SPATIAL AND TEMPORAL VARIATION IN THE DIETARY ECOLOGY OF THE GLAUCOUS-WINGED GULL LARUS GLAUCESCENS IN THE PACIFIC NORTHWEST

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INTRODUCTION

The widespread distribution of contaminants in marine environments is of global concern, particularly for those compounds that do not readily degrade and are relatively volatile, such as persistent organic pollutants (POPs) (Jones & De Voogt 1999, Tanabe 2004). POPs are a group of lipophilic compounds that accumulate in fatty tissues of organisms, leading to their bioaccumulation and biomagnification in marine food webs (Jones & De Voogt 1999, Tanabe 2004), with particularly high concentrations in piscivorous seabirds (Gilbertson et al. 1987, Furness & Camphuysen 1997, Gochfeld & Burger 2001, Becker 2003, Elliott & Elliott 2013). Accordingly, seabirds, including gull species, are integral components of several monitoring programs and provide data on trends, exposure pathways and effects of persistent contaminants (Newton et al. 1990, Elliott et al. 1989, 1992, 2005, Bignert et al. 1998, Hebert et al. 1999a, Becker et al. 2001, Braune 2007, Verreault et al. 2010, Fliedner et al. 2012, Burgess et al. 2013, Miller et al. 2014, 2015a, 2015b). One such program, the Great Lakes Herring Gull Monitoring Program, has successfully used the Herring Gull Larus argentatus since the early 1970s to track spatial and temporal trends in the distribution of many POPs (e.g. Norstrom et al. 1995, Hebert et al. 1999b, Gauthier et al. 2008, 2009). In 2006, the Environment Canada Chemical Management Plan (CMP) expanded annual gull monitoring to the national level, with the intention of tracking emerging contaminant trends in various gull species across Canada (Gebbink et al. 2011, of recent meals rather than assimilated diet (Duffy & Jackson 1986, Brown & Ewins 1996, González-Solís et al. 1997, Barrett et al. 2007, Weiser & Powell 2011). Nonetheless, these methods have the advantage of identifying specific prey items (Karnovsky et al. 2012) and providing insight into broad dietary trends (Furness & Monaghan 1987); as a result, they have been widely used in gull diet research to determine dietary composition (Vermeer 1982, Fox et al. 1990, Ewins et al. 1994, Kubetzki & Garthe 2003, Herrera et al. 2005, Ramos et al. 2009, Weiser & Powell 2010). More recently developed techniques, such as stable isotope and fatty acid signature analysis, are frequently regarded as advantageous, since sampling is often less invasive and allows for time-integrated estimates of diet (Barrett et al. 2007); however, conventional techniques still provide essential knowledge necessary to comprehensively interpret contaminants data.

Because of a lack of recent and reliable data on foraging behaviour and dietary plasticity in Glaucous-winged Gulls in Canada, it is important to re-examine their diet in order to accurately interpret trends in toxicological egg monitoring data. We investigated diet using conventional methods at two colonies on the Pacific coast of Canada in order to: (1) characterize the current feeding ecology of breeding adults before egg laying and during incubation, (2) elucidate inter-colony dietary variation, and (3) examine temporal variation, by comparing our findings with historical studies (Henderson 1972, Ward 1973, Vermeer 1982). Because dietary shifts associated with different stages in the breeding season have been previously documented in large Pacific larids (e.g. Annett & Pierotti 1989), and future monitoring may include contaminant effects on nestlings, we also examined (4) short-term intra-colonial dietary shifts over the course of the breeding season.

METHODS

Study area

Two Glaucous-winged Gull colonies were selected for sampling based on their current use in CMP toxicological monitoring and

TABLE 1
Marine invertebrate and fish prey taxa consumed by adult and chick Glaucous-winged Gulls at Mandarte and Cleland Islands during different breeding stages

	Frequency of occurrence (%)[a]									
	Pellets from adults				Regurgitations from chicks					
	Mandarte Island		Cleland Island		Mandarte Island				Cleland Island	
Food categories	Pre-laying 2010 (n = 61)	Incubation 2010 (n = 17)	Pre-laying 2010 (n = 47)	Incubation 2010 (n = 0)[b]	Early 2009 (n = 46)	Late 2009 (n = 64)	Early 2010 (n = 54)	Late 2010 (n = 28)	Early 2010 (n = 4)	Late 2010 (n = 19)
Marine invertebrates	55.7	64.7	100.0	–	6.52	4.7	–	14.3	–	10.5
Bivalves/gastropods	26.2	23.5	14.9	–	–	3.1	–	3.6	–	10.5
Chitons	3.3	–	–	–	–	–	–	–	–	–
Crabs/Shrimp	27.9	35.3	4.3	–	2.2	1.6	–	7.1	–	–
Euphausiids	–	–	–	–	2.2	–	–	–	–	–
Gooseneck barnacles	–	–	93.6	–	–	–	–	–	–	–
Errant polychaete	19.7	47.1	–	–	–	1.6	–	10.7	–	–
Sea star	–	5.9	2.1	–	4.3	1.6	–	–	–	–
Fish	39.3	29.4	–	–	89.1	81.3	96.3	96.4	100.0	94.7
Samples containing fish, n	24	5	–	–	41	52	52	27	4	18
Herring	[c]	[c]	[c]	–	7.3	11.5	1.9	3.7	–	27.8
Pacific Sand Lance	[c]	[c]	[c]	–	26.8	25.0	50.0	59.3	50.0	50.0
Salmon	[c]	[c]	[c]	–	–	1.9	1.9	–	–	–
Pricklebacks/gunnels	[c]	[c]	[c]	–	–	–	–	7.4	–	–
Midshipman	[c]	[c]	[c]	–	2.4	–	–	–	–	5.6
Unidentified/ digested	[c]	[c]	[c]	–	64.4	65.4	46.2	37.0	50.0	27.8

[a] Fish taxa represented as frequency of occurrence (%) in samples containing fish.
[b] Nest areas were surveyed for pellets but none were found.
[c] Indicates fish species were not identified in pellets.

the existence of historical information on diet (Henderson 1972, Ward 1973, Vermeer 1982). Both colonies were on small- to medium-sized, mostly treeless, offshore islands close to Vancouver Island (Vermeer & Devito 1987, Hayward & Verbeek 2008, BC Conservation Data Centre 2011). Mandarte Island (Georgia Strait/Salish Sea, BC; 48.633°N, 123.283°W) is located near urbanized areas and landfills, where the gulls may acquire anthropogenic food sources. It is currently the largest Glaucous-winged Gull colony in British Columbia (>1800 active nests in 2009; Blight 2012), and gulls nest predominantly in meadow areas with grass cover (Henderson 1972, Vermeer & Devito 1987). Cleland Island, BC (49.167°N, 126.083°W) is a sizable colony (1400 active nests in 2010; pers. comm. Peter Clarkson 2010) located off the west coast of Vancouver Island. The colony represents a more exposed, remote site where diet has historically consisted of marine sources (Henderson 1972, Ward 1973), and gulls are restricted to nesting on the bare rock margin encompassing the island (Henderson 1972, Vermeer & Devito 1987). Designated as an ecological reserve, Cleland Island protects sensitive habitat for several seabird and marine species; accordingly, collection trips were limited to minimize disturbance.

Sample collection

To determine adult Glaucous-winged Gull diet, nesting areas were surveyed for fresh pellets (regurgitations of hard, indigestible food parts) before egg laying (i.e. during nest initiation and construction; Mandarte: 7–9 May 2010, Cleland: 10 May 2010) and during early incubation (Mandarte: 7–9 June 2010, Cleland: 1–2 July 2010). To ensure that the pellets reflected diet during that sampling period, we ignored pellets appearing old, bleached, or fallen apart, similar to Weiser & Powell (2010). Adult gulls occasionally regurgitate a mass of food (sometimes partially digested) in reaction to disturbance. These regurgitations were opportunistically collected during the incubation periods.

To characterize chick diet, regurgitated food samples were collected from chicks during early chick-rearing (approximately two weeks of age; Mandarte: 22 July 2009 and 24–26 July 2010; Cleland: 5 August 2010) and late chick-rearing (approximately four weeks of age; Mandarte: 11 August 2009 and 14–16 August 2010, Cleland: 26 August 2010) stages, based on our knowledge of mean laying or hatching dates for the colonies. Chicks were captured by hand (chicks are usually incapable of flight until 37–53 d of age; Vermeer 1963) and, to avoid sampling multiple chicks fed by the same parents, only one chick was sampled every few metres (Vermeer 1963, BC Conservation Data Centre 2011).

Laboratory analysis

Pellets and regurgitations were weighed and prey items were identified to the lowest possible taxonomic level using a dissecting microscope and local marine invertebrate and fish guides (Lamb & Edgell 1986, Kozloff 1987, Harbo 1999). Along with taxonomic ranking, samples were also scored for the presence/absence of items assigned to one of the following broad diet categories defined by Vermeer (1982): human refuse (e.g. poultry or pork meat/fat; human food items: pizza or sausage; garbage: piece of plastic bag, tinfoil), fish, marine invertebrate, terrestrial invertebrate (insects), digested animal matter (e.g. unidentifiable small terrestrial mammal), and plant matter. The frequency of occurrence (FOO) of each category was then calculated as a

Fig. 1. Composition of Glaucous-winged Gull diet by breeding stage in adults and by year and date in chicks at Mandarte (top) and Cleland (bottom) islands. Data are expressed as frequency of occurrence (%) of six broad food categories: HR – human refuse, Fish – fish, MI – marine invertebrate, TI – terrestrial invertebrate, DA – digested animal matter, PM – plant matter.

measure of dietary composition. This indicates the percentage of total samples that contain a particular food category, or the presence/absence of that category, rather than quantity. FOO was chosen as the measure of interest to facilitate comparison of results with those obtained by Vermeer (1982).

Statistical analysis

Intra-colony and historical differences in diet were examined using a statistical method developed for multiple categorical choices (see Agresti & Liu 1999) in order to avoid violating the assumption of independence required to conduct Pearson's chi-squared tests. Data were broken down into multiple Pearson's chi-squared tests for each comparison using counts of presence/absence data (0 for absence, 1 for presence) and analyzed using JMP (version 8.0.2). An adjusted P-value was then calculated for each individual test using the Bonferroni method to account for multiple comparisons:

$$\tilde{p}_i = \min(cP_i, 1)$$

where c is the number of food categories (or tests), and P_i is the P-value of the ith test. No difference was found between categories when $\tilde{p}_i \geq \alpha$ ($\alpha = 0.05$). To facilitate comparisons between diets of adults and chicks, and with historical results, we pooled adult pre-laying and incubation stages and early and late chick-rearing stages; however, these were not analyzed statistically, since pellets and regurgitations represent different sample types. Historical results from Henderson (1972) and Ward (1973) were used for comparisons, which were qualitative only, as dietary composition was not presented as FOO in these earlier studies.

TABLE 2
Comparison of composition of diet of adult and chick Glaucous-winged Gulls with historical data at Georgia Strait and west coast locations

	Frequency of occurrence (%)			
	Pellets from adults Pre-laying–Incubation			

RESULTS

Adult and chick dietary ecology

Mandarte Island

Adults — Diet did not differ significantly between the pre-laying and incubation stages (P

Chicks — Chicks were fed primarily fish and plant matter at both colonies (Table 2). Although fish occurrence was similar between colonies, the occurrence of specific fish taxa differed (Table 3).

Historical dietary variation

Vermeer's (1982) data were obtained from multiple colonies at two locations: Georgia Strait/Salish Sea (5 colonies) and the west coast of Vancouver Island (3 colonies), but he presented pooled results for each location owing to a low number of intra-regional differences (his Table 1). This allowed us to make spatial comparisons with our sampled colonies in similar locations.

Georgia Strait/Salish Sea

Adults — There was a significantly lower percentage occurrence of human refuse in 2010 than in 1980 ($\chi^2 = 18.172$, df = 1, $P < 0.0001$, $\tilde{p} = 0.0006$), and a significantly higher percentage occurrence of fish (χ

prey from the prey fed to their nestlings (Hodum & Hobson 2000, Davies et al. 2009).

Diet at the more remote Cleland Island colony also differed between pre-hatching adults and provisioned chicks in 2010, with adults consuming primarily marine invertebrates while chicks were fed almost an exclusively fish-based diet. Similar to our findings, Henderson (1972) documented the consumption of Goose-neck Barnacles

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