Yes[bc]	Yes[c]	Yes[c]	Yes[c]	Yes[c]	Yes[c]	Yes[c]
Structure (logs)		Yes[d]	Yes[d]	Yes[d]	Yes[d]	Yes[d]	Yes[d]	Yes[d]	Yes[d]
Structure (tires)		Yes[bc]	Yes[bc]	Yes[c]					
Structure (stakes)		Yes[be]	Yes[be]	Yes[e]					
Nests		Yes[d]	Yes[d]	Yes[d]	Yes[e]				
Gull exclusion tarp						Yes[c]			
Vegetation mowing						Yes[c]			
Topography change							Yes[c]		
Ground nest enhancements: Peninsula B						*Nesting started			
Decoys		Yes[d]	Yes[d]	Yes[d]		Yes[e]			
Structure (logs)		Yes[d]	Yes[d]	Yes[d]	Yes[e]				
Structure (tires)		Yes[c]	Yes[c]	Yes[c]					
Structure (stakes)		Yes[d]	Yes[d]						
Nests		Yes[d]	Yes[d] (32)	Yes[d] (110)	Yes[e] (40)	Yes[d] (50)			

[a]Deterrence was not undertaken due to presence of nesting Black-crowned Night-Herons.
[b]Conspecific attraction study.
[c]Area 1 only.
[d]Area 2 only.
[e]Areas 1 and 2.

χ^2_6= 12.6, P = 0.05). The log-linear model associations showed tires were visited more frequently than stakes (2009: tires 63%, n = 102 visits; stakes 37%, n = 59 visits; 2010: tires 70%, n = 353 visits; stakes 30%, n = 151 visits) across all plots. Overall, across all nest types, low-density decoy plots had the highest cormorant visits (2009: 35%, n = 56 high–density decoy plots, 39%, n = 63 low-density decoy plots and 26%, n = 42 control plots; 2010: 28%, n = 140, high-density decoy plots, 40%, n = 203, low-density decoy plots and 32%, n = 161, control plots).

Peninsula B. Cormorants did not nest in the tires placed on Peninsula B. Knocked down nests, placed in lieu of tires, were quickly dismantled by cormorants to create new nests or add to existing nests. Cormorants nesting in attraction Area 1 steadily expanded from 2008 to 2016, and cormorants nested in attraction Area 2 from 2013 to 2016.

Discussion

The location of the largest cormorant colony in North America in an urban park in Toronto is unique. Although there is an absence of residential areas and commercial activities around Tommy Thompson Park, the variety of recreational, educational and scientific activities resulted in conflict with cormorants. The nature of this conflict is not entirely typical given that there is no commercial fishery in the area and no private property values that may be impacted. However, the loss of forest habitat in an urban area targeting an increase in forest cover was a concern (Taylor *et al.* 2011; City of Toronto 2013). The use of lethal culls to protect tree habitat is a traditional form of management in North America (Wires 2014), but given TRCA's decision not to pursue lethal management, creativity was required to develop innovative non-lethal management techniques where the cormorant colony could thrive while protecting the remaining forest.

Spatial containment of cormorants was a unique and significant shift compared to other jurisdictions that manage for cormorant population reduction (Wires 2014). By undertaking a spatial approach, cormorants were managed for the impacts caused by nesting, rather than simply managed for total population size (Frederiksen *et al.* 2001; Wires 2014). The spatial area of tree damage was successfully limited by management activities, and while it may seem counter-intuitive, ground nesting supports a higher density of cormorant nests than trees due to consistent spacing of nests.

One observation that emerged during the course of this work with important implications for a spatial management approach was related to diurnal disturbance. During ground-nest counts, diurnal disturbance can result in *Larus* sp. predation of cormorant nests and cormorants may respond by changing nest sites the subsequent year (Duerr *et al.* 2007; Suzuki *et al.* 2015). Using the metric of colony growth, minimizing human disturbance to the ground-nesting colony on Peninsula B appeared to be an effective management tool to promote ground nesting. Therefore, we recommend using the least intrusive census technique available, preferably aerial photography or nighttime access where feasible (Lancia *et al.* 2005; Hodgson *et al.* 2016). In terms of the former, intra-nest spacing (Dorr *et al.* 2014) may assist in minimizing error in counting nests in photos.

The tree health data provided a qualitative estimate of the degree of impact cormorants had on trees and allowed managers to demonstrate impact over time to stakeholders. It also assisted in focusing deterrence efforts within the Cormorant Deterrent Areas. However, the tree health data were less useful compared to population trends and nesting localities as most occupied trees quickly changed status from healthy to dead. It is possible that tree-nest density may be used as a proxy for tree health (Dobbie and Kehoe 2012; Koh *et al.* 2012), but this needs to be explored further.

Deterrence is a common technique used in wildlife management (Gilsdorf *et al.* 2002), and a wide range of deterrence techniques have been used on nesting and non-nesting cormorants (Wires *et al.* 2001; Gilsdorf *et al.* 2002). The use of non-lethal deterrence, which combines a variety of frightening approaches, was a key management approach to the spatial restriction of cormorants. Cormorants showed habituation to deterrence efforts or they exhibited reluctance to flush as the nesting season progressed: they flushed easily in April and became increasingly difficult to flush as breeding progressed in May and June. Individuals lower in the trees were consistently easy to flush compared to those nesting high in the canopy. When individuals flushed from deterrence efforts, we were unable to confirm where they relocated because they were unmarked. However, it is unlikely that deterrence caused tree-nesting cormorants to nest on the ground within a season, and we do not recommend deterrence solely for this objective.

Pre-nesting and active-nesting deterrence to protect targeted trees and focal areas prevented colony expansion and limited further forest loss (Table 1). While we recommend this approach, the resource requirements associated with deterrence activities were considerable. Our study site permitted daily access to nesting cormorants with minimal logistics and minimal disturbance to non-target avian species; both may be logistically more challenging for colonies on islands or other more remote areas. In other studies, deterrence to reduce tree-nest density, and therefore tree mortality, has primarily used a mixture of lethal and non-lethal techniques, and it is difficult to separate out the results (Ontario Parks 2008; Dobbie and Kehoe 2012). Knocking down active nests was the final stage of deterrence in our approach (Fig. 3); cormorants repeatedly built nests in the same site (TRCA, pers. commun.), so it is important to prevent nest initiation and consistently remove new nests as they are built. Starting dawn to dusk deterrence early in the nesting season, before cormorants have the opportunity to establish nests, should reduce the staff effort required to prevent cormorants from nesting in these areas over the course of the breeding season.

Cormorants nested within days to 1 year of initiating attraction efforts in the Columbia River basin, Washington, USA (Suzuki *et al.* 2015). While attracting cormorants to new areas on Peninsula B was immediately successful (94% increase in the first year), it took 5 years to attract cormorants to ground nest on Peninsula A; such a delay is not uncommon in attraction efforts (Jones and Kress 2012). Nesting structures are an important feature, and cormorants will use either natural or artificial material (Suzuki *et al.* 2015). While cormorants were attracted to tires, the public did not support their use in a park, which prompted their removal when nesting did not occur within 2 years of attraction efforts on Peninsula A. To attract cormorants to future ground-nesting sites where *Larus* sp. are present, we recommend starting first with vocalizations, as regular decoy maintenance is required. Managers attempting to attract cormorants to ground nest in an area where they have not previously ground nested need to be patient and willing to experiment with different attraction techniques (Jones and Kress 2012).

The non-traditional management methods used at Tommy Thompson Park indicate that under certain conditions cormorants can be successfully managed to limit the spatial area of vegetation damage without resorting to lethal measures. In situations where cormorants have impacted forest health, where nearby ground nesting is a feasible option and where site access and staff resources are not overly limited, non-lethal management options should be considered first. Lethal approaches raise many ethical questions and are also costly both in terms of personnel and communication around such an undertaking (Bédard *et al.* 1999; Batavia and Nelson 2018). By managing the spatial occupancy of the tree-nesting colony and promoting ground nesting in the Cormorant Conservation Zones, TRCA has successfully achieved the strategy's goal of balancing a thriving cormorant population with the other park values and uses.

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