AQUATIC ECOSYSTEM
HEALTH & MANAGEMENT

Population trends of colonial waterbirds nesting in Hamilton Harbour in relation to changes in habitat and management

Carolyn V. Zanchetta,[1] David J. Moore,[2] D. V. Chip Weseloh,[3] and James S. Quinn[1]*

[1]*Biology Department, McMaster University, 1280 Main Street West, Hamilton, Ontario L8S 4L8, Canada*
[2]*Canadian Wildlife Service-Ontario Region, 867 Lakeshore Road, Burlington, Ontario L7S 1A1, Canada*
[3]*Canadian Wildlife Service-Ontario Region, 4905 Dufferin Street, Downsview, Ontario M3H 5T4, Canada*
**Corresponding author: quinn@mcmaster.ca*

*Since 1975, the diversity and abundance of colonial waterbirds breeding in Hamilton Harbour have increased, making it an important nesting site on the Great Lakes. An adaptive management approach has been employed to control hyper-abundant species and guide conservation efforts for vulnerable species, with the goal of maintaining a diverse waterbird community. Four species exhibited increasing or stable population trends (1975–2013): Double-crested Cormorants (*Phalacrocorax auritus*; from 0 to 4747 nests); Black-crowned Night-Herons (*Nycticorax nycticorax*; ranged from 6 to 259 nests); Herring Gulls (*Larus argentatus*; from 0 to 244 nests); and Caspian Terns (*Hydroprogne caspia*; from 0 to 496 nests). Cormorants are currently above (2,500 nests), while Caspian Terns (400–600 nests), Night-Herons (100–200 nests) and Herring Gulls (200–300 nests) are within population targets set out in the Hamilton Harbour Remedial Action Plan. Despite conservation efforts, Common Terns (*Sterna hirundo*) declined from a peak of 1,028 nests (1990) to 333 nests (2013), although currently within the population target (300–600 nests). Ring-billed Gulls (*L. delawarensis*), through long-term management and habitat restrictions, were reduced from a peak of 39,621 nests (1990) to 11,133 nests (2013), but still exceed the target (<10,000 nests). Changes in the amount of available habitat have affected waterbird distributions: the loss of 42 ha (peak in 1999) of former nesting areas to development has been partially offset by the creation or securement of 1.9 ha of dedicated breeding habitat. Continued management, assessed and refined annually, is required to maintain species diversity in the area. Current management techniques focus on preventing Ring-billed Gulls from nesting on private lands and dedicated Tern nesting habitat, excluding Cormorants from nesting at specific sites, and reducing inter-specific competition with Night-Herons and Herring Gulls. Recommendations and considerations regarding future management and conservation efforts to reach Remedial Action Plan targets in the harbor are outlined.*

Keywords: colonial waterbird population trends, population targets, management techniques, conservation, Great Lakes Area of Concern

Aquatic Ecosystem Health & Management, 19(2):192–205, 2016. Copyright © 2016 AEHMS. ISSN: 1463-4988 print / 1539-4077 online
DOI: 10.1080/14634988.2016.1172834

Introduction

Colonial-nesting, fish-eating birds (hereafter, colonial waterbirds) have nested in increasing numbers in Hamilton Harbour, Lake Ontario since the 1970s, making the region one of the largest and most diverse waterbird breeding colonies on the Great Lakes (Blokpoel and Tessier, 1996, 1997; Morris et al., 2001; Weseloh, 2012; Cuthbert and Wires, 2013). Six waterbird species currently nest at various locations throughout the harbour: Double-crested Cormorants (DCCOs, *Phalacrocorax auritus*), Black-crowned Night-Herons (BCNHs, *Nycticorax nycticorax*), Herring Gulls (HERGs, *Larus argentatus*), Ring-billed Gulls (RBGUs, *L. delawarensis*), Caspian Terns (CATEs, *Hydroprogne caspia*) and Common Terns (COTEs, *Sterna hirundo*).

In Hamilton Harbour, waterbirds breed in an industrialized, urban setting with varied land-use priorities. Since the early 1990s, there have been considerable changes in the amount and quality of habitat available to nesting waterbirds. Fallow industrial sites have been developed gradually (Dobos et al., 1988; Moore et al., 1995), and habitat creation projects provided dedicated breeding sites for the six waterbird species (Quinn et al., 1996; Morris et al., 2001). Waterbird conservation issues have centred on securing habitat and the management of over-abundant RBGU and DCCO, and conservation actions aimed at maintaining or increasing numbers for regionally vulnerable species.

In 1987, Hamilton Harbour was designated by the International Joint Commission as one of 43 Areas of Concern on the Great Lakes (Hamilton Harbour RAP, 1992; O'Connor, 2003). A goal of the Remedial Action Plan (RAP) was to maintain a diverse, self-sustaining resident and migratory wildlife community with habitat securement and population objectives specifically identified (O'Connor, 2003). An integrated and adaptive harbour-wide management and conservation approach has been developed, with various strategies evaluated and refined iteratively, guided through the cooperation of a community of stakeholders.

Long-term trends of colonial waterbird distribution and abundance within Hamilton Harbour have not been reported previously. This article synthesizes earlier work (Dobos et al., 1988; Moore et al., 1995; Quinn et al., 1996; Pekarik et al., 1997; Morris et al., 2001) and provides an update since 2001, the period of most intensive management, and when various species were reacting to a significant habitat creation project in the harbour. Waterbird management practices during the past three decades are summarized and evaluated in relation to the population targets set for each species. Finally, recommendations are made regarding future management efforts in the harbour.

Methods

Study site

In Hamilton Harbour, the majority of nesting sites for the six species of waterbirds are found along the eastern shore. In the northeastern corner, Neare and Farr islands (Figure 1) were constructed in the 1920s (Dobos et al., 1988), with Farr Island dismantled in 2010. North, Centre, and South Islands (the Wildlife Islands; Figure 1), were constructed south of Neare I. during the winter of 1995–96 to provide secure, long-term nesting habitat for each species based on their specific needs, including substrates and vegetation (Quinn et al., 1996).

Piers 26 and 27 (part of the Eastport Development Area; Figure 1) were created by the Hamilton Harbour Commission by lake infilling and originally contained two confined disposal facilities (CDFs) used to store contaminated sediments dredged from the harbour (Dobos et al., 1988; Moore et al., 1995). From the early 1990s to present, the amount of available nesting habitat here declined with the capping of one of the CDFs and continued development of the port facilities. Currently, only the northern section of the CDF at Pier 27 remains open and waterbirds are restricted to nesting on its western, northern and eastern containment berms (Figure 1).

The amount of nesting habitat occupied each year was determined by measuring the area of each active colony site using aerial photographs and/or satellite imagery (Google™ Earth).

Nest counts

Counts of all occupied nests (nests contained eggs and/or small chicks, or that had contained young; hereafter nests) were conducted annually

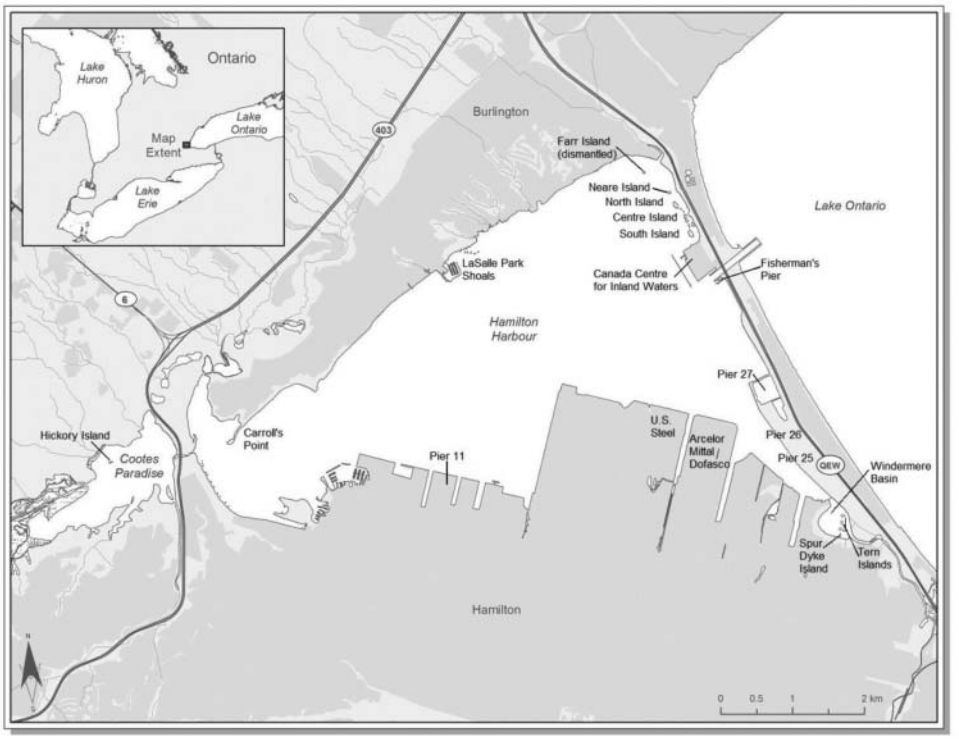

Figure 1. Map of Hamilton Harbour showing the locations of colonial waterbird nesting sites (1959–2013). Inset shows the study area in relation to the Great Lakes region.

for all inhabited sites. In large colonies (>100 nests) field teams walked through the site in strip transects and marked each tallied nest with a small spot of spray paint or marker to avoid double-counting. Although minimal, DCCO eggs or nestlings were depredated occasionally by HERGs. CATE eggs were guarded during censuses to prevent RBGU depredation. When ground counts were not possible, visual counts were performed from an accessible location. Nest counts coincided with the late-incubation phase for each species to minimize disturbance during the mobile chick phase (early to mid-May for gulls, early July for DCCOs and BCNHs, and late May to mid-June for Terns). Multi-species colonies were disturbed briefly by monitoring activities a few times each year, depending on composition, corresponding to these census periods.

Management

Management goals and efforts to approach specific population targets (originally set in 1992, Morris et al., 2001; revised in 2013; Table 1) have always been approached from the perspective of the waterbird community, aiming to maintain diversity, rather than action based on human preferences. The birds are managed to protect nesting habitat locally, which has required several techniques during the last three decades to encourage or discourage nesting by certain species at designated sites throughout the study area. General techniques included scaring, habitat creation or enhancement to attract target species, and physical exclusion and/or removal of nests and/or eggs of DCCO and RBGU (for details, see Quinn et al., 1996; Pekarik et al., 1997; Morris et al., 2001). Scaring was accomplished by: (i) noise (bird bangers, playback of distress calls), (ii) pyrotechnics, (iii) personnel presence, (iv) tethered or flying birds of prey and (v) scarecrows, including life-sized, motion-activated Santa Claus figures (Coleco) that played music and moved arms, heads, and waists scaring DCCO but not HEGU (Neare and North islands). Exclusion techniques included: (i) polyethylene sheeting, laid over CATE nesting areas in late-March to early-April to prevent nesting by earlier-

Table 1. Recent nest numbers and a comparison of original (1992) and revised (2013) population goals, targets and the success in achieving these for the six species of colonial waterbirds nesting in Hamilton Harbour.

			1992 Management Goals			2013 Management Goals		
Species	Recent Nests (2013)	No. years of data	Population Goal	Population Targets	% of years where targets met	Population Goal	Population Targets	% of years where targets met
DCCO	4,747	30	Increase	>200	83%	Decrease and limit distribution	1500–2500	13%
BCNH	79	33	Maintain	200	12%	Maintain or increase	100–200+	55%
HERG	244	33	Maintain	350	3%	Maintain or increase	200–300+	64%
RBGU	11,133	25	Decrease and limit distribution	5000	16%	Decrease and limit distribution	<10,000	16%
CATE	496	28	Maintain or increase	>200	82%	Maintain or increase	400–600+	54%
COTE	333	27	Maintain or increase	>600	52%	Maintain or increase	300–600+	81%

arriving RBGUs, removed once CATEs arrived on site (North and Centre islands), (ii) strategic planting to deter nesting by all waterbirds (e.g. Windermere Basin mainland) or (iii) delayed removal of dead annual vegetation, until arrival of the target species in the spring (e.g. Spur I., to secure habitat for COTEs). If scaring or exclusion were not successful, the removal of eggs and/or nests of RBGUs and DCCOs or egg-oiling for DCCOs occurred in some cases (Shonk et al., 2004).

Annual management efforts to reduce the impacts of DCCO on other species were implemented at sites in the NE section of the harbour starting in 2007. When scaring tactics were limited, DCCO ground nests were removed from Neare and North islands to reduce competition with HERGs and CATEs. Ground and tree nests on South Island were removed twice a week (2007-15) to prevent the degradation and loss of nesting trees and to provide secure breeding habitat for BCNHs.

The creation of dedicated waterbird nesting islands in the harbour, totaling 1.6 ha, includes: Spur Dike Island (1990), the Wildlife Islands (1996; see Quinn et al., 1996), LaSalle Park Shoals (1998) and the Tern Islands in Windermere Basin (2013, during which playback systems [Murremade Music Boxes] and Tern decoys [Mad River] were used to attract COTEs).

Analyses

Historical data (1959–2005) used in analyses were reported previously in Dobos et al. (1988), Moore et al. (1995), Pekarik et al. (1997), Morris et al. (2001) and Weseloh (2006), with formal analyses having been conducted only for the period from 1987–1996 (Pekarik et al., 1997). In the current study, trend analyses were performed over two time periods. Although a few waterbird species nested in Hamilton Harbour during the period from 1959–1974 (Dobos et al., 1988; see also Table S1 in the Appendix, available in the online supplementary information), breeding and/or records were sporadic. Therefore, long-term trends have been analyzed for the period from 1975–2013. Regression analyses were performed on nest count data using linear and polynomial functions of year as the regressor variable (1°–6° polynomial equations were assessed for each species). Candidate models were assessed using Akaike Information Criterion, with correction for finite sample size (AICc; Burnham and Anderson, 2002). Model selection results and parameter estimates for candidate models are included in Table S2 in the on-line appendix; only results for the model with the greatest AICc are reported in the text below. Analyses were performed using SAS v. 9.3 statistical software (SAS Institute, 2010). Means (±1 SE) are reported.

Results

Double-crested Cormorants

Population trends

DCCOs first nested in Hamilton Harbour in 1984 and the number of nests increased steadily after the mid-1990s to 4,747 by 2013 ($F_{2,27} = 219.9$, $p < 0.0001$, $r^2 = 0.94$; Figure 2a; Table S2).

DCCOs nested at Pier 27 each year since 1984, initially in mature cottonwood (*Populus deltoides*) trees. By 2005–2006 most of these trees had died and fallen and DCCOs have since nested on the ground or in a few small trees and shrubs. This site represented the most breeding pairs in the harbour during all but four years (2007–2010), when the highest proportion of nests (26–34%) occurred on Farr I. (Table S1). Artificial nesting platforms for DCCO that were incorporated into the design of Centre I. (Quinn et al. 1996) were occupied at capacity annually since 1998. During 2004–2006: Cormorants colonized North and South islands, and briefly Neare I. (2006–2008), and expanded from the artificial nest platforms to the ground on Centre I. (1,835 ground nests by 2013; Table S1). In 2008–2009 birds briefly colonized trees on the NW shoreline of the harbour (peak of 1,307 nests in 2011) and industrial lands on the western shore (1,002 nests by 2010). The dismantling of Farr I. in winter 2010, which supported 888 nests that breeding season, contributed to marked increases at the Wildlife Islands (mainly Centre I.; increased from 773 to 2,310 nests during 2010–2013) and Pier 27 (from 720 to 2,401 nests during 2010–2013).

Management

The management goal for DCCOs is to decrease their numbers by limiting where they nest. The population target is 1,500–2,500 breeding pairs (Table 1).

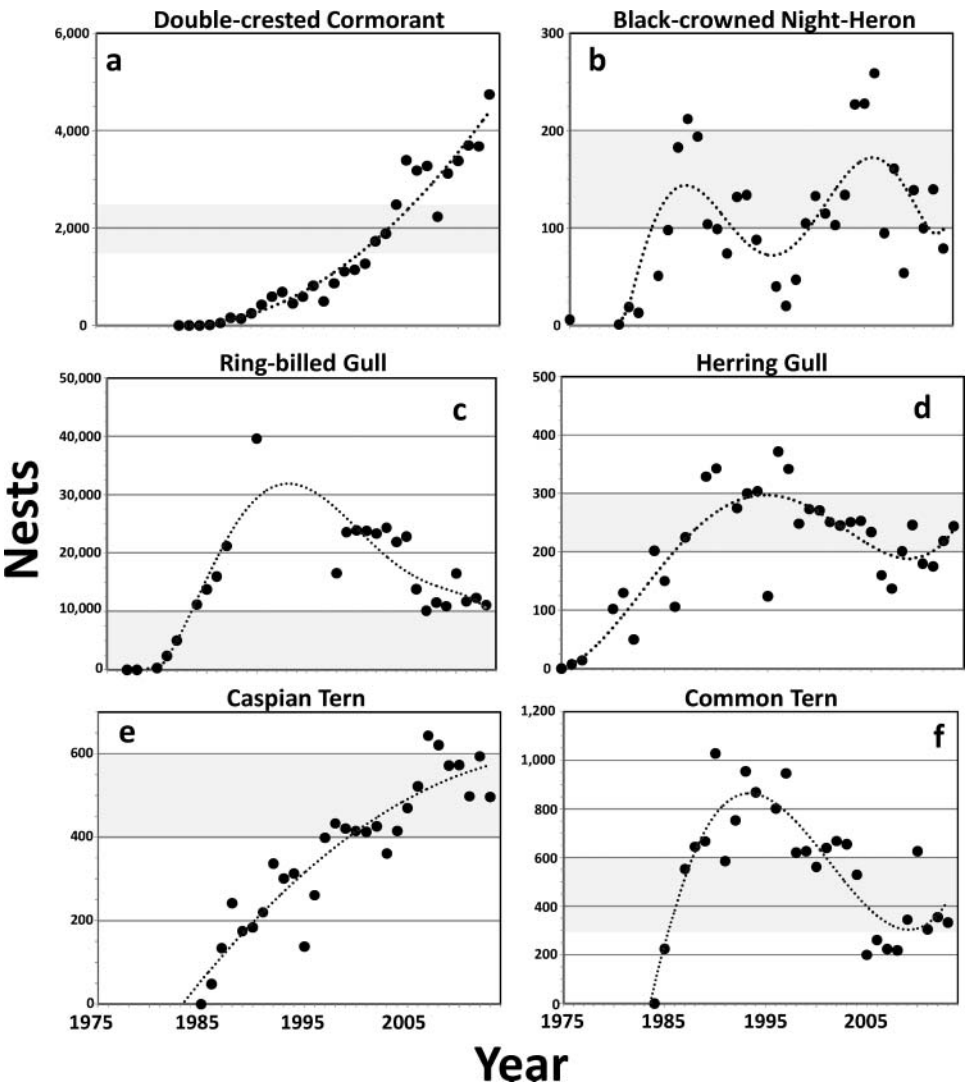

Figure 2. Population trends of colonial waterbirds nesting in Hamilton Harbour. Long-term (1975–2013) trends are indicated by a dashed grey line; short-term (2001–2013) trends are indicated by a solid black line (see Table S2 for model statistics and parameter estimates). 2013 population targets are represented by the grey-shaded areas (allowing for an increased number of nests than what is shown here, except for panels (a) and (d) that have a fixed range and maximum, respectively).

Scaring and nest removal to displace DCCOs from various areas of the harbour have been conducted since 2007. DCCO management to secure habitat for other species in the harbour are summarized below.

Black-crowned Night-Herons

Population trends

BCNHs have bred annually in Hamilton Harbour since 1975. The number of nesting pairs has fluctuated ($F_{6,25} = 6.7$, $p = 0.0003$, $r^2 = 0.61$; Figure 2b; Table S2): numbers peaked in 1987 (212 nests), declined to a low of 20 nests in 1997, then increased to a second peak in 2006 (259 nests), declining thereafter (to 79 nests in 2013).

BCNHs nested at Pier 27 during 37 of 39 years, where most nests occurred until 2004, when the Wildlife Islands gained prominence (Table S1). Five of the six main BCNH nesting sites have also been occupied by breeding DCCOs, four of which were used by BCNHs before DCCO colonization.

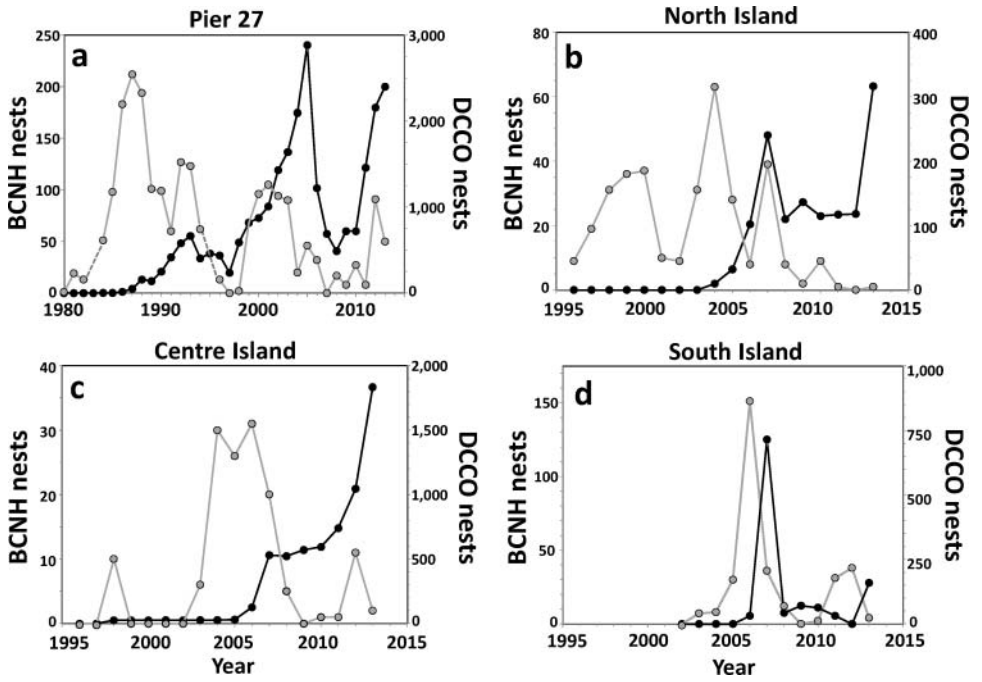

Figure 3. Population trajectories of Black-crowned Night-Herons (BCNH; in grey) at four major nesting sites that were also occupied by Double-crested Cormorants (DCCO; in black). Cormorants were not managed at Pier 27 (a), North Island (b) and Centre Island (c); Cormorant nests were removed from South Island (d; annually from 2008–2013) as a conservation measure for retaining BCNHs at that site.

At Pier 27, BCNHs first nested in mature cottonwood trees, followed by shrubs and small trees, but nest numbers declined as the number of DCCO nests in trees (ca. 1990–1995) and shrubs (ca. 2003–2006) increased, with an concurrent decline in the number of BCNHs breeding at this site (Figure 3a). An initial increase, and subsequent decline as the number of DCCO nests increased, was also observed for BCNHs at North, Centre, and South islands (Figures 3b–d, respectively). BCHNs have also nested at Windermere Basin (2004–2010; peak of 119 nests in 2008) and industrial lands on the western shoreline of the harbour (2009–2013; Table S1).

Management

The goal for this species is to increase the number of breeding pairs to a target of 100 to ≥200 (Table 1). Scaring and nest removal to displace BCNHs from private lands on the western shoreline of the harbor were conducted in 2009–2011 (9–93 nests/year). Trees were planted specifically as nesting habitat for BCNHs on South I., managed primarily for this species. DCCO first bred at South I. in 2006, and the animatronic 'Santas' and nest removal were used. The cumulative number of DCCO nests removed annually (i.e. the pressure on BCNH nesting habitat) increased over the period of management. In response to management, BCNH nests increased from 0 in 2009 to 38 in 2012, but then declined markedly the following year (4 nests; Figure 3d).

Ring-billed Gulls

Population trends

The number of nesting pairs of RBGUs in Hamilton Harbour increased from 17 in 1978 to a peak of 39,621 by 1990 and then declined to an average of 12,049 ± 717 during 2005–2013 ($F_{5,19} = 15.4$, $p < 0.0001$, $r^2 = 0.80$; Figure 2c; Table S2).

Pier 27 represented the highest numbers of nests in the harbour from 1978–2001. In 2013, this location supported 6,782 breeding pairs. South I., occupied since 1997, has supported an average of 2,806 ± 195 in recent years (2006–2013). Several other sites have gained prominence and then waned: Windermere Basin (1990–2009; a peak of 13,839 nests in 2005), U.S. Steel property (2003–2011; a peak of 4,493 in 2010)

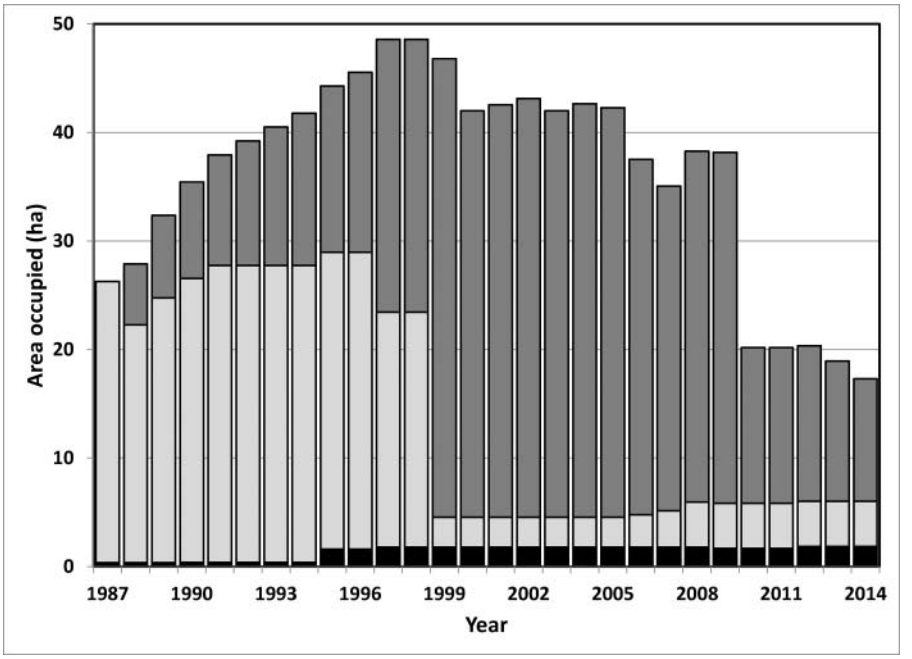

Figure 4. Changes in the area (ha) of available waterbird nesting habitat (1987–2014), where sites are categorized as either secure (dedicated waterbird breeding habitat; black), unsecure (slated for development, but nesting tolerated; light grey) or managed (nesting actively discouraged; dark grey). Values for 2014 are anticipated, based on land-use changes/plans.

and Centre I. (1997–2013; a peak of 2,905 nests in 2005). Smaller colonies have occurred at: Neare (1989–1993, peak = 457 nests), Farr (1985–1991; peak = 166 nests) and North (1996–2013; peak = 154 nests) islands, LaSalle shoals (2002–2013; peak = 91 nests), Fisherman's Pier (2009–2013; peak = 845 nests) and CCIW (2001–2011; peak = 639 nests) and ArcelorMittal Dofasco (2006–2010; peak = 100 nests) properties (Table S1).

Management

Since the early 1990s, management issues for RBGUs have focused on exclusion from areas with conflicting land-use plans, mainly at portions of Windermere Basin and the Eastport piers and other industrial or commercial lands as they were colonized, through daily scaring, generally from mid- to late-March to early to mid-June each year. Scaring was augmented by egg/nest removal when necessary, employed mainly at the Eastport piers (1999–2013; 1,703.6 ± 977.2 eggs/year, range = 142–12,750, n = 13), Windermere Basin (1999–2013; 446.7 ± 113.0 eggs/year, range = 0–1203, n = 13), South I. (1999–2005; 446.7 ± 113.0 eggs/year, range = 0–1,203, n = 13) and CCIW property (2007–2013; 51.0 ± 35.4 eggs/year, range = 0–260, n = 7).

Despite reductions, the number of RBGU nests is still above the current population target of ≤10,000 pairs (Table 1). More than any other species, RBGU distribution and population numbers have been reduced by nesting habitat loss in the harbour (Figure 4).

Herring Gulls

Population trends

The long-term (1976–2013) trend for Herring Gulls was an increase to 372 nests in 1996 followed by a decline to ~200 nests (ca. 2008) and a slight increase again during recent years (244 nests in 2013; $F_{4,28} = 16.4$, $p < 0.0001$, $r^2 = 0.70$; Figure 2d; Table S2).

Pier 27 has been occupied annually since 1976, but declined from 321 nests in 1989 to a mean of 38.0 ± 2.6 nests since 1999 (Table S1). Other areas of concentration have been the Wildlife Islands (1996–2013, 70.6 ± 3.2 nests, 93 ± 1% on North I.), Neare I. (51.6 ± 7.7 nests /year, 1985–2013) and Farr I. (29.5 ± 3.7 nests per year, dwindling with DCCO increases, 1987–2005). HERGs

began nesting on rooftops in 1999: at CCIW, there has been an average of 5.3 ± 0.8 nests annually while at the Hamilton Terminals Warehouse #2, the number of roof nests increased gradually from 25 in 2008 to 60 in 2013. Currently 24.6% of all HERG nests in the harbour occur on rooftops.

Displacement or reduced numbers of breeding pairs (e.g. Pier 27) at some sites is related to increased competition for nesting space with DCCOs, which could be responsible for the increase in roof-nesting by HERGs.

Management

The conservation goal for HERGs is to maintain (or increase) between 200 to ≥300 breeding pairs (Table 1). Combined with the removal of DCCO ground nests, animatronic Santas (one or two per site; locations moved throughout the season) were employed on Neare and North islands from 2007–2012 to preserve HERG breeding habitat (both sites) and prevent encroachment on CATE nesting areas (North I.). In 2007, the first year of management at Neare I., a cumulative 1,507 DCCO nests (including re-nesting attempts) were removed prior to deployment of the Santa unit; no nests were initiated afterward. In an experiment in 2008, 161 Cormorant nests that were initiated after scaring began were not removed. In 2009, 2010, 2012 and 2013, the robot, active or stationary, was sufficient to deter nesting by DCCOs. In 2011, likely due to the displacement of DCCOs from the newly defunct Farr I., it was necessary to remove a total of 3,913 nests from South, North, and Neare islands over the course of the breeding season and habituation to the animatronic santas. Management stabilized the number of HERG nests on Neare I. (45.0 ± 6.4, n = 7), however, fewer breeding pairs used the site compared to the pre-management period (80 ± 10.8, n = 13). During the period of DCCO management on North I., the number of HERG breeding pairs was maintained at previous levels (66.0 ± 5.9 nests (n = 7) vs 65.0 ± 3.1 nests (n = 11) pre-management). The Santas were effective for the first three years of management, particularly when fully functional (disabled periodically by design or due to breakdown), although DCCO became habituated after 2010.

Caspian Terns

Population trends

The number of CATEs increased in the harbour over the long-term (1986–2013; $F_{2,26} = 62.7$, $p < 0.0001$, $r^2 = 0.83$; Figure 2e; Table S2) although the rate of increase decelerated over time.

CATEs nested on Piers 26 and/or 27 annually from 1986–1997 (peak of 337 nests in 1992) and sporadically from 2003–2012 (from 0 to 77 nests; Table S1). CATEs colonized North I. (273.0 ± 22.3 nests/year, n = 18) the first season after it was created in 1996, and began nesting on Centre I. (198.4 ± 22.9, n = 17) the following year. North and Centre islands averaged 273.0 ± 22.3 (1996–2013, n = 18) and 198.4 ± 22.9 (1997–2011, n = 17) nests per year, respectively.

Management

The only conservation technique used to secure habitat for CATEs was covering nesting areas (knolls on the north and south ends of North I. and the north end of Centre I.) with polyethylene sheeting in early spring each year, to exclude RBGUs until the arrival of Terns at the colony. The current population target for CATEs is to maintain (or increase) the number of breeding pairs at between 400 and ≥600 (Table 1).

Common Terns

Population trends

The COTE breeding population in Hamilton Harbour has fluctuated widely. COTEs originally nested on Neare and Farr Islands from 1966–1973 (85.7 ± 14.8 nests/year; Table S1). Since re-colonizing the harbour in 1982, number of nests increased to a peak of 1,028 by 1990, then declined to a low of 200 nests in 2005, and increased thereafter to an average of 333.0 ± 45.8 (range = 218–626) from 2006–2013 (($F_{3,23} = 20.0$, $p < 0.0001$, $r^2 = 0.72$; Figure 2f; Table S2).

Windermere Basin, mainly Spur Dyke I., has been the main colony site, with annual breeding (388.0 ± 50.2 nests/year, n = 21) since 1989, with the exception of 2010–2012 during construction phase of a wetland rehabilitation project (Helka and Bassingthwaite, 2013). During this period, nests increased to a peak of 922 in 1993, then declined to 98 nests by 2009. In the first year post-construction (2013), 273 pairs of COTEs nested at the newly created Tern Islands (82% of all nests in the harbour).

COTEs have also nested on Centre (1996–1998) and South (1996–2005) islands (289.0 ± 43.0 nests/year), at Eastport Piers 26 and 27 (37–151 nests from 1982–1988; also during 2008–2013, with a peak of 626 nests in 2010), at LaSalle shoals (27.7 ±

5.3 nests/year from 1998–2007), on U.S. Steel property (74.7 ± 38.2 nests/year from 1989–1996, n = 7) and re-colonized Neare and Farr Islands (1982–1990, with a peak of 83 nests; 14 nests were also recorded in 1996; Table S1).

Management

The conservation goal for COTEs is to maintain (or increase) the number of breeding pairs to between 300 to ≥600 (Table 1). In addition to habitat creation (e.g. LaSalle shoals, the Tern Islands in Windermere Basin), management has centred on excluding earlier-arriving RBGUs from Tern breeding areas each year (late-April to early-May), by delaying the removal of dense vegetation on Spur Dyke I. (before 1996), by using tethered raptors to dissuade RBGUs (also used at the new Tern Islands in 2013), or by removing RBGU nests/clutches (≤300 cumulative nests). During construction for the Windermere Basin wetland rehabilitation project (2010 to 2012), COTE were prevented from nesting, and temporary habitat was modified at Pier 27 to attract the Terns in the interim. In 2013, decoys and call playback systems were deployed on each of the three Tern Islands to assist in attracting COTEs back to the area, and 273 nests were established in total. South I. was also managed (tethered raptors, egg removal) from 1999–2005 to exclude RBGUs for COTEs. On average, there were 244.6 ± 40.3 COTE nests at South I. during this period, but Terns abandoned the site during the first year after Gull management was terminated.

Discussion

Population management in Hamilton Harbour has aimed to maintain a diverse waterbird community that includes all six breeding species (O'Connor, 2003). There are a number of challenges to achieving this objective. The harbour is a highly industrialized setting with competing land use priorities, and there have been considerable changes over time in the amount of "available" habitat. While distribution and abundance of waterbirds within the harbour is largely influenced by population trends across the Great Lakes region, interspecific competition for nesting space (e.g. Cuthbert et al., 2002; Somers et al., 2007, 2011) adds additional complexity and uncertainty regarding management outcomes. Our response has been adaptive management, where specific objectives, approaches and techniques are implemented, assessed and refined on an annual basis.

Factors affecting population trends

Great Lakes population trends

Population trends for the six waterbird species breeding in Hamilton Harbour generally mirror the trends over the Great Lakes region, where censuses have been conducted at ten year intervals since the late 1970s. DCCOs and CATEs exhibited increasing or stable trends in both the Hamilton Harbour and the Great Lakes. After declining due to eggshell thinning linked to DDT (Weseloh et al., 1983; Prince and Weseloh, 1986 for information on contamination) and human persecution (Weseloh et al., 1995), the population began to rebound in the 1980s and DCCOs have become more numerous than at any time in recorded history, with the bans of DDT and the subsequent decline in concentration in DCCO, the bait fish invasion of the Great Lakes, and a decline in egging by fishermen (Weseloh et al., 1995, 2002, 2012; Weseloh, 2012; Cuthbert and Wires 2013). Remediation of contaminated sediments in Hamilton Harbour will have affected DCCO as habitat availability changed over time to accommodate remediation efforts (e.g. Windermere Basin; Helka and Bassingthwaite, 2013), and as contaminants were contained and made unavailable to the species and its prey fish. CATEs experienced a large increase (63.8%) on the Great Lakes between the late 1970s and late 1980s, but growth has since slowed (+1.3% and +7.2% for the 1998–2000 and 2007–2010 survey periods, respectively) with a total of 6,875 nests in the last census (Morris et al., 2010; Weseloh, 2012; Cuthbert and Wires, 2013), similar to the pattern observed in Hamilton Harbour.

The remaining four species have declined across the Great Lakes region during the last four decades. BCNH nest numbers declined by 40% since the late 1970s, although the rate of decrease between decadal surveys has slowed (−23.6%, −14.7% and −8.0%, respectively; Weseloh, 2012; Cuthbert and Wires, 2013), whereas nest numbers at Hamilton Harbour have generally increased since the early 1980s. RBGUs, the most abundant colonial waterbird on the Great Lakes, have increased by 135.1% from 1976–80 to a peak of ~720,000 nests in 1989–1990, but then declined

by 18.5% during the last (fourth) census period (2007–2009; Morris et al., 2011). In Hamilton Harbour, numbers declined by 70.3% over the same period (1990–2008). The number of HERGs breeding on the Great Lakes has fluctuated slightly but remains around 66,000 nests (Morris et al., 2003; Weseloh, 2012; Cuthbert and Wires, 2013). After the initial period of increase (up to the early 1990s), HERG nests in the harbour have generally fluctuated within or just below the 200–300 nest range. COTEs have experienced a long-term decline in the Great Lakes region. From a peak of 16,000 nests on the lower Great Lakes during 1960–1965 (Courtney and Blokpoel, 1983), there were 9,233 nests by 2007–2010, a decline of 42.3% (Morris et al., 2010, 2012; Weseloh, 2012; Cuthbert and Wires, 2013). COTEs re-colonized Hamilton Harbour just prior to the 1989–1991 census period; the relative change in nest numbers in the harbour (−66.8%) from 1989–1991 to 2007–2009 is similar to the proportional change (−65.8%) observed across the Canadian lower Great Lakes, contrasting with a 72.9% increase in nests in U.S. waters of the lower Great Lakes during the same period (Morris et al., 2010, 2012; Cuthbert and Wires, 2013). The reasons for this shift in distribution are unclear (Morris et al., 2010, 2012).

Inter-specific competition

Inter-specific interactions within tree- (DCCOs, BCNHs) and ground- (DCCOs and HERGs, RBGUs and COTEs) nesting species have also affected waterbird distributions in the harbour. On islands where DCCOs and HERGs both nest, DCCO compete directly with gulls for nest sites and nesting material, contributing to reduced HERG breeding success at mixed-colony sites, compared to single-species colonies (Somers et al., 2007, 2011). This competition may result in HERG abandonment of a site, seen on Farr I., unless DCCO nesting is prevented by scaring DCCO and/or by nest removal, allowing HERGs to nest alone.

DCCOs can have both direct (competition for nest sites) and indirect (alteration of arboreal habitat) effects on other tree-nesting species. The accumulation of acidic DCCO guano can affect soil chemistry (Cuthbert et al., 2002) and vegetation on islands, leading to death and loss of canopy nesting trees over the long term (Weseloh and Ewins, 1994; Hebert et al., 2014), as seen at Pier 27, Farr I. and North I. DCCOs also compete with BCNHs for nesting materials and space. In 2006, 312 marked BCNH nests were monitored weekly at five colony sites in Hamilton Harbour; BCNHs nested alone in trees at two sites and with DCCOs, in shared trees, at three sites. The rate of BCNH nest loss was higher at the mixed-species sites (South I. = 29.5%, Pier 27 = 43.8%, Centre I. = 49.1%) than at sites where BCNHs nested alone (North I. = 0%, Windermere Basin = 12.9%; DJM unpubl. data). Due to the potential for inter-specific competition, a single site each for HERGs (Neare I.) and BCNHs (South I.) will continue to be managed by eliminating DCCO nesting.

Primary nesting sites for both Tern species are managed to exclude other ground-nesting species and minimize competitive interactions (Morris et al., 1992), and efforts have been thus far successful in maintaining both species. COTE abandonment of colonies has been linked to competition for nesting space with earlier-nesting RBGUs (Morris et al., 2001, 2010, 2012). In the present study, COTEs abandoned South I. the year following the cessation of management (using tethered raptors) to prevent RBGUs from nesting on a portion of the site. Continued management to secure breeding habitat for Terns is recommended.

Changes in available habitat

Changes in the amount of available breeding habitat (Figure 4) have affected the distributions and abundance of waterbirds within the harbour. While the 1.9 ha of island habitat created or secured since the mid-1990s will have a positive, long-term effect on waterbird conservation, it has not offset the loss of 42 ha (peak in 1999) of former nesting area to development. A large push to restrict RBGUs nesting at Piers 26 and 27 began in 1999; this restriction, along with coordinated management, drove the reduction in the number of RBGU nests, and similarly, restricted breeding habitat, exacerbated by the loss of Farr I., resulted in the displacement of DCCOs and increased pressure on the remaining nesting sites. As of 2013, the containment dykes surrounding the CDF at the north end of Pier 27 (~4.2 ha) are the only remaining nesting areas on lands planned for development. The eventual loss of this breeding site and the resulting displacement of large numbers of DCCOs and RBGUs will affect community dynamics, putting more pressure on vulnerable species nesting in remaining habitat.

Effectiveness of management

Population targets for the six species of waterbirds were set originally in 1992 were based largely on historical trends and projections regarding future availability of habitat (Hamilton Harbour RAP, 1992). These targets were revised in 2013 (Table 1), to better reflect what was achievable, given the breeding habitat that would be available in the foreseeable future and population trends on a wider scale. Since the 1990s, management efforts have been successful in maintaining a diverse waterbird community in the harbour area. Achieving specific population targets has proven more challenging. The reduction in the number of RBGU nests from nearly 40,000 to approximately 12,000 can be attributed to the long-term, harbour-wide management program to limit the habitat available to this species. CATE numbers increased and have remained stable and within target range, requiring only the placement of plastic sheeting (polyethylene film) each spring to secure nesting space. COTE numbers have begun to rebound after a marked decline since the mid-1990s, but have still fluctuated considerably in recent years. The creation of the Tern Islands in 2013 is might be a turning point, although continuing management to prevent Tern displacement by nesting RBGUs will be necessary.

As of yet, there has been no attempt to manage DCCO numbers, other than localized efforts to prevent nesting at a few sites, to minimize competition with HERGs and BCNHs. Although HERG nest numbers have been relatively stable since the mid-1990s, several factors suggest that they are still vulnerable to decline. First, approximately one quarter of nests are now located on rooftops, which does not represent secure breeding habitat. Second, while initially very effective, DCCOs have habituated to the use of animatronic Santa figures. Alternative techniques will be needed to exclude breeding DCCOs from North I. and other sites unless DCCO numbers decline. Despite persistent removal of DCCO nests on South I., where trees have been successfully preserved, BCNHs have been slow to re-establish a colony at the site, even though it represents some of the best remaining habitat. Removal of DCCO nests from trees is a labour-intensive undertaking, and 2 to 3 visits per week to the site throughout the breeding season were required. It is possible that the low numbers of BCNH nests resulted from a combination of continued DCCO presence and disturbance by the management team at the site. After experiencing a number of years with no reproductive success, it is hoped that DCCOs will eventually abandon this site.

Future management efforts should consider replanting shrubs on South and Centre islands that would support BCNH nests, but not DCCOs and their nest structures. Investigators at two other managed sites on Lake Ontario, Tommy Thompson Park, near Toronto, Ontario (Feldmann, 2011) and Presqu'ile Provincial Park near Brighton, Ontario (D. Tyerman, Presqu'ile Provincial Park, unpubl. data), have started to experiment with techniques to attract Cormorants to ground colonies rather than focusing on excluding them from trees. This approach also has potential as a management tool for Hamilton Harbour.

Conclusions

Over the past four decades, efforts to manage and maintain a diverse colonial waterbird community within an urban landscape have been largely successful. Achieving these results has required ongoing management and monitoring, focusing on reducing local RBGU and DCCO nests, while increasing COTEs, BCNHs, and HERGs. Given the complexity of community and site dynamics for the populations of six waterbird species in industrial Hamilton Harbour, and the influence of extrinsic factors, an adaptive management approach is integral to the management of these species. With continued stewardship, colonial waterbirds will remain a unique and important component of the biodiversity of the Hamilton Harbour area.

Acknowledgements

The Hamilton Port Authority and the City of Hamilton accommodated nesting waterbirds on their lands for many years and integrated and funded various habitat creation projects. Members of the Colonial Waterbird Management Sub-Committee, Hamilton Harbour Remedial Action Plan, especially, Marilyn Baxter, Lisa Geyer, Sue Gilpin, John Hall, Ralph Morris, Kathy Trotter and Robert Wagner, for supporting and guiding waterbird conservation goals. John Helka, Marilyn Baxter and Bill Fitzgerald provided access to sites and logistical support. Marcus Vujacic, Safia Mai,

Dan Re, Katherine Dielman, Kyna Intini, Florence Gonzalves Prabhu, Jasmine Farahbakhsh, Janine Wong, Carolyn Zanchetta, Beth Nagai, and Shakil Salim performed monitoring and management in the Harbour from 2007 until 2013. Jeffrey Costa calculated site areas and extracted data on waterbird management from annual reports. Numerous volunteers assisted with data collection and conservation/management activities, including McMaster biology students, who helped cover Tern nesting habitat every winter. Thank you to Shane de Solla and an anonymous reviewer for helpful comments and suggestions.

Funding

We gratefully acknowledge the following: The Hamilton Port Authority (HPA) and the cities of Hamilton and Burlington for providing annual funding support for monitoring and management work.

Supplemental material

Supplemental data for this article can be accessed on the publisher's website.

References

Blokpoel, H., Tessier, G. D., 1996. Atlas of colonial waterbirds nesting on the Canadian Great Lakes, 1989–91. Part 3. Cormorants, gulls and island nesting terns on the lower Great Lakes system in 1989. Tech. Rep. Ser. No. 225. Canadian Wildlife Service, Ontario.

Blokpoel, H., Tessier, G.D., 1997. Atlas of colonial waterbirds nesting on the Canadian Great Lakes, 1989–1991. Part 2. Cormorants, gulls and island-nesting terns on Lake Huron in 1989. Technical Report Series Number 259, Canadian Wildlife Service, Ottawa, Ontario.

Burnham, K. P., Anderson, D. R., 2002. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach (2nd Ed.)*, Springer, New York, NY.

Courtney, P.A., Blokpoel, H., 1983. Distribution and numbers of Common Terns on the lower Great Lakes during 1900–1980: a review. Colonial Waterbirds 6, 107–120.

Cuthbert, F.J., Wires, L., 2013. The fourth decadal U.S. Great Lakes colonial waterbird survey (2007–2010): Results and recommendations to improve the scientific basis for conservation and management. Final Report. University of Minnesota, St. Paul, MN, USA.

Cuthbert, F.J., Wires, L.R., McKearnan, J.E., 2002. Potential impacts of nesting Double-crested Cormorants on Great Blue Herons and Black-crowned Night-herons in the U.S. Great Lakes Region. J. Great Lakes Research. 28, 145–154.

Dobos, R.Z., Struger, J., Blokpoel H., Weseloh, D. V., 1988. The status of colonial waterbirds nesting at Hamilton Harbour, Lake Ontario, 1959–1987. Ontario Birds 6, 51–60.

Feldmann, I., 2011. Double-crested cormorant management at Tommy Thompson Park: a conspecific attraction experiment and egg-oiling modeling scenarios. Thesis, York University, Toronto, Ontario, Canada.

Hamilton Harbour RAP, 1992. Hamilton Harbour Remedial Action Plan, Volume 2- main report: goals, options and recommendations, November 1992. Environment Canada, Burlington, Ontario, Canada.

Hebert, C.E., Pasher, J., Weseloh, D.V., Dobbie, T., Dobbyn, S., Moore, D.J., Minelga, V., Duffe, J., 2014. Nesting Cormorants and Temporal Changes in Island Habitat. J. Wildlife Manage. 78, 307–313.

Helka, J., Bassingthwaite, M., 2013. On the waterfront: Enhancement project transforms Windermere Basin into a diverse coastal wetland. The Ontario Technologist 55, 22–25.

Moore, D.J., Blokpoel, H., Lampman, K.P., Weseloh, D.V., 1995. Status, ecology and management of colonial waterbirds nesting in Hamilton Harbour, Lake Ontario, 1988–1994. Canadian Wildlife Service Technical Report Series 213, 1–45.

Morris, R.D., Blokpoel, H., Tessier, G.D., 1992. Management efforts for the conservation of Common Tern colonies: two case histories. Biological Conservation. 60, 7–14.

Morris, R.D., Pekarik, C., Weseloh, D.V.C., Quinn, J.S., 2001. Progress towards colonial waterbird population targets in Hamilton Harbour (1998–2000). Ontario Birds 19, 12–25.

Morris, R.D., Weseloh, D.V., Shutt, J.L., 2003. Distribution and abundance of nesting pairs of herring gulls (*Larus argentatus*) of the North American Great Lakes, 1976 to 2000. J. Great Lakes Research 29, 400−435.

Morris, R.D., Weseloh, D.V., Cuthbert, F.J., Pekarik, C., Wires, L.R. and Harper, L., 2010. Distribution and abundance of nesting common and Caspian terns on the North American Great Lakes, 1976 to 1999. J. Great Lakes Research 36, 44−56.

Morris, R.D., Weseloh, D.V., Wires, L.R., Pekarik, C., Cuthbert, F.J., Moore, D.J., 2011. Population trends of Ring-billed Gulls breeding on the North American Great Lakes, 1976 to 2009. Waterbirds 34, 202–212.

Morris, R.D., Pekarik, C., Moore, D.J., 2012. Current status and abundance trends of Common Terns breeding at known coastal and inland nesting regions in Canada. Waterbirds 35, 194–207.

O'Connor, K.M., 2003. Remedial Action Plan for Hamilton Harbour: Stage 2 Update 2002. Environment Canada, Burlington, Ontario, Canada.

Pekarik, C., Nicassio, A. N., Blokpoel, H., Weseloh, D.V., Hall, J., Fink, S., Anderson, C., Quinn, J. S., 1997. Management of colonial waterbirds nesting in Hamilton Harbour: the first two years of colonization of artificial islands and population trends. Technical Report Series No. 287. Canadian Wildlife Service, Ontario Region.

Quinn, J.S., Morris, R.D., Blokpoel, H., Weseloh, D.V., Ewins, P.J., 1996. Design and management of bird nesting habitat: tactics for conserving colonial waterbird biodiversity on artificial islands in Hamilton Harbour, Ontario. Can. J. Fisheries Aquatic Sci. 53 (Suppl. 1), 44–56.

SAS Institute, 2010. SAS v. 9.3 for Windows. SAS Institute Inc., Cary, NC, USA.

Shonk, K.A., S.D. Kevan, Weseloh, D.V., 2004. The effect of oil spraying on eggs of Double-crested Cormorants. The Environmentalist 24, 119–124.

Somers, C. M., Doucette, J.L., Weseloh, D.V.C., Kjoss, V.A., Brigham, R.M., 2011. Interactions between Double-crested Cormorants and other ground-nesting species. Waterbirds 34, 168–176.

Somers, C. M., Lozer, M. N., Quinn, J. S., 2007. Interactions between Double-crested Cormorants and Herring Gulls at a shared nesting site. Waterbirds 30, 241–250.

Weseloh, D.V.C., 2012. Inland colonial waterbird and marsh bird trends for Canada. Canadian Biodiversity: Ecosystem Status and Trends 2010 Technical Thematic Report No. 18. Canadian Councils of Resource Ministers. Ottawa, Ontario, Canada.

Weseloh, D.V., Ewins, P.J., 1994. Characteristics of a rapidly increasing colony of double-crested cormorants (*Phalacrocorax auritus*) in Lake Ontario: population size, reproductive parameters and band recoveries. J. Great Lakes Res. 20, 443–456.

Weseloh, D.V., Cuthbert, F.J., King, T., 2012. Introduction: Double-crested Cormorants of the Great Lakes – St. Lawrence River basin: recent studies, movements and responses to management actions. Waterbirds 35 (Special Publication 1), 1–3.

Weseloh, D.V., Ewins, P.J., Struger, J., Mineau, P., Bishop, C. A., Postupalsky, S., Ludwig, J.P., 1995. Double-crested Cormorants of the Great Lakes: Changes in population size, breeding distribution and reproductive output between 1913 and 1991. Colonial Waterbirds 18, (Special Publication 1), 48–59.

Weseloh, D.V., Pekarik, C., Havelka, T., Barrett, G., Reid, J., 2002. Population trends and colony locations of Double-crested Cormorants in the Canadian Great Lakes and immediately adjacent areas, 1990–2000: A manager's guide. J. Great Lakes Research 28, 125–144.

Weseloh, D.V., Teeple, S.M., Gilbertson, M., 1983. Double−crested cormorants of the Great Lakes: egg−laying parameters, reproductive failure, and contaminant residues in eggs, Lake Huron 1972−1973. Can. J. Zool. 61, 427−436.