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Plastics and other anthropogenic debris in freshwater birds from Canada

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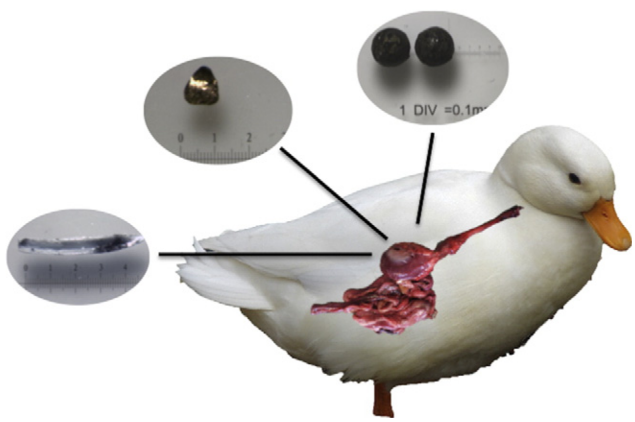
HIGHLIGHTS

- Dissection-based dietary analyses determined freshwater bird debris loads.
- Anthropogenic debris was found in 10 of 18 species.
- Approximately 11% of individuals had anthropogenic debris.

GRAPHICAL ABSTRACT



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ABSTRACT

Plastics in marine environments are a global environmental issue. Plastic ingestion is associated with a variety of deleterious health effects in marine wildlife, and is a focus of much international research and monitoring. However, little research has focused on ramifications of plastic debris for freshwater organisms, despite marine and freshwater environments often having comparable plastic concentrations. We quantified plastic and other anthropogenic debris in 350 individuals of 17 freshwater and one marine bird species collected across Canada. We determined freshwater birds' anthropogenic debris ingestion rates to be 11.1% across all species studied. This work establishes that plastics and other anthropogenic debris are a genuine concern for management of the health of freshwater ecosystems, and provides a baseline for the prevalence of plastic and other anthropogenic debris ingestion in freshwater birds in Canada, with relevance for many other locations.

1. Introduction

Humans have been releasing plastic debris into the environment since the early 1900s (Bijker, 1987). Originally thought to be little more than an eyesore, we now know that the very properties that make plastics ideal for human use (i.e., being lightweight and strong, and having a durable physical configuration) also make plastics serious

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environmental hazards (Laist, 1987; Derraik, 2002). The ubiquity of anthropogenic debris in the environment, such as plastic and waste metal, raises concerns regarding its ingestion by animals, and so has been particularly well-studied for animals living in aquatic habitats (Rochman et al., 2014). Anthropogenic debris is problematic due to its negative effects on wildlife, including entanglement and ingestion (Derraik, 2002; Wright et al., 2013; Provencher et al., 2014). Plastic debris also has an affinity for certain non-essential trace elements and persistent organic pollutants (POPs), such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT; Ashton et al., 2010; Bakir et al., 2014). Once plastics are discharged into aquatic environments, they can persist for up to 50 years, and their complete mineralization may take hundreds or thousands of years (Gregory, 1978; Derraik, 2002; Driedger et al., 2015). Entanglement and ingestion of marine anthropogenic debris negatively affects all seven known species of sea turtle (100%), about half of all species of marine mammals (45%), and one-fifth of all species of seabirds (21%); these numbers represent a 40% increase (from 247 to 663 affected species) from 1997 (Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF, 2012). As of 2015, 56% of seabird species were affected by marine anthropogenic debris (Gall and Thompson, 2015), with predictions that by 2050, 99% of all seabird species will be affected (Wilcox et al., 2015) and the mass of plastics in the oceans will outweigh fish (Neufeld et al., 2016). Whereas much is known about effects of plastic debris on marine birds, virtually no comparable data are available for freshwater species.

Freshwater bodies can have comparable plastic concentrations to marine waters (Castañeda et al., 2014; Lechner et al., 2014; Driedger et al., 2015). In the Great Lakes of North America, over 80% of anthropogenic shoreline debris is composed of plastics (Castañeda et al., 2014; Driedger et al., 2015) and sediments of the St. Lawrence River have microbead (polyethylene and polypropylene microspheres widely used in cosmetics as exfoliating agents; Eriksen et al., 2013) pollution comparable in magnitude to marine microplastic concentrations [Castañeda et al. (2014); microplastics defined by Moore (2008) and Arthur et al. (2009) as plastic fragments <5 mm]. Likewise, a multiyear study on the Danube River in Austria quantified discharges of 1533 t of plastics per year into the Black Sea (Lechner et al., 2014), although the majority turned out to be industrial microplastics from a plastic-producing company (Lechner and Ramler, 2015). A similar study in Mongolia found that Lake Hovsgol has plastic particle concentrations reaching 20,264 particles/km^2 (Free et al., 2014), and a recent study on two lakes in central Italy (Lake Bolsena and Lake Chiusi) found 2.68 to 3.36 particles/m^3 and 0.82 to 4.42 particles/m^3, respectively, in surface waters (Fischer et al., 2016). These studies suggest that not only are plastics a major problem in marine settings, they are also an issue in freshwater ecosystems.

Studies focusing on organisms in freshwater ecosystems have found dietary plastic debris in green algae (*Scenedesmus obliquus*) and zooplankton (*Daphnia magna*) (Besseling et al., 2014), as well as planktivorous fish (Sanchez et al., 2014; Moseman, 2015). Plastics could also potentially affect benthivorous fishes and macroinvertebrates [preliminary results on benthic round goby's (*Neogobius melanostomus*) digestive tracts suggest the presence of microbeads (Castañeda et al., 2014) while reports on benthic gudgeon (*Gobio gobio*) found ingested polymer fibers and pellets (Sanchez et al., 2014)]. Migratory birds, such as red phalaropes (*Phalaropus fulicarius*) and red-necked phalaropes (*P. lobatus*), which eat freshwater zooplankton, also consume plastic debris (Day et al., 1985; Moser and Lee, 1992). English et al. (2015) examined mallard (*Anas platyrhynchos*), American black duck (*A. rubripes*), and common eider (*Somateria mollissima*) wintering in Atlantic Canada, and found an 11.5% prevalence of plastics in 140 birds. However, it was not known whether those birds acquired plastic debris in freshwater or marine locations due to the long residency time of dietary plastics (from two months to a year; Connors and Smith, 1982; Ryan and Jackson, 1987) and known movement patterns of these ducks between marine and freshwater ecosystems in this area (English, 2016).

Encounters between organisms and marine debris have been reported since the 1960s, with the first study on seabird plastic ingestion on Laysan albatross (*Phoebastria immutabilis*) conducted in 1966 (Kenyon and Kridler, 1969; Gall and Thompson, 2015). Between 1969–1977 and 1988–1990, a significant increase (up to 26.3%) was recorded in the frequency of seabird plastic ingestion (Robards et al., 1995). If trends in freshwater waterfowl ingestion of debris mirror seabird historical trends, we may see a similar increase in waterfowl debris consumption over time. This is problematic due to negative consequences of consuming debris. Debris fails to provide nutrition proportional to its mass or volume, and can lead to weakness, false feelings of satiation, irritation of the stomach lining, digestive tract blockage, internal bleeding, abrasion, ulcers, failure to put on fat stores necessary for migration and reproduction, absorption of toxins, and potential death through starvation (Moore, 2008; Wright et al., 2013; Zhao et al., 2016).

Surface-feeding birds and dabbling ducks may be particularly susceptible to plastic ingestion due to the initial buoyancy of plastic. Plastics eventually settle over time from biofilm fouling and hitchhiking organisms (Barnes et al., 2009; Driedger et al., 2015; Frias et al., 2010). However, after settling, they remain available to benthic organisms, and those that feed on benthos, and thus can return to food webs (Wright et al., 2013). Due to biomagnification through debris consumed by fish, piscivorous birds may also be at risk (Day et al., 1985; Castañeda et al., 2014; Sanchez et al., 2014; Moseman, 2015). Additionally, urban birds are at an increased risk of ingesting debris because of a greater density of plastic near industrial centers (Zbyszewski et al., 2014).

We undertook this study to bridge a knowledge gap on anthropogenic debris ingestion by freshwater birds. We asked the following questions: 1) What is the prevalence of anthropogenic debris in freshwater birds? 2) Is there geographic variation in prevalence? 3) Are there differences among species in prevalence and does this relate to their foraging niches? 4) Is prevalence related to body mass? 5) What are the characteristics of ingested particles (i.e., type, color and size)?

2. Material and methods

2.1. Sampling

Ducks, geese, and loons occupying freshwater habitats were collected from across Canada (Fig. 1); 40 common eiders (a marine sea duck) were also acquired as a comparison group. All birds were from hunter kills, airport culls or collisions, and predation, and were shipped frozen to Acadia University where dissections were performed. We recorded species, date, location, and if available, sex, age, and body mass (g). Birds were kept frozen at −22 °C until dissection and analysis, and allowed to thaw for one to two days prior to dissection.

2.2. Processing, separation, sorting and identifying

Methods followed the recommendations of van Franeker and Meijboom (2002) and van Franeker (2004) for quantifying anthropogenic debris ingestion by seabirds. To avoid contamination, work surfaces were thoroughly cleaned with a 1/3 to 2/3 bleach and water mixture and all tools were cleaned under running tap water between each specimen. Gloves, lab coats, and facemasks were worn throughout the study. For each specimen, data from the proventriculus and gizzard were evaluated separately to determine debris residency time, because debris particles located in the proventriculus were likely consumed more recently (van Franeker and Meijboom, 2002). Thawed digestive tracts were opened over their full length, and contents carefully flushed with cold tap water above a 0.5-mm mesh sieve to ensure that no small particles were left behind on organ walls (particles smaller than 0.5 mm were detected due to debris' ability to adhere to larger dietary particles). All material was rinsed under running tap water (van Franeker and

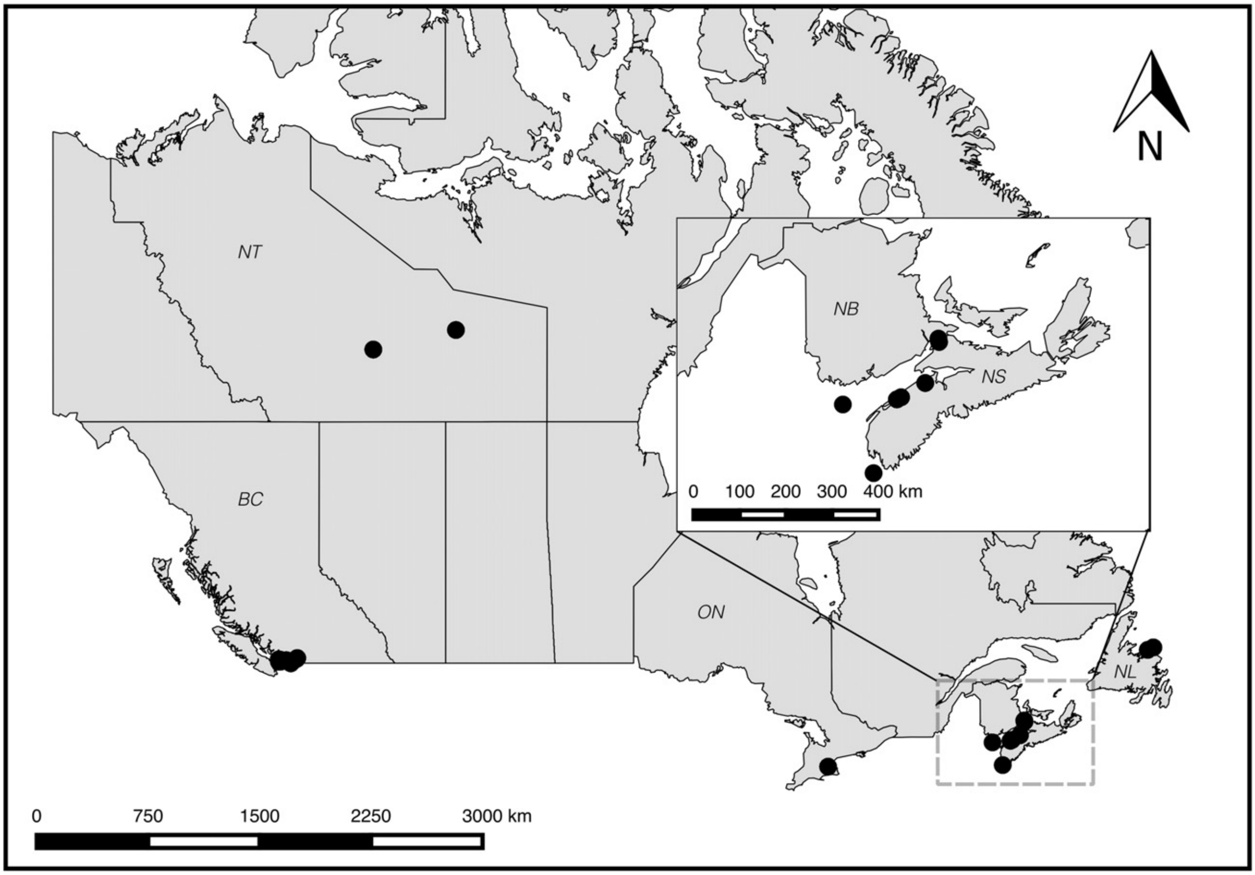

Fig. 1. Sample sites used for this study. Circles indicate collection locations. BC: British Colombia, NT: Northwest Territories, ON: Ontario, NB: New Brunswick, NS: Nova Scotia, NL: Newfoundland.

Meijboom, 2002). Proventriculus and gizzard tissues were examined for inflammation, abrasion, or swelling from exposure to debris. Care was taken to note any indications of damage from birdshot. Proventriculus and gizzard contents were transferred to a Petri dish, and inspected under a dissecting microscope (AmScope SM-2BZ) as follows:

a) Anthropogenic debris was identified (per Desforges et al., 2015; Zhao et al., 2016) if: i) no cellular or organic structures were visible; ii) fibers were uniformly thick over their length and not tapered at the end, bendable, or soft; iii) colored items were homogeneously colored and of hues not usually occurring in food; iv) debris had unnatural edges of obvious anthropogenic origin. All potential microscopic anthropogenic debris was re-examined with extra care and under higher magnification (4.5× zoom objective). Once classified as artificial material, particles were transferred into Petri dishes and ready for step b). If there was an indication of birdshot damage to digestive organs, shot was assumed to have been hunting-related, and not consumed, and was therefore not included in analysis as contaminant debris.
b) Anthropogenic debris was classified following van Franeker and Meijboom (2002): plastic (fragments and other), non-plastic rubbish (thread-like, foil, paint chips, glass, and rubber), and metal (birdshot and metal fragments). Anthropogenic debris was classified as either light (clear-white, yellow, green-blue, pink-tan) or dark (red-orange, green, blue-purple, brown-black; Day et al., 1985; Moser and Lee, 1992). After sorting contents under a dissection microscope, items were counted for each bird. Each particle was measured (in mm) for length, width, and height or diameter (only for round debris, and measured where widest). Debris was photographed for subsequent analyses. Once confirmed, anthropogenic debris items were removed from a sample, and remaining items were categorized as natural.

2.3. Statistical analyses

Previous studies using power analyses have generally found that a minimum of 18 to 40 or more individuals per species are required for reliable estimates of intraspecific prevalence (van Franeker and Meijboom, 2002; Provencher et al., 2015), so we used a minimum sample size of 18 individuals to include a species in interspecific comparisons. We used Fisher exact tests for most comparisons because >20% of the cells had expected counts of less than five (Cochran, 1954). We used logistic regression to test if debris presence was related to interspecific and intraspecific variation in body mass. Statistical analyses were performed in program R (version 3.2.2; R Core Team, 2015) using the "*dplyr*" package (Wickham and Francois, 2015). Values are reported as mean ± SD unless otherwise stated.

3. Results

We obtained data from 350 birds of 18 species, including three herbivorous geese, eight omnivorous dabbling ducks, three omnivorous diving ducks, one carnivorous sea duck, and three piscivorous loons (Table 1; all diving duck and loon species sampled are partially marine species that breed on inland freshwater bodies). All individuals in this study were culled inland (except 29 common eider). Because we recovered no debris from the proventriculus (nor have others, e.g., Day et al., 1985; Moser and Lee, 1992; Robards et al., 1995), hereafter we focus only on the gizzard. We found 110 items of anthropogenic debris, ranging in size from 50 μm to 5 mm (hence all plastic debris would be

Table 1
Sample sizes, body mass ± SE (g), the frequency, and mean number of pieces ± SE for plastic, metal, and any debris. N = number of specimens dissected. Means include birds without ingested debris. GWFG = greater white-fronted goose; SNGO = snow goose; CAGO = Canada goose; GADW = gadwall; AMWI = American wigeon; ABDU = American black duck; MALL = mallard; BWTE = blue-winged teal; NOSH = northern shoveler; NOPI = northern pintail; GWTE = green-winged teal; LESC = lesser scaup; WWSC = white-winged scoter; LTDU = long-tailed duck; COEI = common eider; RTLO = red-throated loon; COLO = common loon; YBLO = yellow-billed loon.

				Ingestion frequency (%)			Mean pieces of debris/bird ± SE		
Foraging niche	Species	N	Mean body mass ± SE (g)	Plastic	Rubbish	Metal	Plastic	Rubbish	Metal
Geese	GWFG	2	1616 ± 203	0.0	0.0	50.0	0.00 ± 0.00	0.00 ± 0.00	0.50 ± 0.71
	SNGO	47	2119 ± 423	2.1	2.0	2.1	0.02 ± 0.15	0.02 ± 0.15	0.02 ± 0.15
	CAGO	43	3584 ± 241	4.7	14.0	0.0	0.05 ± 0.30	0.21 ± 0.51	0.00 ± 0.00
Dabbling ducks	GADW	2	836 ± N/A	0.0	0.0	0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	AMWI	32	738 ± 102	6.3	3.1	0.0	0.06 ± 0.25	0.03 ± 0.18	0.00 ± 0.00
	ABDU	5	1242 ± N/A	0.0	0.0	20.0	0.00 ± 0.00	0.00 ± 0.00	0.25 ± 0.50
	MALL	120	1185 ± 178	5.0	2.5	5.0	0.07 ± 0.34	0.52 ± 5.21	0.08 ± 0.37
	BWTE	1	N/A	0.0	0.0	0.0	0.00 ± N/A	0.00 ± N/A	0.00 ± N/A
	NOSH	1	N/A	0.0	0.0	0.0	0.00 ± N/A	0.00 ± N/A	0.00 ± N/A
	NOPI	10	762 ± 50	10.0	10.0	10.0	0.10 ± 0.32	0.00 ± 0.00	0.20 ± 0.63
	GWTE	15	325 ± N/A	0.0	0.0	0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Diving ducks	LESC	1	N/A	0.0	0.0	0.0	0.00 ± N/A	0.00 ± N/A	0.00 ± N/A
	WWSC	16	N/A	6.3	0.0	0.0	0.06 ± 0.25	0.00 ± 0.00	0.00 ± 0.00
	LTDU	4	N/A	0.0	0.0	0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Sea ducks	COEI	40	1825 ± 126	2.5	2.5	5.0	0.02 ± 0.16	0.10 ± 0.63	0.05 ± 0.22
Loons	RTLO	7	N/A	0.0	0.0	0.0	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
	COLO	1	N/A	0.0	0.0	0.0	0.00 ± N/A	0.00 ± N/A	0.00 ± N/A
	YBLO	3	N/A	33.3	0.0	0.0	0.33 ± 0.58	0.00 ± 0.00	0.00 ± 0.00

classified as microplastics; Moore, 2008; Arthur et al., 2009; Ivar do Sul and Costa, 2014), in 10 of 18 (55%) species, and 39 of 350 (11.1%) birds, with an average of 0.31 (±3.1) items per bird. Sample sizes for the nine species that did not have ingested anthropogenic debris were all <15, so their anthropogenic debris prevalence of zero should be interpreted cautiously. There was no difference in debris ingestion among foraging niches (Table 1; Fisher exact test, $p > 0.99$).

Of the ten species with ingested debris, five had the minimum recommended samples of 18 (Table 1). These species had similar prevalences of anthropogenic debris (Fisher exact test, $p = 0.50$). For species with the recommended minimum sample sizes [we had mass data for ≤12 Canada geese (*Branta canadensis*) and American wigeon (*Anas americana*)], interspecific variation in body mass was not associated with anthropogenic debris ingestion (logistic regression, $t_{1,\ 99} = 0.5$, $p = 0.64$) nor was intraspecific variation in body mass associated with debris ingestion (three species, all N for individuals with body mass ≥ 24, all $t \le 0.34$, all $p \ge 0.60$]. A more detailed breakdown is presented in Table 2 (also see Appendix A), but is not amenable to statistical analysis.

Plastic debris was present in eight species and 15 of 350 (4.3%) birds; prevalence did not differ among species with sufficient samples (Fisher exact test, $p = 0.85$). Non-plastic rubbish was present in five species, and ingested by 13 of 350 (3.7%) birds. Non-plastic rubbish prevalence differed among species with sufficient samples [Fisher exact test, $p = 0.01$; Canada goose (7/43, 16.3%), American wigeon (1/32, 3.1%), mallard (3/120, 2.5%), common eider (1/40, 2.5%), snow goose (*Chen caerulescens*; 1/47, 2.1%)]. Metal debris was present in six species, and ingested by 12 of 350 (3.4%) birds, and prevalence did not differ among species with sufficient samples (Fisher exact test, $p = 0.48$). All ingested birdshot was a non-toxic alternative to lead shot, such as steel, based on uncrushed, rounded shapes of recovered pellets. One northern pintail (*Anas acuta*) had 17 lead birdshot pellets in its gizzard, but was presumably hunted with this shot. Pellet composition was determined visually and with a simple crush test. Lead pellets tend to be deformed and fragmented upon impact with soft tissues and bone, whereas steel shot usually remains round (Wilson, 1999; Peitzman et al., 2012). The remaining metal fragments were metalworking waste (swarf).

Prevalences of anthropogenic debris in British Columbia (23/145, 15.9%), Nova Scotia (6/74, 8.1%), Northwest Territories (5/66, 7.6%), Newfoundland (3/29, 10.3%), Ontario (1/19, 5.3%) and New Brunswick (0/13) (Fig. 1) were not statistically different (Fisher exact test, $p = 0.30$). Of four common eiders without accompanying information on origin, one had ingested debris.

Ingested particle coloration was classified for all debris except birdshot (7/39, 17.9%), because we assume birds encounter this by accident and it becomes retained as if it were grit (a mixture of mineral, rock, and hardened food fragments retained to aid in fibrous food digestion; Thomas et al., 1977). Light-colored anthropogenic debris was more commonly ingested (27/32, 84.2%) than dark colored (5/32, 15.6%).

Table 2
Amount and types of debris recovered from the ten species that ingested debris. N = number of anthropogenic debris fragments recovered. GWFG = greater white-fronted goose; SNGO = snow goose; CAGO = Canada goose; AMWI = American wigeon; ABDU = American black duck; MALL = mallard; NOPI = northern pintail; WWSC = white-winged scoter; COEI = common eider; YBLO = yellow-billed loon.

		Plastic (N)		Rubbish (N)					Metal (N)	
Foraging niche	Species	Fragments	Other	Thread-like	Foil	Paint chips	Glass	Rubber	Birdshot	Metal
Geese	GWFG	0	0	0	0	0	0	0	0	1
	SNGO	1	0	1	0	0	0	0	0	1
	CAGO	2	1	0	5	1	2	0	0	0
Dabbling ducks	AMWI	2	0	0	0	0	1	0	0	0
	ABDU	0	0	0	0	0	0	0	1	0
	MALL	8	0	0	4	0	1	57	8	1
	NOPI	1	0	0	0	0	1	0	1	0
Diving ducks	WWSC	1	0	0	0	0	0	0	0	0
Sea ducks	COEI	1	0	0	4	0	0	0	1	1
Loons	YBLO	1	0	0	0	0	0	0	0	0

Clear and white debris were the most common colors ingested by all species (11/32, 34.4%). Gold was the second most commonly ingested color (4/32, 12.5%), and black was the least common (1/32, 3.1%). All other colors (light yellow, light green-blue, dark green, dark blue-purple) were ingested with the same frequency (2/32, 6.3%).

4. Discussion

Prevalence of anthropogenic debris in freshwater birds and the marine common eider comparison group presented in this study (11.1%) provides compelling evidence that freshwater and marine organisms currently face similar threats from anthropogenic debris ingestion. Although our sample was mostly limited to commonly hunted or culled species, our results suggest that anthropogenic debris ingestion by freshwater birds is likely to apply to a wider range of species, because anthropogenic debris ingestion was found in some species for which we had small samples. We expect that sampling of other waterfowl and freshwater bird species (such as herons and kingfishers) will likely reveal ingestion of anthropogenic debris.

Seabird plastic ingestion is assumed to occur because plastics mimic natural food items (Day et al., 1985; Moser and Lee, 1992). Although freshwater birds may mistake plastic debris as food, the high prevalence of birdshot (which sinks into sediment and does not appear to mimic any known food items) suggests freshwater birds may be retaining birdshot as grit, which they encounter opportunistically (Thomas et al., 1977; Moore et al., 1998). They could also acquire small, broken pieces of plastic debris in this manner. Some seabirds consume specific plastic shapes and colors more frequently, and debris ingestion ties into foraging niche and availability of certain plastics in particular habitats (Day, 1980; Day et al., 1985; Ryan, 1987; Moser and Lee, 1992). Surface-feeding species are most likely to have plastics in their diets, perhaps due to polyethylene's specific gravity of 0.9, enabling plastics to float at the water's surface (Day et al., 1985; Snyder and Vakos, 1966; Moser and Lee, 1992). Although our study supports previous evidence that birds preferentially ingest lighter colored debris (Rothstein, 1973; Day, 1980; Moser and Lee, 1992; Lavers and Bond, 2015), we cannot evaluate whether this reflects selective uptake without knowing availability in the environment. However, we did not find evidence that debris ingestion was related to foraging niche.

Anthropogenic debris ingestion by freshwater birds should also be an important issue to waterfowl hunters. In 2013 alone, approximately 189,844 individuals across Canada hunted approximately 2,286,951 waterfowl (Gendron and Smith, 2013; Environment Canada, 2014). Given that debris can vector various contaminants (Teuten et al., 2007; Ashton et al., 2010; Rios et al., 2010) this may put hunters such as Aboriginal peoples, who rely most heavily on wild foods (Van Oostdam et al., 1999; Johansen et al., 2001; El-Hayek, 2007), at risk of consuming contaminated tissues. Quantifying plastic-associated toxins is crucial to understanding potentially hidden effects of anthropogenic debris ingestion on Aboriginal peoples and other vulnerable groups, and to developing future avian conservation plans.

In contrast to marine anthropogenic debris, microscopic anthropogenic debris in freshwater ecosystems may be perceived as an environmental issue that is closer to home, hopefully resulting in more scientific and public attention. One example of this is the recent passing of the *Microbead Free Waters Act of 2015* in the United States (House Report No. 114-371, 2015). Microbead use has increased in recent years, and their relatively small diameter (<1 mm) means many wastewater treatment plants cannot remove them, leading to an increase of these plastics entering aquatic ecosystems (Castañeda et al., 2014; Doughty and Eriksen, 2014; Driedger et al., 2015). The resultant increase in microbead concentrations in waterways led to public outcry, and shortly thereafter many major companies banned microbeads (Newman et al., 2013). Although care was taken in our study to find microbeads, none were recorded. This could be due to the sieves used. Our finest was a 0.5 mm mesh, the same size used by Castañeda et al. (2014) to sieve microbeads from river sediment. However, despite our similar sieve size, we found that running a microbead-containing product (Clean & Clear® morning burst® facial scrub) through our sieve permitted passage of smaller beads, retaining only less frequent larger beads. Similarly, larger beads could have been ground down over time in gizzards, permitting their passage through our sieve. Therefore our microbead findings should be interpreted cautiously, because waterfowl are likely ingesting them.

Our results on the prevalence of anthropogenic debris ingestion in waterfowl indicate that it is occurring at similar rates to historic trends in some marine birds (Laist, 1997) and current rates in some freshwater birds (English et al., 2015). Future studies examining gut contents of freshwater birds should adopt a screening method for anthropogenic debris similar to that of van Franeker and Meijboom (2002) and van Franeker (2004), and collection points for examination of harvested bird digestive tracts should be established. This could be essential in monitoring anthropogenic debris ingestion over a number of years to reliably assess trends.

5. Conclusions

Our study adds to the limited but mounting evidence (Moser and Lee, 1992; Denuncio et al., 2011; Besseling et al., 2014; Sanchez et al., 2014; English et al., 2015; Moseman, 2015; Fischer et al., 2016) that anthropogenic debris may be a threat to aquatic biota in freshwater environments. We found debris in 55% of species collected from freshwater habitats in Canada, including from remote sites as far as 63°N. However, there was no suggestion of patterns in anthropogenic debris ingestion relative to body mass, geographic location of capture, or foraging niche. This was surprising, because we expected that birds collected near urban or industrial centers (where debris may occur at higher densities; Zbyszewski et al., 2014) or those foraging as carnivores or omnivores might be more likely to ingest anthropogenic debris. We did not acquire many samples from the Great Lakes region, where research has shown significant pollution by plastic (Eriksen et al., 2013; Castañeda et al., 2014; Driedger et al., 2015), and thus we expect that greater sampling effort of birds wintering there will reveal higher prevalence of ingested plastic and other debris. Consequently, we suggest that our data represent a conservative baseline of anthropogenic debris ingestion in waterbirds in Canada and we expect that additional studies will confirm debris ingestion in other species, as has been shown in marine birds (Provencher et al., 2015).

Although there is evidence that anthropogenic debris is a threat to aquatic biota, there is still a need for long term monitoring to provide input for conservation management, to strengthen the basis for educational campaigns, and to provide scientists with better evidence that could be used to increase efforts to mitigate the problem (Derraik, 2002). Our baseline data provide insights suggesting that this may have to occur sooner than expected to prevent waterfowl debris ingestion levels from reaching the levels currently observed in seabirds.

Authorship

All authors designed the study and contributed to editing the manuscript; EH and DS contributed to data analysis; EH wrote the manuscript; DS and MM provided editorial input.

Conflicts of interest

The authors declare no conflicts of interest.

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Appendix A

Details on each bird that ingested anthropogenic debris in this study. N = number of anthropogenic debris fragments recovered per-bird. GWFG = greaterwhite-fronted goose; SNGO = snowgoose; CAGO = Canada goose; AMWI = Americanwigeon; ABDU = American black duck; MALL = mallard; NOPI = northern pintail; WWSC = white-winged scoter; COEI = common eider; YBLO = yellow-billed loon (data on all birds, including those that did not ingest plastic, are available from the authors).

					Plastic (*N*)		Rubbish (*N*)					Metal (*N*)	
Foraging niche	Species	Location	Sex	Age	Fragments	Other	Thread-like	Foil	Paint chips	Glass	Rubber	Birdshot	Metal
Geese	GWFG	49°11′41 N 123°10′48 W	M	Juvenile	0	0	0	0	0	0	0	0	1
	SNGO	49°11′41 N 123°11′02 W	M	Juvenile	0	0	1	0	0	0	0	0	0
	SNGO	49°11′41 N 123°10′48 W	N/A	Juvenile	1	0	0	0	0	0	0	0	0
	SNGO	49°04′34 N 123°09′37 W	F	Juvenile	0	0	0	0	0	0	0	0	1
	CAGO	44°50′29 N 65°17′22 W	N/A	Unknown	0	0	0	0	1	0	0	0	0
	CAGO	49°11′41 N 123°11′02 W	M	Adult	0	0	0	2	0	0	0	0	0
	CAGO	49°10′27 N 121°54′38 W	M	Adult	0	0	0	2	0	0	0	0	0
	CAGO	49°10′27 N 121°54′38 W	F	Adult	0	0	0	1	0	0	0	0	0
	CAGO	49°10′12 N 121°54′36 W	F	Adult	0	0	0	0	0	1	0	0	0
	CAGO	49°10′12 N 121°54′36 W	F	Adult	0	0	0	0	0	1	0	0	0
	CAGO	44°50′29 N 65°17′22 W	N/A	Unknown	2	0	0	0	0	0	0	0	0
	CAGO	44°50′29 N 65°17′22 W	N/A	Unknown	0	1	0	0	0	0	0	0	0
Dabbling Ducks	AMWI	49°06′22 N 122°05′31 W	F	Adult	1	0	0	0	0	0	0	0	0
	AMWI	48°59′34 N 122°13′30 W	M	Adult	0	0	0	0	0	1	0	0	0
	AMWI	49°04′35 N 123°09′39 W	M	Adult	1	0	0	0	0	0	0	0	0
	ABDU	44°48′06 N 65°23′57 W	N/A	Unknown	0	0	0	0	0	0	0	1	0
	MALL	44°48′05 N 65°23′57 W	N/A	Unknown	0	0	0	0	0	0	0	3	0
	MALL	49°12′50 N 121°46′57 W	M	Adult	3	0	0	0	0	0	0	0	0
	MALL	49°12′50 N 121°46′57 W	M	Adult	0	0	0	0	0	0	0	0	1
	MALL	49°09′27 N 122°34′48 W	F	Adult	0	0	0	4	0	0	0	0	0
	MALL	49°12′50 N 121°46′58 W	M	Adult	0	0	0	0	0	0	0	1	0
	MALL	49°12′50 N 121°46′57 W	M	Adult	0	0	0	0	0	0	0	1	0
	MALL	49°06′41 N 123°04′53 W	F	Adult	1	0	0	0	0	0	0	0	0
	MALL	49°12′50 N 121°46′58 W	F	Adult	0	0	0	0	0	0	57	0	0
	MALL	49°12′50 N 121°46′58 W	M	Adult	0	0	0	0	0	1	0	0	0
	MALL	49°16′00 N 121°43′12 W	F	Adult	1	0	0	0	0	0	0	0	0
	MALL	49°12′50 N 121°46′58 W	N/A	Unknown	0	0	0	0	0	0	0	2	0
	MALL	62°44′06 N 115°42′35 W	N/A	Unknown	1	0	0	0	0	0	0	0	0
	MALL	62°44′06 N 115°42′35 W	N/A	Unknown	0	0	0	0	0	0	0	1	0
	MALL	62°44′06 N 115°42′35 W	N/A	Unknown	1	0	0	0	0	0	0	0	0

Appendix A (*continued*)

Foraging niche	Species	Location	Sex	Age	Plastic (*N*)		Rubbish (*N*)					Metal (*N*)	
					Fragments	Other	Thread-like	Foil	Paint chips	Glass	Rubber	Birdshot	Metal
	MALL	45°06′26 N 64°39′19 W	F	Adult	1	0	0	0	0	0	0	0	0
	NOPI	49°04′44 N 123°02′43 W	M	Adult	0	0	0	0	0	1	0	1	0
	NOPI	49°06′41 N 123°04′48 W	F	Adult	1	0	0	0	0	0	0	0	0
Diving Ducks	WWSC	43°19′31 N 79°47′56 W	N/A	Unknown	1	0	0	0	0	0	0	0	0
Sea Ducks	COEI	49°48′44 N 54°07′07 W	M	Adult	1	0	0	0	0	0	0	0	0
	COEI	49°48′44 N 54°07′07 W	F	Adult	0	0	0	0	0	0	0	0	1
	COEI	49°48′44 N 54°07′07 W	M	Juvenile	0	0	0	0	0	0	0	1	0
	COEI	Unknown	F	Adult	0	0	0	1	0	0	0	0	0
Loons	YBLO	63°26′04 N 109°11′10 W	N/A	Juvenile	1	0	0	0	0	0	0	0	0

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