Food Chain Sources of Polychlorinated Dioxins and Furans to Great Blue Herons (Ardea herodias) Foraging in the Fraser River Estuary, British Columbia

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Technical Report Series No. 169
Pacific and Yukon Region 1995
Canadian Wildlife Service

This series may be cited as:

Harfenist, A., P.E. Whitehead, W.J. Cretney and J.E. Elliott. 1995. Food chain sources of polychlorinated dioxins and furans to Great Blue Herons (Ardea herodias) foraging in the Fraser River Estuary, British Columbia.
Technical Report Series No. 169.
Canadian Wildlife Service,
Pacific and Yukon Region,
British Columbia

Issued under the Authority of the
Minister of Environment
Canadian Wildlife Service

Catalogue No. CW69-5-169E
ISBN 0-662-20535-9
ISSN 0831-6481

Copies may be obtained from:
Canadian Wildlife Service
Pacific and Yukon Region
RR1, 5421 Robertson Road
Delta, British Columbia
Canada V4K 3N2

ABSTRACT

Polychlorinated dibenzodioxin (PCDD) and polychlorinated dibenzofuran (PCDF) levels in the prey of Great Blue Herons (*Ardea herodias*) foraging on the Fraser River estuary tidal flats were determined in 1991. Observations of herons foraging at Iona and Westham Islands showed that starry flounder (*Platichthys stellatus*) and Pacific staghorn sculpin (*Leptocottus armatus*) were the major prey species throughout the year. During the summer months the herons at Westham Island foraged extensively on other species as well.

Analysis of samples of inshore fish species consumed by the herons showed that PCDD and PCDF levels were generally low. Residues of 2378-tetrachlorodibenzodioxin (2378-TCDD) were below detection limits (< 1 ng/kg) in all species with the exception of redside shiner (*Richardsonius balteatus*) and peamouth chub (*Mylocheilus caurinum*). The 123678-hexachlorodibenzodioxin (123678-HxCDD) isomer was detected only in plainfin midshipman (*Porichthys notatus*). Shiner perch (*Cymatogaster aggregata*) was the only species containing more than 20 ng/kg, wet weight, of 2378-tetrachlorodibenzofuran (2378-TCDF). No PCDDs and only low levels of PCDFs were detected in a small sample of juvenile salmon collected in the estuary. Results suggest that inshore fish are a more significant route of entry of PCDDs into herons than are juvenile salmon.

RESUME

On a mesuré en 1991 les concentrations de dibenzodioxins polychlorées (PCDD) et de dibenzofuranes polychlorés (PCDF) chez les proies des grands hérons (*Ardea herodias*) se nourrissant dans les waddens tidaux de l'estuaire du fleuve Fraser. L'observation de hérons se nourrissant de poissons aux Iles Iona et Westham a montré que le flet étoilé (*Platichthys stellatus*) et le chabot armé (*Leptocottus armatus*) étaient les principales espèces proies tout au long de l'année. Pendant les mois d'été, les hérons se nourrissaient également et de façon abondante d'autres espèces.

L'analyse d'échantillons d'espèces de poissons côtiers, consommées par les hérons a révélé que les concentrations de PCDD et de PCDF étaient généralement faibles. Les concentrations résiduelles de 2,3,7,8-tétrachlorodibenzodioxine (2,3,7,8-TCDD) se situaient en-dessous des limites de détection (< 1 ng/kg) chez toutes les espèces à l'exception du méné rose (*Richardson balteatus*) et du pilotin tacheté (*Mylocheilus caurinum*). La perche-méné (*Cymatogaster aggregata*) était la seule espèce renfermant plus de 20 ng de 2,3,7,8-tétrachlorodibenzofurane (2,3,7,8-TCDF) par kg de poids humide. On n'a décelé aucune trace de PCDD et seulement de faibles concentrations de PCDF dans un petit échantillon de jeune saumon recueilli dans l'estuarie. Les résultats laissent supposer que les poissons côtiers constituent une voie d'entrée plus significative des PCDD chez les hérons, comparativement aux jeunes saumons.

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INTRODUCTION

There are 75 PCDD congeners and 135 different PCDFs; those with chlorine substituted at the 2,3,7 and 8 positions are particularly toxic to fish (Mehrle *et al.*, 1988), and some birds (Gilbertson *et al.*, 1991) and mammals (Aulerich et al., 1988). PCDDs and PCDFs are produced as by-products of certain manufacturing processes such as the synthesis of some herbicides and chlorophenols (Ramel, 1978; Rappe, 1984), and during incineration of municipal and industrial wastes (Czuczwa and Hites, 1984), and combustion of leaded gasoline (Rappe *et al.*, 1987). Recently it was determined that effluent of kraft pulp mills that use chlorine bleaching contains PCDDs and PCDFs (Amendola *et al.*, 1987; Kuehl *et al.*, 1987). Macdonald *et al.* (1992) reported elevated 2378-TCDF levels, beginning in about 1965, in sediment cores collected near a bleached kraft mill in Howe Sound. The presence of PCDDs and PCDFs, particularly 2378-TCDD and 2378-TCDF, in pulp mill effluent is a consequence of the high concentration of molecular chlorine used in the bleach plant, and the amount of potential precursor dibenzodioxin and dibenzofuran in defoamer products, process water and wood furnish itself (Berry *et al.*, 1989). The use of chlorophenol-treated wood chips by pulp mills also led to the formation of PCDDs and PCDFs. Luthe *et al.* (1990) reported digester-promoted formation of hexachlorinated dioxin (HxCDD) with PCP-treated wood chips. Norstrom *et al.* (1988) proposed that chlorophenoxyphenols present on chlorophenol-treated wood chips could condense to form HxCDD and pentachlorodibenzodioxin (PnCDD). Another source of highly chlorinated PCDDs and PCDFs were chlorophenol products used to protect lumber and preserve wood (Van den Berg *et al.*, 1985; Van den Berg *et al.*, 1987; Krahn *et al.*, 1987; Elliott *et al.*, 1989). These products were removed from the Canadian market in November, 1989.

2378-substituted PCDDs and PCDFs are biomagnified up the foodchain and some fish-eating species have been shown to accumulate very high levels. Since 1982, the Canadian Wildlife Service has used the eggs of Great Blue Herons (*Ardea herodias*) to monitor PCDD and PCDF contamination in the Strait of Georgia, British Columbia. High levels of PCDDs and PCDFs have been found in heron eggs collected from sites along the coast (Whitehead, 1989; Elliott *et al.*, 1989). Increasing TCDD levels in eggs from the colony on the endowment lands of the University of British Columbia (UBC, Fig. 1) between 1983 and 1989 prompted the present study.

The pattern of PCDD and PCDF residues in the eggs of herons nesting near the Fraser estuary, indicates that the source is effluent from bleached kraft pulp mill (Norstrom *et al.*, 1988; Elliott *et al.*, 1989). Five such mills are located several hundred kilometres upstream on the Fraser River at Prince George and Quesnel, and at Kamloops on the Thompson River. In 1989, the mills discharged about 440,000 m^3/day of treated waste to the river (Servizi, 1989). In addition, six pulp and paper mills on the Strait of Georgia and Howe Sound discharge effluent to the Strait which, under the influence of tide and wind, might contribute to PCDD and PCDF contamination of the estuary. The present study was undertaken to identify the routes by which PCDDs and PCDFs from those sources enter Great Blue Herons nesting at the UBC colony. We considered two possibilities: 1) contaminated inshore fish in the estuary and lower reaches of the Fraser River, and 2) juvenile salmon hatched and reared in contaminated reaches of the upper

Fraser and Thompson Rivers and preyed on as they emigrate through the estuary to the sea. The study involved observations of heron prey selection on the tidal flats of the Fraser River estuary, and PCDD and PCDF analysis of prey species which comprised the major part of the herons' diet.

MATERIALS AND METHODS

Opportunistic observations of foraging Great Blue Herons were made along the tidal mudflats in two areas: 1) south of the Iona Island jetty, and 2) along the south, west and north shores of Westham Island (Fig. 1). Those are two of the major foraging areas of herons from the U.B.C. colony (Paine, 1972). Foraging observations were made during daylight hours, weekly throughout most of the spring and summer and biweekly during the fall and winter. Foraging adult herons were observed through a telescope from the time of sighting until the foraging bout ended. A record was made of the size (as a proportion of heron culmen length) of all prey, whether or not they could be identified. The fish were separated into three size classes: small, < 1/4 culmen length (< 35 mm); medium, 1/4 - 3/4 culmen length (35 mm - 105 mm); and large, > 3/4 culmen length (>105 mm).

Most fish samples for PCDD and PCDF analysis were collected by contracted commercial fishing boats using a bottom drag or gill net. Bottom drags were made off Iona and Westham Islands during high tide, usually at a depth of about 1-2 fathoms. One drag was done at a depth of approximately 20 fathoms. Gill nets were set off the northwest and southwest sides of Westham Island. In addition, fish were collected during the summer months from a tidal channel on the northwest side of Westham Island using a gill or seine net stretched across the channel (see Levy and Northcote, 1982). The net was set on a falling tide and the trapped fish were removed at low tide.

In the laboratory, the fish were rinsed with tap water to remove attached sediment and then frozen. The specimens were later thawed, identified to species, weighed and measured (fork length) before being refrozen and sent to Axys Analytical Services Ltd., Sidney, B.C. (formerly Seakem Analytical Services Ltd.) for analysis. The analyses were performed on whole body composites of 1 to 20 individuals, depending on the size and number of fish available. The analyses were performed by GC/MS using internal standard quantization with $^{13}C_{12}$ PCDD surrogates. Internal standard recoveries were required to be in the range 30% to 120% or the analysis was repeated. Analyses were carried out in batches. Each batch consisted of up to nine samples, with a minimum of 10% blanks, duplicates, and spiked samples or reference materials. Quantitation of spiked or reference materials, and agreement between duplicate analyses, was good.

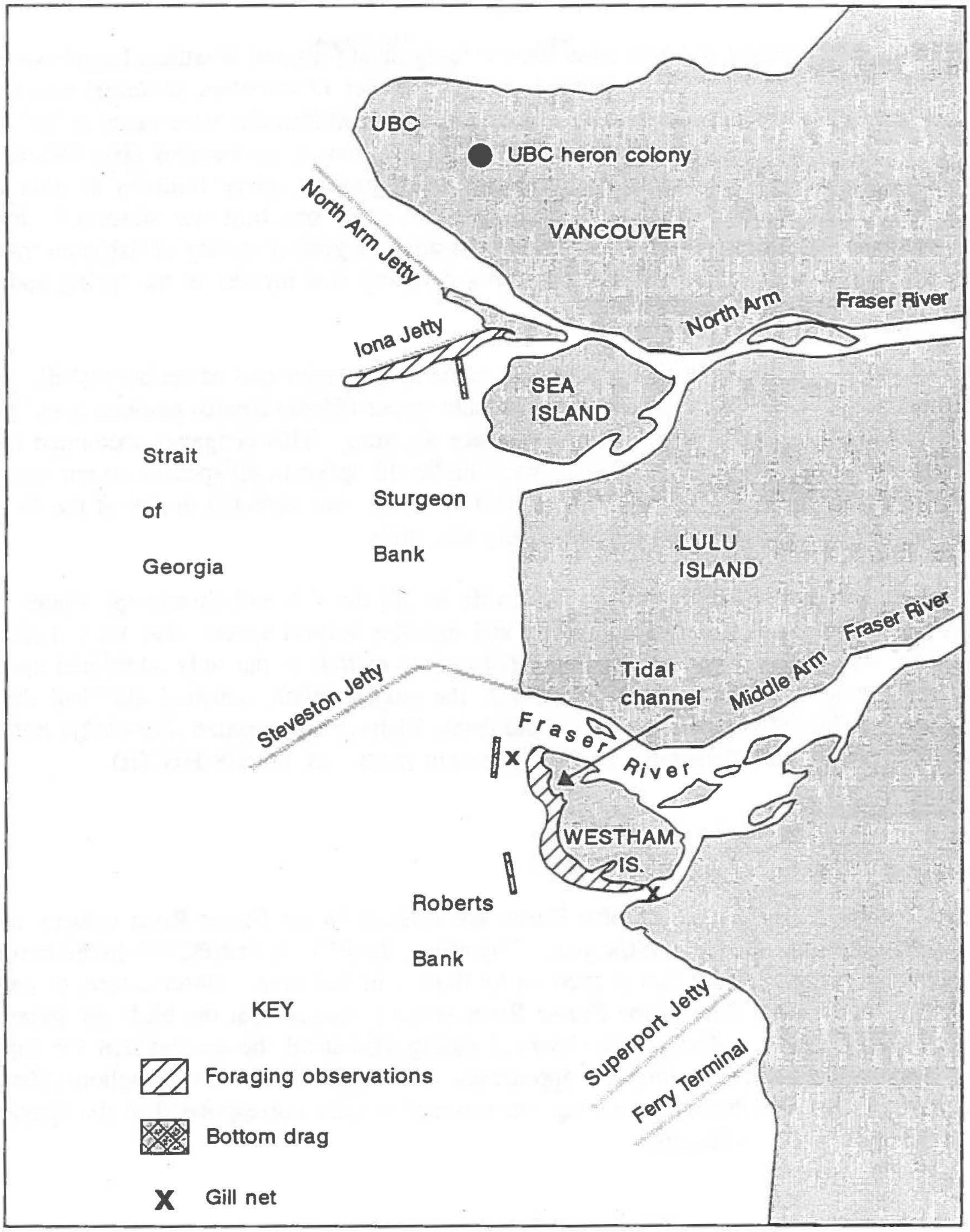


Figure 1. Fraser River estuary, British Columbia, with locations of study sites.

RESULTS

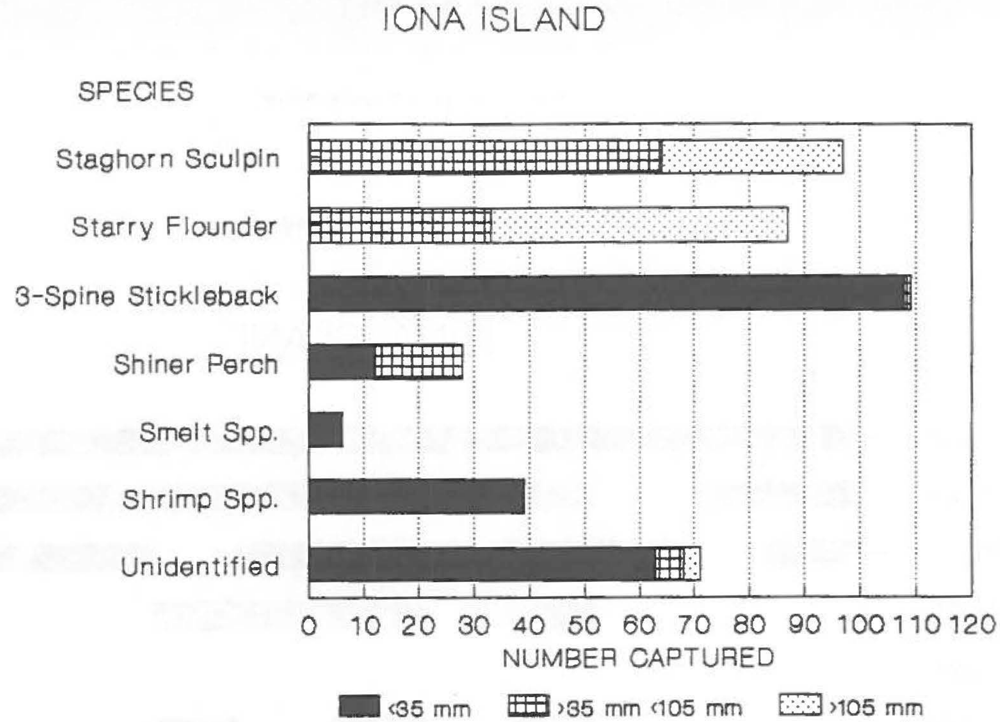
The major prey species of Great Blue Herons foraging at Iona and Westham Islands were Pacific staghorn sculpin (*Leptocottus armatus*), starry flounder (*Platichthys stellatus*) and threespine stickleback (*Gasterosteus aculeatus*) (Fig. 2). Sculpin and flounder were taken at both locations (Fig. 3) throughout the year. A more detailed description of the foraging observations appears in Appendix 1. The apparent discontinuity in foraging on starry flounder at Iona Island in March is likely an artifact of low sampling effort (only one bird was observed) during that month. Herons foraging at Westham Island consumed a greater variety of fish prey than did the birds at Iona Island. At both locations, prey diversity was highest in the spring and summer months.

PCDD and PCDF levels in fish species that made up the major part of the herons' diet are given in Table 1. 2378-TCDD was detected in redside shiner (*Richardsonius balteatus*) and peamouth chub (*Mylocheilus caurinum*), but only in trace amounts. This congener accounted for all the TCDD found. Levels of 2378-TCDF were under 20 ng/kg in all species except shiner perch (*Cymatogaster aggregata*). No other PCDD or PCDF was detected in any of the fish species that were seen to be eaten by herons during this study.

Appendix 2 lists the PCDD and PCDF levels for all the fish and shrimp specimens collected near Iona and Westham Islands in 1991, and includes several species that are not likely to be eaten by Great Blue Herons. Ratfish (*Hydrolagus colliei*) is the only additional species that contained detectable levels of 2378-TCDD; the single ratfish analyzed also had the highest residue of 2378-TCDF and the highest lipid level. Plainfin midshipman (*Porichthys notatus*) was the only species with detectable HxCDD, present mainly as 123678-HxCDD.

DISCUSSION

Butler (1991) found that Great Blue Heron are resident in the Fraser River estuary and lower reaches of the river throughout the year. Therefore, the PCDDs and PCDFs in the herons' eggs were likely acquired from fish preyed on by herons in that area. Observations of heron prey selection on the tidal flats of the Fraser River estuary suggest that the birds are generalists in their feeding habits. They were observed eating almost all the species that we captured in intertidal waters. In addition, the appearance of redside shiner and eulachon (*Thaleichthys pacificus*) in the diet during the spring and summer months corresponded to the appearance of those species in our collections.



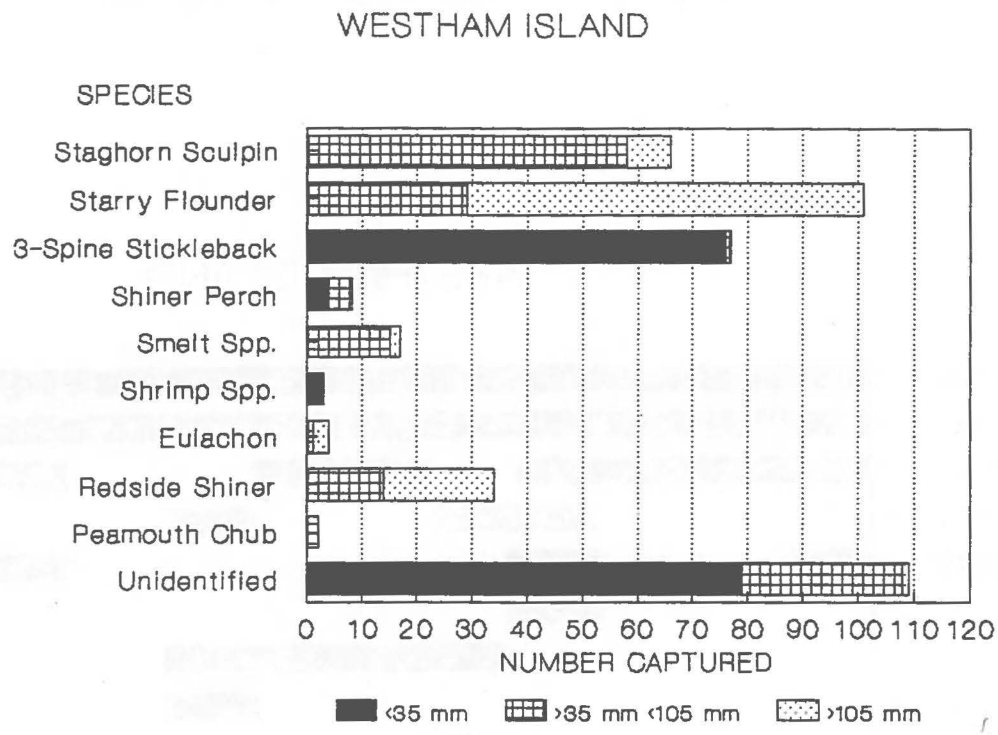
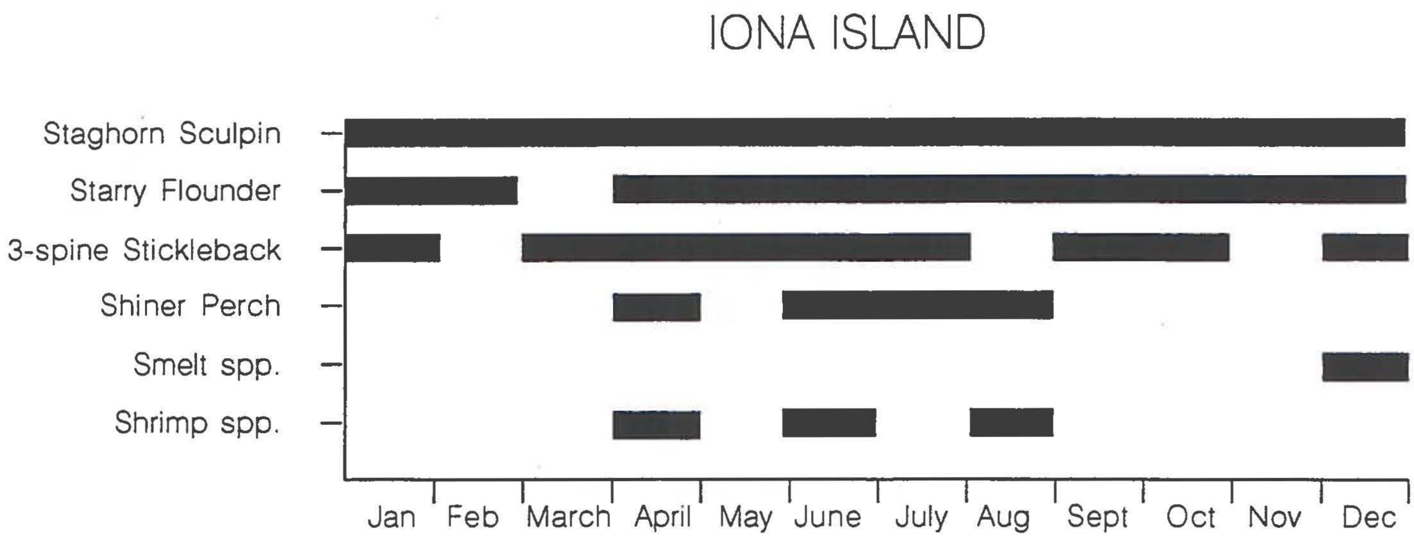


Figure 2. Summary of species and size of prey captured by Great Blue Herons at Iona and Westham Islands, Nov. 1990 - Feb. 1992



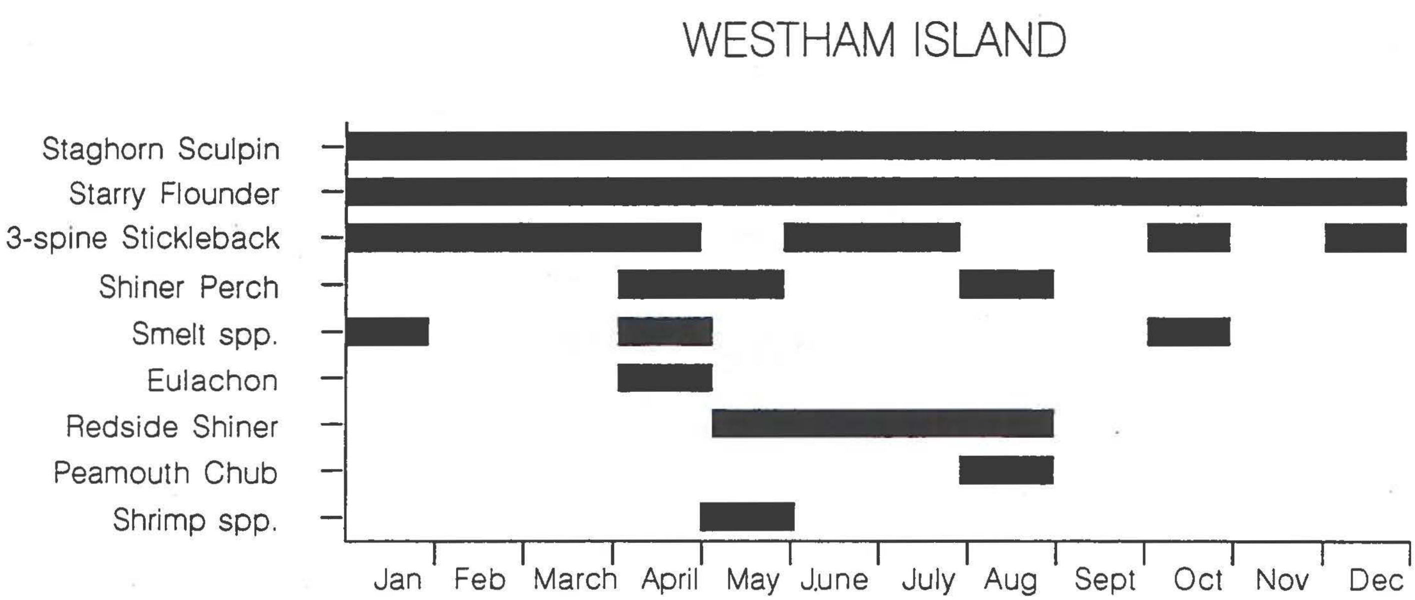


Figure 3. Monthly variation in prey species captured by Great Blue Herons at Iona and Westham Islands, Nov. 1990 - Feb. 1992

Table 1. 2378-TCDD and 2378-TCDF levels (ng/kg, wet weight) in Great Blue Heron prey from the Fraser estuary, 1991.

Species[a]	Location	Date	% Lipid	2378-TCDD	2378-TCDF
Staghorn sculpin	Iona Is.	04/21	1.0	<0.9	5.6
			0.7	<0.9	3.9
			2.0	<0.8	7.6
	Westham Is.	02/07	1.5	<0.9	14.0
		03/19	1.3	<0.6	7.3
Starry flounder	Westham Is.	02/07	0.48	<0.7	5.0
			0.64	<0.7	2.0
			1.06	<0.8	2.8
			0.48	<0.9	2.7
			2.70	<0.9	5.4
		02/21	0.3	<0.7	3.9
		03/19	1.6	<1.1	12.0
3-spine stickleback	Westham Is.	06/03	2.0	<1.6	11.0
		08/12	0.35	<1.2	<0.9
Shiner perch	Iona Is.	04/21	1.6	<1.2	33.0
		04/21	2.5	<1.2	22.0
Eulachon	Westham Is.	04/21	11.7	<1.1	2.0
		04/21	6.4	<0.6	13.0
Redside shiner	Westham Is.	06/03	2.5	0.8	3.8
		08/12	2.4	0.5	2.6
Peamouth chub	Westham Is.	06/01	2.9	1.2	4.3
		08/12	3.0	2.2	15.0
Shrimp spp.	Westham Is.	08/12	0.7	<1.7	<1.2

[a] Fish lengths given in Appendix 2; scientific names given in Appendix 3.

The year-round presence of staghorn sculpin and starry flounder in the estuary and the movement of salmon fry onto the flats have been described in previous studies (Levy *et al.*, 1979; Gordon and Levings, 1984). The seasonal presence/absence patterns we found for some fish species differ, however, from those earlier reports. For example, Levy *et al.* (1979) found redside shiner in tidal channels on Woodward Island (directly east of Westham Island) only in September and October while we observed herons capturing redside shiner near Westham Island during May through August. We do not know if such differences reflect yearly or site variation in distribution.

Since 1987, Environment Canada, the Department of Fisheries and Oceans and British Columbia Ministry of Environment, Lands and Parks have undertaken studies to determine the sources, extent, nature and level of PCDD and PCDF contamination in the estuary of the Fraser River. An extensive collection of biota at selected sites throughout the Strait of Georgia, including the Fraser River estuary, was made in 1987 by Environment Canada (Norstrom *et al.*, 1988). Fish from the lower reaches of the river were sampled again in 1989 (Tuominen and Sekela, 1992). In addition, fish collected in 1983 and in 1985/6 for other purposes have been analyzed (Norstrom, unpubl. data).

The hepatopancreas of crabs appears to accumulate PCDD and PCDF in patterns that reflect what is present in their prey or in the water column (Colodey, 1986; Ryan and Norstrom, in press). This characteristic makes them useful indicators of sources of contamination. In 1987, Dungeness crab (*Cancer magister*) collected near Iona Island were found to be highly contaminated with PCDDs and PCDFs (Norstrom *et al.*, 1988). Hepatopancreatic tissue contained high concentrations of 2378-TCDD and 2378-TCDF, along with elevated PnCDD and HxCDD. In addition, significant levels of 1278-TCDD and 1278-TCDF were present. This pattern of congeners is associated with a bleached kraft source. Much lower levels of PCDDs and PCDFs were found in crabs from Crescent Beach on the Strait of Georgia compared with the crabs in the Fraser River estuary (Norstrom *et al.*, 1988); this is evidence that mills discharging to the river are likely a more important source of PCDD and PCDF contamination than mills discharging to the strait. Furthermore, we found only low levels of PCDD and PCDF in biota in the immediate vicinity of potential sources in the lower river in 1989 (Tuominen and Sekela, 1992), relative to the very high levels in biota near upstream mills in 1988 (Mah et al., 1989); this indicates that upstream mills are the likely source of PCDDs and PCDFs in the estuary.

Since 1983, seventeen species of fish have been collected in the estuary and lower reaches of the Fraser River and screened for PCDDs and PCDFs. Sculpin, flounder and stickleback have been among the most frequently sampled. They also make up a large part of the herons' diet and thus are potentially a major source of the PCDDs and PCDFs in the heron eggs. Fish, like other vertebrates, preferentially accumulate only 2378-substituted PCDDs and PCDFs; consequently, it is difficult to identify sources of contamination. While low levels of 2378-TCDD and moderate levels of 2378-TCDF have been frequently measured in some inshore fish, there are insufficient data to unequivocally show those species are the only source of the PCDDs in the heron eggs. Evidence for the association can be found in the apparent synchrony between

PCDD and PCDF levels in fish and heron eggs over time. Figure 4 shows changes in 2378-TCDD levels in heron eggs, and 2378-TCDF levels in sculpin, flounder, stickleback and peamouth chub over the period 1983 - 1991. Unfortunately, only a few sculpin samples and no flounder or stickleback were collected in the period 1987 through 1989 when 2378-TCDD levels were highest in heron eggs. The data suggest that 2378-TCDF levels in sculpin peaked about the time 2378-TCDD levels were highest in the heron eggs. In making this comparison, we use 2378-TCDF levels as indicators of 2378-TCDD concentrations that are below analytical detection limits. Mah *et al.* (1989) found a good correlation (r^2=0.92) between 2378-TCDD and 2378-TCDF in fish collected near pulp mills discharging effluent into the upper Fraser River (Fig. 5). They found that when 2378-TCDF levels approached 20 ng/kg, 2378-TCDD levels fell below 1 ng/kg - near analytical detection limits. Similarly, in the present study, 2378-TCDD was only detected in fish from the estuary when 2378-TCDF levels were 20 ng/kg or higher (Table 1).

Further evidence that inshore fish might be a source of the PCDDs in heron eggs lies in the ratio of 2378-TCDD levels in heron eggs to those in sculpin. Biomagnification factors (BMFs) of 2378-TCDD levels in heron eggs collected in 1987 and 1988 are 55 and 65 respectively. These BMFs are between two and three times those estimated by Elliott *et al.* (1989) for heron eggs and sculpin collected near Crofton in 1987, and those calculated for alewife to herring gull eggs in the Great Lakes (Braune and Norstrom, 1989). However, 2378-TCDD levels were near detection limits in the sculpin sampled in the Fraser River estuary, so the accuracy of the BMFs is likely poor. Indeed, the unusually high BMFs we calculated (concentrations are higher in the heron eggs than might be expected from the concentrations in the fish analyzed) could be interpreted to mean other significant routes of contamination have been overlooked.

The other possible route of PCDDs and PCDFs into the herons is juvenile salmon that overwinter in areas of the river impacted by bleached kraft mill effluent. The only species of juvenile salmon collected and analyzed were chinook (*Oncorhynchus tshawytscha*) and chum (*O. keta*). The absence of sockeye (*O. nerka*), coho (*O. kisutch*) or pink (*O. gorbuscha*) is likely a consequence of the limited sampling effort made and the migratory behaviour of those species. Although juvenile salmon were never noted as heron prey in the estuary, they probably accounted for some of the small unidentified fish that the herons consumed.

Rogers *et al.* (1989) reported that juvenile chinook salmon captured in 1988, that had spent the winter near outfalls of bleached kraft mills at Prince George and Quesnel, accumulated up to 68 ng/kg of 2378-TCDD and 370 ng/kg of 2378-TCDF. No 2378-TCDD was detected in any of the juvenile salmon we collected in the Fraser River estuary in 1991, and 2378-TCDF levels were generally less than 2 ng/kg. However, chinook salmon spawn in about 65 tributaries throughout the Fraser basin (Servizi, 1989), and not all juveniles overwinter in the upper Fraser River (Tutty and Yole, 1978) near bleached kraft mills. While the origin of the salmon we captured is unknown, Levings (1983) suggested that chinook fry using Sturgeon and Roberts Bank are Harrison River stock. There are no bleached kraft mills in the Harrison drainage system. In any event, the low PCDD and PCDF levels in the salmon we collected indicate that

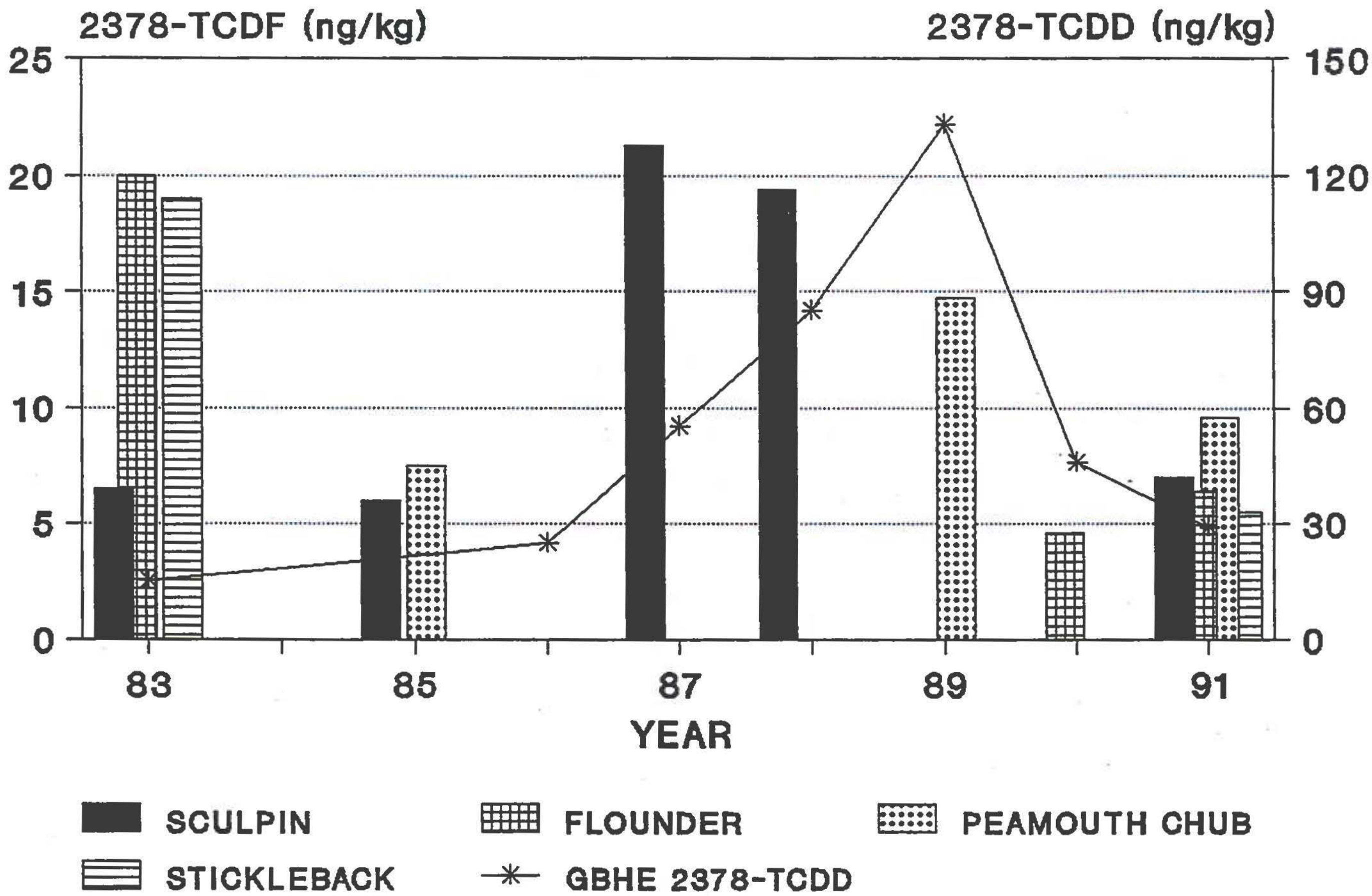


Figure 4. Changes in 2378-TCDD levels in Great Blue Heron eggs and 2378-TCDF levels in inshore fish, Fraser River estuary, British Columbia.

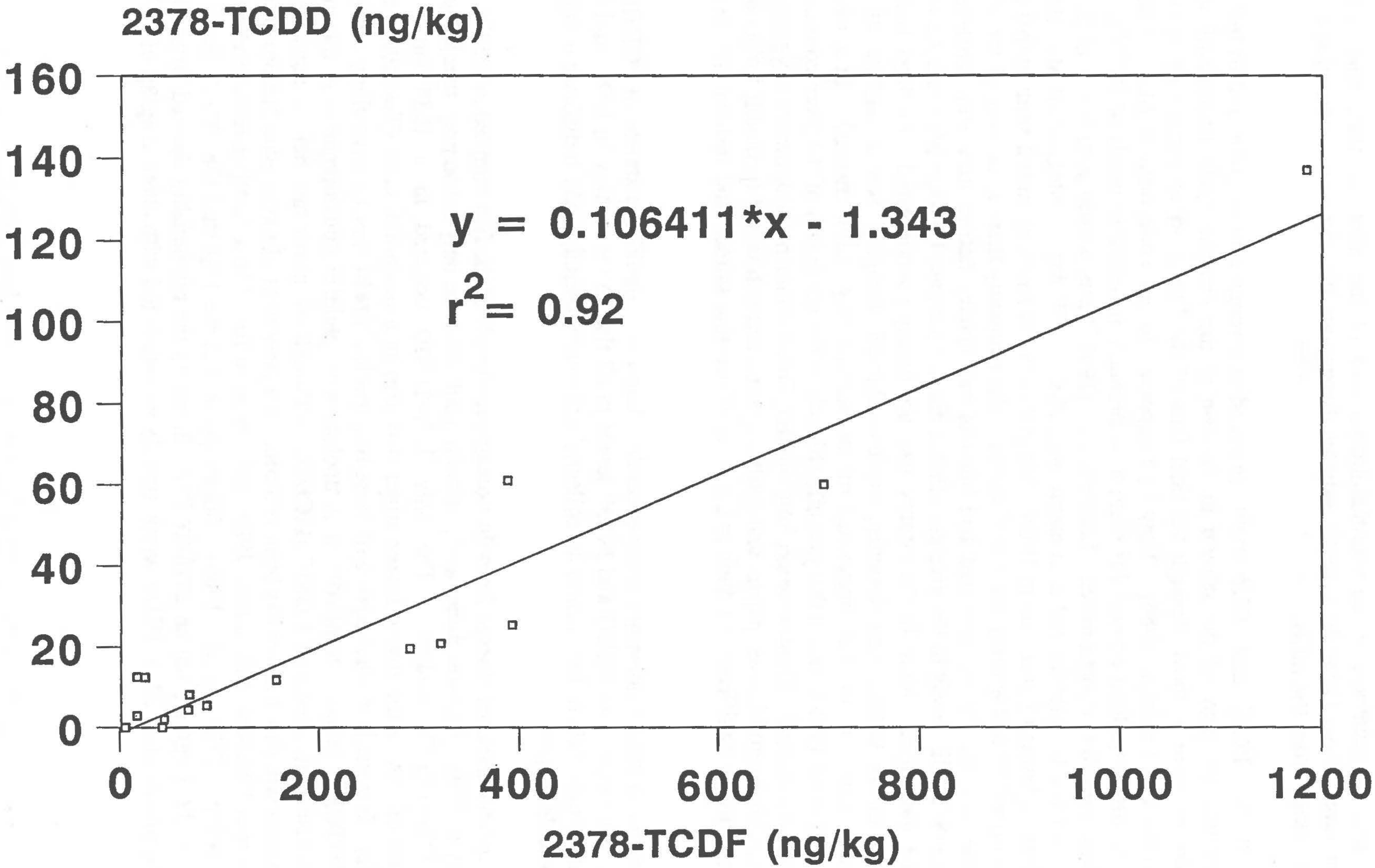


Figure 5. Relationship between 2378-TCDD and 2378-TCDF in fish collected in the upper Fraser River, 1988. (Data from Mah *et al.* 1989.)

either they had overwintered in an uncontaminated area of the river, or that, since 1988, contaminant levels have fallen in juvenile salmon throughout the river as a consequence of reduced emissions from the mills.

In addition, the low PCDD and PCDF levels we found in juvenile salmon compared to inshore fish indicate that the prey of the salmon in the estuary are comparatively uncontaminated. Juvenile salmon begin to move through the tidal flats of the Fraser River estuary as early as March (Gordon and Levings, 1984). They first appeared in our collections in May. That 6 week interval would be long enough for them to accumulate measurable levels of PCDDs and PCDFs if their prey was contaminated. Loonen *et al.* (1991) found steady state levels of 2378-substituted PCDDs in guppies fed a contaminated diet for 56 days. McCain et al. (1990) reported elevated levels of aromatic hydrocarbons and PCBs in hatchery-raised salmon that had foraged in a contaminated estuary for 1 to 6 weeks. Unfortunately there is no way of knowing how long the chinook fry we analyzed had been in the estuary before they were collected. However, 2378-TCDF levels in the juvenile salmon did not increase between May and August, evidence that their food source in the estuary was not highly contaminated. Levings (1982) reported that, unlike sculpin and flounder, juvenile chinook foraging over a sandflat of the Fraser estuary made use of drift organisms on the surface (e.g. adult insects). In a recent report, Levings et al. (1991) noted that juvenile chinook in the north arm of the river consumed oligochaetes, harpacticoids, *Eogammarus* (Amphipoda), *Corophium* ssp. (Amphipoda), Neomysis (Mysidacea), chironomid larvae, papae, and adults, aphids, and fish larvae (probably eulachon). Clearly there can be significant overlaps in the diets of juvenile salmon and inshore fish in the estuary.

These data seem to dispell questions about juvenile salmon as a significant source of PCDDs in heron eggs. However, low PCDD and PCDF levels in all fish in the estuary in 1991, and our inability to determine where the salmon we collected had overwintered, make it difficult to reject this as a possible source.

Several unexpected patterns emerge from the contaminant levels of the fish sampled in the Fraser River estuary in 1991. Redside shiner and peamouth chub were the only heron prey species with detectable 2378-TCDD residues. The only 2378-TCDD detected in a 1989 study of contamination of fish in the lower Fraser River was also in a peamouth chub (Tuominen and Sekela, 1992). It is unclear what aspects of those two species' life history or physiology account for the 2378-TCDD levels. Similarly, it is unclear why plainfin midshipman was the only species with detectable levels of 123678-HxCDD. Although we never saw herons consuming plainfin midshipman, this species has been recorded as a prey item of Great Blue Herons in the Strait of Georgia (Verbeek and Butler, 1989) and has been found in a nestling regurgitation at the U.B.C. colony (Elliott *et al.*, 1989). Shiner perch had the highest 2378-TCDF levels in 1991 (mean = 32.3 ng/kg), but no 2378-TCDD. Based on the relationship derived from Mah *et al.* (1989), this level of 2378-TCDF would usually be associated with about 2 ng/kg of 2378-TCDD.

A significant positive correlation between 2378-TCDF concentration and lipid content in fish muscle tissue was reported by Mah *et al.* (1989). While we found a similar correlation between 2378-TCDF and fat content in inshore fish (sculpin and flounder), juvenile salmon did not show the same relationship (Fig 6). The relatively high levels of 2378-TCDD and 2378-TCDF found in ratfish in the present study are probably related to its high lipid content. No consistent relationships between contaminant level and body length or date of capture were found in the fish from the Fraser River estuary.

In conclusion, the major prey of Great Blue Herons feeding on the tidal flats of the Fraser River estuary have been identified. The PCDD and PCDF levels in these prey are very low, reflecting the low levels found in the heron eggs at the U.B.C. colony in 1991. Although not conclusive, the available data support the hypothesis that the source of PCDDs and PCDFs into the herons is through contaminated inshore fish in the estuary.

ACKNOWLEDGEMENTS

Cameron Eckert made a significant contribution with foraging observations and fish collections from November, 1990 to March, 1991. The assistance of David Wigglesworth and Brent Mowat, along with their boats and crews, in collecting fish was invaluable and is gratefully acknowledged. We would also like to acknowledge the help of Pam Sinclair who participated in the foraging observations, Colin Levings who provided advice on the project and helped identify fish, Ken Hall who loaned us the seine net, and Pamela Whitehead who helped draft the figures.

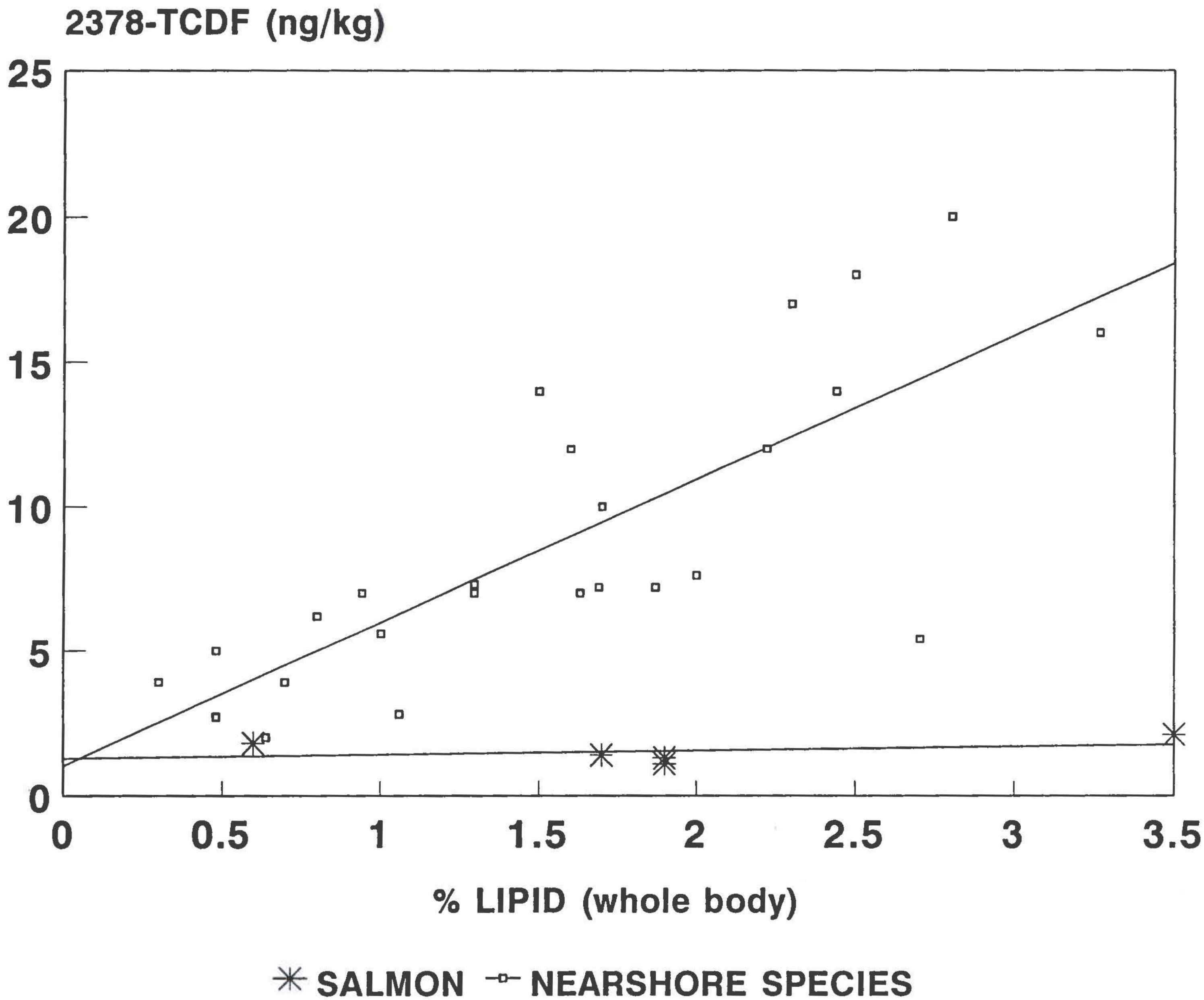


Figure 6. Relationship between 2378-TCDF and whole body fat level in fish collected in the Fraser River estuary, 1991.

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Appendix 1. Monthly summary of Great Blue Heron foraging observations made on the Fraser River estuary, November 1990-February 1992.

Date	Location	No. Obs.[a]	Species[b]	Length[c] S	Length[c] M	Length[c] L
11/90	Iona	6	staghorn sculpin		2	
			starry flounder		2	4
			unidentified	5		
12/90	Iona	2	staghorn sculpin		1	
			starry flounder		1	1
			stickleback	6		
			smelt spp.	6		
	Westham	1	staghorn sculpin		2	
			starry flounder			3
01/91	Iona	1	starry flounder		1	2
			stickleback	3		
	Westham	5	staghorn sculpin		7	1
			starry flounder		1	3
			smelt spp.		8	
02/91	Westham	4	staghorn sculpin		10	
			stickleback	8		
03/91	Iona	1	staghorn sculpin		1	
			stickleback	4		
	Westham	6	staghorn sculpin		7	
			starry flounder		1	3
			stickleback	21		
04/91	Iona	13	staghorn sculpin		6	4
			starry flounder		2	8
			stickleback	19		

Appendix 1. (cont.)

Date	Location	No. Obs.[a]	Species[b]	Length[c] S	M	L
			shiner perch		2	
			shrimp spp.	2		
			unidentified	3		
	Westham	10	staghorn sculpin		1	
			starry flounder		4	6
			stickleback	4		
			shiner perch		3	
			eulachon		1	3
			smelt spp.			2
			unidentified	8		
05/91	Iona	10	staghorn sculpin		10	1
			starry flounder		8	4
			stickleback	11		
			shiner perch	3	1	
			unidentified	2		
	Westham	9	staghorn sculpin		4	
			starry flounder			5
			shiner perch	2		
			redside shiner		3	5
			shrimp spp.	3		
			unidentified	13		
06/91	Iona	16	staghorn sculpin		5	6
			starry flounder		2	5
			stickleback	12	1	
			shiner perch	4		

Appendix 1. (cont.)

Date	Location	No. Obs.[a]	Species[b]	Length[c] S	M	L
			shrimp spp.	33		
			unidentified	46	5	3
	Westham	8	staghorn sculpin			1
			starry flounder		1	10
			stickleback	11		
			redside shiner		2	1
			unidentified		7	1
07/91	Iona	8	staghorn sculpin		5	2
			starry flounder		2	6
			stickleback	14		
			shiner perch	1		
	Westham	10	staghorn sculpin		2	1
			starry flounder		6	5
			stickleback	7	1	
			redsided shiner		5	3
			unidentified	38	3	
08/91	Iona	9	staghorn sculpin		7	4
			starry flounder		3	7
			shiner perch	1	13	
			shrimp spp.	4		
			unidentified	7		
	Westham	9	staghorn sculpin		4	
			starry flounder		2	6
			shiner perch	2	1	
			redsided shiner		4	11

Appendix 1. (cont.)

Date	Location	No. Obs.[a]	Species[b]	Length[c] S	M	L
			peamouth chub		2	
			unidentified	17	11	
09/91	Iona	6	staghorn sculpin		2	2
			starry flounder		6	1
			stickleback	4		
			shiner perch	3	2	
	Westham	7	staghorn sculpin		7	1
			starry flounder		2	4
			unidentified	3	8	
10/91	Iona	8	staghorn sculpin		6	6
			starry flounder			7
			stickleback	14		
	Westham	5	staghorn sculpin		2	
			starry flounder			7
			stickleback	11		
			smelt spp.		7	
11/91	Iona	3	staghorn sculpin		5	2
			starry flounder		2	1
	Westham	4	staghorn sculpin		3	
			starry flounder			3
12/91	Iona	6	staghorn sculpin		7	3
			starry flounder			5
			stickleback	13		
	Westham	6	staghorn sculpin		3	
			starry flounder		1	6

Appendix 1. (cont.)

Date	Location	No. Obs.[a]	Species[b]	Length[c] S	M	L
			stickleback	7		
01/92	Iona	7	staghorn sculpin		7	1
			starry flounder		3	2
			stickleback	8		
	Westham	8	staghorn sculpin		4	2
			starry flounder		11	3
			stickleback	2		
02/92	Iona	3	staghorn sculpin			2
			starry flounder		1	1
	Westham	4	staghorn sculpin		2	2
			starry flounder			8
			stickleback	5		

[a] Number of herons observed during the month.
[b] Scientific names are given in Appendix 3.
[c] Prey size was measured as a proportion of the heron's culmen: $S \leq 1/4$; $1/4 < M \leq 3/4$; $L > 3/4$.

Appendix 2. PCDD and PCDF residues (ng/kg, wet weight) in fish collected from the Fraser River estuary, 1991.

					RESIDUE LEVELS		
Species[a]	Location	Date	Length[b]	% Lipid	TCDD	HxCDD	TCDF
P. Staghorn sculpin	Iona I.	04/21	101 (3)	1.0	< 0.9	< 1.5	5.6
			141	0.7	< 0.9	< 2.0	3.9
			180	2.0	< 0.8	< 1.1	7.6
	Westham I.	02/07	260	1.5	< 0.7	< 1.9	14.0
		03/19	151 (2)	1.3	< 0.6	< 1.3	7.3
	Coal Jetty	03/22	141 (3)	0.7	< 1.0	< 1.8	3.9
			181 (5)	1.3	< 1.1	< 3.4	7.0
Starry flounder	Westham I.	02/07	219 (2)	0.48	< 0.7	< 0.7	5.0
			232 (5)	0.64	< 0.7	< 0.7	2.0
			298 (5)	1.06	< 0.8	< 0.6	2.8
			330 (5)	0.49	< 0.9	< 1.8	2.7
			380 (4)	2.7	< 0.9	< 2.0	5.4
		02/21	333 (5)	0.3	< 0.7	< 2.4	3.9
		03/19	285 (2)	1.6	< 1.1	< 3.2	12.0
English sole	Iona I.	02/07	213 (4)	1.87	< 1.2	< 1.6	7.2
			253 (4)	3.27	< 1.0	< 1.3	16.0
Dover sole	Iona I.	02/07	190 (5)	0.94	< 0.8	< 0.9	7.0
Threespine stickleback	Westham I.	06/03	64 (10)	2.0	< 1.6	< 2.2	11
		08/12	62 (10)	0.35	< 1.2	< 2.3	< 0.9
Shiner perch	Iona I.	04/21	73 (9)	1.6	< 1.2	< 2.0	33
			123 (3)	2.5	< 1.2	< 2.5	22
	Coal Jetty	03/22	98 (3)	3.3	< 1.7	< 3.0	42
Plainfin midshipman	Iona I.	02/07	121 (10)	2.22	< 0.6	< 2.4	12.0
			137 (5)	2.44	< 0.8	3.3	14.0
			193 (5)	1.63	< 0.8	< 2.0	7.0

Appendix 2. (cont.)

Species[a]	Location	Date	Length[b]	% Lipid	RESIDUE LEVELS TCDD	HxCDD	TCDF
			225 (2)	1.69	< 0.9	< 2.2	7.2
		02/21	121 (8)	2.8	< 0.5	2.6	20.0
			140 (9)	2.5	< 0.5	< 0.9	18.0
			222 (3)	1.7	< 0.6	2.7	10.0
	Westham I.	04/21	119 (2)	0.8	< 1.0	1.8	6.2
	Richmond	03/22	122 (5)	2.3	< 1.0	3.1	17.0
Eulachon	Westham I.	04/21	115 (10)	6.4	< 0.6	< 1.8	14.0
			185 (10)	12.2	< 1.1	< 2.0	2.1
Chum	Westham I.	05/16	53 (20)	0.6	< 0.9	< 1.9	1.8
		08/12	62 (7)	1.7	< 1.5	< 2.8	1.4
Chinook	Westham I.	05/16	111 (2)	3.5	< 0.7	< 1.1	2.1
		06/03	56 (12)	1.9	< 1.0	< 1.8	1.3
		08/12	55 (12)	1.9	< 1.1	< 1.5	1.1
Redside shiner	Westham I.	06/03	82 (13)	2.5	0.8	< 1.1	3.8
		08/12	83 (11)	2.4	0.5	< 0.9	2.6
Peamouth chub	Westham I.	06/01	134 (10)	2.9	1.2	< 1.9	4.3
		08/12	206	3.0	2.2	< 1.7	15
Ratfish	Iona I.	02/07	520	25.8	2.7	< 0.8	86
Big-fin eelpout	Iona I.	02/07	219 (4)	1.54	< 0.5	< 0.9	20
Shrimp spp.	Westham I.	08/12	(40)	0.7	< 1.7	< 3.2	< 1.2

[a] Scientific names are given in Appendix 3.
[b] Mean fork length (mm), sample size in parentheses when greater than 1. Sand shrimp were not measured.

Appendix 3. Scientific names of fish species mentioned in this report.

Pacific staghorn sculpin	*Leptocottus armatus*
starry flounder	*Platichthys stellatus*
English sole	*Parophrys vetulus*
Dover sole	*Microstomus pacificus*
three-spine stickleback	*Gasterosteus aculeatus*
shiner perch	*Cymatogaster aggregata*
plainfin midshipman	*Porichthys notatus*
eulachon	*Thaleichthys pacificus*
chum salmon	*Oncorhynchus keta*
chinook salmon	*O. tshawytscha*
redside shiner	*Richardsonius balteatus*
peamouth chub	*Mylocheilus caurinum*
ratfish	*Hydrolagus colliei*
big-fin eelpout	*Aprodon cortezianus*