

ORGANOCHLORINE CONTAMINANTS IN FISHES FROM COASTAL WATERS WEST OF AMUKTA PASS, ALEUTIAN ISLANDS, ALASKA, USA

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Abstract—Organochlorines were examined in liver and stable isotopes in muscle of fishes from the western Aleutian Islands, Alaska, in relation to islands or locations affected by military occupation. Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), and rock greenling (*Hexagrammos lagocephalus*) were collected from nearshore waters at contemporary (decommissioned) and historical (World War II) military locations, as well as at reference locations. Total (Σ) polychlorinated biphenyls (PCBs) dominated the suite of organochlorine groups (Σ DDTs, Σ chlordane cyclodienes, Σ other cyclodienes, and Σ chlorinated benzenes and cyclohexanes) detected in fishes at all locations, followed by Σ DDTs and Σ chlordanes; dichlorodiphenyldichloroethylene (*p,p'*DDE) composed 52 to 66% of Σ DDTs by species. Organochlorine concentrations were higher or similar in cod compared to halibut and lowest in greenling; they were among the highest for fishes in Arctic or near Arctic waters. Organochlorine group concentrations varied among species and locations, but Σ PCB concentrations in all species were consistently higher at military locations than at reference locations. Moreover, all organochlorine group concentrations were higher in halibut from military locations than those from reference locations. A wide range of molecular weight organochlorines was detected at all locations, which implied regional or long-range transport and deposition, as well as local point-source contamination. Furthermore, a preponderance of higher-chlorinated PCB congeners in fishes from contemporary military islands implied recent exposure. Concentrations in all organochlorine groups increased with $\delta^{15}\text{N}$ enrichment in fishes, and analyses of residual variation provided further evidence of different sources of Σ PCBs and *p,p'*DDE among species and locations.

Keywords—Fishes Organochlorines Polychlorinated biphenyls congeners Dichlorodiphenyldichloroethylene
Stable isotopes

INTRODUCTION

Remote polar environments are no longer deemed pristine and are sinks for anthropogenic contaminants [1]. Organic, volatile compounds used in agricultural and industrial regions are transported globally via air and water currents [2]. These compounds precipitate into polar environments as warm air masses meet colder air [3]. Certain compounds that are heavier in molecular weight or less volatile (e.g., dichlorodiphenyltrichloroethane [DDT]) are less likely to traverse long distances and may be elevated in polar regions as a result of localized point sources [3,4].

The Aleutian Archipelago (hereafter Aleutians) comprises more than 200 islands that extend from the Alaska Peninsula west toward Asia and geographically separates the North Pacific Ocean from the Bering Sea (Fig. 1). Although isolated, some Aleutian Islands were impacted by military activity from the 1940s to the 1990s. The strategic importance of the Aleutians played a pivotal role during World War II (WWII) and the subsequent Cold War [5]. A major U.S. military facility that supported upward of 6,000 personnel was located on the east side of Adak Island (hereafter Adak), Alaska, from WWII until 1996 (Fig. 1). Amchitka had up to 15,000 troops in WWII,

with continued use by the military and U.S. Department of Energy until the 1970s.

Persistent organochlorine compounds (hereafter organochlorines) detected in the Aleutians probably resulted from the legacy of military activity. In particular, polychlorinated biphenyls (PCBs) for equipment function and DDT for control of ectoparasites were used globally by the military during and after WWII [6,7]. Bald eagles (*Haliaeetus leucocephalus*), glaucous-winged gulls (*Larus glaucescens*), and sea otters (*Enhydra lutris*) had elevated concentrations of organochlorines at islands that had contemporary or recent military activity [8–12]. Organochlorines in sessile, marine invertebrates provided evidence of a point source at these islands (S.L. Reese, U.S. Geological Survey, unpublished Master's thesis). Furthermore, organochlorines in bald eagles and seabirds sampled at islands with WWII or no military activity indicated possible historical or nonpoint contamination [11,12].

Information is lacking on organochlorines in midtrophic consumers that would further clarify sources and effects of contamination in nearshore Aleutian food webs. The purpose of the present study was to document the extent of contamination originating from local versus nonpoint sources in three species of fishes that were common or incidental prey of bald eagles. The primary objective was to compare contaminant concentrations in year-round or seasonally resident coastal fishes from islands (or island locations) of known point-source pollution related to recent military activity with those from

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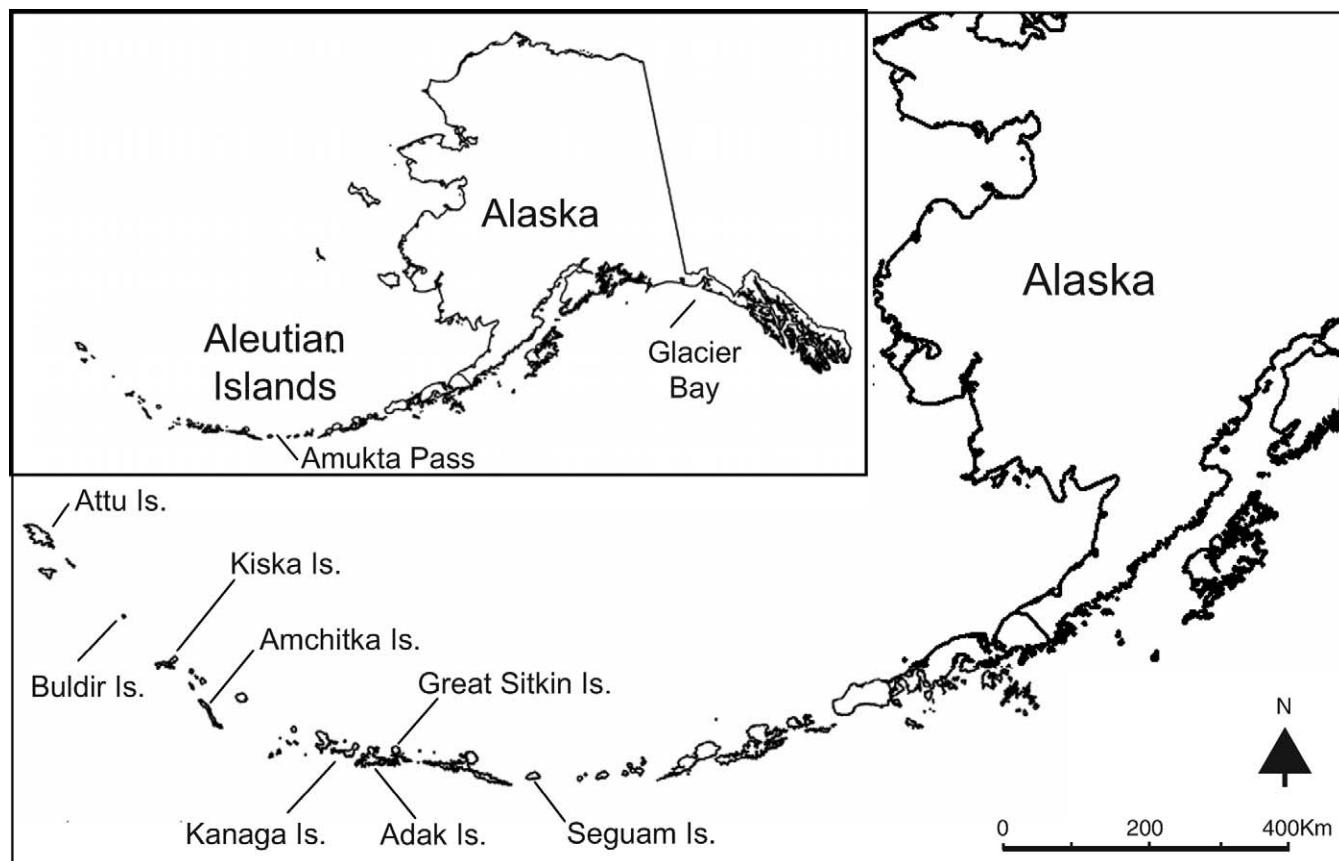


Fig. 1. Islands sampled for nearshore fishes, 1996 to 1997 or 1999 to 2001, Aleutian Archipelago, Alaska, USA; halibut were also sampled at Glacier Bay in 1997.

islands of historical military activity and those with no known 20th century human establishment. Does localized contamination associated with contemporary military activities exceed that from historical (WWII) military activity or possible long-range transport? A subset of samples was also examined for differences in contaminant concentrations among fish species relative to stable isotope analysis of nitrogen signature ($\delta^{15}\text{N}$) and carbon source ($\delta^{13}\text{C}$) [13]. The isotope $\delta^{15}\text{N}$ indicates trophic status [14], where an approximately 4‰ increase equates to a full trophic level step in high-latitude food webs [15]. Marine sources of primary production can be partitioned because nearshore benthic algae have more enriched $\delta^{13}\text{C}$ values than do pelagic phytoplankton [16].

MATERIALS AND METHODS

Sampling strategy

Pacific cod (*Gadus macrocephalus*; hereafter cod), Pacific halibut (*Hippoglossus stenolepis*; hereafter halibut), and rock greenling (*Hexagrammos lagocephalus*; hereafter greenling) were sampled at eight Aleutian Islands and Glacier Bay at least once in the summer from 1996 to 2001 (Fig. 1). Annual island-specific sampling and duration were largely governed by the schedule of the U.S. Fish and Wildlife Service research vessel *Tiglax*. Therefore, the number of samples per species varied over time for each island group. More samples were obtained at east Adak because logistically it was the most accessible of the island locations. Islands or locations were categorized into contemporary military, historical military, and reference island groups. The contemporary group was composed of nearshore sites sampled at east Adak in 1996, 1997,

and 1999 and north Amchitka in 1999 and 2000. These locations were occupied militarily in WWII and afterward as strategic Cold War installations. Historical sites were sampled at east Attu in 2000; east Kiska in 1996, 1997, 2000, and 2001; and west Adak in 1996 and 1999. These locations had documented military activity (e.g., actual combat) during WWII but no postwar activity [5]. Reference sites were sampled at Kanaga in 1996 and 1997, Great Sitkin and Seguam in 1996, and Buldir in 1996, 1997, and 2001. This group was expected to further isolate contaminant patterns indicative of potential long-range transport. Halibut were collected from Glacier Bay in southeast Alaska within the same period (summer 1997) and these samples were included in the reference group. Independence among sampling locations from direct influence of localized contamination was assumed, i.e., a halo effect [1]. Prevailing southwesterly winds or northern ocean currents of the closest sites (east and west Adak [approximately 15 km apart by straight line and 60 km apart by water], Kanaga, and Great Sitkin) indicated little cross-circulation.

Fishes were collected using trammel net, long line, or hook and line and were measured (fork length). At least three sites 1 km or more apart per island location were sampled for 3 to 5 h per species. Whole livers were removed with clean, stainless steel surgical instruments, placed in acid-rinsed I-CHEM™ jars (Thermo Fisher Scientific, Rockwood, TN, USA), and frozen within 2 to 4 h of collection. Capture of multiple specimens was attempted at each site to create composite samples comprising three cod, three halibut, or six greenling. Occasionally, one or two cod or halibut were captured per site, but samples were pooled into respective island

groups for statistical analyses. Although a wide range in size of fish specimens was used for analyses (cod: 40–112 cm; halibut: 51–170 cm; greenling: 15–49 cm) coefficients of variation for size of fish comprising composite samples were low (cod: 13%, halibut: 11%, greenling: 10%). A 6- to 7-g sample of skeletal muscle anterior to the dorsal fin was excised from each fish collected during the 1999 to 2002 period; the sample was then frozen and subsequently analyzed for the isotopes $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Samples for isotope analyses were obtained from the same specimens (individuals or composites) used for contaminant analyses.

Chemical analyses

Liver samples were analyzed by the Geochemical and Environmental Research Group (Texas A&M, College Station, TX, USA) for 27 organochlorines comprising insecticides (or derivatives) and total (Σ) PCBs. Liver samples from halibut at east Adak ($n = 3$), and cod from east Adak ($n = 5$) and Buldir ($n = 4$) collected in 1997 were analyzed for 74 PCB congeners; all liver samples collected from 1999 to 2001 were analyzed for the same 74 congeners.

Tissue samples were prepared for organic analyses as described by MacLeod et al. [17], with minor revisions [18]. Specific details of analytical methods are described in Anthony et al. [11].

The detection limit was 1.0 ng/g for organochlorines and 0.10 ng/g for PCB congeners (wet wt). Standard reference materials (SRM 2261 for organochlorines and SRM 2262 for PCBs) from the National Institute of Standards and Technology (Gaithersburg, MD, USA) of known concentrations were prepared and analyzed with each set of samples to verify instrumental calibration stability. Analytical accuracy and precision were assessed using spiked sample recovery (all which measured within the acceptable range of 75–125%) and duplicate analysis for 10% of the samples. Relative percent difference of duplicate samples averaged 15.2 (standard deviation [SD] = 11.9; 1996 data), 10.5 (SD = 7.7; 1997), and 12.4% (SD = 12.9; 1999–2001) for detected organochlorines, including Σ PCBs, and 13.0 (SD = 9.4; 1997) and 14.7 (SD = 14.0; 1999–2001) for PCB congeners. Quality control and assurance procedures and analytical results were approved by the U.S. Fish and Wildlife Service's Analytical Control Facility (Laurel, MD).

For stable isotope analysis, muscle tissue was first dried in an oven at 60°C for 24 to 48 h and then ground into a fine powder using a mortar and pestle. Lipids were extracted from all samples using prescribed methods [19] to control for effects of high lipid content on carbon isotope ratios [20]. Sample aliquots (1.0–1.5 mg) were analyzed with a Europa Hydra 20/20® continuous flow isotope ratio mass spectrometer (Stable Isotope Facility, University of California, Davis, CA, USA). Stable isotope ratios were expressed in standard delta notation, $\delta X = ((R_{\text{sample}}/R_{\text{standard}}) - 1) \times 1,000$, where δX is the isotope ratio of the sample relative to the standard and R_{sample} and R_{standard} are the fractions of the heavy to light isotopes in the sample and standard, respectively (i.e., $^{13}\text{C}/^{12}\text{C}$ and $^{15}\text{N}/^{14}\text{N}$ [14]). The R_{standard} values are based on PeeDee Belemnite for ^{13}C and atmospheric N_2 for ^{15}N [14].

Data analyses

To facilitate statistical analyses, organochlorines were pooled into groups defined by related parent chemicals, ingredients, byproducts, metabolites, and molecular weight.

These groups were Σ PCBs (equivalent to total Aroclor content), Σ dichlorodiphenylethane (Σ DDT = p,p' DDT, o,p' DDT, dichlorodiphenyldichloroethylene [p,p' DDE], o,p' DDE, dichlorodiphenyldichloroethane [p,p' DDD], and o,p' DDD), Σ chlordane cyclodiene (Σ CHLOR = α and *trans* chlordane, oxychlordane, heptachlor, heptachlor epoxide, and *cis* and *trans* nonachlor), Σ other cyclodienes (Σ CYCLO = aldrin, dieldrin, endrin, mirex, and endosulfan II), and Σ chlorinated benzenes and cyclohexanes (Σ CBCH = hexachlorobenzene; 1,2,3,4- and 1,2,4,5-tetrachlorobenzene; α , β , δ , and γ hexachlorocyclohexane [HCH] isomers; and pentachloroanisole). Noteworthy concentrations of specific compounds are reported. Preliminary evaluation showed that Σ DDTs was predominantly p,p' DDE; therefore, p,p' DDE was statistically analyzed separately due to its known persistence in the environment and documented effects on food webs. Only concentrations greater than the detection limit were included in calculations of group totals to avoid overestimation of rare compounds. For statistical analyses, a value of half the detection limit for a single compound comprising an organochlorine group was substituted when no compounds were detected.

Contaminant concentrations were log-transformed before analysis. A tiered approach was applied to the tests of species, island groups, and temporal differences in organochlorine group concentrations. First, multivariate analysis of variance (ANOVA) was used to test for temporal differences in concentrations among individual islands when an adequate number of composite samples ($n \geq 3$) per sampling period and species was available; this included all three species from east Adak, halibut from Kiska, and cod from Buldir. Years were pooled into two intervals (1996/1997 and 1999–2001, depending on species or location). The time between sampling intervals was not extensive; however, it was suspected that cleanup activities in the late 1990s at east Adak might result in a measurable resuspension of contaminants. Second, multivariate analysis of covariance was used to test for overall differences in organochlorine group concentrations among island groups for each species while controlling for covariate effects. The factor year was not included because most locations did not have multiyear sampling. The length (or mean length for composites) of fishes and percent lipid composition of livers comprising the samples were used as covariates to account for possible effects of these factors on organochlorine concentrations. Assumptions of equal slopes were tested by fitting interactions between categorical treatments and covariates, and insignificant covariates were excluded from subsequent analyses. Covariates were not fitted in the first analysis tier due to inadequate degrees of freedom resulting from low sample size in some cases. One-way ANOVA (first tier) and analysis of covariance (second tier) followed by Tukey Kramer multiple comparison tests were used to determine significant differences in concentrations of specific organochlorines among treatments when mean vectors differed. For the second-tier analysis, island-group differences were interpreted and presented using a back-transformed model based on least-squares means adjusted for significant covariates. Unadjusted geometric mean concentrations are also presented for comparisons to other studies.

Principal components analysis was used to summarize and describe patterns of PCB congener homologues (i.e., the 74 PCB congeners grouped by number of chlorine substituents, from dichlorobiphenyls to decachlorobiphenyls) across species and islands, separating east and west Adak. Concentrations of

PCB homologue groups were normalized by body length (concentration:body length; see results for rationale) and then log_e-transformed. Cumulative percentage of variance (>80%) and eigenvalues greater than 1 were used to determine the number of principal components to retain.

Differences in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values were tested among species and islands sampled during 1999 to 2001 with two-factor ANOVA. Least-squares regression was used to test relationships between organocorine concentrations (normalized by body length and log_e-transformed) and $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values across all species. A two-factor ANOVA was used to determine whether residual variation from regressions between $\delta^{15}\text{N}$ and concentrations of ΣPCBs and *p,p'*DDE differed among species and island groups; positive residuals indicated higher concentrations than expected based on $\delta^{15}\text{N}$, and negative residuals indicated lower concentrations than expected.

Last, the relationship between concentrations of ΣPCBs and *p,p'*DDE in paired liver and muscle (W.M. Jarman, University of Utah, unpublished data) tissue samples ($n = 29$) was examined because one of the goals was to assess relative possible effects of fish contamination on higher-trophic-level consumers.

Organochlorine concentrations are reported in nanograms per gram, wet weight. SAS®, version 8.02 (Cary, NC, USA), was used for all statistical null hypothesis testing, and PC ORD™ 5.10 (MjM Software™, Gleneden Beach, OR, USA) was used for principal components analysis ordination.

RESULTS

Composition and concentrations of organochlorines

Among all organochlorine groups, ΣPCBs made up the highest geometric mean concentrations for all three species of fish, particularly those from contemporary military island groups (Table 1). Concordantly, ΣPCBs made up most of the organochlorine composition in cod (92%) and halibut (91%) at contemporary military compared to historical military (67% cod, 83% halibut) or reference island groups (56% cod, 68% halibut). Total PCBs were 95% of the organochlorines detected in greenling at any island group.

Conversely, ΣDDT made up more of the organochlorines detected in cod (24%) and halibut (16%) from reference island groups than those from historical military (18 and 6%) or contemporary military island groups (4 and 3%). The metabolite *p,p'*DDE was the highest average proportion of ΣDDT in cod (66%), halibut (60%), and greenling (52%), but concentrations within species were relatively similar among island groups (Table 1). Average proportions of *p,p'*DDD and *p,p'*DDT to ΣDDT ranged from 8 to 13% in all species, with higher concentrations in cod from reference and historical military than those from contemporary military island groups (Table 2). Of the *o,p'* class of DDT compounds, only the average proportion of *o,p'*DDT was noteworthy in cod (7%) and halibut (12%), with no clear pattern among island groups. The remaining *o,p'* class compounds were less than 3% of ΣDDT in any species.

Total CHLOR pesticides made up more of the organochlorine composition in cod and halibut from historical military (10% and 4.3%, respectively) and reference (12% and 7%, respectively) than from contemporary military island groups (1–2%). *Trans* nonachlor and α chlordane were detected in more than 50% of cod and halibut samples and were the most elevated of the ΣCHLOR pesticides; these compounds and *cis* nonachlor (detected in 72% of the cod samples) were notably

higher in concentration from historical military and reference than from contemporary island groups (Table 2).

Average ΣCBCH composition of all organochlorines was low for cod (4%), halibut (6%), or greenling (1%), but concentrations of specific compounds were noteworthy. The β and γ HCHs were more elevated at contemporary and historical military than at reference island groups (Table 2). The remaining group ΣCYCLO (other cyclodienes) made up 0 (greenling) to 1% of the total organochlorines detected, with average detected concentrations ranging from 1 to 7 ng/g among specific compounds (Table 2).

Organochlorine group concentrations differed temporally among years for all fish species sampled at east Adak (cod: Wilks' $\lambda = 0.25$, $f_{[d=6,8]} = 3.9$, $p = 0.04$; halibut: $\lambda = 0.08$, $f_{[6,13]} = 24.6$, $p < 0.0001$; greenling: $\lambda = 0.08$, $f_{[6,7]} = 14.2$, $p = 0.001$). The ΣPCB group was higher in 1999 than in 1996/1997 in halibut ($f_{[1,18]} = 19.4$, $p = 0.0003$; 2,566 vs 627 ng/g) and greenling ($f_{[1,12]} = 5.1$, $p = 0.04$; 196 vs 107 ng/g). Other organochlorine groups were also higher in 1999 than in 1996/1997 in halibut ($f_{[1,18]} \geq 20.0$, $p \leq 0.0003$; $\Sigma\text{CBCH} = 148$ vs 15 ng/g; $\Sigma\text{CYCLO} = 30$ vs 6 ng/g) and cod ($f_{[1,13]} \geq 15.0$, $p \leq 0.002$; $\Sigma\text{CBCH} = 62$ vs 12 ng/g; $\Sigma\text{CYCLO} = 22$ vs 4 ng/g) at east Adak. Concentrations of ΣDDT (3–5 ng/g) and ΣCYCLO (2–5 ng/g) increased over time in greenling ($f_{[1,12]} \geq 9.0$, $p \leq 0.01$), but in this case concentrations were less than three times the detection limit. No temporal differences in organochlorine group concentrations in halibut were evident from Kiska ($\lambda = 0.05$, $f_{[6,2]} = 5.8$, $p = 0.2$) or cod from Buldir ($\lambda = 0.02$, $f_{[6,1]} = 8.2$, $p = 0.26$).

Organochlorine group concentrations varied with mean body length for cod ($\lambda = 0.62$, $f_{[6,38]} = 3.9$, $p = 0.004$), halibut ($\lambda = 0.68$, $f_{[6,53]} = 4.2$, $p = 0.002$), and greenling ($\lambda = 0.53$, $f_{[6,25]} = 3.6$, $p = 0.01$) when controlling for difference among island groups. Organochlorine group concentrations did not vary with percent lipid composition, except for greenling ($\lambda = 0.63$, $f_{[6,25]} = 2.5$, $p = 0.05$); as greenling was marginally significant, lipids were not controlled for in ensuing analyses. When length only was included as a covariate, organochlorine group concentrations differed among contemporary, historical, and reference island groups in cod ($\lambda = 0.35$, $f_{[12,76]} = 4.4$, $p < 0.0001$), halibut ($\lambda = 0.50$, $f_{[12,106]} = 3.6$, $p = 0.0001$), and greenling ($\lambda = 0.30$, $f_{[12,52]} = 3.6$, $p = 0.007$). Assumptions of homogeneity of slopes for the relationship between organochlorine group concentrations and fish length by island group were met for cod ($\lambda = 0.59$, $f_{[12,72]} = 1.8$, $p = 0.06$) and greenling ($\lambda = 0.59$, $f_{[12,48]} = 1.2$, $p = 0.3$) but not for halibut ($\lambda = 0.61$, $f_{[12,102]} = 2.0$, $p = 0.03$). The variation in slopes for halibut was apparently driven by a univariate island group by fish length interaction for *p,p'*DDE ($f_{[2,56]} = 3.8$, $p = 0.03$), as all other interactions were not significant ($f_{[2,56]} \leq 1.4$, $p \geq 0.2$).

When controlling for the covariate fish length, certain patterns were evident in organochlorine concentrations by island groups (Fig. 2). Total PCB concentrations in all species were consistently higher at contemporary military island groups than those at historical military or reference island groups. All organochlorine group concentrations were generally higher in halibut from contemporary military islands than from the other island groups. Total CHLOR concentrations were higher in cod at historical military than at contemporary military island groups. Concentrations of *p,p'*DDE differed among island groups for halibut but not for cod or greenling. The difference for halibut appeared confounded by interaction with body

Table 1. Geometric mean concentrations (and ranges, ng/g, wet wt) of organochlorine groups in liver of fishes from the western Aleutian Islands and Glacier Bay, Alaska, USA, 1996 to 2001^a

Species	Island group and island	n	% Lipid	Σ PCBs	Σ DDT	p,p'DDE	Σ CHLOR	Σ CYCLO	Σ CBHC
Pacific cod	Contemporary military								
	East Adak	15	10.9 (0.7–31.2)	885 (95–9,770)	62 (5–252)	42 (5–173)	32 (7–91)	6 (ND–51)	18 (ND–96)
	Amchitka	3	20.2 (6.1–32.3)	1,750 (508–3,510)	95 (75–142)	59 (41–94)	45 (41–48.97)	9 (ND–13)	35 (32–37)
	Historical military								
	West Adak	6	15.9 (0.9–34.3)	411 (243–888)	85 (32–148)	61 (27–106)	49 (26–95)	13 (9–19)	39 (18–67)
	Kiska	4	18.9 (2.5–33.8)	1,080 (875–1,490)	316 (204–526)	226 (149–407)	164 (143–234)	9 (ND–26)	62 (38–86)
	Attu	3	26.7 (9.5–49.1)	365 (267–458)	101 (49–147)	86 (49–115)	55 (24–119)	ND (ND–10)	10 (ND–17)
	Reference								
	Seguam	5	24.2 (2.0–50.0)	345 (94–529)	128 (12–306)	86 (12–155)	87 (13–157)	9 (ND–22)	20 (ND–65)
	Great Sitkin	1	45.2	348	158	81	109	23	54
Pacific halibut	Kanaga	1	1.1	112	54	39	12	5	9
	Buldir	9	36.5 (1.3–61.3)	376 (142–2,320)	130 (34–607)	84 (34–356)	69 (15–349)	13 (ND–41)	35 (ND–153)
	Contemporary military								
	East Adak	20	14.7 (2.7–32.4)	1,180 (172–5,750)	45 (11–123)	21 (7–41)	25 (5–78)	10 (ND–105)	40 (ND–406)
	Amchitka	6	15.6 (2.2–26.0)	1,340 (215–10,200)	55 (22–191)	36 (12–128)	21 (ND–64)	14 (ND–65)	50 (ND–238)
	Historical military								
	West Adak	7	14.3 (7.0–22.4)	1,220 (390–1,980)	35 (18–62)	20 (12–36)	45 (12–160)	20 (9–70)	91 (38–178)
	Kiska	10	21 (4.2–49.2)	335 (90–1,090)	40 (ND–130)	30 (ND–69)	19 (ND–69)	6 (ND–20)	20 (ND–101)
	Attu	6	18.2 (6.2–33.6)	286 (83–1,490)	14 (ND–96)	15 (ND–66)	8 (ND–77)	6 (ND–27)	16 (ND–110)
	Seguam	2	25.1 (22.4–27.8)	243 (233–253)	102 (100–104)	40 (38–42)	59 (57–62)	12 (8–17)	32 (30–34)
Rock greenling	Kanaga	1	19	233	84	50	31	8	31
	Reference								
	Buldir	6	21.9 (14.6–29.5)	195 (111–669)	13 (ND–48)	14 (ND–28)	ND	ND	7 (ND–51)
	Glacier Bay	4	12.1 (10.3–14.5)	159 (72–347)	31 (20–40)	22 (15–33)	22 (13–30)	7 (6–8)	22 (15–28)
	Contemporary military								
Rock greenling	East Adak	14	2.8 (1.4–4.7)	130 (58–294)	4 (ND–7)	2 (ND–5)	3 (ND–7)	2 (ND–2)	3 (ND–12)
	Amchitka	3	4.4 (2.4–5.6)	174 (87–615)	6 (ND–11)	ND (ND–11)	5 (ND–5)	ND	ND
	Historical military								
	West Adak	8	3.4 (1.5–10.6)	83 (19–236)	3 (ND–6)	2 (ND–5)	5 (ND–11)	4 (ND–7)	7 (ND–15)
	Kiska	4	6.3 (2.7–13.3)	23 (ND–58)	5 (ND–7)	5 (ND–5)	5 (ND–6)	ND	3 (ND–1)
	Attu	3	5.4 (3.3–8.1)	66 (58–77)	ND	ND	ND	ND	ND
	Reference								
	Buldir	3	3.5 (2.6–4.8)	11 (ND–72)	ND	ND	ND	ND	ND

^a n = number of composite samples; Σ PCBs = polychlorinated biphenyls; Σ DDT = dichlorodiphenylethane (Σ DDT does not include p,p'DDE); p,p'DDE = dichlorodiphenyldichloroethylene; Σ CHLOR = chlordane cyclodiene; Σ CYCLO = other cyclodienes; Σ CBHC = chlorinated benzenes and cyclohexanes; ND = not detected.

length: when compared to reference island groups, the rate of increase in p,p'DDE concentrations with body size was significant at historical ($t_{[1]} = 2.7$, $p = 0.008$) but not at contemporary military island groups ($t_{[1]} = 1.8$, $p = 0.07$). Overall, most organochlorine concentrations (except PCBs) were near or below detection limits in greenling (Fig. 2).

Concentrations of Σ PCBs and p,p'DDE were positively correlated in paired liver and muscle tissues across all species

(Σ PCBs: $t_{[27]} = 3.4$, $p = 0.002$, $r^2 = 0.27$; p,p'DDE: $t_{[27]} = 5.2$, $p < 0.0001$, $r^2 = 0.48$). Within species, Σ PCB concentrations were correlated in liver and muscle of cod ($t_{[8]} = 3.4$, $p = 0.009$, $r^2 = 0.51$) and halibut ($t_{[9]} = 3.4$, $p = 0.009$, $r^2 = 0.50$) and marginally correlated in greenling ($t_{[6]} = 2.1$, $p = 0.08$, $r^2 = 0.34$). Concentrations of p,p'DDE were marginally correlated in liver and muscle of halibut ($t_{[9]} = 1.9$, $p = 0.08$, $r^2 = 0.30$).

Table 2. Geometric means (ng/g, wet wt) of common compounds comprising organochlorine groups (dichlorodiphenylethane [DDT], chlordanes, chlorinated benzenes and cyclohexanes [CBCH], and other cyclodienes [CYCLO]) in fish livers collected between 1996 and 2001 at western Aleutian Islands and Glacier Bay (halibut, reference group only), Alaska, USA^a

Compound	Island groups and species								
	Contemporary military			Historical military			Reference		
	PC (n = 18)	PH (n = 26)	RG (n = 17)	PC (n = 13)	PH (n = 23)	RG (n = 15)	PC (n = 16)	PH (n = 13)	RG (n = 3)
DDT									
<i>p,p'</i> DDD	9.9	8.2	1.3	18.8	6.0	1.9	16.2	5.8	ND
<i>p,p'</i> DDT	4.3	3.8	1.0	10.7	5.8	ND	11.8	6.4	ND
<i>o,p'</i> DDT	4.5	8.5	1.0	6.4	6.8	ND	8.6	5.9	ND
<i>o,p'</i> DDD	3.8	2.1	1.0	5.4	4.4	ND	5.0	2.8	ND
<i>o,p'</i> DDE	2.0	1.9	1.0	3.9	4.1	ND	3.1	2.4	ND
Chlordanes									
<i>trans</i> Nonachlor	17.2	8.9	1.6	38.5	9.2	3.0	30.3	8.5	ND
α Chlordane	5.9	6.2	1.5	16.1	12.0	3.0	20.3	7.3	ND
<i>cis</i> Nonachlor	4.3	2.8	1.6	9.4	4.8	3.0	9.0	3.4	ND
Oxychlordane	3.9	3.6	1.5	6.7	3.5	2.9	6.8	4.0	ND
γ Chlordane	2.5	2.6	1.0	5.0	5.3	2.1	4.3	3.0	ND
Heptachlor epoxide	2.3	2.7	1.1	4.7	3.7	1.9	3.6	4.2	ND
Heptachlor	1.6	2.0	ND	3.3	3.6	ND	1.7	3.1	ND
CBCH									
γ HCH	6.6	19.7	1.1	11.4	23.2	2.7	5.3	8.7	ND
β HCH	4.8	16.3	1.2	8.9	8.9	2.6	7.5	4.9	ND
α HCH	3.5	4.2	1.4	6.3	4.9	2.7	7.4	4.7	ND
HCB	5.3	4.2	1.8	12.2	6.0	2.9	ND	6.9	ND
CYCLO									
Aldrin	2.6	3.8	1.0	4.7	6.4	2.2	1.5	2.5	ND
Dieldrin	2.7	3.8	ND	5.4	4.6	ND	7.2	5.5	ND
Endrin	1.8	3.1	1.0	3.6	5.2	2.0	2.7	2.3	ND
Mirex	2.3	2.0	ND	4.7	4.1	1.8	3.2	2.6	ND
Endosulfan	2.5	3.3	ND	5.3	4.6	ND	3.2	3.0	ND

^a Contemporary = east Adak, Amchitka; historical = west Adak, Kiska, Attu; reference = Buldir (all species), Kanaga, Seguam (cod, halibut only), Great Sitkin (cod only), Glacier Bay (halibut only); PC = Pacific cod; PH = Pacific halibut; RG = rock greenling; *n* = number of samples; DDD = dichlorodiphenyldichloroethane; DDE = dichlorodiphenyldichloroethylene (see Table 1 for *p,p'*DDE concentrations); HCH = hexachlorocyclohexane; HCB = hexachlorobenzene; ND = not detected.

PCB congeners

Eighty-four percent of the cumulative variation in concentrations among PCB homologue groups was explained by two principal components (Fig. 3). Axis 1 (59%) was positively correlated with all homologues, particularly the highly chlorinated and persistent hexa-, hepta-, and octachlorobiphenyl groups ($r_s \geq 0.67$), whereas Axis 2 (25%) was negatively correlated with less chlorinated (\leq tetrachlorobiphenyl) groups ($r_s \geq -0.59$). Species were variable in ordination space; however, notable island separation occurred along the diagonal between Axis 1 and Axis 2. Fishes from contemporary military islands were associated with a gradient of higher overall concentrations of heavier-chlorinated congeners, whereas fishes from historical military and reference islands were more strongly associated with less chlorinated ones. Separation along Axis 2 was strongest for PCB congeners in cod and halibut sampled in 1996 and 1997.

Stable isotopes

Values of $\delta^{15}\text{N}$ in fishes collected from 1999 to 2001 differed significantly among species ($f_{[2,54]} = 39.4$, $p < 0.0001$) and islands ($f_{[5,54]} = 4.1$, $p = 0.003$), and differences among species were consistent among islands (species · island: $f_{[10,54]} = 1.6$, $p = 0.1$; Table 3). Mean $\delta^{15}\text{N}$ was highest in cod (14.0%), followed by halibut (12.8%) and greenling (12.1%). Mean $\delta^{15}\text{N}$ was lower at Buldir than at all other islands.

Values of $\delta^{13}\text{C}$ also differed among species ($f_{[2,54]} = 13.4$, $p < 0.001$) and islands ($f_{[5,54]} = 32.5$, $p < 0.001$), but species

differences were confounded by island effects (species · island: $f_{[10,54]} = 2.3$, $p = 0.02$); thus, differences among islands were tested separately for each species. Values of $\delta^{13}\text{C}$ differed significantly among islands for each of these species (cod: $f_{[5,15]} = 17.9$, $p < 0.0001$; halibut: $f_{[5,26]} = 18.3$, $p < 0.0001$; greenling: $f_{[5,13]} = 9.2$, $p = 0.006$), where generally $\delta^{13}\text{C}$ was more depleted in fishes from Attu and Buldir than those from east or west Adak and intermediary in specimens from Kiska and Amchitka (Table 3).

The relationship of $\delta^{15}\text{N}:\delta^{13}\text{C}$ indicated that cod occupied a higher trophic position and had less of a nearshore signature than halibut or greenling (Fig. 4). Halibut occupied an intermediate trophic position, and $\delta^{13}\text{C}$ indicated more variable energy sources. Greenling occupied a lower trophic position and had carbon signatures indicative of nearshore benthic production.

Enrichment of $\delta^{15}\text{N}$ was positively correlated with concentrations of ΣPCBs ($p < 0.0001$, $r^2 = 0.28$) and *p,p'*DDE ($p \leq 0.0001$, $r^2 = 0.27$) across all fish species. Values of $\delta^{15}\text{N}$ were similarly correlated and predictable with organochlorine groups ΣDDT (without *p,p'*DDE) and ΣCBCH (both groups = $p \leq 0.0001$, $r^2 = 0.28$) and even more so with ΣCHLOR ($p < 0.0001$, $r^2 = 0.45$) but were less so with ΣCYCLO ($p = 0.004$, $r^2 = 0.11$). Concentrations of ΣPCBs also were positively correlated to $\delta^{13}\text{C}$ values ($p < 0.008$, $r^2 = 0.09$), and those of *p,p'*DDE were inversely related to $\delta^{13}\text{C}$ ($p < 0.008$, $r^2 = -0.09$); however, little variability was explained by the relationship. Similarly, values of $\delta^{13}\text{C}$ were positively corre-

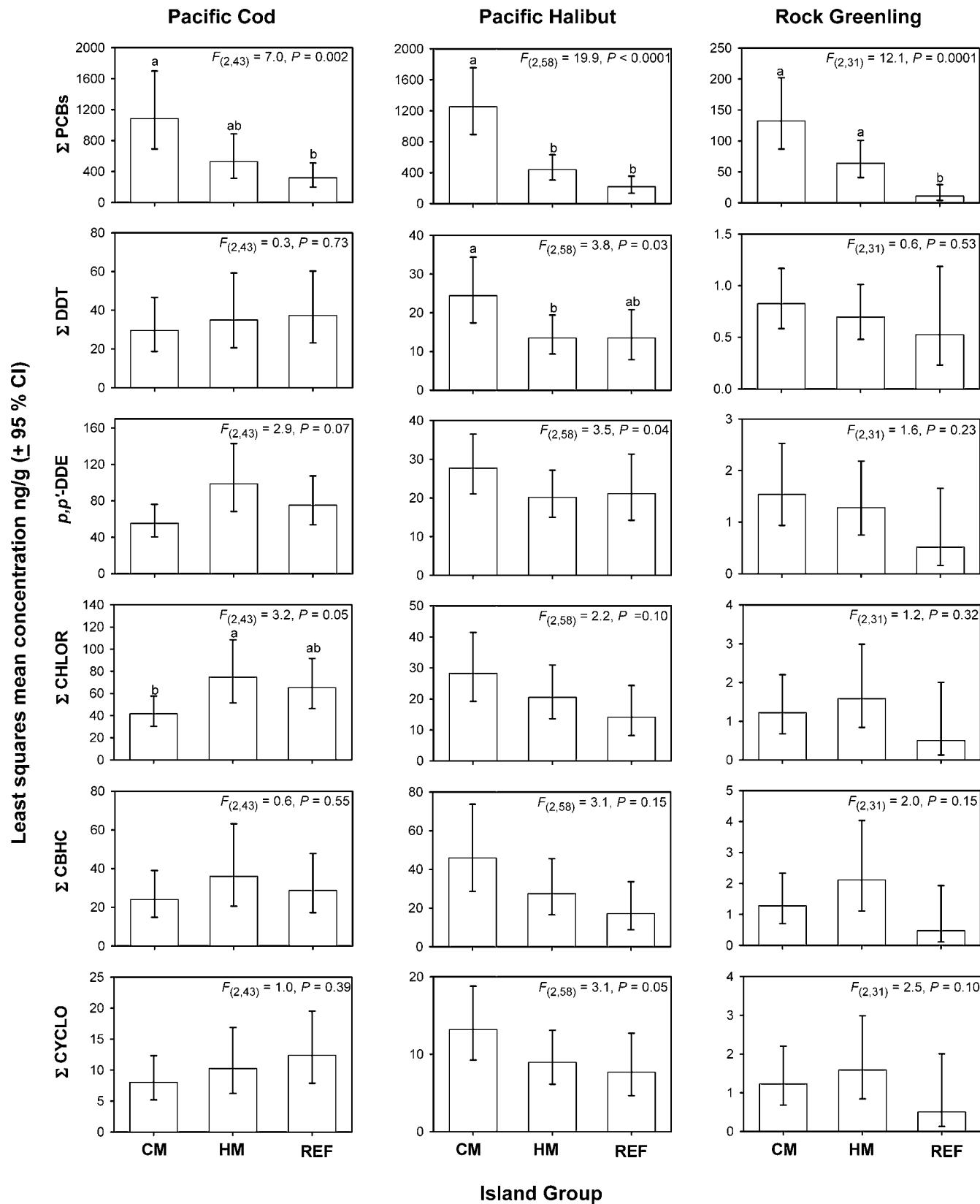


Fig. 2. Body size-adjusted least-squares mean concentrations (ng/g, wet wt) ($\pm 95\%$ confidence interval [CI]) of organochlorine groups in Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), and rock greenling (*Hexagrammos lagocephalus*) from contemporary military (CM), historical military (HM), and reference locations (REF), western Aleutian Archipelago, Alaska, USA, 1996 to 2001. Similar lowercase letters or no letters denote no significant difference (two-factor analysis of variance, Tukey Kramer multiple comparison tests). Note the difference in scale of the y axis. Σ PCBs = total polychlorinated biphenyls, Σ DDT = dichlorodiphenylethane, Σ p,p'DDE = dichlorodiphenyl dichloroethylene, Σ CHLOR = chlordane cyclodiene, Σ CBCH = chlorinated benzenes and cyclohexanes, and Σ CYCLO = other cyclodienes.

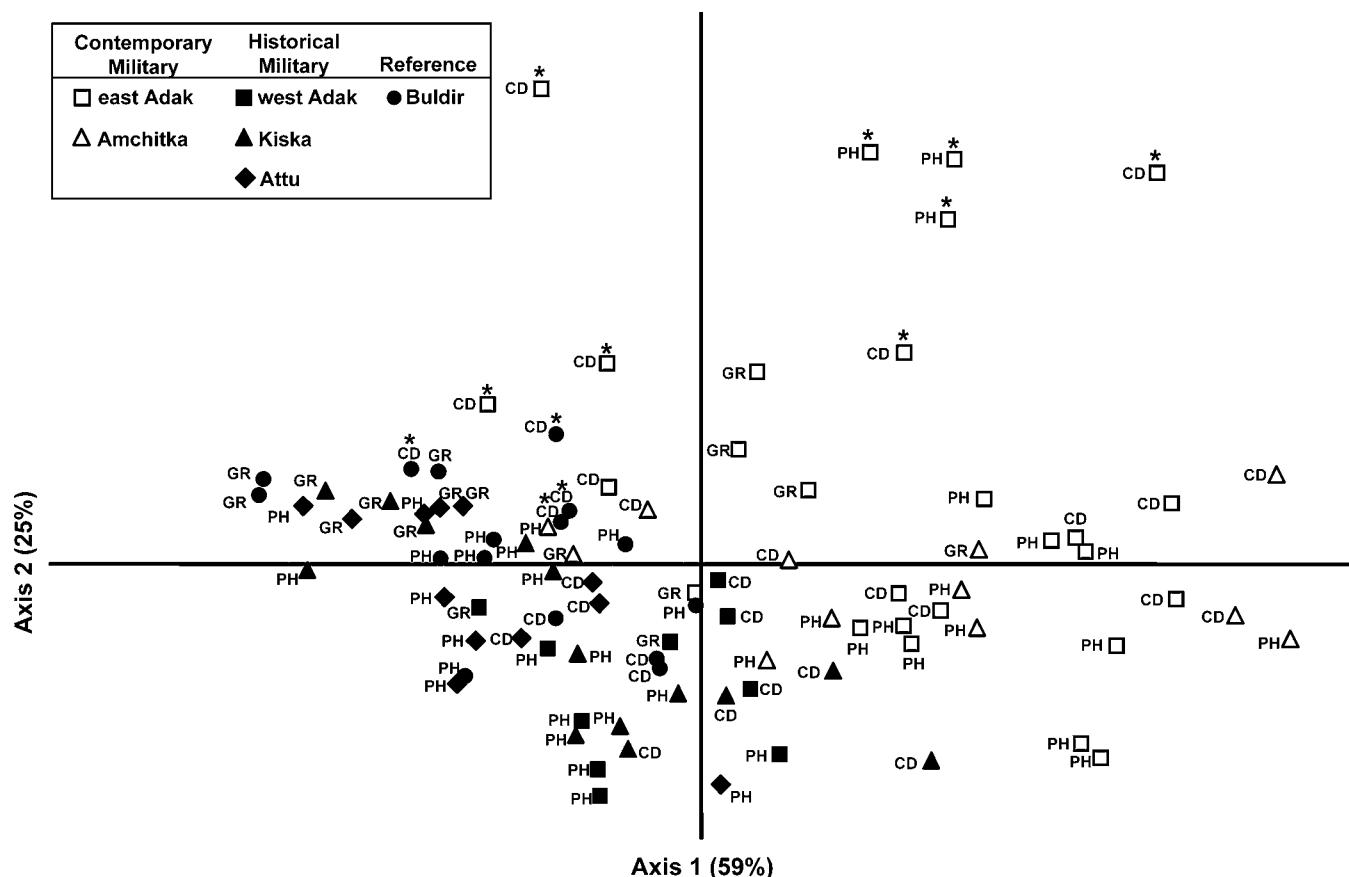


Fig. 3. Principal components ordination of body length-adjusted concentrations of polychlorinated biphenyl (PCB) homologue groups in Pacific cod (PC = *Gadus macrocephalus*), Pacific halibut (PH = *Hippoglossus stenolepis*), and rock greenling (RG = *Hexagrammos lagocephalus*) correlated with locations, western Aleutian Archipelago, Alaska, USA, 1996 to 2001. Axis 1 indicates increasing concentrations for all PCB homologue groups, most strongly correlated with hexa-, hepta-, and octachlorobiphenyl groups, and Axis 2 indicates a negative correlation with no more than tetrachlorobiphenyl groups. Asterisks (*) above symbols indicate samples from 1996 to 1997.

Table 3. Stable nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$) isotopes (‰) in muscle of fishes from nearshore Aleutian Islands, Alaska, USA, 1999 to 2002^a

Species	Island group ^b	Island	n	$\delta^{15}\text{N}^c$				$\delta^{13}\text{C}^d$			
				Mean	SD	Min	Max	Mean	SD	Min	Max
Pacific cod	CM	East Adak	5	13.9 A	0.7	12.7	14.5	-17.0 A	0.2	-17.2	-16.8
		Amchitka	3	14.1 A	0.4	13.8	14.5	-17.1 AB	0.6	-17.7	-16.7
		West Adak	3	14.3 A	1.0	13.6	15.4	-17.1 AB	0.9	-17.8	-16.1
	HM	Kiska	4	14.1 A	0.5	13.6	14.7	-18.9 C	0.1	-19.0	-18.8
		Attu	3	14.4 A	0.6	13.7	15.0	-18.1 BC	0.4	-18.5	-17.7
		REF	3	13.3 B	1.1	12.1	14.2	-19.1 C	0.1	-19.2	-19.0
Pacific halibut	CM	East Adak	7	13.2	0.8	12.5	14.6	-15.9 A	0.5	-16.4	-15.2
		Amchitka	4	13.5	0.8	12.3	14.1	-16.7 AB	0.6	-17.5	-16.2
		West Adak	5	13.4	0.9	12.4	14.8	-16.8 AB	0.7	-17.4	-15.6
	HM	Kiska	4	12.5	0.7	11.7	13.1	-17.1 AB	0.3	-17.5	-16.7
		Attu	6	12.8	0.4	12.1	13.2	-17.6 B	0.6	-18.6	-16.9
		REF	6	11.3	0.9	10.8	13.1	-19.1 C	0.4	-19.4	-18.4
Rock greenling	CM	East Adak	5	12.5	0.4	12.1	12.9	-16.1 A	0.7	-17.5	-15.2
		Amchitka	3	11.6	0.3	11.4	12.0	-17.0 AB	0.8	-17.8	-16.2
		West Adak	2	12.0	0.6	11.5	12.4	-16.6 A	0.6	-17.0	-16.2
	HM	Kiska	3	11.9	0.8	11.2	12.7	-17.0 AB	0.4	-17.4	-16.6
		Attu	3	12.6	0.3	12.3	12.9	-17.7 B	0.4	-18.1	-17.4
		REF	3	11.7	0.8	10.8	12.2	-18.1 B	0.2	-18.3	-18.0

^a Isotopes values among species and islands were compared using analysis of variance (ANOVA).

^b CM = contemporary military; HM = historical military; REF = reference island; n = number of samples; SD = standard deviation; min = minimum; max = maximum.

^c The interaction term for $\delta^{15}\text{N}$ was not significant; therefore, differences among islands are assumed to be similar across species and mean separations are displayed for cod only. Means with different capital letters differ significantly.

^d The interaction term for $\delta^{13}\text{C}$ was significant; therefore, univariate ANOVA and Tukey Kramer multiple comparison tests were conducted for each species by islands.

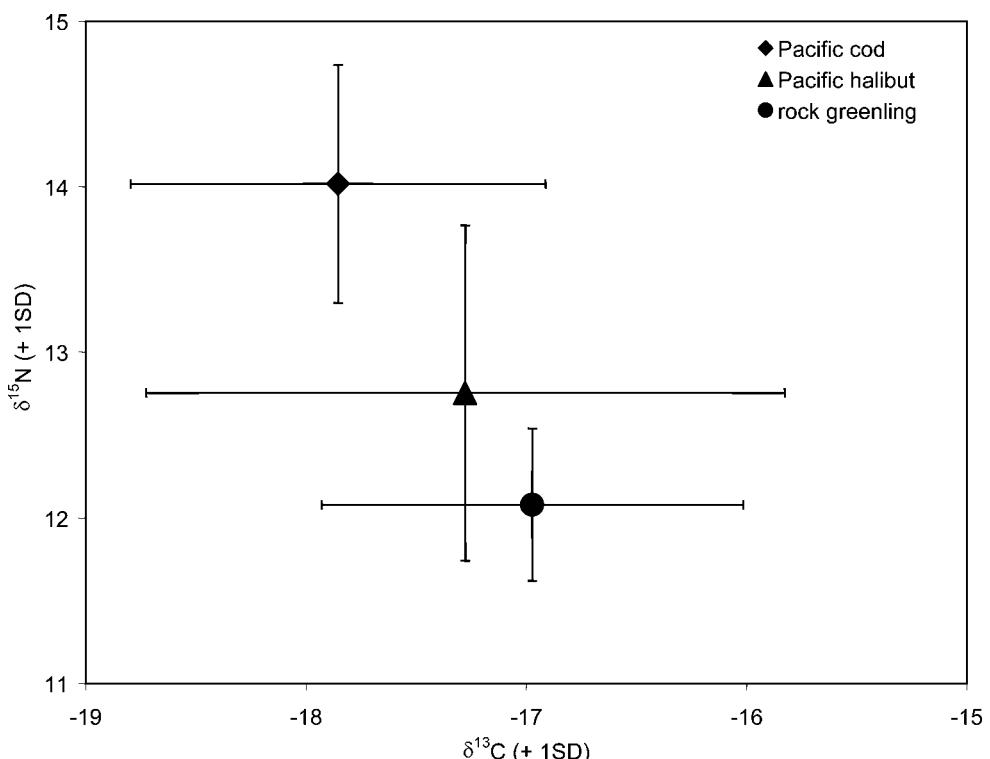


Fig. 4. The relationship of mean stable nitrogen ($\delta^{15}\text{N}$) to carbon ($\delta^{13}\text{C}$) isotope in Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), and rock greenling (*Hexagrammos lagocephalus*), western Aleutian Archipelago, Alaska, USA, 1996 to 2001.

lated with concentrations of ΣCBCH and ΣCYCLO ($p \leq 0.008$, $r^2 \geq 0.09$) but not with ΣDDT and ΣCHLOR ($p \geq 0.4$, $r^2 \leq 0.00$), and predictability was poor in all cases.

Residual variation from the regression of ΣPCBs against $\delta^{15}\text{N}$ varied among species ($f_{[2,67]} = 6.8$, $p = 0.002$) and island groups ($f_{[2,67]} = 20.8$, $p < 0.0001$). Residuals were significantly higher for halibut and cod than for greenling and for contemporary military than for historical military and reference island groups (Fig. 5). For p,p' DDE against $\delta^{15}\text{N}$, residuals varied among species ($f_{[2,67]} = 13.4$, $p = 0.001$) but not by island group ($f_{[2,67]} = 2.6$, $p = 0.08$). Unlike the species pattern for ΣPCBs , residuals were significantly higher for cod than for halibut and greenling (Fig. 5). Interactions between species and island group were not significant for either ΣPCBs or p,p' DDE ($f_{[4,63]} \leq 2.1$, $p \leq 0.09$).

DISCUSSION

Organochlorines

Organochlorines in fishes from the northern Atlantic and freshwater lakes in the Arctic region are well documented [21], and a few studies report on walleye pollock (*Theragra chalcogramma*) from the northern Pacific or Bering Sea [22–24]. No reports were found on species similar to those of the present study that inhabit nearshore waters seasonally or year-round in the northern Pacific, near-Arctic region. Generalized patterns of organochlorine concentrations in all three species in the present study indicated long-range, as well as localized, input. Concentrations of certain pesticides or groups of pesticides were more elevated at historical military and reference island groups than at contemporary military locations; this infers contamination from either global sources or possibly regional distribution from localized input over time. Total PCBs made up the majority of organochlorines detected at all

locations, and localized influence from contemporary military facilities was strongly evident in all three species. The predominance of heavier-chlorinated PCB congeners at contemporary military locations signified localized discharge, whereas that of lighter-chlorinated congeners at historical and reference locations implied possible long-range transport. Moreover, the pattern of contamination in halibut indicated an overall influence of contemporary military activity for all organochlorine groups, with inferred significance ($p \leq 0.05$) for three of the five groups examined, as well as possible inference for the cyclodiene pesticides ($p = 0.05$ –0.15).

Consistently higher concentrations of organochlorines in halibut from military versus reference locations indicated that halibut were probably more representative (and thus a better indicator) of location-specific contamination than were cod or greenling. Halibut and cod are both bottom-dwelling fishes, but most halibut were captured at shallower depths or closer nearshore than cod. Hooge and Taggart [25] reported a very small, summer season home range (95% kernel home range averaged 0.37 km^2) for halibut in southeast Alaska waters, and similar to cod, move seasonally to deeper waters with minimal alongshore movement [26]. Greenling primarily inhabited the more limited area of kelp forests that overlaid rocky substrate. Thus, organochlorine patterns and subsequent liver accumulation for halibut may indicate greater influence of contamination, at least during the summer seasons (when the present study sampling was conducted), from localized or contemporary human occupation of the Aleutians. The Arctic Monitoring and Assessment Program studies [21] also suggested that elevated contamination in the near-arctic Aleutian waters was probably influenced more by localized, military-related sources than by long-range transport.

Organochlorine concentrations observed in the present

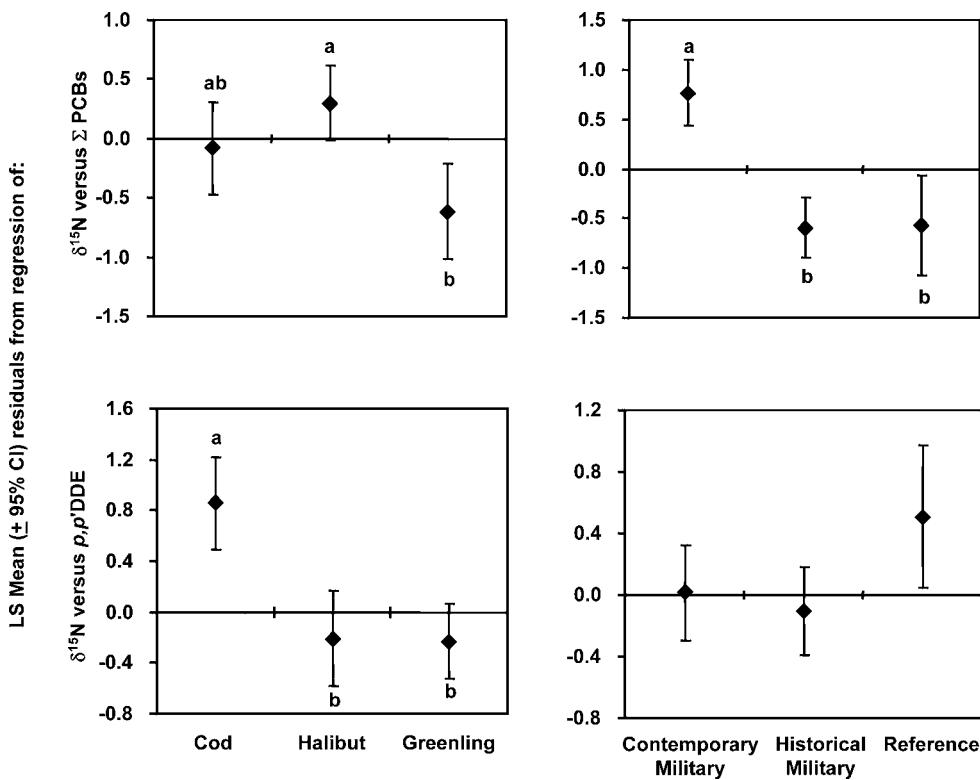


Fig. 5. Least-squares (LS) mean residuals ($\pm 95\%$ confidence interval [CI]) from the regressions of $\delta^{15}\text{N}$ against total polychlorinated biphenyls (ΣPCBs) and dichlorodiphenyldichloroethylene ($p,p'\text{DDE}$) by species and island groups for fishes collected in the western Aleutian Archipelago, Alaska, USA, 1996 to 2001. Similar lowercase or no letters denote no significant difference detected by two-factor analysis of variance and Tukey Kramer multiple comparison tests. Note the difference in scale of the y axis.

study cannot be directly related to those in other studies of north Pacific or Bering Sea fishes because of the apparent influence of interspecific, geographical, temporal, or individual-biology differences on lipid content of livers of fishes in the present study. A much higher variability was found in lipid content among individuals than was generally reported from other studies, which suggested caution against using an average lipid weight for calculation of lipid weight or conversion from wet to lipid weight. Mindful of this, wet weight- or lipid weight-adjusted concentrations in liver detected in the present study were comparable to those reported for fishes in high Arctic waters [27–29]. This was contrary to expectations based on the Arctic Monitoring and Assessment Program [21], which indicated cleaner atmospheric deposition over the Aleutians relative to the higher Arctic waters. Evidently, the western Aleutians were affected by local and regional events; alternatively, global input may be more of an issue in this region than suggested [9,12]. Concentrations generally were expected to be higher in cod and halibut that prey on walleye pollock [30]. Total PCBs were approximately 2 to 10 times higher, ΣDDTs 1 to 5 times higher, and ΣHCHs 1 to 3 times higher in cod and halibut than in walleye pollock [22].

The occurrence of a wide range of molecular weight organochlorines in fishes from (former) military and reference locations implied long-range transport and deposition, as well as regional or local point-source contamination. Migratory colonial seabirds, suspected of long-range transport of organochlorines that may transfer to other trophic levels [12,31], and cod at Kiska (historical military island) had elevated $p,p'\text{DDE}$ concentrations. However, biological contribution from birds was not evident in halibut or greenling from Kiska, nor was

it apparent in fishes from Buldir, where breeding colonies numbered approximately 4 million birds, twice that of Kiska (J.C. Williams, U.S. Fish & Wildlife Service, unpublished survey data).

Elevated PCB concentrations in halibut and cod at east Adak, specifically at Sweeper Cove, may have been associated with morphological anomalies. It was observed that some (one year as much as 50%) of the cod and halibut captured at this site had mouth tumors or improper development of the morphology of the head, whereas no other fishes collected in the present study from other locations had similar anomalies (A.K. Miles, unpublished data). Sweeper Cove may contain elevated petroleum contamination associated with an active fuel dock operated at that location since WWII. Concentrations of certain PCB congeners or organochlorines detected in the present study generally have been associated with morphological, physiological, or biochemical effects in fishes [32]. Furthermore, PCBs and other organochlorines that were more elevated in halibut and cod in 1999 than 1996/1997 were probably related to resuspension of organochlorines associated with remediation cleanup activities instituted at Sweeper Cove in the late 1990s.

In the present study, the weathered form of chlordane (α) was much more common than *trans* chlordane, which is indicative of recent deposition from a point source [33]. These findings were consistent with those in a related study of seabirds [12]. Furthermore, it was not surprising that *trans* nonachlor dominated the chlordanes detected, as this compound is considered the most bioaccumulative of the chlordanes in fish tissues, often exceeding human health recommendations for consumption. Concentrations of α chlordane and *trans* non-

achlor are reportedly the highest and most persistent of chlordane components detected in fish tissue in industrialized areas [34,35], and the present study indicated similar findings for remote regions. Notably, all chlordane compounds were common, particularly in cod and halibut from all island groups.

Higher organochlorine concentrations were expected in halibut than in cod because a greater proportion of the halibut diet is fish [30]; furthermore, cod and other fishes were common in stomach contents of halibut, whereas invertebrates were common in cod in the present study. However, the mean (regardless of island group) concentrations of Σ CHLOR and p,p' DDE were two to three times higher in cod than in halibut, which supported our findings on stable isotopes; the remaining organochlorine groups, including Σ DDT (exclusive of p,p' DDE), were comparable in cod and halibut, and all were lower in greenling. Levels of lipids in the liver of these fishes were not related to interspecific organochlorine differences. Ricca et al. [20] found similar average muscle lipid content in fishes from the present study, which was actually slightly higher in halibut ($6.6\% \pm 0.2$) and greenling ($5.5\% \pm 0.2$) than cod ($5.4\% \pm 0.2$).

Stable isotopes

Results for $\delta^{15}\text{N}$ indicated that cod foraged at a higher trophic position relative to halibut or greenling at all islands. These species differences were not likely confounded by variation in isotopic baselines among islands because $\delta^{15}\text{N}$ values were similar among all islands except Buldir. However, the mean difference in $\delta^{15}\text{N}$ among species ($\leq 2.5\%$ in fishes from the same island locations) was less than the approximately 4% increase between trophic levels typical in high-latitude marine food webs [15]. All three species are opportunistic feeders. Cod and halibut range seasonally from nearshore to offshore and feed on pelagic fishes that venture near the bottom, as well as crustaceans [30]; greenling are resident and eat mostly invertebrates but also consume algae and small fishes or eggs in nearshore kelp forests [36]. The $\delta^{13}\text{C}$ results indicated that cod foraged slightly further offshore than halibut or greenling during the summer months (when skeletal muscle samples were collected), yet $\delta^{13}\text{C}$ signatures in all species more closely matched values characteristic of nearshore (approximately -17%) than pelagic habitats (approximately -22%) [14,16]. Furthermore, values of $\delta^{13}\text{C}$ generally were more depleted in fishes from the westernmost Aleutians. This isotope also tends to be depleted in zooplankton in the western Aleutians [37]. Therefore, absolute inferences between nearshore and pelagic feeding differences in values of $\delta^{13}\text{C}$ among islands may be confounded by the lack of a baseline correction for $\delta^{13}\text{C}$. This may explain the higher variation in mean $\delta^{13}\text{C}$ values (Fig. 4), as well as the lack of a strong relationship between organochlorine groups and $\delta^{13}\text{C}$.

Concentrations of organochlorine groups were correlated with $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$. Although trophic separation as indicated by $\delta^{15}\text{N}$ was limited among the fish species and the relationships (r^2) to organochlorines were fair, the positive correlation of $\delta^{15}\text{N}$ enrichment and increased organochlorine accumulation was consistent across all organochlorine groups and was consistent with other studies [12,13]. Relative to cod, however, halibut had lower p,p' DDE concentrations than expected based on trophic position. These variable patterns may indicate different sources of contaminant exposure for halibut and cod. In particular, positive mean residuals for Σ PCBs in halibut may indicate more point-source exposure. In contrast, lower

mean residuals for p,p' DDE in halibut may indicate less point-source exposure when compared to the highly positive mean residuals for p,p' DDE in cod. By island group, residual variation from the regression of $\delta^{15}\text{N}$ against Σ PCBs indicated that fishes from contemporary military islands had significantly higher concentrations of Σ PCBs than expected based on trophic position and provides further evidence of point-source exposure at these islands. The predictability or relationships (r^2) were poor in most cases of organochlorines and $\delta^{13}\text{C}$. This indicated little to none of the variability was explained by the correlations. Thus, little if any relationship can be inferred from the present study between organochlorine concentrations and $\delta^{13}\text{C}$ values.

Food web implications

The present study indicated that organochlorines remain common in the midtrophic levels of food webs of remote, near-polar locations, as well as the potential for effects on upper trophic levels. Importantly, Pacific cod and Pacific halibut are commercially valued finfish. Although greenling, which were the most common prey of eagles of the fish species studied, had low concentrations of organochlorines relative to cod and halibut, developmental problems in American kestrels (*Falco sparverius*; used commonly as a surrogate species for bald eagles) were associated with dietary PCB concentrations at 50 ng/g or greater [38]. This concentration is far lower than that detected in some greenling sampled at both historical and contemporary military sites. Furthermore, concentrations in samples from point sources of pollution such as Sweeper Cove far exceeded cautionary environmental levels. Productivity problems in bald eagles have yet to be detected in the Aleutians, where our fish samples were collected [11], but continued monitoring of this remote region is warranted because of the persistence of elevated organochlorines in this system.

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