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TEMPORAL AND GEOGRAPHIC PATTERNS OF AGE-SPECIFIC GULL PLUMAGE IN RELATION TO POTENTIAL EXPOSURE TO POLYCHLORINATED BIPHENYLS

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Abstract.—Study skins of Herring Gulls (*Larus argentatus*) and Great Black-backed Gulls (*L. marinus*) collected over a period of ~150 years in the northeastern United States were used to test the hypothesis that potential exposure to polychlorinated biphenyls (PCBs) has an effect on age-related plumage coloration. We found no changes in the average age class (as determined by plumage) of gulls collected before and after 1930 (date PCBs began to be used) and no differences in average age class in birds collected near PCB-contaminated sites versus those collected far from such sites. We found significant skews in the age distributions of birds in our sample because of an under-representation of birds of intermediate age classes, but those skews were similar in pre- and post-1930 data sets and thus likely represent sampling errors and not the effects of PCBs. There was no difference in the age distribution of gulls collected near or far from contaminated sites. Our study, albeit indirectly, shows no evidence that PCB exposure affects plumage maturation rate in piscivorous gulls. *Received 12 February 2004, accepted 14 February 2005*.

Key words: age-class, Great Black-backed Gull, Herring Gull, *Larus argentatus*, *Larus marinus*, plumage, polychlorinated biphenyls.

Patrons Géographiques et Temporels du Plumage chez les Laridés en Fonction de l'Âge et de l'Exposition Potentielle aux Polychlorobiphényles

Résumé.—Des spécimens de démonstration de *Larus argentatus* et *L. marinus* collectés au cours d'une période d'environ 150 ans dans le nord-est des Etats-Unis ont été utilisés pour tester l'hypothèse que l'exposition potentielle aux polychlorobiphényles (PCB) pourrait avoir un effet sur la coloration du plumage en considérant l'âge. Nous n'avons trouvé aucun changement dans la classe d'âge moyen (tel que déterminé par le plumage) des laridés prélevés avant et après 1930 (date à laquelle les PCB ont commencé à être utilisés) et aucune différence pour la classe d'âge moyen des oiseaux collectés près de sites contaminés aux PCB versus ceux prélevés plus loin de ces sites. Nous avons trouvé un biais significatif dans la distribution de l'âge des oiseaux de notre échantillon en raison d'une sous-représentation des classes d'âge intermédiaire. Par contre, ces spécimens étaient similaires dans les jeux de données d'avant et après 1930, ce qui traduirait des erreurs d'échantillonnage et non les effets des PCB. Il n'y avait pas de différence dans la distribution de l'âge des laridés prélevés proche ou loin des sites contaminés. Notre étude montre indirectement qu'il n'y a pas de preuve que l'exposition aux PCB affecte le taux de maturation du plumage chez les laridés piscivores.

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Many industrial contaminants are known to disrupt the endocrine system of animals, resulting in numerous health and behavioral effects (Colborn et al. 1993, Keith 1997). Polychlorinated biphenyls (PCBs), a group of >200 congeners that vary in toxicity with their degree of chlorination, are some of the most widespread and persistent of those contaminants. Exposure to PCBs is known to cause abnormal reproductive behavior, impaired endocrine function, decreased immuncompetence, and congenital deformities in a variety of bird species (Barron et al. 1995, Hoffman et al. 1996, Scanes and McNabb 2003). Those effects are exacerbated in piscivorous species, because of the tendency of PCBs to biomagnify at upper trophic levels (Hebert et al. 1997, Helander et al. 2002).

Much attention has been paid to identifying simple, reliable, and inexpensive biomarkers of chemical contamination (Peakall 1992, Hill 1995, Clotfelter et al. 2004). An area that has received little attention until recently is that of sexually selected, or ornamental, traits in birds. Ornamental traits, such as plumage, may be good biomarkers, because their expression is influenced by environmental and physiological conditions (Hill 1995). In particular, plumage characteristics may be indicative of endocrine disruption, because feather development depends on thyroid and steroid hormones (Owens and Short 1995), both of which are disrupted by contaminants such as PCBs. Plumage may also be a useful biomarker because of its important fitness consequences; it mediates a wide variety of social interactions, including mate choice and territoriality (Andersson 1994). Evidence from several species indicates that variation in plumage characteristics may indicate social status or physiological state (Hill 1991, Bortolotti et al. 2002).

Data from a population of Tree Swallows (*Tachycineta bicolor*) found along PCB-contaminated stretches of the Hudson River (McCarty and Secord 1999, Secord et al. 1999) suggest that variation in ornamental traits can indicate chemical contaminants in the environment. Tree Swallows are one of the few bird species in which females (but not males) have distinctive subadult plumage coloration during their first breeding season. McCarty and Secord (2000) found that subadult females from four breeding colonies located in contaminated areas had significantly more adult blue-green coloration than subadult females from museum collections. Here, we present the results of a similar study in which we focused on age-related plumage in Herring Gulls (*Larus argentatus*) and Great Black-backed Gulls (*L. marinus*) collected in the northeastern United States, where both species are year-round residents. We examined temporal and geographic variation in plumage in relation to potential industrial contaminants (primarily PCBs) and discuss the significance of plumage as an indicator of contamination in these species.

Methods

We used data from gull specimens collected in the northeastern United States (New York, Connecticut, Rhode Island, Massachusetts, and Maine) from the following institutions: Roger Williams Park Museum (Providence, Rhode Island), the Rhode Island Audubon Society (Smithfield, Rhode Island), the Peabody Museum of Natural History of Yale University (New Haven, Connecticut), the Harvard University Museum of Comparative Zoology (Cambridge, Massachusetts), and the American Museum of Natural History (New York, New York). Age class for each specimen was determined on the basis of specific plumage characteristics described by Pierotti and Good (1994) and Grant (1986) (see Table 1). Similar criteria were used to assign age classes for Great Black-backed Gulls. Because of initial difficulties in discriminating between juvenile and first-year birds, we combined the two groups into a single age class. We obtained latitude and longitude coordinates of the collection site for each specimen, as well as the location of 15 National Priority List (NPL) sites in the northeastern United States known to be contaminated with PCBs. National Priority List sites are those of top concern to regulatory agencies such as the U.S. Environmental Protection Agency. Figure 1 shows a map of the 15 sites; a brief description of each is provided in the Appendix. Using the U.S. Environmental Protection Agency's internet application ENVIROMAPPER (see Acknowledgments), we determined which gull specimens were collected within 16 km of any of these NPL sites. Those specimens were considered potentially contaminated in subsequent analyses (see below). We used a 16-km radius from each collection site because that is

Table 1. Criteria used to assign Herring Gull museum specimens to age classes.

Age class	Description [a]
Juvenile	Head and underparts streaked gray-brown, with paler face and nape. Mantle and scapulars gray-brown and form a scaly pattern. Rump streaked gray-brown. Outer wing mainly blackish-brown. Bill dark, and legs and feet dark gray with flesh overtones.
First year	Plumage similar to juvenile, except head and underparts whiter. Dark areas of wings and tail often fade to pale brown. Bill black, but lightening toward base. Feet and legs unchanged.
Second year	Head white, usually with extensive dusky streaking. Underparts and rump mainly white with variable amounts of dark streaking. Tail is extensively whitish at base. Bill drab at base. Legs and feet pale pinkish white.
Third year	Head and body white with extensive dusky streaking, especially around eye and on crown, nape, and hindneck. Mantle and scapulars uniform pale gray. Wings pale gray, except for black and white on outer primaries. Bill yellowish with black bar or spots behind nostrils. Legs and feet remain pinkish white.
Adult	Head and underparts white. There are no brown markings on inner wing or under-wing. Bill yellow with scarlet or orange spot on each side of the lower mandible. Legs and feet pale pinkish cinnamon.

[a] Based on Grant (1986) and Pierotti and Good (1994).

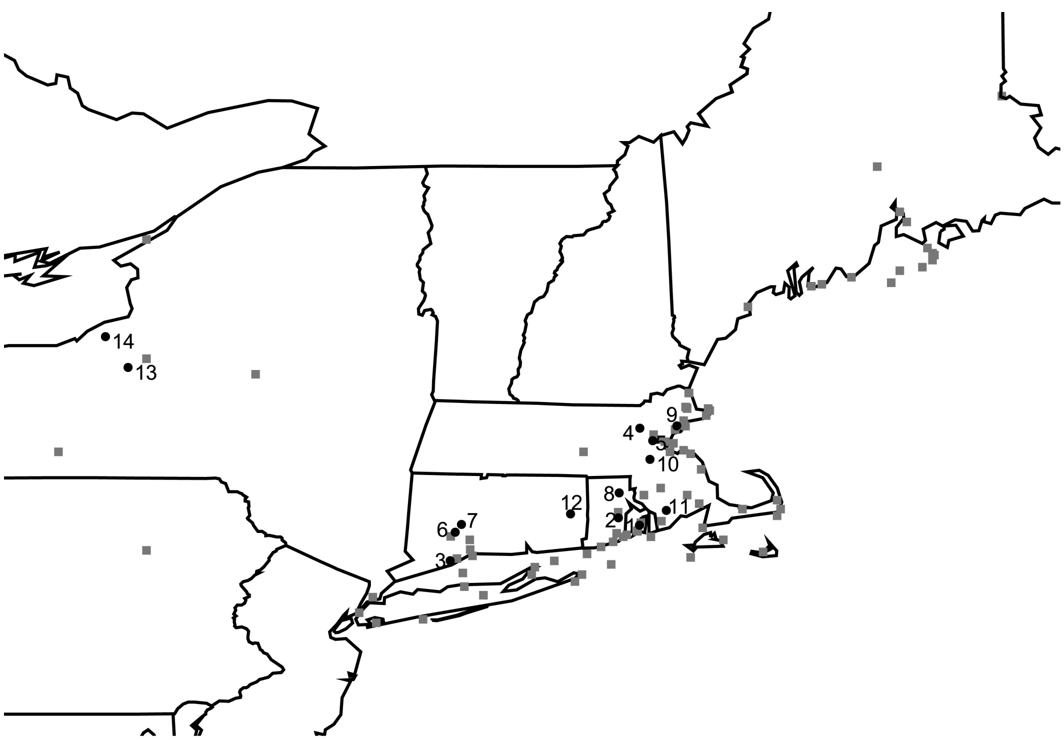

Fig. 1. Collection sites of gull specimens (squares) and National Priority Listing (NPL) sites (numbered dots) used in the study. See Appendix for descriptions of NPL sites.

the average Herring Gull home-range size (Grant 1986, Pierotti and Good 1994). Polychlorinated biphenyls were introduced in 1929; thus, we used 1930 as the date after which birds could potentially have been exposed to them.

Statistical analyses were conducted using SPSS, version 11.5 (SPSS, Chicago, Illinois). All tests were two-tailed and differences were considered significant if $P < 0.05$.

RESULTS

Study skins.—We used 197 Herring Gull and 66 Great Black-backed Gull study skins, collected between 1851 and 1992. Some skins were excluded from analyses because the collection site or year was unavailable, or because their poor quality made it too difficult to assign them to age classes. There were no species differences in any of our variables of interest ($P > 0.16$ for all comparisons); thus, hereafter we consider data from the two species together.

Temporal variation.—There was a weak trend for birds collected in more recent years to be of older age classes ($F = 1.71$, df = 1 and 241, $P = 0.19$, $n = 242$; Fig. 2). If only birds collected from known locales after 1930 are used, however, that trend disappears ($\beta = -0.002$, $t = -0.23$, $P = 0.82$, $n = 46$). Table 2 shows the distribution of age classes of birds collected before and after 1930. Chi-square analyses show significant deviations in those distributions, both in one-way tests on the pre-1930 ($\chi^2 = 17.86$, df = 3, $P = 0.0005$) and post-1930 ($\chi^2 = 43$, df = 3, $P < 0.0001$) data, and in a two-way test of both data sets combined ($\chi^2 = 13.51$, df = 3, $P = 0.0037$). However, those significant differences are likely attributable to significant under-representation of second- and third-year birds in our sample (Table 2), rather than changes induced by the use of PCBs in the 1930s.

Geographic variation.—Proximity to NPL sites with known PCB exposure was shown to have no significant effect on gull age class as estimated by plumage coloration ($\beta = 0.28$,

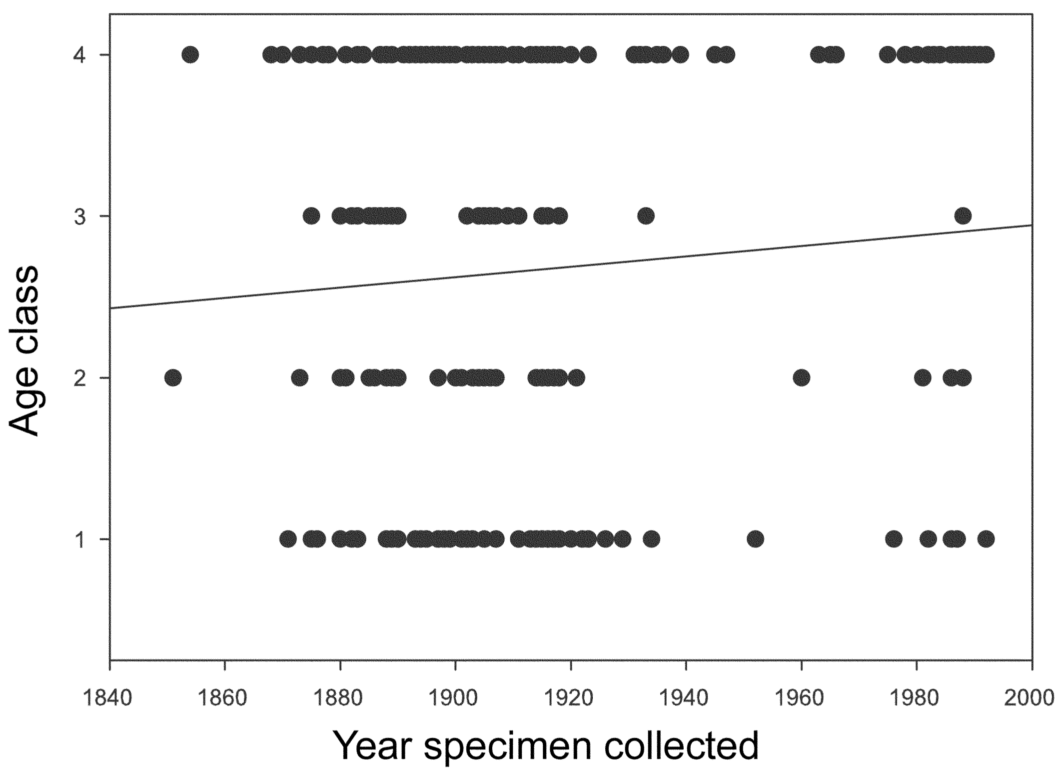

FIG. 2. Gull specimens plotted by year in which they were collected (x-axis) and age class as determined by plumage (y-axis). A linear regression showed a nonsignificant trend (indicated by regression line) between those variables ($r^2 = 0.007$, $F = 1.71$, $P = 0.19$, $n = 242$).

Table 2. Age-class distributions of gull specimens analyzed both by year collected and by proximity of collection location to National Priority Listing (NPL) sites.

	Date specimen collected		Location specimen collected	
Age class	Pre-1930	Post-1930	>16 km to nearest NPL site	<16 km to nearest NPL site
Juvenile–first year	54	14	43	17
Second year	39	5	24	11
Third year	28	3	14	11
Adult	66	34	58	23
One-way chi-square	$\chi^2 = 17.86$ $P = 0.0005$	$\chi^2 = 43$ $P < 0.0001$	$\chi^2 = 33.23$ $P < 0.0001$	$\chi^2 = 6.39$ $P = 0.094$
Two-way χ^2	$\chi^2 = 13.51$ $P = 0.0037$		$\chi^2 = 2.44$ $P = 0.49$	

$t = 0.62$, $P = 0.54$). We also compared mean age classes of birds collected within 16 km of PCB-contaminated NPL sites with those found farther from such sites. Neither birds collected after 1930 ($t = -0.69$, $P = 0.50$, $n = 47$) nor those collected after 1960 ($t = -0.031$, $P = 0.98$, $n = 31$) showed significant age-related plumage differences as a function of proximity to NPL sites. Table 2 shows the distribution of age classes of birds collected both near and far from NPL sites. A one-way chi-square analysis showed a significant deviation in the age-class distribution in gulls collected far from NPL sites ($\chi^2 = 33.23$, df = 3, $P < 0.0001$) but, as mentioned above, that difference was largely attributable to relatively small numbers of second- and third-year birds in our data set. One-way tests on the age-class distribution of birds collected near NPL sites, as well as the two-way comparison of the two groups, revealed no significant differences in age-class distribution (Table 2).

Discussion

Using a broad-scale temporal and geographic approach, we found no evidence that possible exposure to PCBs is linked to accelerated (or delayed) plumage maturation in Herring Gulls or Great Black-backed Gulls in the northeastern United States. Gulls collected before or after the advent of PCBs, or collected near or far from contaminated sites, showed no significant differences in age-related plumage patterns. Our results are generally consistent with those of Quinn et al. (2002), who fed Aroclor 1242 (a mixture of several PCBs) to American Kestrels (*Falco sparverius*) and found no effect on plumage coloration or timing of molt, but differ from McCarty and Secord's (2000) data on Tree Swallows.

One factor that might bias analyses based on study skins is nonrandom collection of specimens with respect to bird age. If museum collectors, particularly those in the 19th century, selectively took mature birds in bright white plumage, that bias might mask any real phenomena attributable to contaminant exposure. The relatively large number of first-year birds collected before 1900 (Fig. 2), however, does not suggest a systematic bias against birds in juvenal plumage. Age distributions before and after 1930 are similar (Table 2), further suggesting no collection bias between the 19th and 20th centuries. Collection bias may explain the paucity of second- and third-year birds in our sample.

More studies, both correlative and experimental (Blus and Henny 1997), are needed to understand the effects of endocrine-disrupting chemicals on bird plumage. To achieve that, additional information will be needed on age-specific bioaccumulation of contaminants (Burger and Gochfeld 1997). If, as McCarty and Secord (2000) found, contamination affects secondary sexual traits, such as plumage, in addition to primary sexual traits, such as gonadal differentiation and gamete production (Crisp et al. 1998), ecotoxicologists may consistently underestimate the population-level consequences of such contamination. If sufficient resolution can be obtained regarding the relationship between contaminant load and plumage maturation rate, field studies employing plumage markers as bioindicators of contamination may make significant, low-cost contributions to risk assessment.

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Appendix. Descriptions of National Priority Listing (NPL) sites included in this study.

	Site name	Known contaminants
1	Newport Naval Education and Training Center (Rhode Island)	Acids, solvents, paint, PCB-contaminated oil
2	Davisville Naval Construction Battalion Center (Rhode Island)	Contaminated oil, paint thinners, PCBs, solvents
3	Raymark Industries (Connecticut)	Asbestos, lead, PCBs
4	Hanscom Air Force Base (Massachusetts)	Chlorinated solvents, jet fuel, PCBs
5	Materials Technology Laboratory (Massachusetts)	PCBs, pesticides, radioactive substances, VOCs
6	Laurel Park (Connecticut)	Hydrocarbons, oils, PCBs, solvents
7	Scovill Industrial Landfill (Connecticut)	Metals, organic chemicals, PCBs
8	Centredale Manor Restoration (Rhode Island)	Dioxins, metals, PCBs, VOCs
9	Salem Acres (Massachusetts)	Arsenic, chromium, PCBs, VOCs
10	Norwood PCBs (Massachusetts)	PCBs
11	Re-Solve, Inc. (Massachusetts)	Acids, solvents, waste oils, PCBs
	Sullivan's Ledge (Massachusetts)	Chlorinated solvents, PCBs, vinyl chloride
12	Gallup's Quarry (Connecticut)	VOCs, semi-VOCs, PCBs
13	Onondaga Lake (New York)	Hydrocarbons, pesticides, PCBs, heavy metals
14	Fulton Terminals (New York)	PCBs, waste oil

Abbreviations: PCB = polychlorinated biphenyl; VOC = volatile organic chemical.