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Gull contributions of phosphorus and nitrogen to a Cape Cod kettle pond

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Abstract

Nutrient excretion rates and the annual contribution of P from the feces of the gulls *Larus argentatus* and *L. marinus* (and of N from *L. argentatus*) to the nutrient budget of Gull Pond (Wellfleet), a soft water seepage lake, have been estimated. Intensive year-round gull counts by species were combined with determinations of defecation rate and the nutrient content of feces to quantitatively assess the P loading rates associated with regular gull use of this coastal pond on a seasonal and annual basis. Total P loading from gulls was estimated to be 52 kg yr^{-1}, with 17 kg from *L. argentatus* and 35 kg from *L. marinus*, resulting from about 5.0×10^6 h yr^{-1} and 1.7×10^6 h yr^{-1} of pond use. This compares with P loading estimates of 67 kg yr^{-1} from upgradient septic systems, 2 kg yr^{-1} from precipitation and 3 kg yr^{-1} from unpolluted ground water. Fifty-six percent of annual gull P loading was associated with migratory activity in late fall. Estimated annual N loading by *L. argentatus* was 14 kg TKN, 206 g NO_3-N, and 1.85 g NH_3-N.

Introduction

Phosphorus and nitrogen and their sources have received widespread study because of their key roles in algal and macrophyte nutrition. The estimation of P loading rates has become an accepted approach for predicting lake productivity (Rast *et al.*, 1983) as well as a management tool for controlling cultural eutrophication in disturbed watersheds (Vollenweider & Kerekes, 1980). Loading calculations and P control programs require the determination of the relative importance of each potential nutrient source from beyond the drainage basin. In our studies of a nutrient-enriched Cape Cod seepage lake set in a nutrient-poor outwash plain, we have hypothesized that loading is predominantly from two sources: septic effluent and gull feces. In this report we (1) present nutrient excretion rates for the two most abundant gull species of the northeast U. S. coast which habitually roost on coastal ponds, (2) estimate annual N and P loading by gulls to a typical roosting site, and (3) compare gull nutrient loading to other major P sources.

High mobility, sociality and metabolic rate make many species of birds important agents in both the transport of nutrients and the enrichment of the terrestrial and aquatic communities they favor. Fecal enrichment of terrestrial habitats, at gull and heron colonies for example, can stimulate herbaceous growth, alter vegetative succesion, or even poison and eliminate plants (Gronlie, 1948;

Wiese, 1978; Sobey & Kenworthy, 1979). Enrichment of aquatic habitats has been discounted where birds feed regularly within the lake or watershed (see Vollenwieder, 1968), or where fecal components are deposited in sediments below the trophogenic zone (McColl & Burger, 1976). Nevertheless, for those species that feed elsewhere, and especially in lakes with nutrient-poor watersheds, these additional nutrients can stimulate algal growth, reduce water clarity, and accelerate lake succession (Leentvaar, 1967).

Gulls especially have been implicated in the transport of both nutrients and human pathogens to habitually-used freshwater ponds and reservoirs (Fennel *et al.*, 1974; Williams *et al.*, 1976; Gould & Fletcher, 1978). With their recent population increases, attributed to enhanced winter survival around large, Atlantic coastal urban landfills (Kadlec & Drury, 1968; Erwin, 1979), herring gulls (*Larus argentatus* Coues) and great black-backed gulls (*L. marinus* Linnaeus) may be particularly important in this regard. Because these maritime populations rarely feed at freshwater sites, but rely on nearby marine habitats and/or landfill, fish and sewage wastes, they comprise a potentially significant source of nutrients to coastal freshwater systems.

Sobey & Kenworthy (1979) found that feces, of all foreign matter deposited by gulls at terrestrial breeding sites, had the greatest influence on soil-nutrient concentrations. Presumably, fecal nutrients shed over freshwater resting areas would be of the same relative importance.

Estuaries, inshore fishing activities, and landfills on outer Cape Cod support a summer gull population of at least 40000 birds(R. Andrews, unpubl. data) and a fall migrant population of probably many more (Portnoy, unpubl. data). Their habitual use of specific freshwater ponds near landfills for bathing and resting is typical of a regional and hemisphere-wide phenomenon (Fennel *et al.*, 1974; B. Blodgett, pers. com.). Pond usage is restricted to several traditionally-visited locations on the Cape, in particular our study site Gull Pond.

Study area

Gull Pond is the largest (44 ha) of 20 kettle ponds located within 2 km of the Atlantic Ocean in Cape Cod National Seashore. Most of these deep kettle ponds are highly acidic (pH 4.5–5.5) and probably have been so since their formation 12000 years B. P. (Winkler, 1988). Gull Pond has a relatively high pH (6.0–6.5). Maximum and mean depths are 19 m and 8.5 m, respectively; estimated volume is 3.78×10^6 m^3. Most water moves in and out of the pond as underground seepage with an estimated residence time of from 10 to 15 yr (Dowd, 1984); surface runoff usually occurs only with heavy rain because of the high permeability of the surrounding, porous glacial outwash deposits. Dominant upland vegetation is pitch pine (*Pinus rigida* Mill.) and black oak (*Quercus velutina* Lam.), with an understory of *Vaccinium* spp. and *Gaylussaccia baccata* (Wang.).

Although probably oligotrophic for most of its ca. 12000 years of existence (Winkler, 1988), Gull Pond would presently be classed as mesotrophic with Secchi transparencies in August of less than 5 m and clear symptoms of cultural eutrophication (hypolimnetic oxygen depletion, occasional *Anabaena flos-aquae* blooms). Current total P concentrations rarely exceed 0.02 mg l^{-1} in the water column. Major sources of nutrient loading include septic leachate from 20 dwellings upgradient of the shoreline, precipitation including salt spray (see Vollenweider, 1968; Gorham, 1961; Winkler, 1985), and gull excreta.

Perhaps because of the protection afforded by its relatively large size, herring and great black-backed gulls habitually drink, bathe and rest on Gull Pond during the day, and only occasionally in the other 19 local ponds. In August, and again in November and December, flock size at mid-day can exceed 2000 birds.

Importantly, on only one occasion out of 183 days of bihourly observations was a gull observed to feed within the Gull Pond watershed. Small numbers of migrant waterfowl also used Gull Pond; however, these birds fed regularly within the watershed and were thus more likely to recycle rather than import nutrients.

Gull use of the pond is restricted to the daylight hours; birds roost on coastal islands during the night.

Methods

We calculated phosphorus and nitrogen input from gulls resting on Gull Pond from three data sources: 1) the amount of time spent on the pond by gulls (hereafter 'gull use' in hours), 2) gull defecation rate, and 3) total phosphorus and nitrogen content of feces. Pond use by two different species of gulls, herring gulls and great black-backed gulls, of different weights, diets and, presumably, nutrient excretion rates, required species-specific data collection.

We measured gull use by counting all gulls (by species) on the pond at 2-h intervals throughout the daylight hours, averaging flock size for each day and multiplying average flock size by the number of daylight hours. The gull use estimate was expressed as 'gull-hours', where a single bird on the pond for two hours equaled 2 gull-hours, etc. We conducted day-long counting every two hours on several days per week from July 1979 through June 1980, and less frequently through May 1981, at all seasons and for a total sample size of 183 days. Whenever interruptions precluded a complete day's bihourly counts, that day's data were excluded from gull-use calculations. The variability of daily gull-use estimates was very high, especially during fall migratory shifts (Fig. 1).

Defecation was not observable for gulls resting on the pond surface, although we often observed defecation by gulls ascending into flight. Thus, we could not determine defecation rate directly for pond-resting birds and based our estimates on recorded events from the continuous observations of standing individuals. For the determination of variability in defecation rate, we divided gull observation periods into 10-min blocks. We observed individual herring gulls at nearby dump and ocean-beach resting areas for a total of 46 10-min blocks, with continuous observation periods on a single bird ranging from 30 to

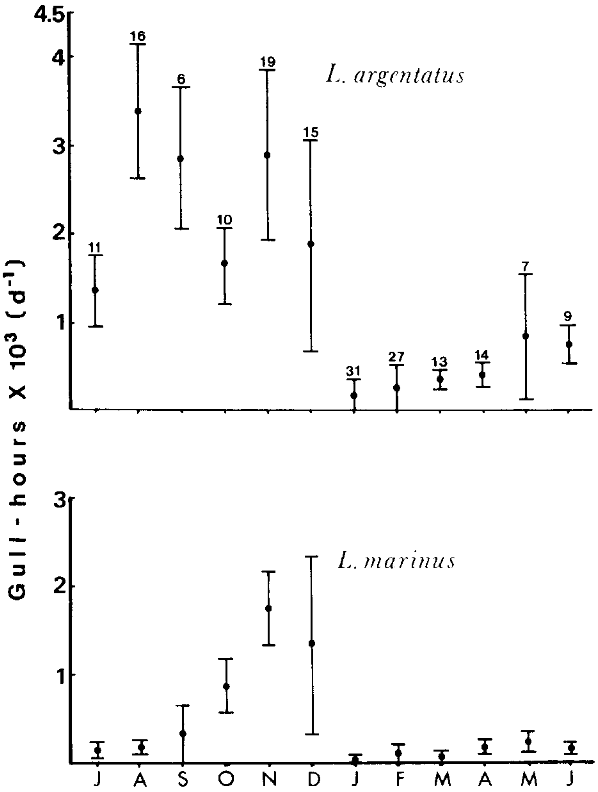

Fig. 1. Mean daily gull use ($\pm 95\%$ C. L.) of Gull Pond based on bihourly daytime counts. Numbers above bars are complete days of bihourly observations.

196 min. We observed the defecation rate of great black-backed gulls by monitoring individual birds as they stood on a raft which we had placed in Gull Pond primarily to collect fecal samples (see below). Observations of *L. marinus* ranged from 10 to 97 min in length, and amounted to 30 10-min periods.

Bird feces include both urinary excretion products (the characteristically white avian droppings) and digestive wastes. Individual excreta vary considerably in the relative amounts of urinary and fecal materials, no doubt explaining much of the variability in nutrient content (see below).

We collected fecal samples for total P determinations from polyethylene sheets spread out in habitual gull loafing areas at landfills and beaches near Gull Pond (except for a group of herring gull feces scraped from Gull Pond ice in January 1980). A concurrent study of gull movements

(Portnoy, unpubl. data) showed regular interchange of marked individuals between the pond and two nearby landfills. We therefore presume that feces collected at these nearby resting areas did not differ from herring gull excreta at Gull Pond. Birds defecated on the plastic sheets after they either walked or flew onto them; we tried to disturb birds as infrequently as possible. We collected great black-backed gull excreta individually from a plastic sheet spread on a small (1.2×1.2 m) raft placed in the middle of Gull Pond. *Larus marinus* agressively excluded the smaller *L. argentatus* from the raft, allowing separate collection of *L. marinus* feces. We removed each sample within 5 min of being deposited by carefully cutting the upper layer of the doubled plastic sheet. We quickly enclosed samples individually in air-tight polyethylene containers and froze them within an hour of deposition and collection.

Samples were quantitatively transferred with a wash bottle from their plastic sheets and containers into clean glass bottles. They were then diluted with distilled and deionized water, homogenized with an ultrasonic tissue grinder for approximately 30 s, oxidized by persulfate digestion, and diluted to a final volume of one liter. The concentrations of nutrients in this homogeneous liter were determined colorimetrically for an aliquot of the dissolved sample; the result expressed in mg l^{-1} could thus be converted directly to mg in the original fecal sample. *Larus marinus* fecal analysis did not include N species due to analytical limitations at the time of collection.

Gull use (as gull-hours) times defecation rate (as feces h^{-1}) times nutrient content of gull feces (as nutrient mass per excretum) yielded an estimated loading of total P (both gull species) and N (herring gulls only) for a given observation period.

For comparative purposes, potential P loading from other major sources within the watershed was approximated. The amount leached annually from surrounding domestic sewage facilities was estimated by multiplying occupancy (in person-years) by reported per capita P excretion rate, 1.4 kg person^{-1} yr^{-1} (Koppelman, 1978; Environmental Protection Agency, 1980). Only upgradient leaching areas, determined by concurrent ground water studies (Dowd, 1984), were included. Based on interviews and personal observations, we estimated maximum occupancy of the seven year-round and 34 seasonal dwellings upgradient of the pond to be 48 person-years.

Total annual P from precipitation was estimated by multiplying watershed area (90 ha) by precipitation depth (1.26 m yr^{-1}) and P concentration (1.94 μg l^{-1}, data from the National Atmospheric Deposition Program's analysis of weekly aggregate samples collected 1.5 km north of Gull Pond). Fertilized lawns and gardens are rare within the watershed and are therefore discounted from this analysis. Importantly, watershed removal of P, for example by plant assimilation and soil adsorption, was not measured; thus, P loading from precipitation and sewage to the pond is likely overestimated.

'Background' P input from uncontaminated ground water was estimated by multiplying average P concentrations from undeveloped areas (ca. 10 μg l^{-1}, Deubert, 1974) by annual inflow into Gull Pond (3.1×10^5 m^3 yr^{-1}, Dowd, 1984).

No estimation of N from precipitation and sewage is attempted, in part because of the lack on N data for *L. marinus*, and also in consideration of the greater importance of P as a limiting nutrient.

Results and discussion

Daily gull use of Gull Pond was highly variable at all seasons for both *Larus argentatus* and *L. marinus* (Fig. 1); however, seasonal trends are apparent. From mid-winter through April, gull numbers on the pond were at a minimum, reportedly because most individuals (especially *L. argentatus*) winter and forage around large coastal cities much removed from outer Cape Cod (Drury & Nisbet, 1972). The return of both breeding and non-breeding herring gull populations in summer, together with increased daylength and pond availability, produced the increase in calculated herring gull-hours by August. Sustained high *L. argentatus* use into the fall, combined with an annual peak in *L. marinus* numbers in November and December, probably reflected the seasonal influx of post-breeding coastal migrants (Drury & Nisbet, 1972). Over 43% of total annual pond use occured between 15 October and 31 December; this represents about 70% and 35% of the total annual use by *L. marinus* and *L. argentatus*, respectively.

For estimates of herring gull defecation frequency, we observed shore- and dump-loafing birds for 26 and 20 10-min blocks, respectively; defecation frequency was not significantly different (F-test, $P > 0.05$) in these two habitats and data were therefore pooled in subsequent calculations. Mean defecation frequency (and 95% confidence limits) was 3.1 ($\pm$ 1.0) def h^{-1}. This,

Table 1. Phosphorus and nitrogen content of gull feces (mass per defecation ± SE) in the vicinity of Gull Pond.

		N	Total P (mg)	TKN (mg)	NO_3 (μg)	NH3 (μg)
L. argentatus	Aug, Sep	28	12.3 ± 1.6	9.72 ± 1.30	148 ± 26	1204 ± 227
	Oct, Nov, Dec	11	7.5 ± 1.5	6.63 ± 1.37	79 ± 23	1052 ± 177
	Jan +	19	8.5 ± 1.2	–	–	–
	Fall and winter (pooled) #	30	8.1 ± 0.9			
	Summer and fall (pooled)	39		8.85 ± 1.03		
L. marinus	Nov	8	41.7 ± 13.5			
	Apr	13	52.5 ± 9.4			
	Fall & Spring	21	48.4 ± 7.7			

+ Collected from ice on Gull Pond.
# Data were pooled where F test showed no significant difference between variances ($P = 0.05$).

Table 2. Estimation of annual total P contribution to Gull Pond from *Larus argentatus* and *L. marinus*. Minimum and maximum values of pond use, defecation rate, and P content of feces represent 95% confidence limits about the mean values of these three variables. Mean (best estimate), maximum and minimum total P per annum loading estimates are multiplication products of the above three variables. For *L. argentatus*, spring/summer and fall/winter P loadings were calculated separately due to seasonal differences in P content of feces (Table 1).

		Mean	Min.	Max.	N
L. argentatus	+ Pond use: Apr–Sep (h)	304,530	207,174	401,886	77
	Oct–Mar (h)	207,056	115,588	300,364	101
	Defecation rate (h^{-1})	3.12	2.16	4.08	46
	Total P $def.^{-1}$: Apr–Sep (mg)	12.3	10.7	15.5	28
	Oct–Mar (mg)	8.1	6.4	10.0	11
	Total P: Apr–Sep (kg)	11.7	4.8	25.5	
	Oct–Mar (kg)	5.3	1.6	12.3	
	Total P yr^{-1} (kg)	17.0	6.4	37.8	
L. marinus	+ Pond use (h)	165,682	85,434	247,106	178
	Defecation rate (h^{-1})	4.38	2.88	5.88	30
	Total P $def.^{-1}$ (mg)	48.4	32.8	64.4	21
	Total P yr^{-1} (kg)	35.1	8.0	93.6	
Both species	Total P yr^{-1} (kg)	52.0	14.4	131.4	

+ Summed by month and calculated monthly from average daily counts.

Table 3. Annual nitrogen loading by *Larus argentatus* to Gull Pond. Mean, minimum and maximum values are summations of the calculated monthly means and lower and upper 95% C.L.'s respectively.

	Mean	Min.	Max.	N
TKN (all seasons pooled)[+]				
Pond use (h)	511,586	322,762	702,250	178
Defecation rate (h^{-1})	3.12	2.16	4.08	46
TKN (mg $def.^{-1}$)	8.85	6.77	10.93	39
TKN (kg yr^{-1})	14.13	4.72	31.32	
NO_3 Pond use Apr–Sep (h)	304,530	207,174	401,886	77
Oct–Mar (h)	207,056	115,588	300,364	101
Defecation rate (h^{-1})	3.12	2.16	4.08	46
NO_3 (mg $def.^{-1}$): Apr–Sep	148	95	201	28
Oct–Mar	79	28	130	11
NO_3 Apr–Sep (g)	141	43	330	
Oct–Mar (g)	51	7	159	
NO_3 (g yr^{-1})	192	50	489	
NH_3 Pond use Apr–Sep (h)	304,530	207,174	401,886	77
Oct–Mar (h)	207,056	115,588	300,364	101
Defecation rate (h^{-1})	3.12	2.16	4.08	46
NH_3 (μg $def.^{-1}$): Apr–Sep	1,204	738	1,669	28
Oct–Mar	1,052	663	1,441	11
NH_3 Apr–Sep (g)	1,144	330	2,737	
Oct–Mar (g)	680	166	1,766	
NH_3 (g yr^{-1})	1,824	496	4,503	

[+] Data were pooled where f tests showed no significant difference between variances (P = 0.05).

Table 4. Comparison of daily per capita production of fecal nutrients by gulls, Canada geese and humans. All units are g cap^{-1} d^{-1}.

	TP	TKN	TN	NO_3	NH_3
Domestic sewage					
Bauer *et al.* (1979)	4	6	6.1[a]	0.1	2
Larus argentatus					
Gould and Fletcher (1978)	>0.115	1.819	1.8[a]	–	0.402
This study: summer	0.92	0.67	0.68[a]	0.01	0.09
This study: fall/winter	0.61	0.67	0.68[a]	0.006	0.08
L. marinus					
This study	5.09	–	–	–	–
Branta canadensis					
Manny *et al.*, 1975	2.1		6.8		

[a] Estimated by summing TKN and NO_3.

coupled with a mean defecation mass of 0.529 g ($\pm$0.087; $N = 39$), yielded a 24-h dry weight excretion total of 39.4 g per bird per day for the wild birds followed in our study. This is over twice the 17.1 g per capita production observed for caged birds by Nixon & Oviatt (1973) and may point out the limitations of data from captive individuals.

Defecation frequency of great black-backed gulls, observed on the Gull Pond raft for 20 10-min periods in November and December 1981; averaged 4.4 ($\pm$ 1.5) def h^{-1}.

The results of gull feces analyses for total P and N are tabulated by season (Table 1). Phosphorus data from fall and winter for *L. argentatus*, and from fall and spring for *L. marinus*, were pooled after F-tests revealed no significant difference. Similarly, herring gull TKN values for summer and fall were not different ($P > 0.05$) and were pooled. Interestingly, however, *L. argentatus* feces were much higher in total P during late summer (12.3 mg defecation^{-1}) than in fall (8.1 mg defecation^{-1}), possibly due to changes in diet (Sobey & Kenworthy, 1979).

Our observations indicate that a 'best estimate' of total P contributions from gulls to Gull Pond is 52 kg yr^{-1} (Table 2), or 118 mg m^{-2} yr^{-1} areally and 13 mg m^{-3} yr^{-1} volumetrically, two-thirds of which is deposited by the larger of the two gull species predominantly in the fall (Fig. 2). With the higher defecation frequency and fecal P content of *L. marinus* during its period of maximum pond use, this species excreted over eight times as much P per unit time as *L. argentatus* (212 mg hr^{-1} vs. 25.4 mg hr^{-1}, fall *L. marinus* vs. fall *L. argentatus*). This, together with a massive seasonal influx of black-backs, resulted in over 56% of the annual P loading from gulls being deposited from mid-October to late December; of this, 84% is derived from *L. marinus* feces alone.

Table 3 presents N loading estimates for herring gulls only; feces from great black-backed gulls were not analyzed for N species. We estimate total N excretion rates from *L. argentatus* at about 0.6 g bird^{-1} d^{-1}, most which is included in TKN.

In an attempt to relate gull nutrient loading

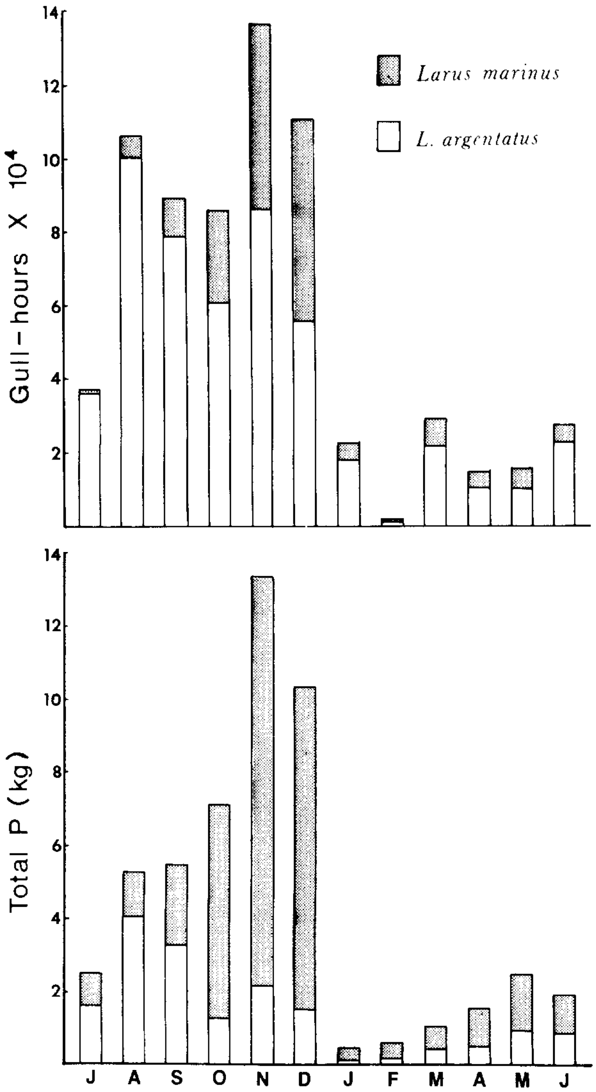

Fig. 2. Monthly pond use and total P loading by two species of gulls to Gull Pond.

Table 5. Phosphorus inputs into Gull Pond.

Source	Annual P loading (kg)	Percent
Unpolluted ground water	3.1	2
Direct precipitation	2.2	2
Septic leachate	67	54
Gulls	52	42

to human impacts on water quality, Gould & Fletcher (1978) compared N and P excretion by a small sample of captive birds of several gull species to the amounts of those nutrients contained in domestic sewage. The free-living herring gulls of this study excreted about six times the P of Gould & Fletcher's captives, tantamount to one-third the human per capita input to domestic sewage (Table 4). Our estimates of P excretion rates for herring and great black-backed gulls are four and 16 times, respectively, that reported for Canada geese (*Branta canadensis* Linnaeus) relative to live body weight (Manny *et al.*, 1975). This is not surprising in consideration of the higher P diet of piscivorous birds.

Gull import of P to Gull Pond (52 kg yr^{-1}) appears significant both in relation to background levels in unpolluted Cape Cod waters and compared to the other major sources of this nutrient (Table 5). Our 'worst case' estimates (i. e. ignoring watershed uptake) of upgradient sewage inputs (67 kg yr^{-1}) were only slightly higher than the gull component.

P loading of Gull Pond from gulls alone, converted to normalized L(P) using Vollenweider's empirical models (Rast *et al.*, 1983), is sufficient to explain observed summer secchi depths of 3 to 5 m. Our data suggest that large gull concentrations, especially including *L. marinus*, may be an important source of P in lake eutrophication. Daily per capita P loading from the latter species is over twice that observed for the Canade geese believed by Manny *et al.* (1975) to explain hypereutrophy at Wintergreen Lake; however, due to the greater number of birds involved, the areal loadings to this lake were much higher than from the gulls of Gull Pond (393 mg vs. 118 mg m^{-2} yr^{-1}, respectively).

Although nutrient loading by waterfowl to ponds and coastal waters has been of widespread concern (Branvold *et al.*, 1976), these data suggest that current North Atlantic gull populations also provide substantial nutrients to traditional resting ponds. At Gull Pond, the birds which contributed over 40% of the estimated annual P load represent gull populations that have increased geometrically as a direct result of increased winter survival around large, urban landfills (Kadlec & Drury, 1968). In this way, human developments affecting coastwide wildlife populations can in turn impact distant freshwater resources.

References

Branvold, D. K., C. J. Popp & J. A. Brierley, 1976. Waterfowl refuge effects on water quality: II. Chemical and physical parameters. J. Wat. Pollut. Cont. Fed. 48: 680–687.

Deubert, K. H., 1974. Impact of the cranberry industry on the quality of ground water in the Cape Cod area. Univ. Mass., Amherst, 33 p.

Dowd, J. F., 1984. Modeling groundwater flow into lakes. Ph. D. thesis. Yale Univ. 232 p.

Drury, W. H. & I. C. T. Nisbet, 1972. The importance of movements in the biology of Herring Gulls in New England. In Population ecology of migratory birds: a symposium. U. S. Dept of Interior Wildl. Research Report 2: 173–212.

Environmental Protection Agency, 1980. Design manual for onsite wastewater treatment and disposal systems. EPA 625/1-80-012. 412 p.

Erwin, R. M., 1979. Coastal waterbird colonies: Cape Elizabeth, Maine to Virginia. U. S. Fish and Wildlife Service, Office of Biological Services, FSW/OBS-79/10. 212 p.

Fennel, H., D. B. James & J. Morris, 1974. Pollution of a storage reservoir by roosting gulls. Wat. Treat. Exam. 23: 5–24.

Gorham, E., 1961. Factors influencing supply of ions to inland waters, with special reference to the atmosphere. Geol. Soc. Amer. Bull. 72: 795–840.

Gould, D. J. & M. R. Fletcher, 1978. Gull droppings and their effects on water quality. Wat. Res. 12: 665–672.

Gronlie, A. M., 1948. The ornithocoprophilous vegetation of the bird cliffs of Rost in the Lofoton Islands, northern Norway. Nyatt magasin for Naturvidenskapene 86: 117–243.

Kadlc, J. A. & W. H. Drury, 1968. Structure of the New England herring gull population. Ecology 49: 644–676.

Koppelman, L., 1978. The Long Island comprehensive waste treatment plan. Nassau-Suffolk Regional Planning Board, Hauppauge, N. Y. 364 p.

Leentvaar, P., 1967. Observations on quanotrophic environments. Hydrobiologia 29: 41–489.

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. Verh. int. Ver. Limnol. 19: 949–951.

McColl, J. G. & J. Burger, 1976. Chemical inputs by a colony of Franklin's Gulls nesting in cattails. Am. Midl. Nat. 96: 270–280.

Nixon, S. W. & C. A. Oviatt, 1973. Ecology of a New England salt marsh. Ecol. Monog. 43: 463–498.

Rast, W., R. A. Jones & G. F. Lee, 1983. Predictive capability of U. S. OECD phosphorus loading – eutrophication response models. J. Wat. Pollut. Cont. Fed. 48: 90–1003.

Sobey, D. G. & J. B. Kenworthy, 1979. The relationship between Herring Gulls and the vegetation of their breeding colonies. J. Ecol. 67: 469–496.

Vollenwieder, R. A., 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Organ. Econ. Coop. Dev. Rep., OECD, Paris. DAS/CSI/68.27. 192 p.; Annex 21 p. Bibliography 61 p.

Vollenweider, R. A. & J. J. Kerekes, 1980. The loading concept as a basis for controlling eutrophication philosophy and preliminary results of the OECD program an eutrophication. Prog. Water Technol. 12: 5–38.

Wiese, J. H., 1978. Heron nest-site selection and its ecological effects. pp. 27–34 In A. Sprunt, IV, J. C. Ogden, and S. Winkler, (eds) Wading birds. New York, Natl. Audubon Soc., Res. Rept. No. 7: 27–34.

Williams, B. M., D. W. Richards & J. Lewis, 1976. Salmonella infection in the Herring Gull (*Larus argentatus*). Vet. Rec. 98: 51.

Winkler, W. G., 1985. Diatom evidence of environmental changes in wetlands: Cape Cod National Seashore. Final Report, North Atlantic Regional Office, Natinal Park Service, 120 p.

Winkler, M. G., 1988. Paleolimnology of a Cape Cod kettle pond: diatoms and reconstructed pH. Ecological Monogr. 58: 197–214.