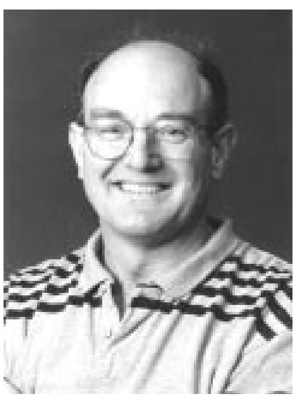
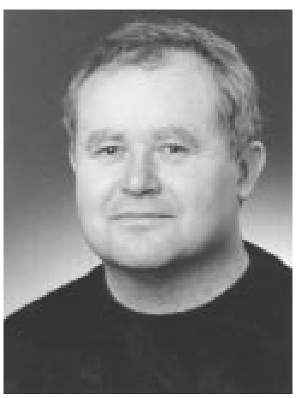
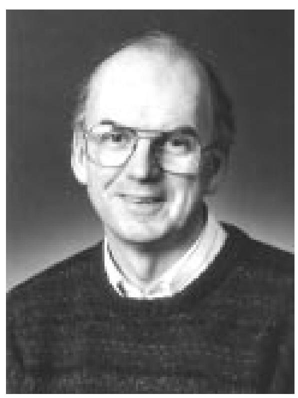
Organochlorine Levels in the Marine Food Web of the Southern Gulf of St. Lawrence

G. Harding, P. Vass and B. Hargrave

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The southern Gulf of St. Lawrence accounts for approximately one-quarter of the commercial fishery landings off the east coast of Canada. This large body of water receives substantial quantities of organochlorines from the more populated and industrialized regions of the continent , mainly from atmospheric transport and subsequent precipitation and from river flow. The total freshwater drainage area of the Gulf is 1.35 X 10^6 km^2, of which the highly urbanized and industrialized (about 45 million people ; Environment Canada figures for 1991) St. Lawrence River-Great Lakes region makes up 1.18 X 10^6 km^2 (Canadian Government 1973) with an average annual outflow of 10,730 m^3. s^{-1} (1959-1989; K. Drinkwater pers. comm.) Moreover, the Gulf of St. Lawrence is located on the lee side of the continental atmospheric circulation and thereby receives atmospheric fallout from the major industrial centres of the Great Lakes region and the eastern seaboard of the United States (Bryson *et al.* 1974).

Organochlorines are a chemical class of compounds, not known to exist naturally in the environment, which were produced in large quantities in N. America for their toxic properties for agriculture [eg DDT family, lindane , toxaphene, etc] and their heat resistent qualities for industry [eg. polychlorinated biphenyls (PCBs)] . Although pesticides such as DDT were all but banned from North America in the early 1970s, considerable quantities still escape to the global atmosphere from Central and

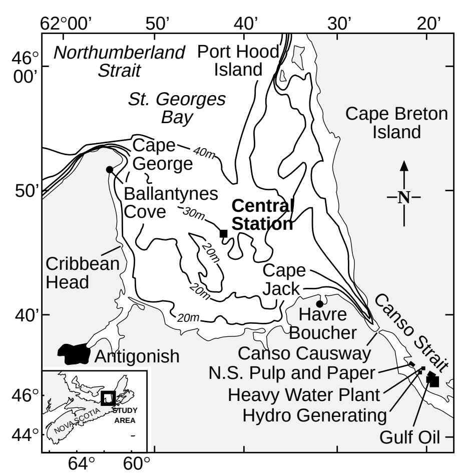

Figure 1: Study area showing the collection sites in St. Georges Bay, N.S., and the urban and industrial centres of the region.

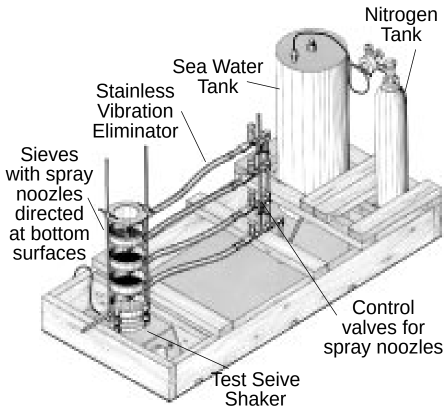

Figure 2: The vibrating sieve apparatus developed and used to sort plankton into size categories from 1977 to 1993.

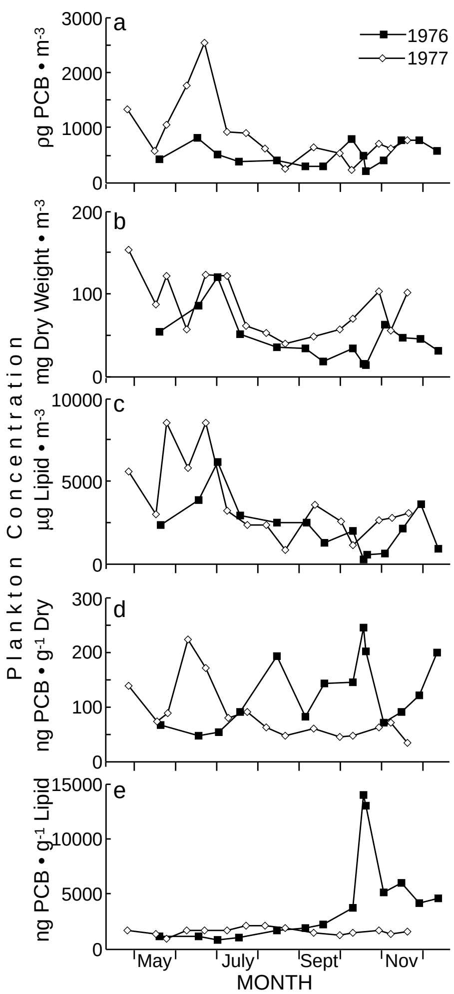

Figure 3: Seasonal distribution of PCB, dry and lipid content of plankton per m^3 and PCB concentrations on a dry and lipid weight basis in the combined 66-2035um size fractions from St. Georges Bay, 1976 and 1977.

South America where its use continues as an inexpensive method for malaria control. Similarly, PCBs continue to escape from dump sites in spite of the near-global ban on their manufacture since the 1980s. Organochlorines have a high lipid but low water solubility and are highly resistent to degradation (Hutzinger *et al*. 1974) which results in their bioaccumulation in marine food chains (Hargrave *et al*. 1992). The toxic properties of organochlorines are of concern to human health because of our own position in the trophic chain (Feely 1995, Hansen 1996). It is important to the fisherman, the fish plant worker, the consumer and government regulators that we understand more fully the dynamics of these contaminants in the marine environment.

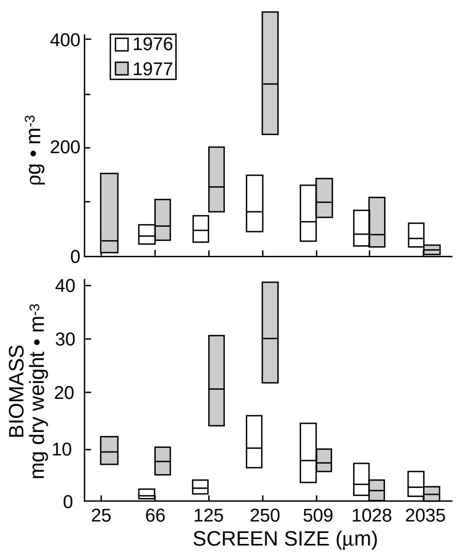

Figure 4: Size-frequency distributions of PCB content and dry weight of plankton per m^3 in St. Georges Bay in 1976 and 1977 (G.M. and 95% CI shown).

In the present account we report results of research which provided measurements of organochlorine levels in the pelagic marine food web of southern Gulf of St. Lawrence from the mid 1970's through to the 1990's. St. Georges Bay, Nova Scotia, was chosen as a representative embayment within the southern Gulf of St. Lawrence to study organochlorine pollution because it is relatively remote from local sources of industrial and domestic effluents (Fig. 1). To understand bioaccumulation of organochlorines in an ecological entity such as the Gulf, organisms were studied as components of a food chain. Simplistically, or-

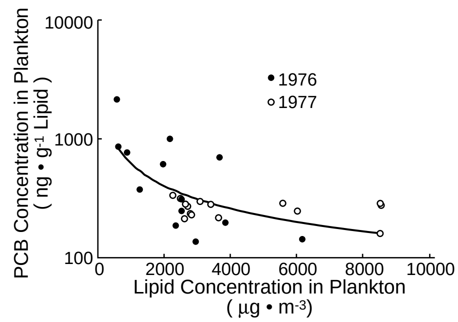

Figure 5: The relationship between planktonic PCB concentration normalized to lipid content and lipid content of plankton per unit volume seawater filtered for combined size fractions for individual sampling trips in 1976 and 1977. The solid line represents the best least squares fit to log-transformed data: $Y = 57764X^{-0.655}$, $r = 0.73$, $N = 28$.

ganisms can be grouped within trophic levels, such that all plants are the primary producers, herbivores are the primary consumers, carnivores are secondary, tertiary , etc. consumers. Plankton was collected with three to four nets with different mesh sizes and sorted to seven to nine size categories (logarithmic) with a specially designed and constructed vibrating sieve apparatus (Fig. 2) . Silversides and smelt were collected at night under the glare of spotlights with a dip net. White hake were collected by otter trawling in the bay. Capelin, gaspereau, herring and mackerel were obtained free of contamination from boat paint, grease etc. from a local gillnet and a trap fishermen.

PCBs, as Aroclor 1254, were quantified

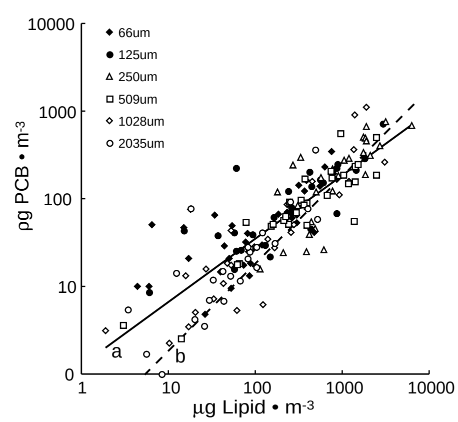

Figure 6: The relationship between PCB and lipid content in plankton in the water column, plotting individual sieve size fractions collected in 1976 and 1977. The solid line represents the least squares fit to log-transformed data: $Y = 1.26X^{o.72}$, $r = 0.86$, $N = 176$; whereas the dashed line represents a best fit to a linear equation passing through the origin; $Y = 0.187X$.

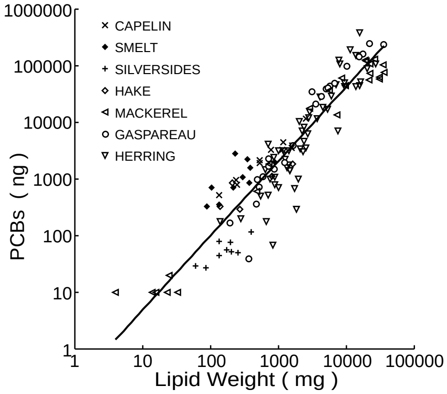

Figure 7: The relationship between PCB content (ng) and lipid weight (mg) of seven fish species collected in St. Georges Bay, N.S., during 1977. The fitted line represents a least squares fit to log-transformed data: $Y = 0.236X^{1.313}$, r = 0.94, N =135.

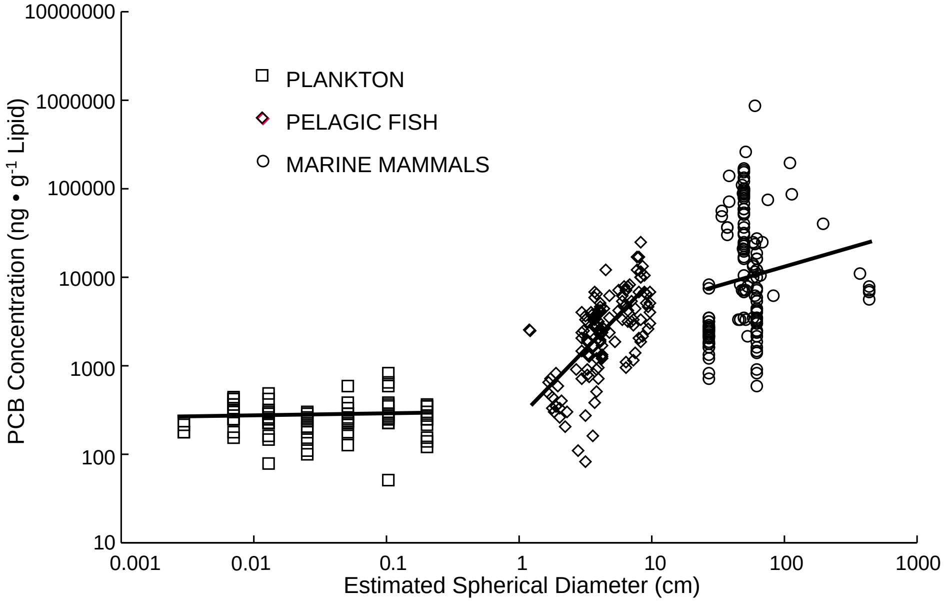

Figure 9: PCB levels in plankton, pelagic fish and marine mammals normalized to lipid content and plotted against body size (Equivalent Spherical Diameter). The plankton and fish were collected in 1977 from St. Georges Bay, N.S. Information on marine mammals was collected in the 1970s and published in the literature (see Harding et al. *in press).*
Plankton are fitted by: $Y = 254X^{0.01}$, r = 0.03, n = 88.
Fish are fitted by: $Y = 216X^{1.58}$, r = 0.68, N = 135.
Marine mammals are fitted by: $Y = 1337X^{0.51}$, r = 0.18, N = 131.

in bulk seawater from St. Georges Bay in the late 1970s at 3.1±1.0 ng.L^{-1} (X±SD; parts per trillion), whereas the contamination measured in plankton was three orders-of-magnitude greater at 2.9±3.3 ng.g^{-1} wet weight (parts per billion). However on an ecosystem basis, it is necessary to express PCB contamination of plankton on a habitat volume basis. The PCB levels in plankton of 25um to >2.0mm ESD (nominal equivalent spherical diameter) in the water column was 62±49 pg.m^{-3}, which is four orders-of magnitude less than that measured in seawater. Seasonal concentrations of PCBs in the plankton component of the

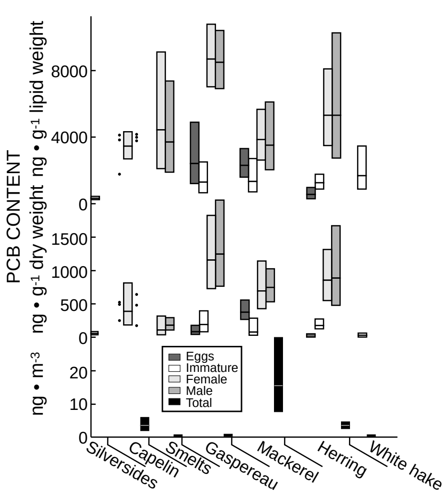

Figure 8: PCB concentrations, based on a lipid weight, dry weight and per m^3 basis, present in eggs, immatures, adult female and male individuals of seven fish species collected in St. Georges Bay, N.S., during 1977 (GM and 95% C.I.).

ecosystem tended to be highest in the spring and lowest in the summer, followed by slightly elevated but variable levels in the late fall (Fig. 3a). A similar pattern was evident in the seasonal distribution of plankton standing stock (Fig. 3 b&c) but not in the PCB concentration per unit biomass (Fig. 3 d&e). The seasonal decline noted in total planktonic PCBs (pg PCB.m^3) of the southern Gulf of St. Lawrence is mainly due to the reduced summer biomass present in the 509 and 1028um seive fractions between mid-july through to the beginning of October (Fig. 4), because the relative PCB concentration present in terms of dry or lipid weight did not change consistently during this period (Fig. 3 d&e).

This dependence of planktonic PCB concentrations on standing stock also is evident from a plot of PCB concentration versus lipid concentration in the plankton (Fig. 5). The lower the planktonic lipid content of the St. Georges Bay ecosystem, the more concentrated the PCBs are in the remaining lipid pool. Planktonic PCB concentrations , expressed on a lipid basis, were found to be correlated with cumulative rainfall 21 days before sampling for the two years analysed to date. Ware and Addison (1973) found a similar correlation between planktonic PCB concentrations and rainfall 10 to 20 days prior to collection. This suggests that the shorter-term pulses of PCB input into the southern Gulf, reflected in the plankton, are most likely due to atmospheric input washed out with the rain. The 1976 and 1977 time series of planktonic PCB and lipid content per m^3 were analysed for each size fraction by cross-correlation techniques after the common trends were

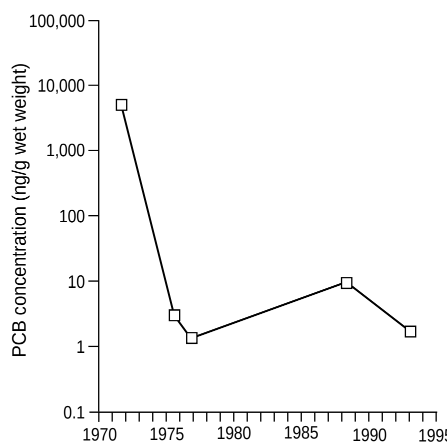

Figure 10: Mean PCB content in plankton in the size range 125 to 509um collected in the southern Gulf of St. Lawrence between 1972 and 1993.

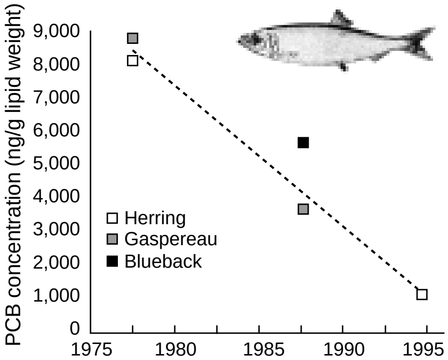

Figure 11: Mean PCB content of clupeid fish in the southern Gulf of St. Lawrence between 1977 and 1994.

removed from the data (Wilkinson *et al*. 1992). In the majority of cases , a significant positive correlation was obtained between PCBs and lipid content of the planktonic community with no time lag. One conclusion is that the plankton sampling interval chosen of three to four weeks was too long to be able to detect an increased uptake of PCBs as a result of atmospheric input or an expanded 'lipid pool' in a prolific feeding population.

PCB concentrations in both plankton and fishes are very dependent on the lipid concentration of the organism (Fig. 6 & 7), which follows from their lipophilic nature. Adult fish were found to be more contaminated by PCBs than either their eggs or juveniles (Fig. 8). PCBs were transferred from mother to offspring in fish, but at lower levels than that present in the parent, and the maximum accumulation from the environment occurred between immature and adult fish . Highest concentrations of PCBs in fish in the mid-1970s were found in gaspereau, herring and smelt in contrast to mackerel, capelin, white hake and silversides. However, the bulk of the PCBs in the southern Gulf of St. Lawrence was present in the mackerel population and this was due to the overwhelming abundance of mackerel during this period (Fig. 8). No difference was found between PCB contamination of the sexes of fish species analysed.

	Year	$pg.m^{-3}$	%
Bulk seawater	1976	3.1×10^{6}	97.96
Plankton	1976/77	6.0×10^{2}	0.02
Fish	1977	2.3×10^{4}	0.73
Mammals	1970s	4.1×10^{4}	1.30

Table 1. Tabulation of PCB levels in the Pelagic Ecosystem of the Southern Gulf of St. Lawrence

Biomagnification of polychlorinated biphenyls occurs between the larger categories of plankton to fish to marine mammals but not within the lower planktonic trophic levels (Fig. 9). PCB concentrations in fish increased with size and on average were ten times the levels found in plankton. Marine mammals collected by other researchers in the region during the 1970's had accumulated up to several orders-of-magnitude higher concentrations than those found in fish, with an apparently more gradual increase in concentration with size of organism. Lipid content and age, or exposure period, appear to be the main factors which determine PCB concentrations in the marine food web of the southern Gulf of St. Lawrence (Harding *et al*. in press).

PCB levels in plankton have dropped exponentially from the early 1970s to the 1980s , but thereafter the decline has levelled out (Fig. 10). There is the possibility that the high values measured by Ware & Addison (1973) in plankton collected north of Prince Edward Island in 1972 might be a result of PCBs escaping from the sunken oil barge *Irving Whale*, however PCB were matched with Aroclor 1254 and not Aroclor 1242 which is the PCB signature of the barge (Gilbert *et al*. 1996). PCB concentrations of clupeid fish (herring family) species collected in the Gulf have consistently declined over the decades between the mid 1970's and 1990's (Fig. 11). The presence of discontinued pesticides , such as DDT, in the undegraded form in our local plankton and fishes indicates recent atmospheric transport of pesticides from Central America or further south. We are presently attempting to evaluate the transport of organochlorines to the Canadian east coast marine environment. A preliminary PCB tabulation for the pelagic realm of the Gulf of St. Lawrence, based on information collected in the 1970's, demonstrates that most of the contamination in the pelagic ecosystem was present in the water column but that the marine mammals had by far accumulated most of the organochlorines present in the biosphere (Table 1). The present studies form a very fortuitous data time series to evaluate any further damage caused by the recovery of the *Irving Whale* oil barge which originally had 7,600 L of Aroclor 1242 (PCBs) on board when it sank between PEI and the Magdellan Islands in 1970.

References

BRYSON, R.A. and F.K. HARE. 1974. The climates of North America. p. 1-46. In: R.A. Bryson and F.K. Hare [ed.]. Climates of North America. World Survey of Climatology. Vol. 11. Elsevier, New York.

CANADIAN GOVERNMENT. 1973. The National Atlas of Canada. Fourth Edition. Dept. of Energy Mines and Resources, Surveys and Mapping Branch, Ottawa, 254p.

FEELEY, M.M. 1995. Biomarkers for Great Lakes priority contaminants: halogenated aromatic hydrocarbons. Environ. Health Perspect. 103: 7-16.

GILBERT, M. and G. WALSH 1996. Potential consequences of a PCB spill from the barge Irving Whale on the marine environment of the Gulf of St. Lawrence. Can. Tech. Rep. Fish. Aquat. Sci. 2113: 59p.

HANSEN, J.C. 1996. Human health and diet in the arctic. Sci. Total Environ. 186: 135.

HARDING, G.C., R.J. LEBLANC, W.P. VASS, R.F. ADDISON, B.T. HARGRAVE, S. PEARRE Jr., A. DUPUIS and P.F. BRODIE. "In press". Bioaccumulation of polychlorinated biphenyls (PCBs) in a marine pelagic food web, based on a seasonal study in St. Georges Bay in the southern Gulf of St. Lawrence. Mar. Chem.

HARGRAVE, B.T., G.C. HARDING, W.P. VASS, P.E. ERICKSON, B.R. FOWLER and V. SCOTT. 1992. Organochlorine pesticides and polychlorinated biphenyls in the Arctic Ocean food web. Arch. Environ. Contam. Toxicol. 22: 41-54.

HUNZINGER, O., S. SAFE and V. ZITKO. 1974. The chemistry of PCB's. CRC Press, Inc., Cleveland, Ohio. 269p.

WARE, D.M. and R.F. ADDISON. 1973. PCB residues in plankton from the Gulf of St. Lawrence. Nature 246 (5434): 519-521.

WILKINSON, L., M. HILL, S. MICELI, P. HOWE and E. VANG. 1992. Systat for the Macintosh, Version 5.2. Systat Inc., Evanston, Illinois. 724p..