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PRIMARY RESEARCH PAPER

The impact of nutrient loading from Canada Geese (*Branta canadensis*) on water quality, a mesocosm approach

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Abstract A mesocosm experiment determined the impact of Canada Goose (*Branta canadensis*) feces on water chemistry. After 30 days of fecal additions (treatments of 1.209, 2.419 g, and 12.090 g every 3 d to 0.811 m^3 size mescosms), no significant changes in water column total phosphorus, nitrate, N:P ratios, total Kjeldahl nitrogen, chlorophyll-*a*, or phycocyanin were observed among treatment groups. Soluble reactive phosphorus showed a marginally significant increase in the high treatment group. A settling experiment suggested that goose feces and associated nutrients settled quickly to the sediment. Since fecal material settles quickly to the sediment, the impact of additional fecal material would not become evident in a lake until a wind event mixes the sediment into the water column or through alteration of the productivity or community structure of the benthos.

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Introduction

Canada goose (*Branta canadensis*) populations have grown at a tremendous rate in many areas of North America (Ankney, 1996; Hope 2000; Dennis et al., 2000; Maccarrone & Cope, 2004). Several subspecies of Canada goose reside in the northeastern United States (*B. canadensis maxima, B. canadensis canadensis, B. canadensis interior*) during some part of the year. All of these subspecies have increased in population (between 4 and 19%) from 2002 to 2003 except the Southern James Bay population of Canada geese, which decreased slightly (less than 1%) (U.S. Fish and Wildlife Service, 2003b). Reasons for the large increase in North American Canada goose populations include changes in agricultural land use (development of rice fields in Texas and Louisiana and cereal grains in the Midwest and northeast ultimately increases the amount of available food for geese along the flyways), changes to hunting regulations, decreased migration, changes in the distribution of geese in the Atlantic flyway and the creation of aquatic habitat (Abraham & Jefferies, 1997; Hope, 2000, Maccarrone & Cope, 2004). Other causes certainly exist as large, non-migratory, over winter-

ing populations, now exist which previously did not exist in New York State (U.S. Fish and Wildlife Service, 2003a). Breeding populations of the largest sized group, *Branta canadensis maxima*, were established in the 1950s and 1960s by wildlife managers to combat declining goose populations due to hunting. These populations grew quickly moved to suburban areas with abundant food and few predators (James 2000).

Landscape-scale studies suggest that waterfowl can contribute up to 40% of allochthonous nitrogen and 75% of allochthonous phosphorus to the lake annually (Manny et al., 1975, 1994; Marion, 1994, Kitchell et al., 1999—see Table 1). Concerns about goose population growth include a greater abundance of pathogens, eutrophication of water bodies caused by excess nutrients in the water column, nutrient stimulation of phytoplankton populations, changes in phytoplankton species composition, and the development of cyanobacteria blooms and the related production of cyanotoxins (Pettigrew et al., 1998; Manny et al., 1975, 1994; Kitchell et al., 1999; Marion et al., 1994; Harris et al., 1981; Bédard & Gauthier, 1986; Zhou et al., 2004, Olson et al., 2005). Large scale (whole system) field studies (Manny et al., 1994; Post et al., 1998; Kitchell et al., 1999, Olson et al., 2005) suggested that geese contribute significant amounts of nutrients to freshwater systems. Yet Pettigrew's et al. (1998) experimental mesocosm approach revealed no long-term increase in nutrient levels after the addition of goose feces. This result was attributed to nutrient uptake by phytoplankton and a likely increase in phytoplankton populations. It follows that phytoplankton diversity may be affected as the low nitrogen to phosphorus ratios typical of goose feces (N:P = 8:1, Post et al., 1998; Watson et al., 1997) may favor cyanobacteria populations.

Previous research suggests several avenues and questions for research. We tested the hypothesis that continuous addition of goose fecal material to mesocosms would increase nitrogen and phosphorus levels and stimulate the growth of phytoplankton populations. We expected that a low N:P ratio, typical in geese fecal material , would lead to dominance of cyanobacteria and increase the production of cyanotoxins, such as anatoxin or microcystin (Dawson, 1998; James and James 1993; Hisbergues et al., 2003). These hypotheses were tested using an intermediate-duration mesocosm experiment to further develop our understanding of bird fecal droppings on bodies of water.

Materials and methods

General

To test these hypotheses, goose feces was added to six mesocosms at loading rates suggested from the literature. Each experimental mesocosm and the pond, where they were located, were monitored for nutrient chemistry and phytoplankton. Where appropriate, two-way ANOVA and non-parametric corollaries were employed to determine the impact of the fecal additions on water chemistry and phytoplankton populations.

Experimental design

Six mesocosms, modeled after Pettigrew et al. (1998), were placed in pond number four, one of the eight experimental ponds at the State University of New York College at Brockport, NY. Each mesocosm, constructed of *Layflat Polyethylene Tubing* (Action Plastic Sales, Minneapolis, MN), extended from 4 cm above the water's surface and was anchored into the sediment (water depth of 1.8 m) by two concrete blocks. At both ends the mesocosms were framed by 1.27 cm PVC piping formed into a circle and attached to the tubing with duct tape. Each mesocosm (diameter = 0.76 m, volume = 0.8 m^3) was supported by a square of 10.16-cm PVC piping. Pipe insulation was attached to the PVC circle to provide further buoyancy, and the entire system was tethered to trees at three sides of the pond for additional stability.

The six mesocosms were arranged in a two-by-three pattern with PVC square frames attached to each other. Fecal additions were assigned to mesocosms using a random number generator. Two of the mesocosms received no feces (control), two received moderate fecal loading (50% of average daily load) and two received 100% of the daily load. Because there was no change in chlorophyll-*a* or TP after 15 d, we altered the

Table 1 Typical goose fecal loading rates

Study	Manny et al. (1975, 1994)	Marion et al. (1994)	Oliver and Legović (1988)	Post et al. (1998)	Olson et al. (2005)
Water Body	Wintergreen Lake	Lake Grand-Lieu (France)	Okefenokee	Bosque del Apache NWR	Middle Creek Reservoir
Location	Michigan, USA	Nantes, France	Georgia, USA	New Mexico, USA	Pennsylvania, USA
# of Geese	2100	1,728,300 (all birds)	8000	40,000 lesser & snow geese	100,000 snow geese
Area (m^2)	150,000	63,000,000	1.8×10^9	4,940,000	1,620,000
Volume (m^3)	350,239	ND	ND	ND	1,620,000[a]
Geese m^{-2}	0.014	0.027	4.4×10^{-6}	8.1×10^{-3}	0.062
Geese m^{-3}	6.0×10^{-3}	ND	ND	ND	0.062
Loading Rate ($g\ m^{-2}\ d^{-1}$)	2.18	4.20	6.8×10^{-4}	1.26	ND
Loading Rate ($g\ m^{-3}\ d^{-1}$)	0.934	ND	ND	ND	ND
Total phosphorus in lake (μg/L)	0.029–0.434	ND	5[b]	ND	ND
Conductivity (μhmos, 25°C)	230–280	ND	ND	ND	ND
Chlorophyll-*a* (μg/l)	5–175	ND	17.6[c]	ND	ND

[a] mean depth is 1.0 m

[b] Soluble reactive phosphorus

[c] value in mg m^{-2}

Loading rate equals mass of droppings (wet weight) per unit area or volume

50% treatments to 500% on 28 July 2004, 18 days into the experiment.

Fecal additions

Reports on defecation rates in geese are variable. Manny et al. (1975) found that migrant geese defecated an average of 28 times d^{-1} with an average fresh and dry dropping weight of 5.56 g and 1.17 g per event, respectively. Kear (1963) estimated Atlantic Canada goose dropping frequency at 92 d^{-1} with an average dry weight of 1.9 g. Unlike Pettigrew et al. (1998), who added feces in two pulses four weeks apart, we attempted to simulate goose dropping intervals by adding feces regularly (every 3 d) and at a fecal loading rate suggested by other field studies. Utilizing the conservative estimate of Manny and estimates of ''typical'' abundance per unit area in New York State, daily loading of goose fecal material into each mesocosm was calculated to be 0.806 g wet weight per day for the 100% feces treatment (see Table 2 for other treatments). Feces were collected from a local park and analyzed for NO_3-N, TKN, SRP, TP (Table 3). Fresh feces were stored in a watertight container and added every 3 d for 33 d (10 July 2004 to 12 August 2004) in a 1-l slurry and mixed gently within the mesocosm by lowering and raising a small desk fan blade. This method of feces addition may increase the residence time of feces in the water column as fecal material tends not to be in slurry but is more formed and thus may sink to the sediment faster.

Table 2 Amount of fecal material (wet weight) added to mesocosms. Pulsed fecal addition represents the amount added to a mesocosm every third day

Treatment (%)	Daily loading rate (g d^{-1})	Pulse fecal addition (g)
0	0	0
50	0.403	1.209
100	0.806	2.419
500	4.03	12.09

100% represents the ''typical'' or average amount of fecal material estimated to be produced by geese

Table 3 Analysis of feces used in the experiment

Nutrient	Concentration (μg/g feces)
NO_3-Nitrate	9.9
TKN	2105.9
SRP	185.0
TP	338.1

Determined by adding 12.09 g feces (wet-weight) to 2 l of distilled water

Sampling regimen

Water samples were collected from the mescosms and the pond with a vertical Van Dorn bottle at a depth of 1 m every third day (28 June 2004–12 August 2004) in the morning from a small rowboat and placed on ice in a cooler for transport back to the lab. Approximately 30 ml of water was filtered (Magna 0.45-μm nylon filter) in the field for dissolved phosphate and nitrate analysis and frozen. Similarly, pond water for microcystin analysis was filtered (maximum of 20 l) through a Whatman 1.5-μm glass microfiber filter until the filter clogged, placed in a 50-ml centrifuge tube and frozen in dry ice (Carmichael & An, 1999). Samples were stored at 4°C. Water temperature was measured in each mesocosm with a YSI thermometer probe.

Settling experiment

A settling experiment was performed to determine the rate at which fecal materials settled out of the water column. Fecal slurry, as created for the field experiments, was added to a column of water (0.5 m in height), and turbidity was measured every day for four days with a Scientific, Inc Micro 100 Turbidimeter.

Sample analysis

The following parameters were analyzed: chlorophyll (Wetzel & Likens, 2000; fluorometry, APHA, 1999), soluble reactive phosphorus (SM 4500-P F), total phosphorus (persulfate digestion, SM 4500-P F), nitrate-nitrite (SM 4500-NO_3 F), and total Kjeldahl nitrogen (EPA 351.2). Phycocyanin was analyzed by fluorometry (Turner Designs TD-700 [excitation 595 nm, emission 670 nm]) by producing a standard curve and

fitting sample values to the regression. The Water Quality Lab at SUNY Brockport is NELAC certified (ELAP #11439, EPA # NY 01449). MCYST-LR was determined by the Protein Phosphatase Inhibition Assay (PPIA) following Carmichael and An (1999).

Statistical analysis

To analyze the data, we selected two groups of dates (time periods). We compared the first four sampling dates (''initial time period'': 10, 13, 16 and 19 July 2004) of feces additions to the final four dates (''final time period'': 3, 6, 9 and 12 August 2004) to assess impact, if any, of the 100% and 500% (increased from 50% early in the experiment) treatments. The selected data and log-transformed data for each parameter was tested for normality using a Kolmogorov-Smirnov test (Zar 1999). Log-transformed chlorophyll-*a* was normally distributed so it was analyzed using a two-way ANOVA (time period and treatment as factors). All other parameters were not normally distributed even when log-transformed so they were examined for differences in treatments and time periods using two separate Kruskal-Wallis tests (Zar 1999). Differences in nitrate-nitrogen were not statistically analyzed due to a large number of non-detects.

Results

Goose feces (Table 3) contained levels of Nitrate–Nitrogen, TKN, SRP and TP that upon addition to the mesocosms would be expected to alter water chemistry. No significant differences in chlorophyll-*a*, phycocyanin, TP or N:P ratio concentrations were observed among treatments for the two periods compared (Table 4). Time trend plots confirmed this observation (Figs. 1–3). Marginally significant ($P = 0.047$ and 0.043 for TKN and SRP, respectively) differences between treatments were found for TKN in the ''initial time'' period (with the 100% treatment having the greatest rank sum) and SRP in the ''final'' time period. Examination of time trend plots suggests that these differences were not meaningful (Fig. 4). Significant differences occurred in all parameters between the two time periods. All parameters decreased over time except N:P ratio and phycocyanin.

Microcystin samples collected on the last two sampling dates of the experiment were analyzed. The average concentrations for treatments were 0.004, 0.017, 0.053 and 0.015 for the pond, 0, 50/500 and 100% treatments, respectively. A Kruskal-Wallis test determined that there was no significant difference among the four treatments ($P = 0.125$) or the three mesocosm-based treatments ($P = 0.492$). Upon visual examination of the mesocosms, there were no obvious differences among the six mesocosms and there was no noticeable growth of plankton on the surface of the mesocosms.

In the settling experiment ($n = 1$), turbidity decreased exponentially ($y = 4.7491e^{-0.0078t}$, $R^2 = 0.97$) with time. Within 100 min of the fecal addition, turbidity decreased from 101 NTU to 4.84 NTU.

Discussion

We found that the fecal additions had almost no immediate impact on water chemistry. It is possible that an effect did occur in our experiment, but the change in nutrients was so small compared to the variability in the data that we were not able to observe significant differences with only two replicates per treatment. Cyanobacteria (as measured by phycocyanin) did increase over time. However, there was no difference between the control and high treatment (500%) mesocosms, and microcystin production was not evident.

The impact of waterfowl on water quality has differed among studies. Manny et al. (1975, 1994); Harris et al. (1981); Post et al. (1998); Marion et al. (1994) and Olson et al. (2005), observed that waterfowl contribute significant nutrients in some freshwater systems. Each study estimated the contribution of nitrogen and phosphorus by birds to reach as high as 40% of nitrogen and 85% of phosphorus input to a lake. Accordingly, this level of fecal loading must lead to changes in

Table 4 Statistical tests for differences among treatment groups for parameters measured

Parameter	Test used	Significance
Chlorophyll-*a* (log)	Two-way ANOVA	***P* = 0.039** (treatment—no significant pairwise differences upon Tukey test) ***P* < 0.001** (time period—1st time period was greater) ***P* = 0.101** (interaction)
SRP	Kruskal-Wallis	*P* = 0.842 (treatments in 1st time period) ***P* = 0.043** (treatments in 2nd time period—500% treatments with greatest rank sum) ***P* < 0.001** (time period—1st time period was greater)
Phycocyanin	Kruskal-Wallis	*P* = 0.672 (treatments in 1st time period) *P* = 0.985 (treatments in 2nd time period) ***P* < 0.001** (time period—2nd time period was greater)
TP	Kruskal-Wallis	*P* = 0.721 (treatments in 1st time period) *P* = 0.741 (treatments in 2nd time period) ***P* < 0.001** (time period—1st time period was greater)
TKN	Kruskal-Wallis	***P* = 0.047** (treatments in 1st time period—100% with greatest rank sum) *P* = 0.853 (treatments in 2nd time period) ***P* = 0.020** (time period—1st time period was greater)
N:P Ratio	Kruskal-Wallis	*P* = 0.783 (treatments in 1st time period) *P* = 0.818 (treatments in 2nd time period) ***P* < 0.001** (time period—2nd time period was greater)
Microcystin	Kruskal-Wallis (last two days)	*P* = 0.125 (with pond included in analysis) *P* = 0.492 (without pond in analysis)

Values in bold were significant

water quality parameters, nutrient ratios, phytoplankton abundance and species diversity. Other, field-based, experimental studies have shown little or no impact from waterfowl fecal loading (Pettigrew et al., 1998; Bédard et al., 1986). In this study, we addressed the differences in the results from the previous studies by using fecal loading rates from the studies that found an impact while employing an experimental design similar to that of the studies that did not find an impact.

Our results are consistent with earlier studies that did not detect an impact. Waterfowl fecal loading had little or no impact on water quality or phytoplankton. Over 213 mg of phosphorus was added to the 50/500% mesocosms during the experiment. Ambient levels of P as fecal material

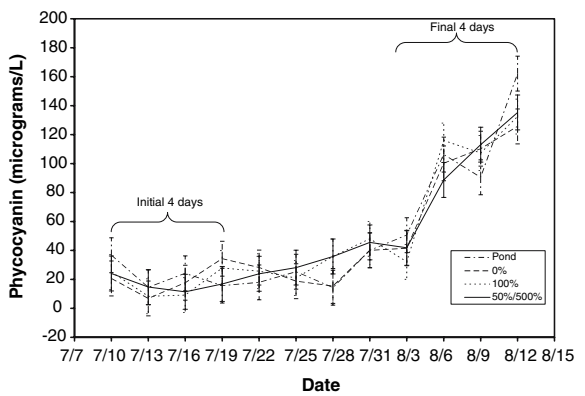

Fig. 1 Phycocyanin concentration over time for three treatments and pond. Error bars (values are mean ± 2 SE) are included. Treatment percentages are based on a loading rate of 0.806 g/d (wet weight). 50/500% began as 1/2 of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004

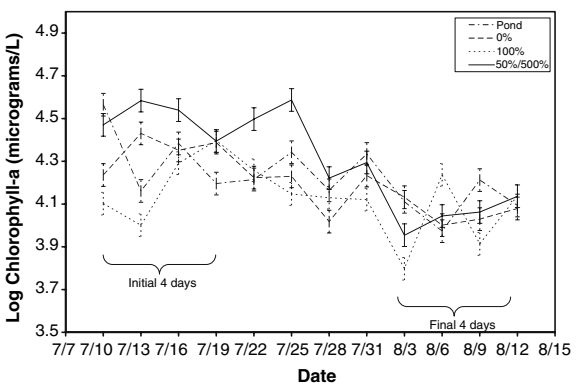

Fig. 2 Log chlorophyll-*a* concentration over time for three treatments and pond. Error bars (values are mean ± 2 SE) are included. Treatment percentages are based on a loading rate of 0.806 g/d (wet weight). 50/500% began as 1/2 of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004

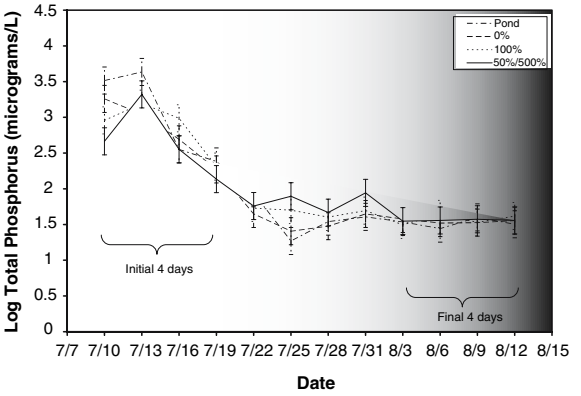

Fig. 3 Log total phosphorus concentration over time for three treatments and pond. Error bars (values are mean ± 2 SE) are included. Treatment percentages are based on a loading rate of 0.806 g/d (wet weight). 50/500% began as 1/2 of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004

should have reached 262.7 μg P/l, but this was not observed. Total phosphorus levels never exceeded 156.4 μg/l (other than anomalous high levels before additions began) and ended at 30.3 μg/l in mesocosm 2 and 43.0 μg/l in mesocosm 6. Fecal material was added as slurry from the surface and mixed with a suspended fan blade and hence would be in a very labile form. The added phosphorus must have either sunk to the bottom or been taken up very quickly into the aquatic food web.

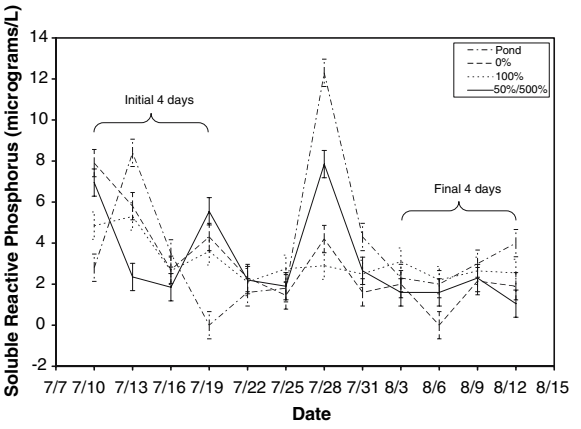

Fig. 4 Soluble reactive phosphorus concentration over time for three treatments and pond. Error bars (values are mean ± 2 SE) are included. Treatment percentages are based on a loading rate of 0.806 g/d (wet weight). 50/500% began as 1/2 of the 0.806 g per day and was increased to 500% of 0.806 g per day on 28 July 2004

Despite the slurry form of the fecal additions and mixing with a fan blade, it is likely that most of the nutrients and organic material and nutrients in the mesocosm simply sank to the bottom of the pond. The laboratory settling experiment supported this suggestion. Unfortunately, nutrient loading into the sediment at the bottom of the mesocosms was not measurable in the mesocosms. It is important to note that the method of fecal loading by slurry used in this study was much more likely to dissolve in water than ''fecal'' inputs from a goose which would likely sink.

Pettigrew et al. (1998) also concluded that phosphorus and nitrogen did not remain in the water column after nutrient additions. Nutrients were assimilated by plankton, adsorbed into the sediment or denitrified (nitrogen only). It is likely that nutrient concentration in sediments would be similar in all mesocosms and, therefore, difficult to differentiate, since the bottom of the pond was largely decaying plant material (similar to the contents of the feces).

If the fate of most of the fecal nutrients is to end up in the sediment, the impact of those nutrients on water quality may not be manifested until a mixing event occurs. Nutrients may have also passed quickly through the food web and ended up in zooplankton communities, but there is no evidence for this in either water chemistry data or phytoplankton community data.

The expectation that cyanobacteria (as measured by phycocyanin) would dominate the community in the 50/500% treatments was not realized as the N/P ratio in experimental columns did not change significantly. It follows that no increase in cyanotoxins was observed.

Much of the work of where impacts were detected (Manny et al., 1975, 1994; Scherer et al., 1995; Kear 1963; Olson 2005, Post et al., 1998, Kitchell et al., 1999) was based on large lakes and bays and may not provide an accurate measure of the per capita impact of geese on smaller ponds with reduced volume and flow rates. These studies that implied that goose feces had on impact on water quality did not examine water chemistry or phytoplankton but simply estimated the relative contribution of nutrients to these systems by the feces. A recent study by Mallory

et al. (2006) on small ponds suggested that waterfowl did in fact change the water chemistry.

Goose feces is unlikely to have immediate impacts on chemical limnology, but over time the buildup of nutrients in the sediment may have significant effects on the water body. Natural water bodies, especially shallow ponds, are likely to experience greater mixing of fecal-containing sediments with the water column and may experience a more significant impact from ornithogenic inputs via this mechanism. From this perspective, mesocosm experiments such as ours are limited as they are designed to test the effect of additional nutrients on the water column—not the effects of wind-induced mixing of fecal-laden sediments. Lastly, if nutrients do settle to the sediment, benthic food webs may take up N and P, leading to localized impacts even in large lakes.

A logical follow-up to this study is to examine the impact of feces on the sediment, whether the nutrients added in feces is accumulating in the sediment and what happens to those nutrients during a mixing event in natural systems. If the nutrients are released into the water column, then some of the original concerns discussed in this study may again be relevant. Finally, if there is a significant amount of loading to the sediment, then is there a change in the sediment community and the detritus food web? These bottom-up (both trophic and depth) effects may lead to significant changes in water chemistry and plankton community structure. The overall impact of ornithological inputs will depend on numerous factors including the size, depth and natural chemistry (oligotrophic versus eutrophic) of the water body, avian populations and behavior, and the rate at which other nutrient sources (fertilizer runoff, manure from livestock, sewage, etc.) enter the water body.

Conclusions

In the short term, nutrient loading by geese seemed to have no measurable impact on water chemistry in the mesocosms or phytoplankton. We suggest that the bulk of the nutrients contained in the feces simply sank to the sediment where they will eventually become part of a benthic detritus food web or be cycled back into the water column during a mixing event. Therefore, the impact of these nutrients will not be evident until long after they have been added. Because cyanobacteria populations were unaffected by fecal loading, we, therefore, observed no increase in cyanotoxin concentrations in the high treatment groups.

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References

Abraham, K. F. & R. L. Jefferies, 1997. High goose populations: Causes, impacts and implications. In Batt, B. (ed.), Arctic Ecosystems in Peril: Report of the Arctic Goose Habitat Working Group. Arctic Goose Joint Venture, Canadian Wildlife Service, Ottawa and US Fish and Wildlife Service, Washington, D.C., 7–72. (ISBN 0-9617279-3-4).

Ankney, C. D., 1996. An embarrassment of riches: too many geese. Journal of Wildlife Management 60: 217–223.

APHA. 1999. Standard Methods for the Examination of Waste and Wastewater. 19th edn. American Public Health Association, Washington, D.C.

Bedard, J. & G. Gauthier, 1986. Assessment of faecal output in geese. Journal of Applied Ecology 23: 77–90.

Carmichael, W. W. & J. An, 1999. Using an enzyme linked immunosorbent assay (ELISA) and a protein phosphatase inhibition assay (PPIA) for the detection of microcystins and nodularins. Natural Toxins 7: 377–385.

Dawson, R. M., 1998. The toxicology of microcystins. Toxicon 36: 953–963.

Dennis, D. G., N. R. North & H. G. Lumsden (2000) Range expansion and population growth of giant Canada geese in southern Ontario: benefits, drawbacks, and management techniques. Pages 159–165 In Dickson, K. (ed.). Towards conservation of diversity of Canada geese (Branta Canadensis) Can. Wildl. Serv. Occas. Pap. 103, 168 pp.

Harris, H. J. Jr., J. A. Ladowski & D. J. Worden, 1981. Water-quality problems and management of an urban waterfowl sanctuary. Journal of Wildlife Management 45: 501–507.

Hisbergues, M., G. Christiansen, L. Rouhiainen, K. Sivonen & T. Börner, 2003. PCR-based identification of microcystin-producing genotypes of different cyanobacterial genera. Archives of Microbiology 180: 402–410.

Hope, J., 2000. The geese that came in from the wild. Audubon 102: 122–127.
James, C.P. and H.A. James, 1993. An analytical method for anatoxin-a, a blue green algal neurotoxin in reservoir water. Report no. FR0363. Foundation for Water Research.
James, R. A. 2000. Dispersal patterns of giant Canada geese (*Branta canadensis maxima*), in the Central United States. Masters thesis, University of Arkansas, Arkansas, USA, 1–2.
Kear, J. 1963. The agricultural importance of wild goose droppings. The Waterfowl Trust, 14th Annual Report, 1961–1962, 72–77.
Kitchell, J. F., D. E. Schindler, B. R. Herwig, D. M. Post, M. H. Olson & M. Oldham, 1999. Nutrient cycling at the landscape scale: the role of diel foraging migrations by geese at the Bosque del Apache Wildlife Refuge. Limnology and Oceanography 44: 828–836.
Maccarrone, A. D. & C. H. Cope, 2004. Recent trends in the winter population of Canada Geese *(Branta canadensis)* in Wichita, Kansas: 1998–2003. Transactions of the Kansas Academy of Science 107: 77–82.
Mallory, M. L., A. J. Fontaine, P. A. Smith, M. O. Wiebe Robertson & H. G. Gilchrist, 2006. Water chemistry of ponds on Southampton Island, Nunavut, Canada: effects of habitat and ornithogenic inputs. Archiv fur Hydrobiologie 166: 411–432.
Manny, B. A., R. G. Wetzel & W. C. Johnson, 1975. Annual contribution of carbon, nitrogen and phosphorus by migrant Canada geese to a hardwater lake. Verhandlungen—Internationale Vereinigung für Theoretische und Angewandte Limnologie 19: 949–951.
Manny, B. A., W. C. Johnson & R. G. Wetzel, 1994. Nutrient additions by waterfowl to lakes and reservoirs: predicting their effects on productivity and water quality. Hydrobiologia 279/280: 121–132.
Marion, L., P. Clergeau, L. Brient & G. Bertru, 1994. The importance of avian-contributed nitrogen (N) and phosphorus (P) to Lake Grand-Lieu, France. Hydrobiologia 279/280: 133–147.
Olson, M. H., M. M. Hage, M. D. Binkley & J. R. Binder, 2005. Impact of migratory snow geese on nitrogen and phosphorus dynamics in a freshwater reservoir. Freshwater Biology 50: 882–890.
Oliver, J. D. & T. Legović, 1988. Okefenokee marshland, before during and after nutrient enrichment by a bird rookery. Ecological Modeling 43: 195–223.
Pettigrew, C. T., B. J. Hahn & L. G. Goldsborough, 1998. Waterfowl feces as a source of nutrients to a prairie wetland: responses of microinvertebrates to experimental additions. Hydrobiologia 362: 55–66.
Post, D. M., J. P. Taylor, J. F. Kitchell, M. H. Olson, D. E. Schindler & B. R. Herwig, 1998. The role of migratory raterfowl as nutrient vectors in a managed wetland. Conservation Biology 12: 910–920.
Schindler, D. W., F. A. J. Armstrong, S. K. Holmgren & G. J. Brunskill, 1971. Eutrophication of Lake 227, Experimental Lakes Area, Northwestern Ontario, by addition of phosphate and nitrate. Journal of the Fisheries Research Board of Canada 28: 1763–1781.
Scherer, N. M., H. L. Gibbons, K. B. Stoops & M. Muller, 1995. Phosphorus loading of an urban lake by bird droppings. Lake and Reservoir Management 11: 317–327.
U. S. Fish and Wildlife Service, 2003a. New York, Eastern Ontario and Southern Quebec Waterfowl Breeding Population Survey. U.S. Department of the Interior, Washington, D.C.
U. S. Fish and Wildlife Service, 2003b. Waterfowl population status, 2003. U.S. Department of the Interior, Washington, D.C.
Ward, H. B. & G. C. Whipple, 1918. Freshwater Biology. 2nd ed. John Wiley and Sons, Inc., New York, NY.
Watson, S. B., E. McCauley & J. A. Downing, 1997. Patterns in phytoplankton taxonomic composition across temperate lakes of differing nutrient status. Limnology and Oceanography 42: 487–495.
Wetzel, R. G. & G. E. Likens, 2000. Limnological Analyses. 3rd edn. Springer-Verlag, New York, Inc.
Zar, J. H., 1999. Biostatistical Analysis, 4th edn. Prentice Hall, Upper Saddle River, NJ.
Zhou, L., H. Kassa, M. L. Tischler & L. Xiao, 2004. Host-adapted cryptosporidium spp. in Canada geese (*Branta Canadensis*). Applied and Environmental Microbiology 70: 4211–4215.