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Plastic consumption and diet of Glaucous-winged Gulls (*Larus glaucescens*)

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ABSTRACT

We analyzed dietary habits and presence of plastic in 589 boluses of Glaucous-winged Gulls (*Larus glaucescens*) as one of two studies on the impact of plastics on marine life in the US Salish Sea. Volunteers dissected boluses collected (2007–2010) from Protection Island, Washington. Components were separated into 23 food and non-food categories. Plastic was found in 12.2% of boluses, with plastic film being the most common plastic form. No diet specialization was observed. Vegetation was the most abundant component, found in 91.3% of boluses. No relationship was observed between any dietary items and occurrence or type of plastic found. Load and potential ecological impact in the marine environment can be expected to increase concurrently with increasing plastic use and number and variety of plastic sources. Future studies are necessary to understand the impacts of plastic ingestion on this species.

1. Introduction

Plastic in the environment has been shown through numerous previous studies to have a variety of negative effects on marine organisms (Laist, 1987; Derraik, 2002). The varieties of observed impacts range from physical entanglement, ingestion, physical blockage or damage to feeding appendages or the digestive tract, to possible increased exposure to plastic components and persistent organic pollutants from ingested plastics (Moore et al., 2001; Arthur et al., 2009). Release of plastic into the environment continues to rise in concert with its increased human use (Thompson et al., 2004; Shah et al., 2008) and input greatly exceeds the rate at which it is removed from the marine environment (Moore, 2008; Andrady, 2009). As such, it is important to monitor the impacts of plastic on marine organisms as their exposure to plastic is expected to rise (Robards et al., 1995).

Although plastic ingestion has been widely observed and reported for marine birds (Azzarello and Van Vleet, 1987; Laist, 1997; Moore, 2008), specific impacts have been less well documented and appear to vary with species. For example, plastic ingestion by the Laysan Albatross (*Phoebastria immutabilis*) has been extensively studied because of a high chick mortality rate caused by plastic particles in the gizzard interfering with food intake (Sievert and Sileo, 1993; Auman et al., 1997). In a study simulating the effect of ingested plastic on seabirds, chickens fed a diet including plastic pellets were found to have shortened foraging time, lower food consumption, and a slower growth rate than birds fed a plastic-free diet (Ryan, 1988). In another study investigating the potential transfer of plastic-associated contaminants to seabirds which ingest marine plastics, an analysis of PCBs in preen gland oil excreted from Streaked Shearwater chicks that had been fed contaminated plastic resin pellets suggested that lower-chlorinated congeners from the plastics were transferred to the birds (Takada, 2009). However, more generalized causal links between plastic ingestion and consequences remain poorly quantified.

Seabird diet studies have relied upon many techniques, including biochemical methods such as stable isotope analysis, as well as examination of stomach content, food remains, and boluses, pellets of non-consumable food items containing non-digestible items such as shells, bones and plastic (Barrett et al., 2007; Ryan, 1988). Collecting and analyzing boluses is a non-invasive technique (Barrett et al., 2007) and boluses alone have been shown to provide a reasonable representation of gull diets (Schmutz and Hobson, 1998). However, because of variations in the rate at which pellets are produced, bolus analysis is best used for diet composition, not quantification of consumption (Barrett et al., 2007).

Glaucous-winged Gulls are common seabirds in the Salish Sea (USA), Washington, whose plastic ingestion has not been well documented. Glaucous-winged Gulls are omnivorous opportunists that feed on forage fish, invertebrates and other birds (Trapp, 1979; Schmutz and Hobson, 1998). In the gull population, both generalists and selective, or specialist, feeders have been reported. Using Pierotti and Annett, 1991 definition, Glaucous-winged Gulls are considered specialists if 75% or more of boluses were found to contain remains of one prey type.

Other areas of study have centered on monitoring the amount of plastic in seawater and marine sediments, including plastics accumulating on beaches. Current studies on plastic accumulation predict an increase in plastic debris in the marine environment

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(Barnes et al., 2009). Our work was done in parallel with another study on plastics in which the Port Townsend Marine Science Center (PTMSC) quantified eight categories of plastic debris in two size fractions (1–5 mm and >5 mm) on 33 beaches around the US Salish Sea from 2007–2011. Preliminary conservative extrapolation of those results suggests that US Salish Sea beaches could contain more than 6.4 metric tons of plastic debris (J. Kingfisher, unpublished results). Plastic on US Salish Sea beaches could impact many organisms in the environment, including Glaucous-winged Gulls.

In this study, we examined the overall diet of Glaucous-winged Gulls from one near-shore island in Washington State looking for patterns in food consumption and for the presence of several forms of plastic. We focused on the following research objectives: determining the overall level of plastic consumption, as well as the relationship, if any, between plastic consumption, specific food types and specific types of plastics consumed. In addition to our primary research objective, we also studied the effectiveness of utilizing citizen science volunteers in a study of this type.

2. Materials and methods

Boluses from Glaucous-winged Gulls were collected from the Protection Island National Wildlife Refuge in Puget Sound, Washington, USA (48°08′N, 122°55′W; Fig. 1). The refuge lies approximately 3 km offshore in the southeastern end of the Strait of Juan de Fuca at the mouth of Discovery Bay. The island is a federally protected refuge used by approximately 72% of Puget Sound nesting seabirds (United States Fish and Wildlife Service, 2010). Protection Island is covered with grass and scattered forested areas and offers a relatively undisturbed area unoccupied by humans except for a caretaker and seasonal researchers. There are few if any significant land predators, although Bald Eagles (*Haliaeetus leucoceplaus*), common in the area, are known to prey on several species of bird chicks. In 2010 we noted that, despite its offshore location, there were visible amounts of weathered plastic debris on Protection Island, presumably windblown or washed up onto the shore via currents.

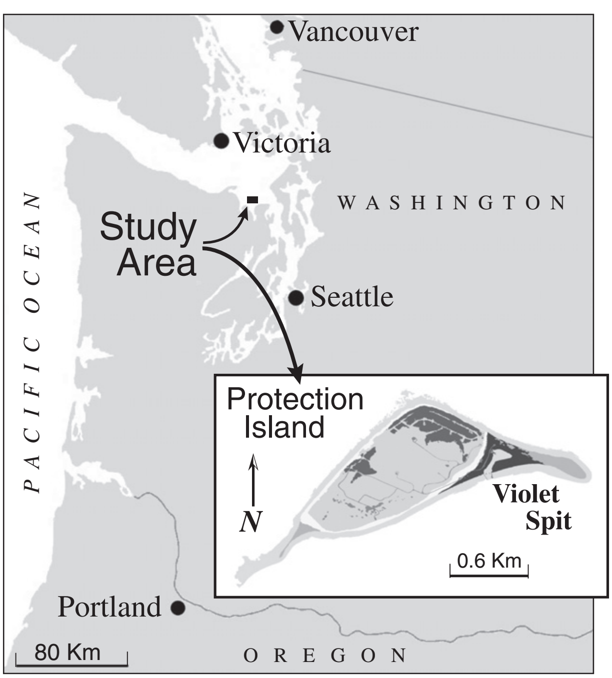

Fig. 1. Location of study area with respect to Puget Sound and regional cities. Inset shows geometry of Protection Island and location of Violet Spit on eastern end. Inset adapted from Figure 4.1 in the Comprehensive Conservation Plan, Protection Island and San Juan Islands NWRs, US Fish and Wildlife Service, April 2011.

Glaucous-winged Gulls inhabit Protection Island all year, with the colony size increasing during nesting season. Violet Spit, which extends to the southeast of the island, contains a breeding colony of Glaucous-winged Gulls that in 2005 exceeded 2400 nesting pairs, the largest breeding colony of this species in Puget Sound (Henson et al., 2007).

We collected boluses in June and early July of four consecutive years (2007–2010), after eggs were laid but before they hatched to minimize disturbance to chicks. We walked the gull colony in a systematic grid fashion to locate the boluses, which were individually placed into labeled envelopes. The relative location of the sample in the colony, date of collection, and collector were noted for each bolus. It was not possible to determine with any certainty which nesting pair had produced which boluses. More than 200 boluses were collected per year from Protection Island in 2007 and 2008. Only 22 boluses were collected in 2009 due to limited access to the island; 140 boluses were collected in 2010.

The collected boluses were dried in three inch aluminum pans in an Excaliber Food Dehydrator for at least one week at 57 °C. After the mass was constant for two consecutive days, each bolus was placed into a numbered envelope for later sorting. Volunteers from PTMSC's citizen science volunteer program were thoroughly trained on bolus dissection, component identification and measurement techniques. Volunteers quantified 18 categories of bolus components in addition to 5 types of plastic. Close-up photos and samples were used to aid in the identification of easily confused materials. Any items identified as 'unknown' were later reviewed by PTMSC staff for final classification. The approximate volumes of intact boluses were measured using a caliper to find the length, width and height in millimeters (mm) and the estimates were recorded before dissecting. Dissection of the boluses was completed by gently pulling apart the bolus with two forceps. Each bolus fragment was then categorized as: mollusk (further identified, if possible, as clam, snail, or mussel), fish, arthropod (crab or barnacle), insect, egg shell, egg membrane, wood, vegetation, other bone, other organic, feather, rock, other inorganic, and plastic (pre-production pellet, hard fragment, filament, foam or film). The plastics categories are those used in PTMSC's companion research project on occurrence of plastics on US Salish Sea beaches (J. Kingfisher, unpublished results). Volunteers were trained to differentiate plastic from mollusk and barnacle shell, the materials most easily confused with hard plastic fragments, by the reaction of the material when exposed to vinegar. Shell, which contains calcium carbonate, quickly reacts with vinegar to produce visible bubbles of carbon dioxide; plastic shows no reaction to vinegar (Chernicoff and Whitney, 2002).

Individually, each component was piled as uniformly as possible on graph paper with each component piled to the same approximate height in order to estimate relative percent volume of each component. The length and width of each bolus component were measured using the 10 mm grid on the graph paper. The height of each component was assumed to be one and the volume was calculated (length × width × height). Volume measurements were then used to estimate the proportion of total bolus volume occupied by each component. The component pile was brushed into a pre-weighed individual manila envelope and placed into a bag for later analysis. Volumes for the 2010 samples were determined as described above, except the height of each component pile was measured in mm with a caliper, which was easier for volunteers.

To ensure that no water was absorbed while components were stored in the paper envelopes, each bolus component was re-dried in the envelope for one hour at 57 °C prior to weighing. Each envelope with the component sample was weighed using a GD-503 Sartorius scale to the nearest 0.0001 g. Use of pre-weighed envelopes minimized handling of the component samples and potential loss of material during the weighing process. Envelopes were not pre-weighed for boluses collected in 2010; instead the average tare mass of envelopes was estimated based on 16–20 replicate determinations. Variability between envelopes was observed to be less than 1.5%. Small samples, whose mass approached that of the envelope, were removed from the envelope and weighed separately in an aluminum pan, ensuring that the uncertainty in the mass measurement was less than 2%. The same pan was used for all mass measurements and the scale was calibrated every tenth bolus to ensure accuracy. Researchers confirmed volume measurements and calculations of the dried boluses, percent volumes of the components, and category placement for every bolus for 2007 data and for every fifth bolus in subsequent years. Every bolus that contained plastic was double-checked for accuracy and correct categorization for all years. To ensure accuracy in data entry, every third bolus was compared to the original data sheet for all years. Mann–Whitney *U* test analyses were performed using StatView, third edition (1999), copyright by SAS Institute, Inc.

3. Results

Five hundred eighty-nine boluses were collected, dried, weighed and categorized by component. The mass distribution of boluses collected in each year was quite consistent. More than half of all boluses weighed <2 g in all years, while 20–30% of boluses weighed 2–4 g. No more than 5% of boluses collected weighed >6 g, with rare boluses above 10 g. The occurrence (number and percentage), total average estimated volume, and total average mass for each of the major components were tabulated (Table 1). Results obtained in individual years were similar, with only relatively minor variations in mean percent of bolus volume for each component (Fig. 2). The difference in calculation methods among years as mentioned above did not result in any significant differences when compared with other years.

To better represent the entire colony, the results are shown as percent volume for all boluses, whether or not each individual bolus contained a particular component. As indicated by occurrence data (% present in Table 1), each individual component is absent in more than half of all boluses analyzed, with the exception of vegetation and feathers. Distribution, volume and mass values are, therefore, non-normal and highly skewed. Although the colony may feed non-selectively, individual boluses are often highly selected by content, dependent upon immediate food supply. The skewness of constituent distribution results in many zero values for any given constituent. Calculation of standard deviations is not meaningful in strongly non-normal data. Any standard deviation that is more than half the value of the mean results in a negative lower limit, an impossibility in physical data. Therefore, we report the mean percent volume and percent mass as well as the maximum and minimum range for each constituent as percent volume and as mass (g).

3.1. Plastic consumption

Plastics comprise a notable but not dominant portion of gull bolus material, with 12.2% of boluses collected containing plastic (Table 1), dominated by plastic film of the type used in plastic bags and wrappers. Five categories of plastic were observed in those boluses that contained plastics (Table 2).

In general, the plastic consisted of pieces less than 1 cm, not entire plastic objects. However, occasional boluses consisted largely of plastic; 2.9% of all boluses contained 50% or more plastic by volume.

Plastic film was present in 8.2% of all boluses studied, and was present in 66.7% of the boluses that contained plastic. That is, of the 48 boluses in which film was identified, 15 (31%) comprised more than 75% film. Hard plastic fragments were found in 4.1% of all boluses, and in 33.3% of boluses that contained plastic. Filaments (such as fishing line), foam (such as polystyrene) and pre-production pellets were found less frequently, in 1.4%, 1.4% and 0.5% of all boluses, respectively. The percent volumes of plastic components for all boluses studied and for those in which plastic was measured were calculated (Fig. 3).

3.2. Relationship between plastic consumption and diet

In order to ascertain whether there was any relationship between diet preferences and plastics ingestion, boluses were also characterized by the food remnants found in them. Of the 589 boluses dissected, 91.3% contained vegetation. However, because of the low density of organic matter relative to many of the other bolus components, vegetation comprised only 27.6% of the total mass of boluses that contained vegetation. Of those boluses containing vegetation, 45.8% contained 50% or more vegetation by volume. Other food items were found at lower incidences (Table 1).

The co-occurrence within the same bolus of all possible combinations of component pairs, including all food types, all varieties of plastic and inorganic items such as pebbles and aluminum foil, was not significantly different ($p > 0.05$) from that predicted from the observed individual occurrence rates (Table 1) and assumed random distributions. Most boluses were made up of various components, however, 28.7% of the boluses consisted of more than 75% of one material by volume (excluding vegetation). Just as there was no observed relationship in occurrence of any of the food items with one another, the occurrence of plastic was not associated with any other component found in the boluses.

3.3. Diet

Because of the surprising amount of vegetation found in the boluses, we considered whether, in the process of bolus collection in the field, we had over-collected intact boluses, which might contain more vegetation, versus non-intact boluses, which were harder to collect and which might contain more friable bone or shell

Table 1
Bolus component distribution.

	Mollusk	Fish	Arthropod	Insect	Egg	Wood	Vegetation	Bone	Organic other	Feather	Rock	Inorganic other	Plastic total
# Present	223	253	163	143	112	94	538	71	189	358	281	74	72
% Present	37.9	43.0	27.7	24.3	19.0	16.0	91.3	12.1	32.1	60.8	47.7	12.6	12.2
Mean volume %	4.3 (100–0)	7.9 (100–0)	8.9 (100–0)	1.5 (100–0)	3.2 (100–0)	1.1 (86–0)	44.8 (100–0)	1.4 (100–0)	6.2 (100–0)	11.3 (100–0)	1.4 (38–0)	4.8 (100–0)	3.2 (100–0)
Mean mass %	15.8 (11.2–0)	6.8 (6.1–0)	14.1 (12.8–0)	0.9 (2.2–0)	7.1 (8.4–0)	1.0 (3.4–0)	27.6 (6.8–0)	4.0 (14.4–0)	5.4 (4.6–0)	4.9 (5.0–0)	6.9 (6.6–0)	4.1 (5.8–0)	1.4 (2.0–0)

Total number of boluses examined = 589. Values are for number and percent of boluses where named component is present, and for mean volume and mean mass as percents of total volume and mass. Values in parentheses are maximum and minimum values as percent volume and as mass (g) for all boluses examined.

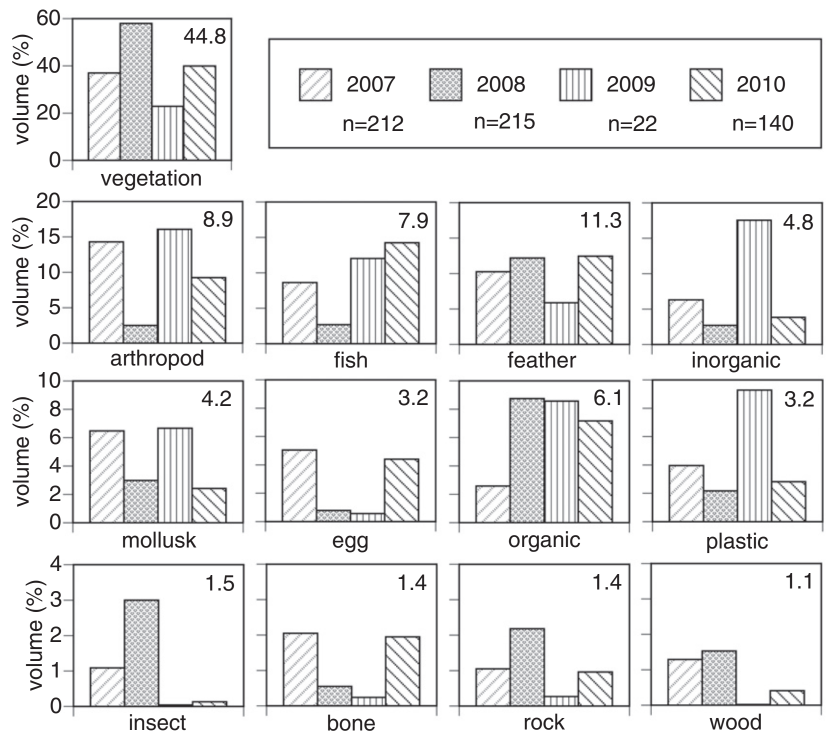

Fig. 2. Bolus components shown as volume percent of all boluses collected in a given year. Numbers in the upper right of each graph are the volume percent average for all 589 boluses collected. Note the substantial change in scale of the y axis among rows. Vegetation was always dominant by volume (top row), averaging from 30% to 60% by year. Arthropods, fish, feathers and inorganic debris were sometimes greater than 10% by volume (second row). Mollusk, egg, organic debris and plastic accounted for no more than about 8% by volume, and often much less. Finally, insects, bone, rocks and wood rarely appeared as more than 1% or 2% of total volume (bottom row).

Table 2
Bolus plastic component distribution by year.

	Pellet	Fragment	Film	Foam	Filament
Percent of boluses containing plastic that contain named plastic class					
2007	3.4	34.5	69.0	6.9	6.9
2008	4.3	34.8	56.5	4.3	21.7
2009	0.0	25.0	75.0	0.0	0.0
2010	6.3	31.3	75.0	31.3	6.3
All boluses w/plastic	4.2	33.3	66.7	11.1	11.1
Percent of all boluses collected that contain named plastic class					
2007	0.5	4.7	9.4	0.9	0.9
2008	0.5	3.7	6.1	0.5	2.3
2009	0.0	4.6	13.6	0.0	0.0
2010	0.7	3.6	8.6	3.6	0.7
All boluses	0.5	4.1	8.2	1.4	1.4

material. Of the 589 boluses collected, 512 were judged to be intact at time of drying while 77 were considered ‘not intact’. Simple comparison of means and standard deviations of measured component masses between the intact and non-intact boluses revealed no significant differences. However, because the composition data are severely skewed and often are dominated by zeros as discussed earlier, these simple statistical tests may not be sensitive to differences between intact and non-intact boluses.

To further assess whether the composition of intact and non-intact boluses differed, the nonparametric Mann–Whitney *U* test was applied to all component pairs. For the majority of components there is no detectable difference. Importantly for the discussion here, no difference in the pattern of distribution of plastic or vegetation in intact versus non-intact boluses was observed. Possible differences were calculated ($p < 0.02$) for fish, arthropod, egg and feather categories. However, since these differences might be related to specifics of individual feeding and our focus here is on colony ingestion of plastic, this was not examined further and all boluses, intact and non-intact, were treated in aggregate.

3.4. Volunteer effectiveness

Through the process of lab staff checking volunteer data, we found a 1.3% error rate in identifying bolus components and a 2.4% error rate in data entry for 2008 through 2010 data. The error rate was determined by staff rechecking categorization of bolus components and comparing entered data to original data sheets. In 2007 each preliminary bolus dissection done by a volunteer was checked for accuracy by one of the authors and corrected if necessary, but no error rate was recorded.

4. Discussion

Given that plastics have only been used in large quantities since the 1950’s, the observation that more than 12% of boluses contained plastic obviously represents a recent shift in ingested materials in this gull population. Studies in the late 1970’s of Glaucous-winged Gull dietary habits in the more remote Western Aleutian Islands had reported no plastic in boluses with relatively minor occurrences (0.3% of boluses analyzed) of other human debris: aluminum foil, glass and paper (Trapp, 1979). The intuitive conclusion that ingestion rates are increasing is in keeping with earlier observations that plastic ingestion by numerous bird species had increased between the late 1960s and late 1980s (Robards et al., 1995). Given that plastic in the environment is anticipated to increase (Rios et al., 2010), ingestion rates and potential impacts on marine birds are expected to rise.

4.1. Plastic consumption

Film often dominated the bolus when present (Fig. 3). One possible explanation for this is that film may often be ingested as one large piece such as a complete plastic bag. Once ingestion of an in-

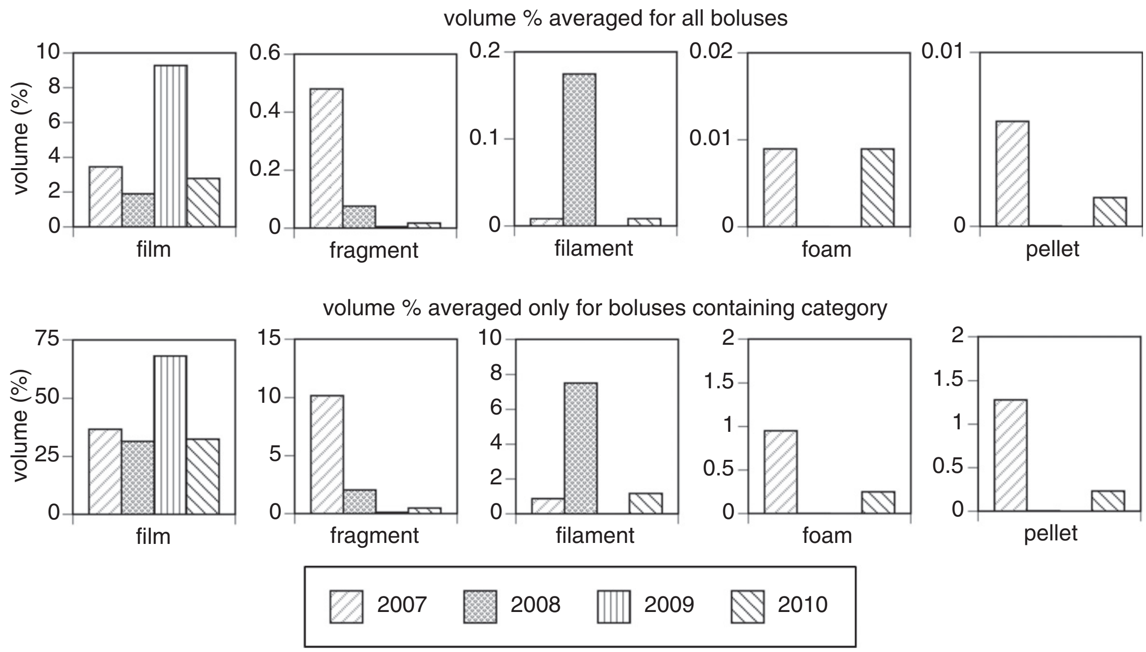

Fig. 3. Plastics in boluses shown as volume percent of all boluses collected in a given year (upper row) and as volume percent of only those boluses which contained the plastic component (lower row).

tact plastic bag is initiated, the whole bag must be consumed as it is not easily severed (D. Jahnke, personal observation). Consequences of ingestion of large single pieces of plastic film are unknown, but it is likely that regurgitation would be required before normal feeding activities could be resumed.

Impact of ingestion of large quantities of plastic on gulls is at present unknown, in contrast to information available on members of the order Procellariiformes such as albatross and petrels, which have a distinct constriction between the gizzard and the proventriculus. The high mortality rate of the Laysan Albatross associated with plastic ingestion could be due to this constriction preventing plastic pieces from being regurgitated. Glaucous-winged Gulls have not been shown to be affected in similar ways. Birds in the order Charadriiformes (gulls) have no distinction between the two organs, which allows them to more easily regurgitate items (Furness, 1985). While gulls regurgitate indigestible materials, procellariiformes in general do not.

Material residence times within birds are also relevant to evaluate the transfer of marine contaminants. Plastic surfaces can accumulate persistent organic pollutants such as PCBs and thus may transfer the pollutants to organisms via ingestion. This may occur even if the carrier plastic is regurgitated if the contaminant is released while ingested. A positive correlation between the amount of plastic ingested and the concentration of PCBs in birds has been shown in a recent study (Teuten, 2009).

4.2. Relationship between plastic consumption and diet

The occurrence of plastic was not associated with occurrence of any other component found in the boluses, suggesting that the gulls are not mistaking plastic for a specific food item of similar appearance. If that were the case, then one might expect a correlation between occurrence of plastic and that particular food item. Some of the smaller pieces of plastic may be ingested incidentally through consumption of prey that had ingested plastic lower in the food chain. Presently, it is not known if plastic is inadvertently ingested along with other food items or whether other factors may contribute to its relative uptake.

4.3. Diet observation

To our knowledge, previous studies have not reported large amounts of vegetation in the diet of Glaucous-winged Gulls. For example, Trapp (1979) reported gulls eating berries with only incidental occurrence of marine algae and unidentified vegetation. This is in contrast to our observation that most of the boluses dissected (91.3%) contained some amount of vegetation, mainly grass. It is not known whether the vegetation was deliberately ingested in feeding; it could also be ingested as a stress response or during nest maintenance.

4.4. Volunteer effectiveness

The time-consuming nature of bolus dissection and analysis limits the extent and frequency at which studies such as that reported here can be performed by active professionals. However, as demonstrated, volunteers can effectively perform these tasks. Some research has found that volunteers collecting data tend to over-report rarities (Galloway et al., 2006). If true, one might have expected to find that volunteers in this study had reported higher amounts of plastic in the boluses, which can appear similar to glass or mollusk shell during bolus dissection, relative to measurements by more experienced staff. However, this was not observed. The high accuracy rate achieved by the volunteers in this study was likely due to a combination of high levels of volunteer motivation, training methods, and encouraging volunteers to describe uncertainties as 'unknown' for follow-up by the researchers.

5. Conclusion

Load and potential ecological impact of plastic in the marine environment can be expected to increase concurrently with increasing plastic use and the number and variety of plastic sources. Our study found that Glaucous-winged Gulls in the Salish Sea are ingesting plastic in several forms, especially film similar to that found in plastic bags. Future research will be needed to document whether plastic consumption by these gulls increases in parallel with anticipated increases in the environment. Studies should also compare the relative abundance of various types of plastics found in sea water or beach sediment with observed ingestion rates to determine if gulls or other organisms are selectively ingesting or avoiding certain plastic types. Most importantly, potential biological impacts of plastics ingestion by gulls, including possible transfer of plastic-bound pollutants, should be a focus of future research efforts.

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