Population characteristics and contaminant burdens of the white sucker (*Catostomus commersoni*) from the St. Lawrence River near Cornwall, Ontario and Massena, New York

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ABSTRACT

The objective of this study was to measure and compare several physical and chemical characteristics of two white sucker (*Catostomus commersoni*) populations from the St. Lawrence River, near Cornwall, Ontario and Massena, New York, that could be used to address environmental quality issues in this area. Seven hundred and sixty-two white suckers from the St. Lawrence River were collected upstream and downstream of the Moses-Saunders power dam near Cornwall, Ontario and Massena, New York during 1994 and 1995. Upstream white suckers were shorter and weighed less at older ages, had a lower average fecundity, a greater mean egg diameter, lower condition factor at older ages, greater overall mean age, and a higher incidence of lip and body papillomas than the downstream fish.

In addition, a total of 80 fish (40 fish upstream and 40 fish downstream) were analysed for organic chemical contaminants. The mean total concentration of 34 polycyclic aromatic hydrocarbon compounds (PAH), analysed in muscle tissue using GC-MS-SIM techniques, were significantly higher in white suckers caught upstream of the dam (75.2 ± 30.4 ng/g dry wt.) than in those caught downstream (53.6 ± 29.7 ng/g dry wt.). There was no significant relationship between the concentration of PAHs in the muscle tissue and the length, weight, age, sex, total number of eggs (fecundity), mean egg diameter, gonadosomatic index (GSI), condition factor, or lipid content of a fish. Concentrations of 132 polychlorinated biphenyl (PCB) congeners and 31 organochlorine pesticides were also analysed in muscle tissue using GC electron-capture detectors (ECD). Detectable levels of PCB and organochlorine pesticides were found in nearly all fish sampled. However, there was no statistical difference between organochlorine contaminant concentrations of upstream and downstream fish, except for total aldrin (3.4 ± 4.0

ng/g dry wt. upstream, 1.9 ± 2.7 ng/g dry wt. downstream). Concentrations of most organochlorine compounds increased linearly with lipid content, but no relationship was found between contaminant concentration and age of the fish, except for DDT and mirex.

One possible reason for the higher PAH contaminant concentrations in white suckers residing upstream is the presence of the dam. Chemicals exported from the Great Lakes and other upstream sources are likely settled out in the sediments trapped upstream of the dam due to the slower currents in the Lake St. Lawrence reservoir. As a result, contaminants may be more concentrated in the sediments upstream in comparison to sediments in the high flow zone downstream of the dam. The differences found in population characteristics between upstream and downstream could not be related solely to PAHs, but may be affected by PAHs acting in synergy with the other contaminants present.

RESUME

L'objectif principal de cette étude était de mesurer et comparer les caractéristiques physiques et chimiques de deux populations de meunier noir *(Catostomus commersoni)* du fleuve Saint-Laurent, près de Cornwall, Ontario et Massena, New York, ces caractéristiques pouvant être utiles dans le cadre d'une étude des problèmes associés avec la qualité de l'eau dans cette région. Sept cent soixante meuniers ont été capturés en amont et en aval du barrage hydro-électrique Moses-Saunders près de Cornwall, Ontario et Massena, New York, en 1994 et 1995. Les meuniers capturés en amont sont plus courts et moins lourds chez les individus plus agés, ont une fécondité moyenne plus basse, des oeufs de plus grand diamètre, un coefficient de condition plus faible à tous les âges, une moyenne d'âge plus élevée, et une plus grande fréquence de papillomes sur les lèvres et sur le corps.

Quatre-vingt poissons (40 en amont et en aval, respectivement) ont été analysés afin d'établir leur contenu en contaminants organiques. La concentration moyenne totale de 34 composés d'hydrocarbures aromatiques polycycliques (HAP), examinés dans les tissus musculaires en utilisant les techniques d'analyses GC-MS-SIM, est plus élevée chez les poissons capturés en amont du barrage (75.2 ± 30.4 ng/g poids sec) que chez les poissons capturés en aval (53.6 ± 29.7 ng/g poids sec). Aucune relation significative a été trouvée entre la concentration de HAP dans le tissu musculaire et la longueur, le poids, l'âge, le sexe, le nombre total d'oeufs (fécondité), le diamètre des oeufs, l'index gonadosomatique, le coefficient de condition ou le contenu lipidique des poissons. Les concentrations de 132 congénères de byphenyl polychlorés (BPC) et de 31 pesticides organochlorés dans le tissu musculaire des meuniers ont également été obtenues par chromatographie en phase gazeuse utilisant des détecteurs de capture d'électrons.

Des BPC et des pesticides organochlorés ont été détectés chez presque tous les poissons échantillonnés. Cependant, aucune différence statistique, au niveau des contaminants organochlorés, n'a été détectée entre les poissons capturés en amont et ceux capturés en aval du barrage, sauf pour la quantité totale d'aldrine (3.4 ± 4.0 ng/g poids sec en amont, 1.9 ± 2.7 ng/g poids sec en aval). Les concentrations de la plupart des composés organochlorés augmentent, d'une manière linéaire, avec le contenu lipidique, mais aucune relation n'a été trouvée entre la concentration des contaminants et l'âge des poissons, sauf pour le DDT et le mirex.

Une des raisons possibles servant à expliquer la plus haute concentration de HAP en amont est la présence du barrage. Les produits chimiques exportés des Grands Lacs ainsi que ceux provenant d'autres sources situées en amont du barrage ont probablement tendance à sédimenter dans le réservoir en amont du barrage (lac Saint-Laurent) en raison de la faiblesse des courants dans cette portion du fleuve. Ainsi, les contaminants en amont sont peut-être plus biodisponibles que ceux dans la zone de courant plus rapide située en aval du barrage. Les différences observées au niveau des caractéristiques des populations entre l'amont et l'aval ne peuvent être reliées uniquement aux HAPs, mais peuvent résulter de la synergie entre les HAPs et les autres contaminants présents dans l'environnement.

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GENERAL INTRODUCTION

Rationale

The International Section of the St. Lawrence River that flows through Cornwall, Ontario and Massena, New York was designated as an Area of Concern (AOC) by the International Joint Commission (IJC) in 1985 (International Joint Commission 1985) (Fig. 1). This designation was a result of poor water quality conditions near and downstream of this area (Lake St. Francis) (RAP 1992). The major cause of the poor water quality is believed to be due to industrial activities along both shores of the Cornwall/Massena region since the late 1800's. The two contaminants of most concern in the St. Lawrence ecosystem are polychlorinated biphenyls (PCB) and mercury, based on concentrations in sediment and fish (International Joint Commission 1989). During 1959 and 1973, General Motors in Massena, New York discharged considerable amounts of PCB into the St. Lawrence River. The Aluminium Company of America (ALCOA) and Reynold's Metals, also on the American side, have both had historical uses of PCB (RAP 1992). On the Canadian side, Courtauld's Fibres (closed in 1992)/Courtauld's Films (closed in 1989) and Boise Cascade Limited (BCL) in 1985 had high levels of PCB in the sediments near their common discharge, and the CIL chlor-alkali plant in Cornwall, discharged large quantities of mercury from 1935 to the early 1970's. Domtar Fine Papers was a lesser source of mercury on the Canadian side (RAP 1992). In addition to PCB and mercury contamination, high levels of polycyclic aromatic hydrocarbons (PAH) have been detected in the sediments of Lake St. Francis and in the vicinity of General Motor's (International Joint Commission 1989). Significant quantities of mirex have also been detected in the St. Lawrence River (Suns et al. 1993). Currently, Domtar in Cornwall, Ontario, and ALCOA, Reynold's

Metals, and General Motors in Massena, New York are the largest known dischargers of contaminants to the River (International Joint Commission 1989). In addition to these local industrial sources of pollution, a significant quantity of the contaminant burden in the St. Lawrence River is exported downstream from the Great Lakes (International Joint Commission 1989).

The pollution in this area caused the local governments and citizens to decide that the Cornwall-Lake St. Francis ecosystem was highly degraded and in need of rehabilitation. As a result, a remedial action plan (RAP) was initiated in 1986 to identify sources of pollution and to recommend solutions to clean up this part of the river (RAP 1992). This study provides contaminant and population data for white suckers (*Catostomus commersoni*), which can be used in future recommendations for the International Section of St. Lawrence River ecosystem.

Background

Approximately 95% of the water that flows through the Cornwall/Massena ecosystem originates from the Great Lakes (RAP 1992), 0.1% of the flow originates from industrial wastewater dischargers, and 3% originates from tributaries (International Joint Commission 1989). The effect of this flow on the distribution and transboundary movement of contaminants within the Cornwall/Massena ecosystem remains poorly known. As well, the potential contribution of the industrial activities on the shorelines downstream of the Moses-Saunders power dam has resulted in very little attention being given to the non-industrialized area immediately upstream.

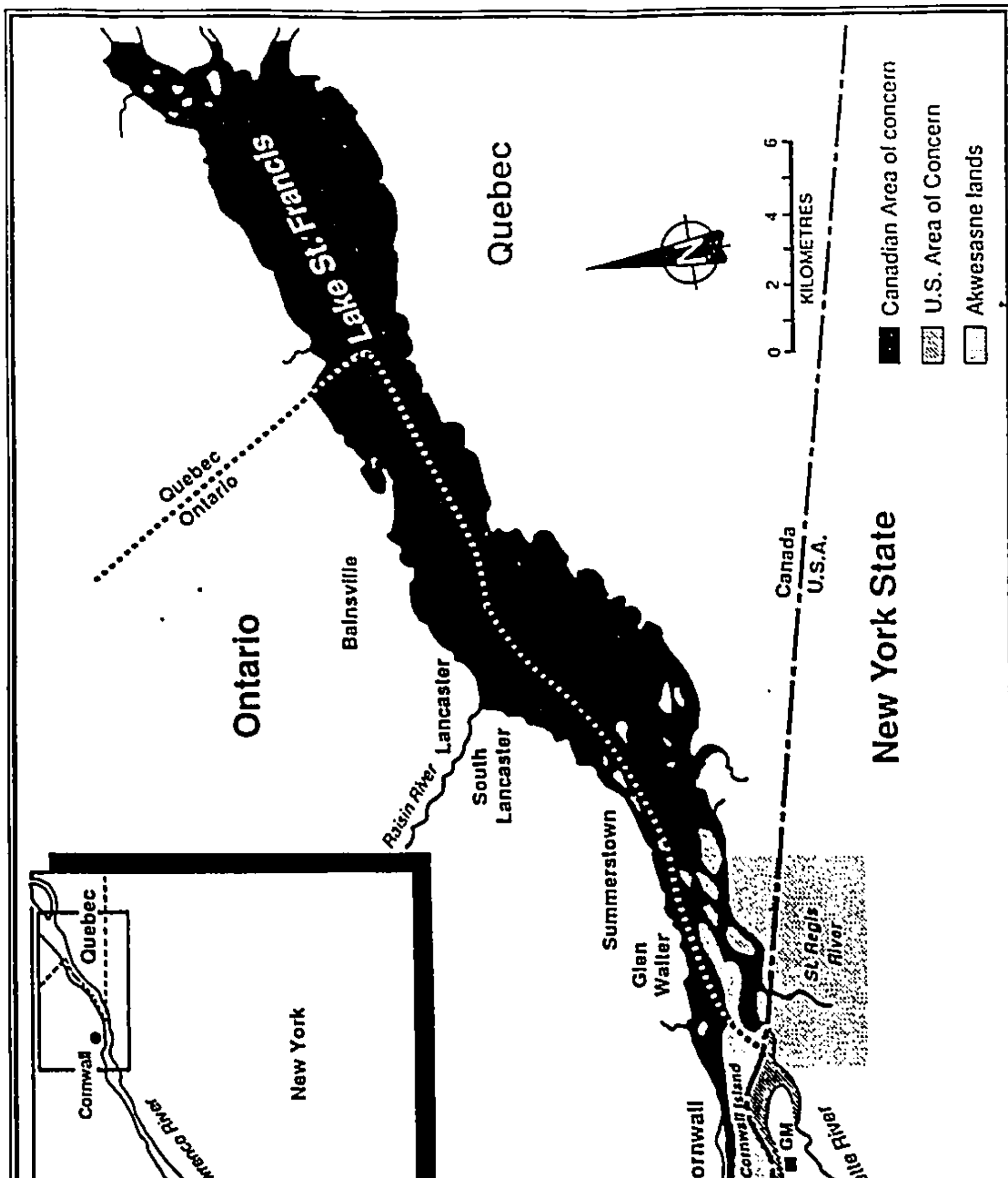
For the purpose of our study, we divided the International Section of the St. Lawrence River at Cornwall/Massena into two regions. The first region is upstream of the Moses-Saunders power dam (Lake St. Lawrence) while the second region is the Canadian AOC downstream of the Moses-Saunders hydro-electric dam in Cornwall (including the western end of Lake St. Francis) (Figure 1). To the west, the Iroquois dam, located approximately 50 kilometres upstream of Cornwall, is the first dam downstream of Lake Ontario. It controls the downstream hydrology and marks the beginning of artificial Lake St. Lawrence, the reservoir for the Moses-Saunders hydro-electric dam. Below Cornwall/Massena, Lake St. Francis acts as the reservoir for the Beauharnois hydro-electric dam at the western end of Lake St. Louis (RAP 1992). The effect the presence of the Moses-Saunders hydro-electric dam has on contaminant behaviour, and on the fisheries resource, is unknown.

Fish populations have often been used as biomonitors of ecosystem health (Munkittrick and Dixon 1989a) and as indicators of contaminant stress on the environment (McFarlane and

Franzin 1978, Munkittrick and Dixon 1989b, Adams et al. 1992, Bresch 1992, Gagnon et al. 1995). The present study used white sucker (*Catostomus commersoni*), a species previously shown to be a good biomonitor (McFarlane and Franzin 1978, Munkittrick and Dixon 1989b, Munkittrick et al. 1991, McMaster et al. 1992, Gagnon et al. 1994). The white sucker is one of the most abundant and widely distributed fishes in North America and therefore a great deal is known about its biology (Scott and Crossman 1973). White suckers are indigenous benthic foragers that are generally considered to be secondary consumers that feed on bottom dwelling invertebrates, microcrustaceans, and detritus (Ahlgren 1990). Thus, their food source is in direct contact with sediments where many contaminants are concentrated, and they ingest what is available to them in the sediments. The effects of benthic contaminants, and associated disease, on the white sucker have been studied (Munkittrick and Dixon 1989b). As well, this species tolerates poor water quality, being a dominant species in physically degraded wetlands and other fish habitat of poor quality (Kelso 1977, Jude and Pappas 1992).

The primary goal of this study was to provide population and contaminant information (PAH, PCB, and organochlorine residue burdens) on white suckers residing upstream and downstream of the Moses-Saunders power dam at Cornwall, Ontario/Massena, New York. The data collected were used to 1) evaluate if there were any differences between upstream and downstream fish population characteristics; 2) determine if there was any significant difference in the body burdens of contaminants between upstream and downstream fish and; 3) determine if there was a relationship between population characteristics and the concentrations of contaminants in muscle tissue. To answer these questions, numerous population characteristics and the contaminant burdens of polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and selected organochlorine pesticides (OC) were measured and compared in muscle tissue of the white sucker from upstream and downstream of the Moses-Saunders power dam.

Figure 1- The Cornwall/Massena area of concern (AOC) in the St. Lawrence River as identified by the International Joint Commission in 1985. Reprinted from the Government of Canada (1990).



Lake St. Francis
Quebec
Quebec
Ontario
Ontario
Bainsville
Lancaster
Raisin River
South Lancaster
Summerstown
Glen Walter
Cornwall
Cornwall Island
GM
Reynolds
Raquette River
St. Regis River
Moses-Saunders Power Dam
Long Sault
ALCOA
Grass River
Massena
Canada
U.S.A.
New York State
0 2 4 6
KILOMETRES
Canadian Area of concern
U.S. Area of Concern
Akwesasne lands
Ontario
Quebec
New York
Cornwall
Maitland
Kingston
Lake Ontario
St. Lawrence River

CHAPTER 1

Population Characteristics of White Sucker (*Catostomus commersoni*) from Upstream and Downstream of the Moses-Saunders Power Dam at Cornwall, Ontario/Massena, New York

INTRODUCTION

Fish respond to environmental stressors, such as increased contaminant body burdens, through changes in population characteristics, which have included mean age, age distribution, growth rate, condition factor, age at maturation, gonad size, gonadosomatic index, fecundity, egg size, secondary sexual characteristics, tumour incidence, and population size (catch per unit effort) (McFarlane and Franzin 1978, Bresch 1982, Neuhold 1987, Munkittrick et al. 1991, McMaster et al. 1992, Munkittrick et al. 1992, Van Der Kraak et al. 1992, Gagnon et al. 1994, Gagnon et al. 1995, Premdas et al. 1995). The direction of change that occurs (either an increase or decrease in the value of a trait) within any fish population depends on the main target of the stress (i.e. directly on the adults, their eggs, their fry, the food source, or as a result of habitat degradation), and, in many cases, is site specific (Munkittrick and Dixon 1989a, b). This last point requires that studies involving the effects of contaminants on fish populations be carried out on a site by site basis.

In this chapter, the characteristics of the white sucker (*Catostomus commersoni*) populations upstream and downstream of Cornwall, Ontario/Massena, New York, are investigated to determine if any significant difference exists between the characteristics of the two populations. There is reasonable certainty that the two white sucker populations do not intermix. White suckers generally forage and reside within a 20 km radius of their spring spawning grounds (Smith et al. 1989). This, coupled with the physical barrier that the Moses-Saunders and Long Sault spillway dams provide, strengthens our ascertation of independent populations. Consequently, the data collected in this study will determine if population differences between the two regions can be related to environmental conditions in the area. The null hypothesis in this study is that there will be no difference in population characteristics of white suckers collected from upstream and downstream of the Moses-Saunders power dam.

METHODS

Study area and sampling

Sampling of white suckers took place in the St. Lawrence River near Cornwall, Ontario/Massena, New York, upstream of the Moses-Saunders hydroelectric power dam (Lake St. Lawrence) and downstream of the dam (Lake St. Francis). Sampling sites during the summer of 1994 spanned 40 kilometres from as far west as Farran Provincial Park upstream (75° 00' W, 44° 59' N) to as far east as Thompson Island downstream (74° 31' W, 45° 04' N). Nine sites were sampled upstream and eleven sites were sampled downstream. In addition, fish were captured on two spawning sites: Hoople Creek (74° 58' W, 45° 01' N) upstream of Cornwall (April 1994 and 1995) and the Raisin River (74° 30' W, 45 ° 08' N) downstream of Cornwall (April 1994) (Fig. 2; Table 1).

Sampling in the St. Lawrence River began in late May, 1994, and continued until mid-August 1994. The sampling gear included 10m and 30m seines, two trap nets (9.1 x 0.9 m lead, mesh size of 6 mm, rings 76 cm in diameter), two cotton multifilament experimental gill nets (61 m width x 2.4 m depth containing eight 7.6 m panels with stretched mesh sizes of 3.8 cm, 5.1 cm, 6.4 cm, 7.6 cm, 8.9 cm, 10.2 cm, 12.7 cm, and 15.2 cm), and one nylon monofilament experimental gill net (40 m width x 1.8 m depth containing five 7.6 m panels with stretched mesh sizes of 1.3 cm, 1.9 cm, 2.5 cm, 3.1 cm, and 3.8 cm). Gill nets were set in 3 to 7 m of water in areas with relatively low current. Trap nets were set in 1 to 2 m of water in embayments. Stationary gear were left in the water for approximately 24 hours. This method of sampling was used to ensure the capture of all sizes of white suckers that may have been present. Catch per unit effort (CPUE) was determined as the number of fish caught per hour of fishing.

To determine CPUE, only trap nets and multifilament gill nets were used. Trap nets that were overturned and gill nets that had been tangled by zebra mussels were not included in the analysis.

Captured fish were frozen whole at -20°C in plastic bags for further analysis or fixed in formalin and preserved in alcohol. Only frozen fish were used in the contaminant analysis.

Fecundity

Sex was determined, when possible, through visual inspection of gonads or fins (Spoor 1935, Trippel 1984). The gonads from spawning fish were weighed to the nearest gram. Ovaries were preserved in Gilson's fluid (100 ml 60% methanol, 880 ml water, 15 ml 80% nitric acid, 18 ml glacial acetic acid, 20 g mercuric chloride) (Snyder 1983) for six weeks before their analysis. The mean number of eggs in triplicate subsamples (3 x 5.0 g) was used to establish fecundity. Ten measurements of egg diameter (± 0.05 mm) were used to determine mean egg size. The gonadosomatic index (GSI) was calculated as the percent ratio of gonad wet mass to total body wet mass (Snyder 1983). Spawning fish were examined for lip and body papillomas with occurrence and exact anatomical location recorded.

Growth and ageing

Total, fork, and standard lengths of all fish were measured (±1.0 mm). Spawning fish were measured when collected, all other fish were measured after being frozen and thawed. Fish were weighed to the nearest 0.01 g. The condition factor (k) was measured as $k = 100 * \text{weight}/\text{length}^3$. Both pectoral fins were removed for ageing. Fins were cleaned in bleach, air dried, and coated with epoxy. Using a jeweller's saw, three or four thin sections were cut perpendicular to the central axis and adjacent to the ray's origin on the coraco-scapular complex. The sections were mounted on glass slides, cleared with xylene and fixed with Permount®. Length-frequency distributions were used as an aid to determine the age of younger fish (Chalanchuk 1984).

Statistical analysis

Differences in catch per unit effort (CPUE), total length, weight, condition factor, GSI, and mean age between upstream and downstream were analysed using ANOVA with region as the classification factor. The relationship of fecundity to carcass weight was compared using an ANCOVA with carcass weight as the linear covariate and region as a classification factor. The relationship of egg diameter to carcass weight was analysed in the same manner. The relationship of tumour presence versus condition factor and total length was analysed using ANOVA, with tumour presence as the classification factor. Males and females were analysed as separate groups for all ages except ages 0, 1, and 2 where sex could not be determined.

For all tests, $p \leq 0.05$ was chosen as the level of significance. Assumptions for ANOVA and ANCOVA were tested for all analyses by examining the variance of each group (equal variance assumption), and the independence of the group means and standard deviations. All fish were randomly sampled. In cases were assumptions did not hold, log transformation of the data remedied the problem. Therefore, logged transformed values of length, weight, and age were used in all the statistical analyses. Results for multiple tests were adjusted for random effects by multiplying the initial p-value by the number of tests conducted for a particular analysis. Statistical tests were conducted using SYSTAT 6.0® (Systat 1994).

Figure 2- Stations sampled on the St. Lawrence River upstream and downstream of the Moses-Saunders power dam at Cornwall, Ontario and Massena, New York during 1994 and 1995. See Table 1 for corresponding site names.

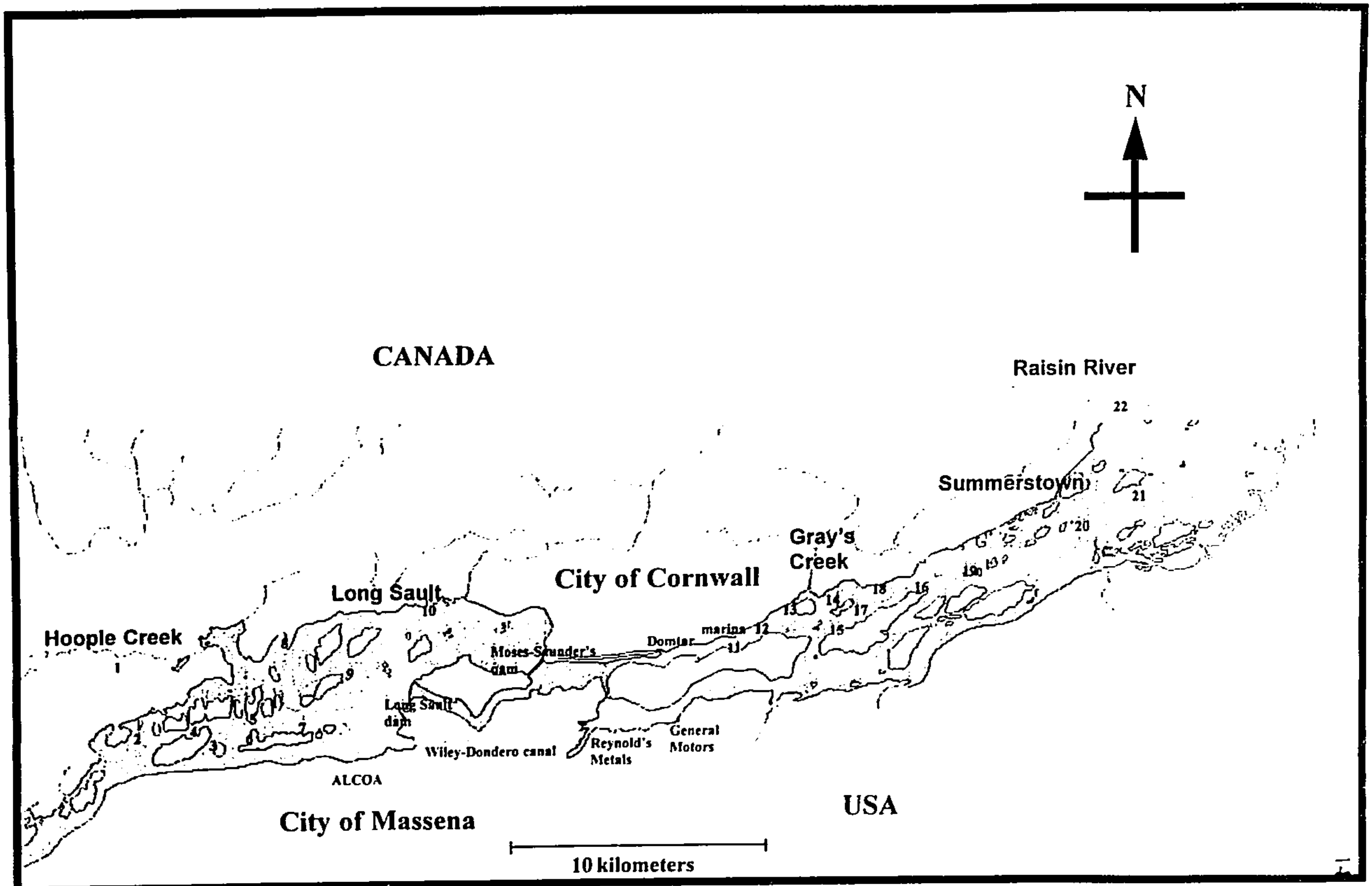

N
CANADA
Raisin River
Summerstown
Gray's Creek
City of Cornwall
Long Sault
Hoople Creek
Moses-Saunder's dam
Domtar
marina
Long Sault dam
Wiley-Dondero canal
Reynold's Metals
General Motors
ALCOA
City of Massena
USA
10 kilometers

Table 1. Location of sampling sites upstream and downstream of the Moses-Saunders power dam in the St. Lawrence River near Cornwall, Ontario/Massena, New York.

Region	Site	No. on map	Longitude	Latitude
Upstream	Hoople Creek	1	74° 58' W	45 ° 01' N
	Farran Prov. Park	2	75° 00' W	44 ° 59' N
	S.E. Croil Isl.	3	74° 58' W	44° 58' N
	Croil Isl.	4	74° 58' W	44° 59' N
	Hoople Isl.	5	74° 56' W	44° 59' N
	W. Long Sault Isl.	6	74° 56' W	44° 59' N
	E. Long Sault Isl.	7	74° 54' W	44° 59' N
	Wales Isl.	8	74° 55' W	45 ° 01' N
	Mille Roches Isl.	9	74° 53' W	45° 00' N
	Lakeview Heights	10	74° 51' W	45° 02' N
Downstream	Cornwall Isl.	11	74° 41' W	45 ° 01' N
	Courtauld's	12	74° 41' W	45 ° 01' N
	W. Pilon Isl.	13	74° 40' W	45 ° 01' N
	Farlinger's Pt.	14	74° 39' W	45° 02' N
	W. St. Regis Isl.	15	74° 39' W	45 ° 01' N
	E. St. Regis Isl.	16	74° 37' W	45 ° 01' N
	Colquhoun Isl.	17	74° 39' W	45 ° 01' N
	Flanigan's Pt.	18	74° 38' W	45° 02' N
	Dickerson Isl.	19	74° 35' W	45° 02' N
	Little Hog Isl.	20	74° 33' W	45° 03' N
	Thompson Isl.	21	74° 31' W	45° 04' N
	Raisin R.	22	74° 30' W	45° 08' N

RESULTS

Appendix A provides population data for individual white suckers. A total of 762 white suckers were captured in the St. Lawrence River during 1994 and 1995 (489 downstream; 75 females, 29 males, 385 undetermined sex, and 273 upstream; 83 females, 50 males, 140 undetermined sex). When CPUE was determined using only trap nets and multifilament gill nets, there was no significant difference in the CPUE of large white suckers between upstream and downstream ($p > 0.05$) (Table 2). On average, the capture time of one white sucker was every 23.3 hours when fishing (upstream and downstream) with trap nets, and 16.9 hours, when fishing with multifilament gill nets downstream, or 12.9 hours when fishing upstream.

Total length upstream was significantly greater for fish aged 0, 1, and 2 (both sexes) ($F = 13.913$, $p < 0.001$, $F = 8.000$, $p = 0.006$, and $F = 177.356$, $p < 0.001$, respectively) (Figures 3a, b; Table 3). Females were significantly longer downstream compared to upstream from ages 5 to 10 ($F = 15.719$, $p = 0.002$, $F = 24.094$, $p < 0.001$, $F = 36.185$, $p < 0.001$, $F = 44.452$, $p < 0.001$, $F = 13.134$, $p = 0.011$, and $F = 6.756$, $p = 0.029$, respectively) (Figure 3a; Table 3). Length at age 11 was not significantly different between populations above and below the dam, and fish aged 3, 4 and 12 could not be compared due to insufficient sample sizes. Males aged 8 to 10 were significantly longer downstream relative to upstream ($F = 7.542$, $p = 0.021$, $F = 12.834$, $p = 0.004$, and $F = 23.337$, $p = 0.002$, respectively) (Figure 3b; Table 3). At age 4, length of the fish did not differ significantly between the two regions, and fish aged 3, 5, 6, 7, 11, 12, and 13 could not be compared due to insufficient sample size.

Results obtained for carcass weight-age relationships were similar to those for the length-age relationships (Figure 4a; Table 3). The carcass weight of upstream fish was significantly greater at ages 0, 1, and 2 (both sexes) ($F = 24.671$, $p < 0.001$, $F = 7.507$, $p = 0.007$, $F = 194.067$, $p < 0.001$, respectively). Females were significantly heavier downstream compared to upstream from ages 5 to 10 ($F = 19.388$, $p = 0.001$, $F = 46.576$, $p < 0.001$, $F = 61.894$, $p < 0.001$, $F = 40.932$, $p < 0.001$, $F = 11.189$, $p = 0.016$, and $F = 10.695$, $p = 0.010$, respectively) (Figure 4a; Table 3). Weight at age 11 was not significantly different between populations above and below the dam, and fish aged 3, 4, and 12 could not be compared due to insufficient sample sizes. Males aged 9 and 10 were significantly heavier downstream relative to upstream ($F = 17.074$, $p = 0.001$, and $F = 19.036$, $p = 0.003$, respectively) (Figure 4b; Table 3). At ages 4 and 8, weight of the fish was not significantly different between the two regions, and fish aged 3, 5, 6, 7, 11, 12, and 13 could not be compared due to insufficient sample sizes.

The mean age of fish captured upstream (1.66 years) was significantly higher than mean fish age downstream (1.15 years) ($F = 46.101$, $p < 0.001$). This does not include spawning fish (Table 4). When only spawning fish were compared, there was no difference in the mean age of males or females between populations ($p > 0.05$) (Table 4). Overall condition factor was significantly higher for upstream white suckers than downstream ($F = 35.941$, $p < 0.001$) when caught in the summer , but spawning females caught downstream had significantly higher condition factors ($F = 18.988$, $p < 0.001$). There was no significant difference in condition factor between upstream and downstream for spawning males ($p > 0.05$) (Table 4).

Each population had a significant positive relationship between fecundity and carcass weight ($F = 37.958$, $p < 0.001$ downstream, $F = 71.136$, $p < 0.001$ upstream). When weight was used as a linear covariate, downstream females had significantly higher fecundity than upstream females ($F = 10.461$, $p = 0.002$) (Table 4). Mean egg diameter had a significant positive relationship with carcass weight ($F = 4.612$, $p = 0.039$ downstream, $F = 9.728$, $p = 0.003$ upstream). Upstream females had significantly greater mean egg diameter than females downstream ($F = 4.944$, $p = 0.029$) (Table 4). There was no significant difference in GSI between upstream and downstream for either females or males ($p > 0.05$) (Table 4).

Spawning white suckers from Hoople Creek (upstream) had a higher incidence of both lip and body papillomas than white suckers from the Raisin River (downstream) (Table 5). There was no relationship between the presence of tumours and the condition factor of a fish for females upstream ($p > 0.05$), although there was a significant relationship for males upstream ($F = 5.549$, $p = 0.025$). Males upstream with tumours had a lower condition factor. As well, there was no relationship between the total length of a fish at a particular age (ages 6, 7, and 8 for females upstream) and the presence of tumours ($p > 0.05$). Although spawning fish aged 3 to 11 were examined for the presence of tumours, tumours were not evident until age 6 in both sexes. Tumour incidence after age 6 did not appear to increase linearly with age, although the sample size at each age may have been too small to detect any trend.

Figure 3- Mean total lengths versus age for female (A) and male (B) white sucker (*Catostomus commersoni*) populations from downstream (open circles) and upstream (filled circles) of the Moses-Saunders power dam in the St. Lawrence River. Data points to the left of the dashed line represent fish whose sex has not been determined. Data points to the right of the dashed line represent fish whose sex is determined. Vertical bars represent one standard deviation. (n = 762).

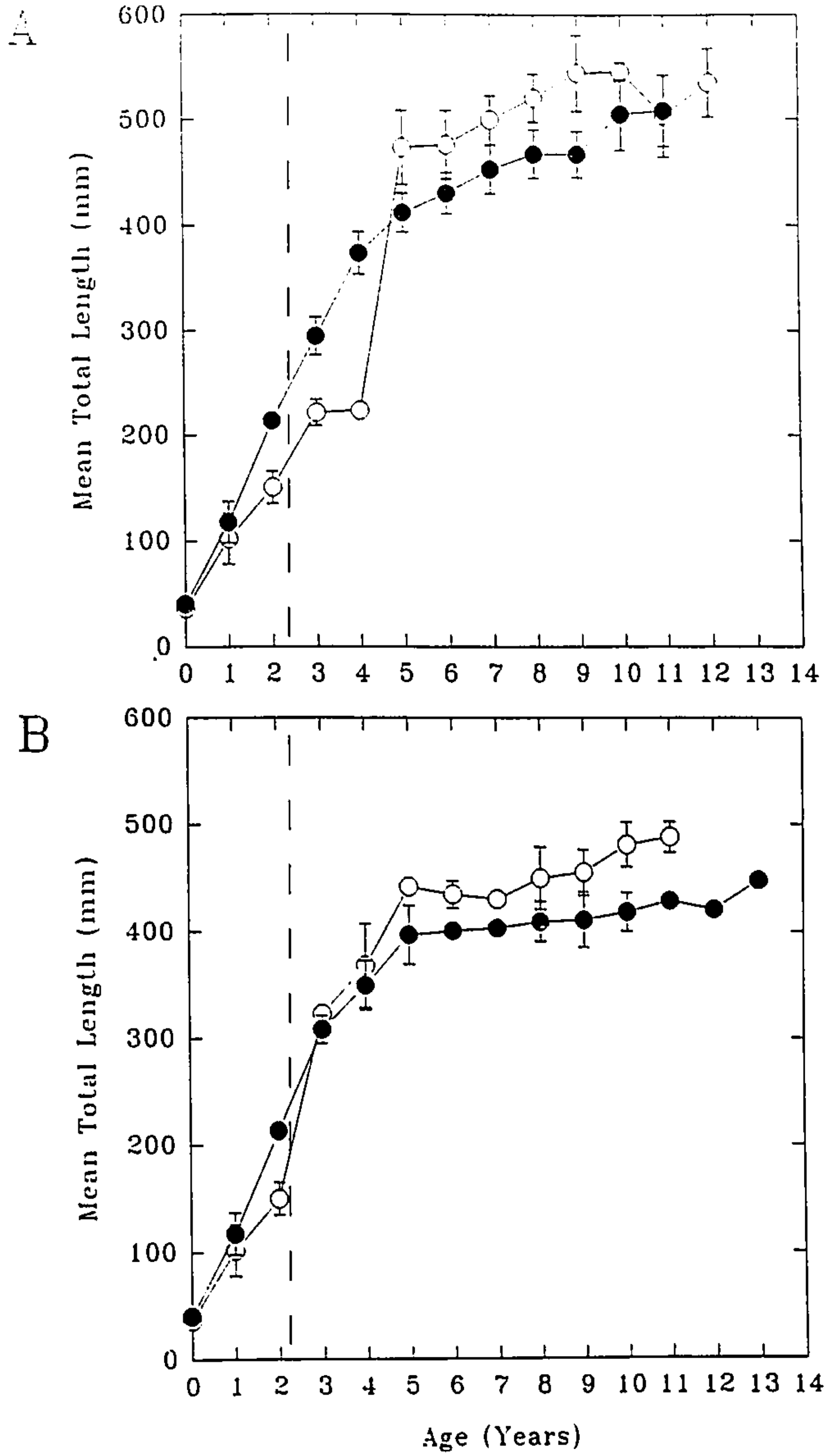

A
B
Mean Total Length (mm)
Age (Years)
0
100
200
300
400
500
600
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Figure 4- Mean carcass weights versus age for female (A) and male (B) white sucker populations from downstream (open circles) and upstream (filled circles) of the Moses-Saunders power dam in the St. Lawrence River. Data points to the left of the dashed line represent fish whose sex has not been determined. Data points to the right of the dashed line represent fish whose sex is determined. Vertical bars represent one standard deviation. (n = 762).

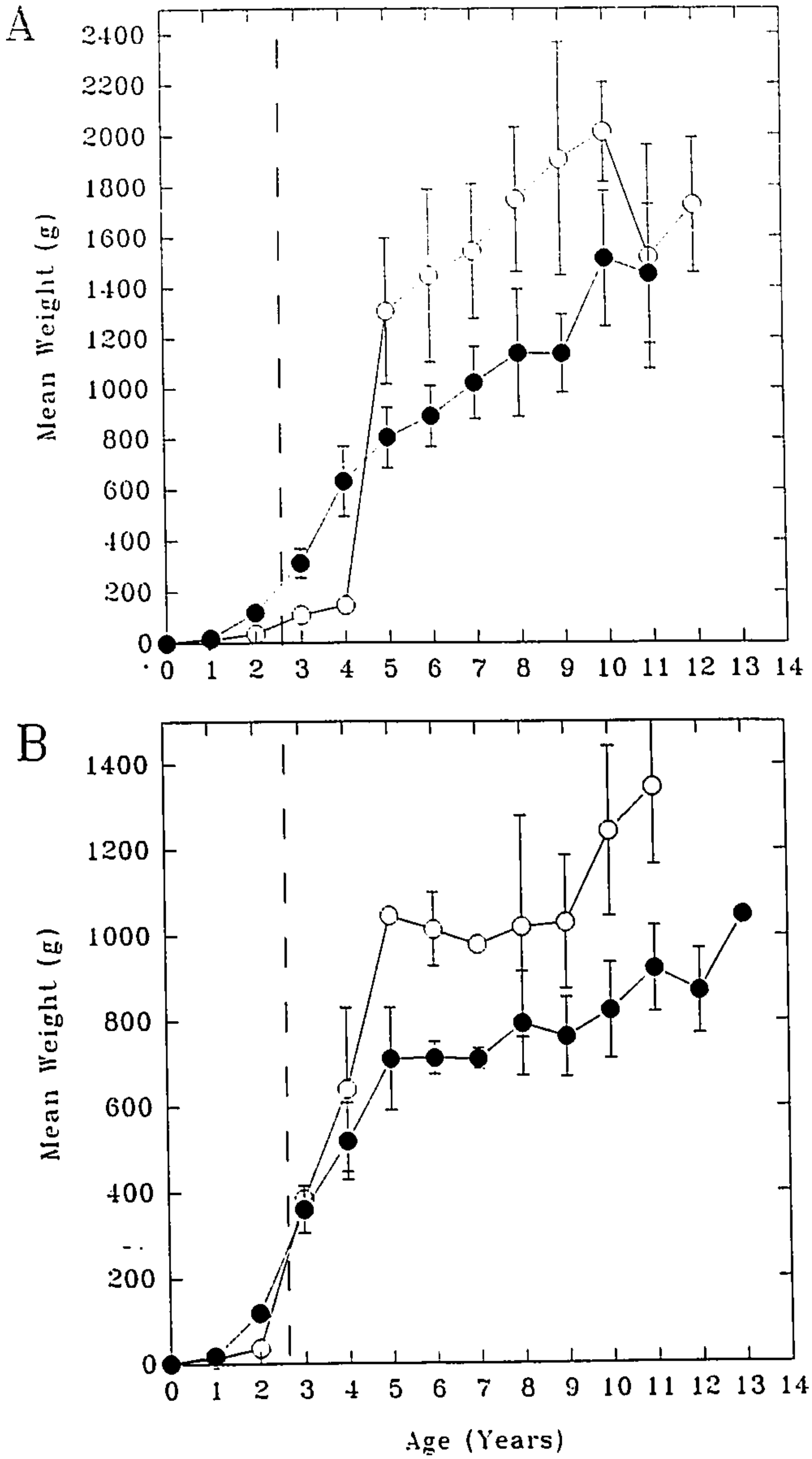

A
Mean Weight (g)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
B
Mean Weight (g)
1400
1200
1000
800
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (Years)

Table 2. Catch per unit effort (CPUE) of white suckers upstream and downstream of the Moses-Saunders power dam at Cornwall, Ontario/Massena, New York. Data were analysed using ANOVA. Values reported are mean ± SEM (n). *n.s. indicates no significant difference between regions.

Region	Trap nets (CPUE)	Gill nets (CPUE)
Downstream	0.043 ± 0.013 (10)$^{n.s}$	0.059 ± 0.012 (9)$^{n.s}$
Upstream	0.043 ± 0.043 (6)	0.077 ± 0.019 (8)

SEM = standard error on the mean
n = number of sites analysed

Table 3. Total lengths and carcass weights of male and female white suckers from upstream and downstream of the Moses-Saunders power dam in the St. Lawrence River. Data were analysed using ANOVA. Values are reported as mean ± SEM (n). Statistical differences between regions: * p < 0.05; ** p < 0.01; *** p < 0.001.

	Age	Upstream (total length) (mm)	Downstream (total length) (mm)	Upstream (carcass weight) (g)	Downstream (carcass weight) (g)
Unknown	0	40.3 ± 0.8 (100)***	36.7 ± 0.5 (264)	0.74 ± 0.05 (100)***	0.49 ± 0.02 (264)
sex	1	117.5 ± 3.9 (24)**	102.1 ± 2.7 (79)	17.7 ± 2.1 (24)**	12.1 ± 0.9 (79)
	2	213.5 ± 2.3 (14)***	150.2 ± 2.3 (44)	118.3 ± 4.9 (14)***	35.9 ± 2.0 (44)
Females	3	294.0 ± 8.9 (4)	221.0 ± 9.0 (2)	310.5 ± 27.8 (4)	107.5 ± 9.5 (2)
	4	373.0 ± 10.0 (4)	223.0 ± 0.0 (1)	632.0 ± 68.6 (4)	146.0 ± 0.0 (1)
	5	411.2 ± 7.5 (6)**	472.4 ± 13.2 (7)	803.5 ± 48.9 (6)**	1306.3 ± 109.4 (7)
	6	429.7 ± 4.7 (17)***	475.2 ± 8.6 (14)	887.6 ± 29.2 (17)***	1445.5 ± 91.5 (14)
	7	452.0 ± 4.9 (22)***	498.4 ± 5.9 (16)	1020.1 ± 30.7 (22)***	1543.3 ± 66.3 (16)
	8	466.1 ± 5.5 (17)***	519.1 ± 5.7 (16)	1138.7 ± 61.6 (17)***	1745.1 ± 71.0 (16)
	9	466.0 ± 10.9 (4)*	543.5 ±18.4 (4)	1136.0 ± 77.5 (4)*	1905.3 ± 230.1 (4)
	10	503.5 ± 13.8 (6)*	544.4 ± 4.1 (5)	1512.5 ± 109.2 (6)*	2010.4 ± 87.3 (5)
	11	507.7 ± 19.6 (3)	503.0 ± 15.9 (6)	1450.3 ± 159.1 (3)	1516.8 ± 179.9 (6)
	12		534.3 ± 18.9 (3)		1722.3 ± 265.9 (3)
Males	3	308.6 ± 5.8 (5)	323.0 ± 0.0 (1)	359.8 ± 24.7 (5)	384.0 ± 0.0 (1)
	4	350.1 ± 8.8 (7)	368.5 ± 19.6 (4)	518.7 ± 34.2 (7)	639.5 ± 95.9 (4)
	5	395.0 ± 10.9 (5)	442.0 ± 0.0 (1)	710.6 ± 65.5 (5)	1046.0 ± 0.0 (1)
	6	401.3 ± 3.8 (4)	435.0 ± 13.0 (2)	712.5 ± 19.1 (4)	1014.5 ± 60.5 (2)
	7	403.5 ± 2.5 (4)	430.5 ± 5.5 (2)	711.3 ± 12.1 (4)	978.5 ± 10.5 (2)
	8	409.9 ± 6.3 (9)*	450.3 ± 16.8 (3)	794.0 ± 40.8 (9)	1020.3 ± 149.4 (3)
	9	411.2 ± 10.6 (6)**	455.3 ± 6.9 (8)	762.0 ± 37.9 (6)**	1030.3 ± 55.2 (8)
	10	418.6 ± 8.0 (5)**	481.3 ± 10.4 (4)	823.2 ± 50.3 (5)**	1243.3 ± 99.3 (4)
	11	429.0 ± 5.0 (2)	488.6 ± 6.3 (5)	921.5 ± 71.5 (2)	1344.8 ± 80.1 (5)
	12	421.0 ± 6.0 (2)		869.5 ± 70.5 (2)	
	13	448.0 ± 0.0 (1)		1048.0 ± 0.0 (1)	

Table 4. Condition factor, age, GSI, fecundity, and egg diameter of white suckers upstream and downstream of the Moses-Saunders power dam at Cornwall, Ontario/Massena, New York. Data were analysed using ANOVA and ANCOVA. Values are reported as mean ± SEM (n). Statistical differences between regions: *p<0.05; **p<0.01; ***p<0.001. (n.s. indicates no significant difference between regions).

Region	Age (yr)	Condition factor (k)[a]	GSI[b]	Fecundity	Egg diameter (mm)
Summer fish					
downstream	1.15 ± 0.12 (429)*	0.91 ± 0.01 (428)***			
upstream	1.66 ± 0.18 (183)	1.01 ± 0.02 (183)			
Spawning females					
downstream	7.45 ± 0.23 (48)[n.s]	1.29 ± 0.01 (48)***	14.47 ± 0.33 (48)[n.s]	62199 ± 2455 (37)**	1.77 ± 0.03 (37)*
upstream	7.45 ± 0.22 (56)	1.13 ± 0.01 (56)	13.51 ± 0.44 (39)	33751 ± 1508 (35)	1.74 ± 0.02 (46)
Spawning males					
downstream	9.17 ± 0.58 (12)[n.s]	1.17 ± 0.03 (12)[n.s]	5.18 ± 0.43 (12)[n.s]		
upstream	7.94 ± 0.48 (31)	1.14 ± 0.01 (31)	4.17 ± 0.32 (29)		

[a]k = 100(wt/length^3) for summer fish, k = 100(wt - gonad wt/length^3) for spawning fish

[b]GSI = (gonad wt/body wt)*100

SEM = standard error on the mean

n = number of fish analysed

Table 5. Incidence of lip and body papillomas on spawning white suckers upstream (Hoople Creek) and downstream (Raisin River) of the Moses-Saunders power dam at Cornwall, Ontario/Massena, New York. (n) = sample size.

Site	Lip Papilloma	Body Papilloma
Spawning females		
downstream	0% (48)	0% (48)
upstream	44.6% (60)	8.9% (60)
Spawning males		
downstream	3.2% (12)	0% (12)
upstream	35.5% (31)	9.7% (31)

DISCUSSION

Several differences were found in the population characteristics of white sucker from upstream and downstream of the Moses-Saunders power dam in the St. Lawrence River at Cornwall, Ontario/Massena, New York. Fewer younger white suckers were caught upstream, while there were no differences in the upstream and downstream catch per unit effort of older white suckers when using trap nets or multifilament gill nets (Table 2). White suckers from upstream were significantly shorter and weighed less at older ages (ages 5 to 10 for females, ages 8 to 10 for males) (Figures 3 and 4; Table 3), and had lower average fecundity, greater mean egg diameter, higher overall condition factor, greater mean age (Table 4), and, a greater incidence of lip and body papillomas (Table 5) than downstream fish.

Forty-four fish older than age two (26 females, 18 males) and 385 fish aged two or younger were caught downstream during the summer of 1994, compared to 43 fish over the age of two (24 females, 19 males) and 140 fish aged two or younger which were netted upstream. These numbers do not include spawning white suckers. Approximately the same number of older fish were caught both upstream and downstream, however, far more younger fish were caught downstream. These younger fish were the reason for the large difference in the total number of fish caught upstream and downstream. The large number of young fish caught downstream also decreased the mean age of the population so that the population upstream had a significantly higher mean age (Table 4).

The fact that white suckers aged 0, 1, and 2 (sexes combined) were significantly longer and heavier upstream (Figures 3 and 4; Table 3) may be due to the smaller numbers of young fish upstream which results in less intraspecific competition. This increased growth of younger white suckers upstream could explain why the overall condition factor of fish upstream is higher than those captured downstream (Table 4). The large numbers of young fish in the sample make the condition factor for the population appear higher, even though spawning females downstream had a higher condition factor than spawning females upstream (Table 4). Therefore, it appears that white suckers from upstream grow faster and have a higher condition factor than white suckers downstream until about age 3. After age three, white suckers from downstream grow faster than those from upstream. This results in the older white suckers from downstream being larger than white suckers from upstream. As well, it results in the fish downstream having a higher condition factor than fish upstream at older ages. It is unlikely that the apparent faster growth of young white suckers from upstream was due to their date of capture. Sites from upstream and downstream were sampled alternatively each week over the summer of 1994, and young white suckers were captured throughout the entire sampling season.

The growth of white suckers that we caught in the St. Lawrence River was comparable to the growth of white suckers from other locations in Ontario. Chen and Harvey (1995) measured the fork lengths of white suckers aged 2, 3, and 4 from 23 Ontario lakes. The fork lengths of white suckers from the St. Lawrence fell within the ranges measured for white suckers from the 23 lakes, with the exception of 2 year old fish from downstream which were slightly smaller.

Fecundity and egg diameter both increased with the weight of the fish. An increase in fecundity with weight can be expected. Fecundity is a function of body size and typically the relationship with length (L) takes the form $F = aL^b$. A survey of 62 species found that the exponent b ranges from about 1.0 to 5.0, and lies most commonly between 3.25 and 3.75 (Wootton 1979). This relationship has previously been established with white suckers. Gagnon et al. (1995) found a positive significant relationship between fecundity and carcass weight in white suckers from the St. Maurice and Gatineau Rivers, although they suggested that an increase in the relative growth rate of gonads in their populations was related to increased energy availability.

Mean egg size has also been shown to increase with female length in some species, including salmonids and dace (Wootton 1990), although reasons for this relationship are not clear. It is possible that species with small females might need to maximise the number of eggs produced because their fecundity is relatively low, whereas species with large females may be able to sacrifice some fecundity in order to increase the quality of their eggs in terms of size (Wootton 1990).

Once the variation due to carcass weight was removed, white suckers downstream had a higher average fecundity, and a smaller mean egg size than white suckers from upstream (Table 4). It is thought that it is advantageous for a species to have more smaller eggs, instead of fewer large eggs, in order to achieve greater reproductive success (Wootton 1990). The optimal egg size is that which maximises the number of offspring surviving to become reproductively active, so it is the size at which the product of fecundity and juvenile survival is a maximum. An increase in egg size is likely to increase juvenile survival because there is a correlation between egg and larval size: bigger eggs produce bigger larvae (Ware 1975). Larger larvae can take a wider range of prey sizes, can probably survive periods of food shortage better, and have fewer predators (Wootton 1990). Yet, if we look at the data from the St. Lawrence River, white suckers from downstream produced, on average, 28,500 more eggs than white suckers from upstream. The increase in egg size for upstream compared to downstream, although significant, was only 0.03 mm (Table 4). Therefore, in this case, it is likely that the large difference in fecundity confers a greater advantage over the small increase in egg size.

Even though there were differences in fecundity and egg size between upstream and downstream populations, there was no difference in GSI for either female or male populations between upstream and downstream (Table 4).

There are several factors which have been shown to contribute to an increased mean age, and a decreased growth rate, condition factor, and fecundity in the white sucker (Munkittrick and Dixon 1989b). These responses are generally apparent when the sressor acts directly on the juveniles in a population. If either a contaminant event or stress restricts the food supply, decreasing energy flow through juveniles, or there is size-selective mortality of small fish induced by habitat change or loss of food supply, the result is an increase in mean age, a decrease in growth rate, a decrease in condition factor, and a decrease in fecundity (Munkittrick and Dixon 1989b). This type of response occurred in a white sucker population exposed to elevated radionuclide levels in a northern Saskatchewan lake (Swanson 1985). In this study, an increased mean age was associated with poor recruitment, and a decrease in fecundity and condition was associated with a poor food supply.

In our study, there was a decreased number of juveniles upstream which increased the overall mean age of the population compared to downstream. It is unclear why there appear to be fewer young white suckers upstream, but may be a result of the sampling scheme. The shoreline seine hauls resulted in over 50% of the young-of-the-year being caught at one site, both upstream and downstream, which indicates that young white suckers likely school and have a clumped distribution. Therefore, we may have simply sampled a large school of young-of-the-year fish downstream at a particular site which skewed our results and in turn affected the calculation of mean age and condition factor.

One reason for the decreased growth rate may be differences in food availability between the two regions. The most important organisms in the white sucker diet are chironomid larvae followed by water mites, cyclopoids, and ephemeropterans (Chen and Harvey 1995). Abundance of these benthic invertebrates upstream and downstream of the Moses-Saunders power dam was measured during the summer of 1994 (Mercier 1995, unpublished data). Preliminary results showed that chironomid larvae were the most abundant benthic invertebrates present both upstream and downstream (densities of 0.43/cm^2 and 0.22/cm^2, respectively). There was no significant difference of chironomid density between upstream and downstream, although the chironomid larvae downstream were significantly larger (Mercier 1995, unpublished data). Cyclopoids were not present and there was a low abundance of water mites (0.0192/cm^2 upstream and 0.0032/cm^2 downstream) and ephemeropteran larvae (0.0053/cm^2 upstream and 0.0001/cm^2 downstream). The densities of both water mites and ephemeropteran larvae were both significantly higher upstream. Since chironomid larvae are significantly larger downstream, and are the most important food source for the white sucker, white suckers downstream may have more energy available for growth.

One of the more interesting results was the incidence of lip and body papillomas (Table 5). Female white suckers upstream had lip papillomas 44.6% of the time, and body papillomas 8.9% of the time, while females downstream had no incidence of lip and body papillomas. Male white suckers upstream had lip papillomas 35.5% of the time and body papillomas 9.7% of the time, compared to low occurrences (3.2%) of lip and no occurrence of body papillomas in downstream males. Many studies have shown higher tumour frequencies in fish species living in proximity to contaminated bottom sediments (Black 1983, Malins et al. 1984, Sonstegard 1977, Smith et al. 1989, and Premdas et al. 1995), although no studies have directly related the occurrence of lip papillomas in white suckers to environmental contaminants (Environment Canada 1991b). In Premdas et al. (1995), the muscle tissue of white suckers from the Ganaraska River, compared to tissue from the Squaw River, had concentrations of PCBs, DDT, chlordanes, hexachlorobenzenes (HCB), and mirex that were, on average, 15, 30, 12, 4, and 80 fold higher, respectively. In addition, white suckers from the Ganaraska River had a high prevalence of lip papillomas (46% of the population) in comparison to white suckers from the Squaw River (5% of the population). Smith et al. (1989) found that 43% and 46% of white suckers spawning in the highly polluted Grindstone and Oakville Creeks, respectively, had lip papillomas. The Oakville and Grindstone Creeks drain into the western basin of Lake Ontario, adjacent to the heaviest concentration of industrialisation in Canada. In a review of skin, lip, liver, and gonadal tumours in fish, Baumann (1984) concluded that tumour incidence increased in areas contaminated by industrial effluents containing PCBs and PAHs, and suggested that tumour incidence in certain species of fish provided an indication of carcinogenic compounds in the environment. In eastern Lake Erie, white sucker populations, in areas where sediments were contaminated by PAHs, had a high prevalence of epizootic carcinoma and had stomach contents high in PAH concentrations (Maccubbin et al. 1985).

Although a relationship between condition factor and tumour incidence was observed in males, no relationship between tumour incidence and the total length of a fish was found. This is consistent with the findings of Johnson and Cooley (1992). They found that white suckers from

Hamilton Harbour and Grindstone Creek had a high incidence of tumours that was unrelated to growth measurements. As well, no relationship was found between age and prevalence of papillomas in white suckers from the Ganaraska River or Squaw River (Premdas et al. 1995). Baumann et al. (1987) found no correlation between the presence of lip and skin tumours and age for brown bullheads taken from the Black River, an industrialised Lake Erie tributary, polluted with high PAH concentrations in the sediment. Only Smith et al. (1989) reported that the prevalence of epidermal papilloma was correlated with the age (length) of white suckers taken from polluted Oakville Creek. Smith et al. (1989) also found that papillomas first appeared on fish at reproductive maturity (5 - 6 years) which is consistent with our finding that white suckers from Hoople Creek did not develop papillomas until age 6 in this population (even though fish aged 3 to 11 were examined).

The many differences noted between white suckers from upstream and downstream support the assumption that two different populations reside on either side of the Moses-Saunders power dam. Although, at this point, reasons for the observed population differences between the two regions are unclear. Construction of the St. Lawrence Seaway and the Moses-Saunders power dam resulted in tremendous damage to the ecosystem of the International Section of the St. Lawrence River (International Joint Commission 1989). Major changes in water depth and current speed, coupled with dredging operations, resulted in changes to sedimentation patterns and the density and distribution of aquatic vegetation. A major loss of very important fish and wildlife habitat resulted from the complete flooding of the Sault Rapids (the largest rapids in the Great Lakes drainage basin) when Lake St. Lawrence was created to form the power pool for the hydro project (RAP 1992). Those rapids formerly had provided excellent spawning and nursery habitat for many fish species. Equally important, the rapids had afforded a natural continuous mixing and cleansing that was beneficial for kilometres downstream (International Joint Commission 1989). It is possible that the construction of the water control and power structures not only negatively affected fish habitat, but altered the sedimentation patterns of contaminants in this area.

CHAPTER 2

Polycyclic Aromatic Hydrocarbon Burdens in White Sucker (*Catostomus commersoni*) from the St. Lawrence River at Cornwall, Ontario/Massena, New York

INTRODUCTION

Of the many types of pollutants that are discharged into the St. Lawrence River at Cornwall, Ontario/Massena, New York, polycyclic aromatic hydrocarbons (PAHs) are a concern, although information regarding their impact on fish is limited (Environment Canada 1991a, Hellou et al. 1994a). PAHs are a class of widely distributed compounds that are toxic, carcinogenic, and mutagenic (Baek et al. 1991). Sixteen unsubstituted (parent) PAHs have been recommended as priority contaminants by the World Health Organisation (WHO), the European Economic Community (EEC) and the US Environmental Protection Agency (EPA) (Hellou et al. 1994a). PAHs contain carbon and hydrogen atoms and have more than one aromatic ring in their structure. Parent PAHs may enter the atmosphere through natural sources of combustion, such as forest fires and volcanic eruptions, but emissions resulting from the combustion of fossil fuels are the predominant source. Alkyl substituted PAHs have often been detected entering the aquatic environment from non-combusted petroleum sources, in discharge from ships, oil seepage, and runoff from roads (Baek et al. 1991).

PAHs, which are hydrophobic and lipophilic, partition in aquatic environments between water, sediments, and interstitial water and organisms with levels in sediments and interstitial water usually being several orders of magnitude greater than the concentrations in overlying water (Clements et al. 1994, Hellou and Payne 1995). The high concentrations of PAH in sediments results in benthic invertebrates playing an important role in the transfer of contaminants from sediments due to their significance as a food source for bottom-feeding fish such as white suckers (*Catostomus commersoni*) (Clements et al. 1994).

In this study, we measured the concentrations of 17 parent and 17 alkyl substituted PAHs in muscle tissue of white sucker from the St. Lawrence River at Cornwall/Massena, and examined the potential effects these levels of contaminants had on population characteristics. More specifically, we investigated 1) differences between total PAH concentration in muscle tissue of white suckers upstream and downstream of the Moses-Saunders power dam and 2) if the differences found had any relationship with growth and age characteristics of white suckers from each region that could be used as biomonitors (see Chapter 1 for population characteristics).

When investigating the levels of PAH in muscle tissue of white suckers, the null hypothesis was that levels of PAH would be as high downstream of Cornwall as they are upstream of the Moses-Saunders power dam.

METHODS

Forty fish from upstream and 40 fish from downstream were used in the analysis of PAHs. Fish were kept frozen at -20°C until processed for analysis. Fish were partially thawed and two sections of dorsal muscle tissue, above the lateral line, were removed from each fish. One section was taken for analysis and the other was archived. Muscle tissue was analysed for a number of reasons. In fish, the half life of hydrocarbons is longer in muscle than in other tissues. In particular, liver concentrations appear to provide information regarding short-term exposure, while muscle concentrations inform about long-term bioaccumulation (Hellou and Payne 1995). Consequently, the analysis of hydrocarbon levels in muscle gives a longer integrated overview of PAH concentrations (Hellou et al. 1991). In addition, concentrations of PAH in lean dorsal muscle tissue are of greater importance from the viewpoint of risk to the human consumer.

Filets were wrapped in solvent-washed aluminium foil and refrozen. Whole filets were homogenised in a stainless steel Omni® blender. The homogenate was transferred to a pre-cleaned glass jar, covered with a Kimwipe® and placed in a freeze-dryer for 72 hours. The average muscle water-content was determined from the ratio of freeze-dried weight to wet weight.

The freeze-dried tissue was ground to a flaky consistency. Approximately 10 grams (weighed to 4 decimal places) of the tissue was transferred to an extraction flask and spiked with 100 µl of octachloronapthalene (OCN). The sample was mechanically extracted three times (Ultra-Turrax® and dispersing probe type) with a total of 250 ml of dichloromethane and 50 ml of hexane. Each sample was eluted through fired sodium sulfate using an Allihn funnel and collected in a round-bottom flask. The eluent was spiked with 100 µl of 1,3-dibromobenzene

(DBB) and 10 μl of deutarated PAH standard. Spiked surrogates provided final sample concentrations of 300 ng/ml (PAH) and 100 ng/ml OCN and DBB. Samples were rotary evaporated to 10 ml and nitrogen evaporated to 1 ml using a temperature/pressure controlled N-Evap®. Lipids were removed from the sample by gel permeation chromatography (GPC) with Biobeads S-X3, 200-400 mesh, and 50:50 hexane/dichloromethane as the solvent. The lipids were collected in the first 100 ml fraction and the lipid content was determined after evaporating the solvent to dryness. The second fraction was rotary evaporated and nitrogen evaporated to 1 ml and fractionated by column chromatography with activated silica gel (EM-Science 7734-7). The column was eluted with 60 ml hexane to yield fraction A, and was eluted with a 50 ml aliquot of 50:50 hexane/dichloromethane to yield fraction B which contained the PAHs. Each fraction was then rotary evaporated and nitrogen evaporated down to exactly 1 ml before being transferred to autosampler vials.

Determination of polycyclic aromatic hydrocarbons

Identification and quantitative determinations of the PAHs were based on analysis using an HP 5890 gas chromatograph coupled to a 5971 HP mass selective detector. The capillary column used was an HP-5MS. The sample (2μl) was automatically injected in splitless mode with a time delay of 1.25 minutes from injection. The initial oven temperature of 60°C was held for 2 minutes and then programmed to increase by 10°C /min to 150°C; temperature programmed at 3°C/min to 280°C, temperature programmed at 10°C/min to 300°C and held for a further 5 minutes. The injector temperature was 250°C and the transfer line 280°C. The carrier gas was helium with an initial column head pressure of 15 psi. The system was equipped with Electronic

Pressure Control (EPC) and operated in constant flow mode. The filament and the multiplier were turned on at 6 minutes. The system was operated in the SIM mode. Standard midmass autotunes were performed before each set of environmental samples analysed.

The concentrations of PAHs were calculated by single point calibration. For each set of environmental samples the GC/MS instrument was calibrated using an external standard mix. A measured aliquot of the standard solution was injected onto the column. The response of the GC to each analyte is the basis of the single point calibration. An external standard mix was run after every 10 samples with the retention times and responses updated. The concentrations of the PAHs in the samples were then corrected based on the recovery of the appropriate surrogate PAH. The nominal detection limits based on 10 g of sample (dry wt.) varied between 0.54 and 2.5 ng/g. The ions monitored and the surrogates used are given in Appendix B.

Compound identification was ascertained by verification with performance standards, compliance with specified fractionation procedures, and continuous monitoring with method spikes. Quantitation procedures and standard reliability were checked regularly through quality control samples and participation in interlaboratory quality assurance studies. Spiked control samples (n = 5), without sample matrices, were analysed in the same manner. Contaminant concentrations are expressed in parts per billion (ppb) (nanograms per gram) of sample dry weight.

Statistical analysis

Differences in PAH concentration and lipid content between white suckers from upstream and downstream were analysed using ANOVA. The relationship between PAH concentration and total length, weight, age, and lipid content of white suckers was analysed using simple linear regression. Each region was analysed separately. The relationship between PAH concentration and total length and weight for individual fish (regions, sexes, and ages analysed separately) was also analysed using simple linear regression. The relationship between PAH concentration, fecundity, and carcass weight was analysed using multiple regression. The relationship between PAH concentration, egg diameter, and carcass weight was also analysed by multiple regression. The relationship between PAH concentration and GSI and condition factor were analysed using simple linear regression (region and sexes were analysed separately).

For all tests, $p \leq 0.05$ was chosen as the level of significance. Assumptions were tested for all analyses (see Chapter 1) and the logged values of PAH concentration, length, and weight were used in all of the analyses. Results for multiple tests were adjusted by multiplying the initial p-value by the number of tests conducted for each analysis. Statistical tests were conducted using SYSTAT 6.0® (Systat 1994).

RESULTS

Appendix C provides population and contaminant data for the eighty fish used in the analysis. The mean concentration of total PAHs in the muscle tissue was significantly higher in white suckers upstream of the dam ($F = 8.180$, $p = 0.005$) (Table 6). PAHs were detected in all muscle samples except for one fish downstream. No significant relationship was found between the PAH concentration and the physical characteristics of the fish such as lipid content, total length, weight, or age in upstream or downstream fish ($p > 0.05$). As well, the concentration of PAHs was found not to be related with total length and weight of same sex individuals of the same age class for each region (downstream females aged 6 and 7, males age 9, upstream females age 6 and 7, due to sample size limitations) ($p>0.05$). PAH concentration was not correlated with fecundity, mean egg diameter, GSI, or condition factor ($p>0.05$). As well, there was no significant difference in the lipid content of white suckers upstream and downstream ($p>0.05$) (Table 6). The average muscle water-content of the white suckers was 78.65 ± 1.80 %.

The average concentration of each measured PAH compound is given in Table 7. The predominant parent PAH compounds were napthalene (although napthalene is not included in the final analysis due to its presence in the first silica gel fraction), phenanthrene, anthracene, fluoranthene, and pyrene in both upstream and downstream fish. The predominant alkyl-substituted derivatives were 1-methylanthracene, 2-methylphenanthrene, 1-methylphenanthrene, 2,6 & 2,7-dimethylnapthalene, and 3,6-dimethylphenanthrene in both upstream and downstream fish. The relationship of PAH composition between upstream and downstream is described in Figure 5.

Figure 5- Concentrations of individual PAH compounds found in the muscle tissue of white suckers from upstream and downstream of the Moses-Saunder's power dam in the St. Lawrence River. The first 17 compounds represent parent PAHs and the remaining 17 compounds represent alkyl-substituted derivatives (n = 40 for both regions). See Table 4 for the reference numbers for each compound.

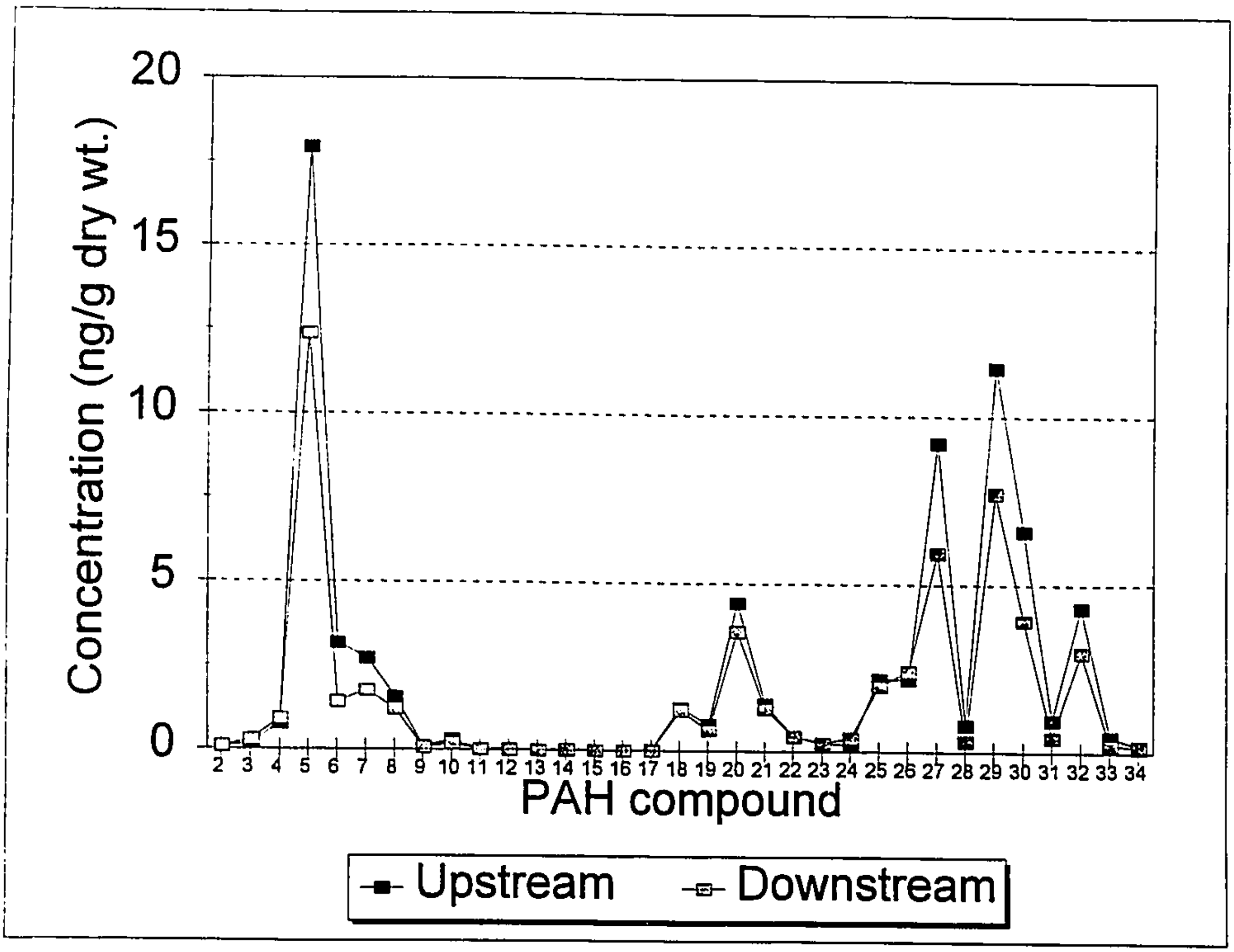

Concentration (ng/g dry wt.)
20
15
10
5
0
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
PAH compound
Upstream
Downstream

Table 6. Total polycyclic aromatic hydrocarbon concentrations (ng/g dry wgt.)* (minus napthalene) and lipid content (g/g dry wt.) in white sucker muscle tissue from the St. Lawrence River above and below the Moses-Saunders power dam near Cornwall, Ontario/Massena, New York (n = 39 for both regions). Data were analysed using ANOVA. Values are reported as (range) mean ± std. dev. BDL = below sample detection limit. ** $p < 0.01$ for differences between regions. (n.s. denotes no significant difference between regions).

Region	PAH Concentration	Lipid Content
Upstream	(12 - 146) 75.2 ± 30.4**	(0.0015 - 0.0447) 0.0204 ± 0.0121$^{n.s.}$
Downstream	(BDL - 103) 53.6 ± 29.7	(0.0029 - 0.0485) 0.0245 ± 0.0166

* Mean PAH concentrations are blank-corrected and adjusted for percent recoveries of surrogates.
* A value of 0 was used for compounds that were below the detection limit when calculating means and std.dev. (One fish downstream had levels of PAH below the detection limit).

Table 7. Mean concentrations and molecular weights of parent and alkylated PAH compounds in muscle tissue of the white sucker from upstream and downstream of the Cornwall/Massena area. (Values are presented in order of decreasing concentration). BDL = below detection limit.

Compound (upstream)	Conc. (ng/g dry wt.)	Molec. wt.	Compound (downstream)	Conc. (ng/g dry wt.)	Molec. wt.
PARENT			**PARENT**		
Naphthalene	39	128	Phenanthrene	12	178
Phenanthrene	17	178	Naphthalene	10	128
Anthracene	3.2	178	Fluoranthene	1.8	202
Fluoranthene	2.7	202	Anthracene	1.4	178
Pyrene	1.6	202	Pyrene	1.2	202
Fluorene	0.78	166	Fluorene	0.91	166
Chrysene	0.31	228	Acenapthene	0.27	154
Acenapthene	0.16	154	Chrysene	0.2	228
Benz(a)anthracene	0.09	228	Acenapthylene	0.09	152
Acenapthylene	0.06	152	Benz(a)anthracene	0.07	228
Benzo(k)fluoranthene	0.02	252	Perylene	0.01	252
Benzo(b)fluoranthene	0.02	252	Benzo(b)fluoranthene	0.01	252
Benzo(g,h,i)perylene	0.01	276	Benzo(g,h,i)perylene	BDL	276
Benzo(a)pyrene	0.004	252	Dibenz(a,h)anthracene	BDL	278
Perylene	0.002	252	Ideno(1,2,3-cd)pyrene	BDL	276
Ideno(1,2,3-cd)pyrene	BDL	276	Benzo(a)pyrene	BDL	252
Dibenz(a,h)anthracene	BDL	278	Benzo(k)fluoranthene	BDL	252
ALKYLATED			**ALKYLATED**		
1-Methylanthracene	11	192	1-Methylanthracene	7.7	192
2-Methylphenanthrene	9.2	192	2-Methylphenanthrene	5.9	192
1-Methylphenanthrene	6.6	192	1-Methylphenanthrene	3.9	192
2,6 & 2,7-Dimethylnapthalene	4.4	156	2,6 & 2,7-Dimethylnapthalene	3.6	156
3,6-Dimethylphenanthrene	4.3	206	3,6-Dimethylphenanthrene	2.9	206
2,3,5-Trimethylnapthalene	2.2	170	2,3,5-Trimethylnapthalene	2.4	170
2,3,6-Trimethylnapthalene	2.2	170	2,3,6-Trimethylnapthalene	1.9	170
1,6-Dimethylnapthalene	1.4	156	1,6-Dimethylnapthalene	1.3	156
2-Methylnapthalene	1.3	142	2-Methylnapthalene	1.2	142
9-Methylanthracene	0.97	192	1-Methylnapthalene	0.62	142
2-Methylanthracene	0.8	192	9-Methylanthracene	0.45	192
1-Methylnapthalene	0.79	142	2,3 & 1,4-Dimethylnapthalene	0.44	156
9,10-Dimethylanthracene	0.48	206	1,2-Dimethylnapthalene	0.41	156
2,3 & 1,4-Dimethylnapthalene	0.45	156	2-Methylanthracene	0.33	192
1,5-Dimethylnapthalene	0.26	156	1,5-Dimethylnapthalene	0.25	156
1,2-Dimethylnapthalene	0.19	156	9,10-Dimethylanthracene	0.24	206
2-Methylfluoranthene	0.19	216	2-Methylfluoranthene	0.16	216

DISCUSSION

Results indicated that white suckers from the Cornwall/Massena area of the St. Lawrence River bioaccumulate PAHs at both upstream and downstream sites. This means that white suckers have accumulated PAHs at a rate faster than they have been excreted or metabolised. However, upstream white suckers were significantly more contaminated with PAHs than downstream white suckers (Table 6). There are two possible scenarios that would give us this result. First, it is possible that PAHs travelling downstream from the Great Lakes have settled out in sediments upstream of the Moses-Saunders hydro-electric dam. Given that PAH concentrations in sediments are generally much higher (> 1000 times) than in water (Hellou and Payne 1995), and the presence of the hydro-electric dam along with the Long Sault spillway dam creates a slow current reservoir (Lake St. Lawrence), this provides conditions suitable for deposition of contaminated sediments. These sediments are then grazed upon by white suckers searching for food. Even if a significant amount of PAH is contributed by Cornwall/Massena, the levels may not be high enough to mask the effect of the sedimentation occurring upstream. As a result of this deposition, it is difficult to determine the extent of PAH inputs at Cornwall/Massena, since the hydrology of the river has a large influence on the concentration of PAHs in the sediment.

This leads to the second scenario which is that the Cornwall/Massena area is a significant contributor to PAH contamination, but the PAH are deposited further downstream in Lake St. Francis due to the high flow of water below the Moses-Saunders power dam. As well, even if sedimentation of contaminants does occur above the dams, we do not know what quantity of

PAH coming from upstream of Lake St. Lawrence settles out, and how much passes through the dams into the downstream area.

Many of the characteristics observed in the upstream population of more contaminated white suckers (smaller size and weight, lower fecundity, lower condition factor at older ages, greater overall mean age, fewer juveniles in the population) occur in white sucker populations exposed to bleached kraft-mill effluent or metals (Munkittrick and Dixon 1989b, Munkittrick et al. 1991, Swanson et al. 1992, Adams et al. 1992). Unfortunately, little research has been done on the specific effects of PAHs on such fish population characteristics (Environment Canada 1991a). When we tested for direct relationships of PAH on population characteristics, we found no significant correlation between the concentration of PAH in muscle tissue and the lipid content of a fish, condition factor, length, weight, age, number of eggs (fecundity), mean egg diameter, or GSI. Since aromatic hydrocarbons are hydrophobic and lipophilic molecules, it is interesting that no correlation between lipid content and PAH concentration was found, although this result agrees with the findings of Payne et al. (1988). Their results supported the hypothesis that several point sources of sediment hydrocarbon contamination are deleterious to fish health overall (changes in MFO enzyme levels and fat content of liver), although they found no relationship of PAH contaminated sediment exposure on either condition indices (overall condition factor and organ indices) of winter flounder or the lipid content of muscle.

We also found no significant relationship between the concentration of PAHs in muscle tissue and the length or weight of a fish for any particular age and sex class.

Our result that white suckers from Cornwall/Massena did not accumulate PAHs relative to the length, weight, age or lipid content of the fish, agrees with the findings of Hellou et al.

(1994a). They noticed that PAH concentrations in cod were not related to the length, weight, or age of the fish, and Hellou et al. (1991) found no relationship between bioaccumulation of PAH with age in harp seals, and found no linear correlation between PAH concentration and fat content.

Toxic chemicals are metabolised by oxidation, hydroxylation, and dealkylation into polar and water-soluble metabolites which are subsequently excreted (Luxon et al. 1987). Upshall et al. (1993) mentioned that there is a threshold level of exposure to PAHs that causes the induction of mixed function oxidase (MFO) enzymes which initiate the metabolism of these contaminants. MFO enzymes play an important role in the metabolism of liposoluble foreign compounds, including PAHs, drugs, pesticides, and endogenous substrates such as steroids and bile acids, although there can be a saturation of the enzymatic activity at high exposures of contaminants (Hellou and Payne 1995). The PAHs measured in white suckers from the St. Lawrence River are therefore unmetabolised PAHs. The metabolism of PAHs may also explain the difference in concentrations of PAH in fish between the two regions. White suckers from upstream have a slower growth rate and attain a smaller maximum length than white suckers from downstream (Chapter 1). The slower growth rate indicates that metabolism may be slower and therefore white suckers from upstream may metabolise PAHs at a slower rate as well.

Since no relationships were found between the concentration of PAH and any of the measured population characteristics, it seems likely that characteristic differences noted between upstream and downstream populations are probably not related to PAHs. Several reasons may explain this. First, it is unlikely that PAHs would act alone in their effect on the white sucker population. They can act with other chemicals, either antagonistically, synergistically, or additively, such that any relationships would be impossible to differentiate statistically (Niimi 1990). Second, effects of PAH (in addition to other chemicals) that may be seen on fish at the population level may not be seen as clearly by examining the effects of these chemicals on individual fish. Third, the concentrations of available PAHs in the sediments of Lake St. Lawrence may not be high enough to cause induction, and change the fish population characteristics. To test this assumption, one would need to determine the bioavailability of PAHs in the sediment of Lake St. Lawrence. Although, Payne et al. (1988) found winter flounder exposed to relatively low levels of petroleum-based PAHs in the sediments (1 ppm dry weight, summation of (Σ) 18 PAH) produced sublethal deleterious effects on fish health (change in MFO enzyme levels and fat content of the liver). Long (1992) concluded that 1 ppm (dry weight) of fluoranthene in sediment represented a threshold value at which a biological effect could be observed. Also, Stein et al. (1992) noticed sublethal effects (changes in hepatic monoxygenase activity, aryl hydrocarbon hydroxylase, and ethoxyresorufin-O-deethylase) in English sole, rock sole, and starry flounder exposed to low PAH concentrations in the sediments (0.061 ppm wet weight, Σ18 PAH). Finally, the observed population differences may not at all be related to contaminant concentrations but may simply be due to the fact that Lake St. Lawrence (an artificial reservoir) and the river portion downstream of Cornwall (including Lake St. Francis) are two separate ecosystems. Studies of PAH contamination in freshwater fish, and the effects of this contamination on the health of freshwater fish, are scarce, which makes comparison of PAH levels detected in white suckers quite difficult.

One population characteristic that could be related to levels of PAH is the occurrence of lip and body papillomas. White suckers upstream (both males and females) had a greater incidence of lip and body papillomas than white suckers from downstream (Chapter 1, Table 5). As previously mentioned, tumour incidence increased the closer the contaminated area was to industrial effluents discharging PCBs and PAHs (Baumann 1984). In our study, the high papilloma incidence upstream coincided with an area of higher concentrations of PAH in white sucker and an area that had detectable levels of PCB (see Chapter 3).

Table 8 gives the concentrations of parent and alkyl-substituted PAH analysed. The abundance of alkylated PAHs in conjunction with parental PAHs, in particular alkyl-phenanthrenes, suggests that a significant portion of the PAH in this region of the St. Lawrence River ecosystem are derived from non-combusted petroleum mixtures (Hellou and Payne 1995). The most predominant parent PAHs detected were (phenanthrene, anthracene, fluoranthene, and pyrene) which are the same abundant PAHs detected by Hellou et al. (1991) in harp seals from the Northwest Atlantic. The concentrations of PAH are highly correlated between upstream and downstream fish with the same compound trends being present in both populations (Figure 5; see Appendix B for corresponding compound names). Hellou et al. (1994a) stated that whatever the exposure levels of PAHs in the environment, inducible enzyme systems can adapt to maintain constant levels, more or less, in body tissues and the concentrations that are detected reflect levels of PAH which have not undergone metabolism. We found that concentrations of parent PAH compounds with a molecular weight greater than or equal to 252 were near or below detection limits in our samples (Table 7). Varanasi et al. (1989) have pointed out the tendency for the accumulation of the relatively lower molecular weight PAH (2 and 3 rings) under the free form. The higher molecular weight PAH (4, 5, and 6 rings), with higher chemical reactivity and carcinogenic potential, appear to undergo metabolism.

Therefore, it is also interesting to note that two of the highest molecular weight PAH, benzo[a]pyrene and the dibenzanthracenes, which are also two of the most actively carcinogenic and mutagenic PAHs (Francis 1994), were non-detectable in most of our samples suggesting that either they are readily metabolised by white suckers or they are not available to them in the sediments. (Table 7).

CHAPTER 3

Polychlorinated Biphenyl and Organochlorine Pesticide Burdens in White Sucker (*Catostomus commersoni*) from Upstream and Downstream of the Moses-Saunders Power Dam in the St. Lawrence River at Cornwall, Ontario/Massena, New York

INTRODUCTION

Polychlorinated biphenyls (PCBs) and chlorinated pesticides are ubiquitous contaminants in the aquatic environment as a result of their popular use and widespread application (Sanchez et al. 1993, Francis 1994). PCBs are produced by substitution of chlorine atoms to a biphenyl molecule. Up to 10 chlorine atoms may be attached at various locations, giving 209 possible PCB congeners. They have been used in different industrial applications since the 1930s, but were not recognised as environmental contaminants until 1966 (Jensen 1972). PCBs are one of the most stable classes of organic compounds known. They have a low dielectric constant and high heat capacity which render them ideal for use in electrical capacitors and transformers (Waid 1986). Many of these properties that made PCBs ideal for industrial and commercial use have contributed to their becoming environmental contaminants. Thus, they do not decompose or biodegrade significantly in the natural environment, they tend to migrate widely through natural atmospheric and water transport mechanisms, and, though only slightly soluble in water, they dissolve readily in oils and the fatty tissues of fish, birds, animals and humans (Environment Canada 1991a). For these reasons, PCBs are prevalent in our environment today, even though their use has been banned in North America since 1977.

Many of the organochlorine pesticides, like PCBs, resist degradation and persist in the environment. Although most of them have been banned for use in North America for decades (i.e. DDT in 1971 and mirex in 1976), measurable levels still accumulate in the tissues of fish, birds, animals and humans (Francis 1994). The highly lipophilic nature and persistence of some of these pesticides has resulted in programs being established to monitor their concentrations in wildlife. The Canadian Wildlife Service monitors levels of 29 organochlorines in the eggs of 12 waterbird species within the Great Lakes (Bishop et al. 1992, Weseloh et al. 1995). The Ontario Ministry of Environment and Energy monitors levels of several pesticides including aldrin, chlordane, dieldrin, heptachlor, lindane, mirex, DDT, and chlorobenzenes in the muscle tissue of several fish species in Ontario to produce guidelines for human consumption (Hayton 1993). Measurable levels of all of these contaminants have previously been detected in fish from the St. Lawrence River near Cornwall/Massena. (International Joint Commission 1989, Sergeant et al. 1993, Suns et al. 1993).

In this study, we determined the concentrations of individual PCB congeners and 31 organochlorine pesticide compounds in muscle tissue of white suckers upstream and downstream of the Moses-Saunders power dam to investigate differences in the abundance of these chemicals between the two regions. The null hypothesis was that there would be no difference in levels of contaminants between the two regions, provided there is no additional input of PCB and organochlorine pesticides at Cornwall/Massena.

METHODS

Forty fish upstream and forty fish from downstream were used in the analysis of PCBs and selected organochlorine pesticides. Fish were kept frozen at -20°C until processed for analysis. Fish were partially thawed and two sections of dorsal muscle tissue were removed from each fish. One section was taken for analysis and the other was archived. Filets were wrapped in solvent-washed aluminium foil and refrozen.

Samples were analysed for monochloro- to decachlorobiphenyl congeners and are identified according to the nomenclature given by the International Union of Pure and Applied Chemistry (IUPAC) (Waid 1986). For the PCBs detected, they are listed as the following homologues (grouped according to the number of chlorine atoms attached to each biphenyl molecule): monochlorobiphenyls 1 and 3; dichlorobiphenyls 4-10, 12, 13, and 15; trichlorobiphenyls 16-20, 22, 24-29, and 31-33; tetrachlorobiphenyls 40-42, 44-49, 51-57, 59, 60, 63, 64, 66, 67, 70, 71, 74, 76, 77, and 81; pentachlorobiphenyls 82-85, 87, 91, 92, 95, 97-101, 103, 105, 107, 110, 114, 118, and 119; hexachlorobiphenyls 128-138, 141, 144, 146, 147, 149, 151, 153, 156-158, 163, and 167; heptachlorobiphenyls 170-180, 182, 183, 185, 187, 189, 190, 191, and 193; octachlorobiphenyls 194-203, and 205; nonachlorobiphenyls 206-208; and decachlorobiphenyl 209. The sum of all quantified congeners was reported as "total PCBs". Samples were also analysed for 31 organochlorine pesticides. The chlorobenzene pesticides 1,2-, 1,3-, and 1,4-DCB, 1,2,3-, 1,2,4-, and 1,3,5-TCB, and 1,2,3,5-, 1,2,3,4-, and 1,2,4,5-TTCB, pentachlorobenzene, and hexachlorobenzene were reported as "total chlorobenzenes". The cyclodiene pesticides aldrin, endrin, and dieldrin were reported as "total aldrin", and o, p'- and p,p'-DDT, o,p'- and p,p'-DDE, and o,p'- and p,p'-DDD were reported as "total DDT". The hexachlorocyclohexane pesticides a-HCH, b-HCH, g-HCH (Lindane), and d-HCH were reported as "total HCH". Heptachlor, heptachlor epoxide, g-chlordane, and a-chlordane were reported as "total chlordane". Together, a-endosulfan and b-endosulfan were reported as "total endosulfan". Mirex and methoxychlor were analysed separately.

Determination of PCBs and OCs

Extracts were analysed by dual capillary column gas chromatography utilising electron capture detectors and a HP 5890 gas chromatograph. Two fused silica high performance capillary columns (i) 30-m OV-1 and (ii) 30 m DB-5 with 0.25 mm internal diameter and 0.11 µm phase thickness were employed. Samples (2 µL) were injected automatically into a split/splitless injector (250 °C), operated with a splitless hold time of 0.2 min. Initial chromatography conditions were 65 °C, isothermal for two minutes, 10 °C/min to 110 °C, 3 °C/min to a final temperature of 280 °C, isothermal five minute hold. The carrier gas was hydrogen.

Individual PCB congeners were identified and quantified by dual capillary column gas chromatography as described by Swackhamer (1988). PCB quantitation was performed using the NOI PCB-3 version standard (National Water Research Institute, Environment Canada, Burlington, Ontario). The NOI PCB standard was prepared from purchased 200 $ug \cdot mL^{-1}$ solutions of Aroclors 1016, 1221, 1242, 1254, and 1262 (Supelco 4-8701; 4-8705; 4-8706; 4-8707; 4-4810) and constituted at ratios of 1:1:1:1:1 in hexane to a concentration of approximately 3 $ug \cdot mL^{-1}$. The NOI standard was fortified with additions of congener 86 and 209 for analytical purposes. The standard contains 130 measurable PCB constituents. The NOI version 3 PCB standard solution was calibrated using individual PCB congener solutions obtained from AccuStandard (New Haven, Connecticut) for which the physical and chromatographic properties have been given by Bolgar et al. (1995). The calibration of the NOI PCB standard using individual standards, yields a total PCB value approximately 15% greater than when the standard was calibrated using the Green Bay mass balance PCB standard originally supplied by Mullin (1985). No proportional difference in percent homologue composition was observed as a result of each calibration. However, certain congeners exhibited significant differences with respect to previously stated concentrations.

Quantification of organochlorines and PCB was based on dual-column confirmation and acceptance of averaged signal responses for differences of ≤ 40%. For dual column signals above this difference that were greater than the detection limit, the lower value was repeated. Compound identification was verified by comparison with performance standards, compliance with specified fractionation procedures, and continuous monitoring with method spikes. Quantitative values were assigned according to response factors based on instrument performance standards and retention-time matching for the compounds of concern. Acceptance windows were ± 0.05 min on both columns. Quantitation procedures and standard reliability were checked regularly through quality control samples and participation in interlaboratory quality assurance studies. Contaminant concentrations are expressed in parts per billion (ppb) (nanograms per gram) of sample dry weight. The nominal detection limits based on 10 g of sample varied between 0.036 and 2.2 ng/g for PCBs, depending on the congener, and between 0.026 and 3.4 ng/g for the other organochlorines. Spiked control samples (n = 5), without sample matrices, were analysed in the same manner.

Statistical analysis

The relationship of lipid content in muscle tissue with PCB and organochlorine concentration was investigated using simple linear regression. Differences in organochlorine concentrations between regions were analysed using ANCOVA with lipid content as a covariate and region as a classification factor only for those organochlorines that had a significant relationship with lipid content. For those organochlorines that didn't have a significant relationship with lipid content, an ANOVA was used to detect differences between regions. The relationship between organochlorine pesticide concentration and the age of a fish was analysed using simple linear regression, and the relationship between PCB concentration and the length, weight or age of a fish was analysed in the same manner.

Statistical power ($1 - \beta$) and minimum sample size required to achieve a power level = 0.80 were determined when no significant difference in concentrations of contaminants were found between regions. This analysis was conducted using STPlan (version 4.0, June 1993). Power was determined with the known sample sizes and variances. Minimum sample sizes required to achieve a power level = 0.80 were determined using the observed variances in the study and an $\alpha = 0.20$.

For all tests, $p \leq 0.05$ was chosen as the level of significance. Statistical assumptions were tested for all analyses (see Chapter 1), and the log-transformed values of all organochlorine concentrations, and length and weight were used in all the analyses. Statistical tests were conducted using SYSTAT 6.0® (Systat 1994).

RESULTS

Appendix C provides population and contaminant data for the eighty fish used in the analysis. A significant, positive linear relationship between lipid content and organochlorine concentration was found for total PCBs ($F = 18.644$, $p < 0.001$), total chlordane ($F = 24.288$, $p < 0.001$), total HCH ($F = 20.712$, $p < 0.001$), total DDT ($F = 38.107$, $p < 0.001$), total aldrin ($F = 7.013$, $p = 0.010$) total endosulfan ($F = 39.724$, $p < 0.001$) and mirex ($F = 44.137$, $p < 0.001$). No significant relationships were found between lipid content and the concentrations of total chlorobenzene or methoxychlor ($p > 0.05$).

There was no significant difference in the concentration of organochlorine pesticides between the two regions ($p > 0.05$) with the exception of total aldrin ($F = 7.855$, $p = 0.006$) (Table 8). Detectable amounts of total chlorobenzene and total aldrin were found in all white suckers sampled. Total chlordane was detected in 87.5% of downstream samples and in 80% of upstream fish, total HCH was detected in 97.5%, mirex in 95%, and total DDT in 97.5% of samples from both populations. Total endosulfan was detected in 87.5% of downstream samples and 82.5% in upstream fish, while methoxychlor was only detected in 25% of samples downstream and 35% upstream. Of all the organochlorine pesticides monitored, total chlorobenzenes were present at the highest concentrations in both upstream and downstream fish (Table 8).

The results for the power analysis and minimum sample size required to detect differences at a power level = 0.80 are presented in Table 9. Power for all tests of differences in contaminant levels was generally low. Minimum sample sizes required to achieve a power level = 0.80 ranged from 74 to 716.

No significant relationship was found between organochlorine concentration and the age of a white sucker, except for concentrations of total DDT ($F = 5.373$, $p = 0.023$) and mirex ($F = 6.530$, $p = 0.013$) both of which had a significant positive relationship with age.

One hundred twenty-seven PCB congeners were detected in muscle tissue of downstream white suckers, and 126 congeners were detected in white suckers from upstream. All of the white suckers sampled had detectable levels of PCBs in their muscle tissue. No significant difference in PCB concentrations were found between upstream and downstream once the variation due to lipid content was taken into account ($p > 0.05$) (Table 8). Significant relationships were not observed between PCB concentration and the length, weight, or age of a white sucker ($p > 0.05$). Homologue concentrations of PCBs from upstream and downstream are presented in Figure 6. Downstream fish appear to have a higher percentage of the lower chlorinated PCBs in comparison to the upstream fish. Upstream fish appear to have a higher percentage of the higher chlorinated PCBs. In both cases the 4, 5, and 6 homologues make up the greatest percentage of total PCBs.

Figure 6- Distributions of PCB homologues, expressed as percentages, in the muscle tissue of white suckers from upstream and downstream of the Moses-Saunder's power dam in the St. Lawrence River.

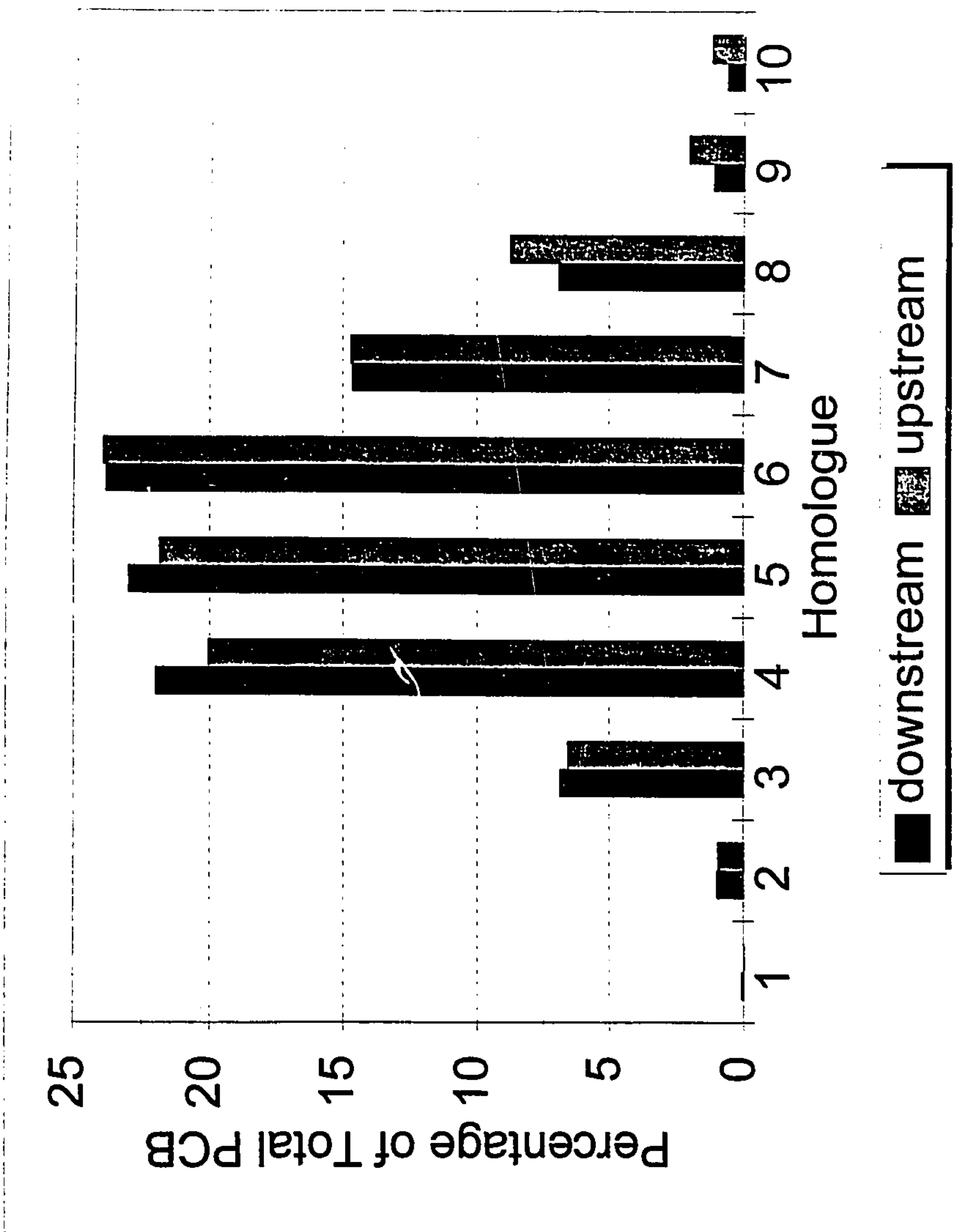

Percentage of Total PCB
0
5
10
15
20
25
1
2
3
4
5
6
7
8
9
10
Homologue
downstream
upstream

Table 8. Range, mean, and standard deviation of organochlorine contaminant concentrations (ng/g dry wgt.) in muscle tissue of white sucker from the St. Lawrence River above and below the Moses-Saunders power dam near Cornwall, Ontario/Massena, New York (n = 40). Data were analysed using ANOVA and log-transformed values. Statistical differences between regions: ** p<0.01; n.s. denotes no significant difference between regions. BDL = below sample detection limit.

Region	Compound	Range	Mean ± Std. Dev.
	Total Chlorobenzene	1.0 - 280	$37 \pm 46^{n.s.}$
	Total Chlordane	BDL - 2.4	$0.82 \pm 0.61^{n.s.}$
	Total HCH	BDL - 2.9	$0.92 \pm 0.55^{n.s.}$
	Total DDT	0.7 - 110	$17 \pm 0.44^{n.s.}$
Upstream	Total Aldrin	0.5 - 22	3.4 ± 4.0**
	Total Endosulfan	BDL - 1.3	$0.41 \pm 0.44^{n.s.}$
	Mirex	0.2 - 13	$2.1 \pm 2.8^{n.s.}$
	Methoxychlor	BDL - 1.5	$0.31 \pm 0.46^{n.s.}$
	Total PCB	26 - 1400	$260 \pm 360^{n.s.}$
	Total Chlorobenzene	1.1 - 620	53 ± 100
	Total Chlordane	BDL - 3.9	0.98 ± 0.79
	Total HCH	BDL - 2.4	0.88 ± 0.53
	Total DDT	BDL - 160	21 ± 30
Downstream	Total Aldrin	0.25 - 16	1.9 ± 2.7
	Total Endosulfan	BDL - 5.4	0.62 ± 0.90
	Mirex	BDL - 8.3	1.7 ± 2.1
	Methoxychlor	BDL - 2.0	0.27 ± 0.53
	Total PCB	23 - 2700	290 ± 430

Table 9. Statistical power and minimum sample sizes required to detect significant differences in chemical concentrations between regions at a power level = 0.80, for the chemicals analysed that did not show significant differences in concentrations between regions. A sample size of 40 was used.

Chemical	Power (1 - β)	Minimum Sample Size (each treatment)
PCB	0.32	78
Total Chlorobenzene	0.25	119
Total Chlordane	0.21	155
Total HCH	0.11	716
Total DDT	0.11	560
Total Endosulfan	0.34	74
Mirex	0.16	264
Methoxychlor	0.13	386

DISCUSSION

The concentration of lipid in the tissue represents the potential amount of organochlorine residues that can be accumulated and stored. Therefore, the determination of lipid concentrations is an important parameter when determining uptake of organic compounds into biological tissues (Hyatt et al. 1993). The effect of lipid content on organochlorine uptake and retention has previously been studied by many authors (Reinert 1970, Rasmussen et al. 1990, Borgmann and Whittle 1992, Rowan and Rasmussen 1992). Rasmussen et al. (1990) showed that PCB concentrations in lake trout (*Salvelinus namaycush*) and other pelagic fish from Laurentian headwater lakes were determined by the length of the food chain, the fish lipid content and the distance from urban-industrial centres. Borgmann and Whittle (1992) determined that elimination rates of PCB and DDE in lake trout were inversely proportional to lipid concentration, although lipid content in lake trout had only a modest effect on final PCB and DDE concentrations. Rowan and Rasmussen (1992) examined data on twenty-five species of fish from each of the Great Lakes and determined that fish lipid content, trophic position, and trophic structure of the food chain were the most important factors that determined the ecological partitioning of persistent organic contaminants. The only organochlorine contaminants that we measured that were not positively related to lipid content were chlorobenzenes and methoxychlor. This may in part be due to the low occurrence of methoxychlor in our samples.

Out of all the organochlorine compounds analysed, only concentrations of total aldrin significantly differed within the two populations, with concentrations being higher in the upstream fish (Table 8). Since there are known point sources of PCB input downstream of the Moses-Saunders power dam (mainly from industries on the south shore) (International Joint

Commission 1989, Suns et al. 1993), and no known point sources of PCB upstream of the dam, other than the Great Lakes, we would expect higher concentrations of PCB in white sucker downstream.

There is a scenario that would explain the consistency of PCB and organochlorine pesticide concentrations between upstream and downstream. It is possible that some of the contaminants exported from the Great Lakes settle out in the sediments above the Moses-Saunders power dam as was hypothesised for PAH (Chapter 2), but the inputs of these contaminants are high enough downstream of the dam to mask the effect of sedimentation upstream, resulting in no significant difference between the two regions. This could occur even if some of the contaminants are flushed further downstream by the higher flow of water. The presence of mirex in the St. Lawrence River supports the notion that the Great Lakes is a source of contamination for the St. Lawrence River. Mirex, a flame retardent and pesticide, is unique among the organochlorine contaminants in the Great Lakes as its occurrence is restricted to Lake Ontario due to its two sources at the Niagara and Oswego Rivers (Comba et al. 1993). It was not manufactured anywhere else in the Great Lakes basin and its use was banned in 1976 (International Joint Commission 1989). Therefore, the concentrations of mirex are now fairly consistent throughout the St. Lawrence and its presence in fish from the St. Lawrence River is a useful indicator of present and past movements of organochlorines from the Great Lakes.

The above scenario supports the hypothesis that there is greater sedimentation upstream of the dam, sediments being a sink for PAHs and organochlorines being imported from upstream of Lake St. Lawrence, and that the majority of organochlorines inputted at Cornwall/Massena are flushed further down into Lake St. Francis through the higher flow of water downstream.

Since virtually no significant difference in organochlorine concentration was detected between upstream and downstream, power analysis was conducted to determine the power of our tests. Statistical power is defined as $1 - \beta$, where β is the probability of failing to reject the null hypothesis when in fact the null hypothesis is false (type II error). Power thus reflects the probability of correctly rejecting the null hypothesis (Peterman 1990). Generally, one would like β to be at least < 0.2, or power > 0.8 (Peterman 1990), therefore we set our desired power level = 0.80. We calculated statistical power for all tests of differences in chemical concentrations between regions for which we did not reject the null hypothesis of no difference (Table 9). Also, using the desired power level, we calculated the minimum sample size required to achieve the desired level of power. Therefore, we wanted to find the minimum sample size required to make the differences in chemical concentrations between regions detectable in the sense that there would be an 80% chance of finding a statistically significant result if the differences existed (i.e. if the null hypothesis that there is no difference in chemical concentrations between regions is false). In general, power levels determined for the ANOVAs that we performed on our data were low, ranging from 0.11 for total HCH and DDT, to 0.34 for total endosulfan (Table 9). These low power levels are likely due to large sampling variability and/or small sample sizes. The most interesting result is the minimum sample sizes required to achieve a power level of 0.80 for the tests that we conducted. The necessary sample sizes ranged from 74 fish (each from upstream and downstream) for total endosulfan to 716 fish (each from upstream and downstream) for total HCH (Table 9). These sample sizes are higher than our sample size of n=40, and are very high for many investigators, as it would be cost and time prohibitive to sample and conduct chemical analyses on this many fish. Thus, it is likely that many studies, that have not conducted power analyses on the results of their tests, have low power and may not have had the ability to detect differences or effects that may have been present.

Despite having little ability to detect differences in contaminant concentrations, the organochlorine compounds analysed appear to be ubiquitous in the St. Lawrence River Cornwall/Massena ecosystem, with all compounds, except methoxychlor, being present in virtually every white sucker analysed. Concentrations of two of these compounds appear to be much lower than those reported for salmonids from Lake Ontario. Concentrations of mirex and PCBs were 30-80 and 4-13 (Σ33 and Σ51 congeners, respectively) fold higher, respectively, in the muscle tissue of brown trout (1430 ± 360 g), small rainbow trout (1140 ± 120 g), and small coho salmon (1190 ± 190 g) from Lake Ontario (Niimi and Oliver 1989), than we measured in muscle tissue of white suckers from the St. Lawrence River. Concentrations of hydrophobic contaminants tend to increase in aquatic organisms with trophic level (Thomann 1989, Rowan and Rasmussen 1992). The lower concentrations of these compounds in white suckers relative to salmonids may in part be related to their position in the Lake Ontario food chain. Trout and salmon are piscivorous (i.e. tertiary consumers) and are therefore more susceptible to the effects of biomagnification of contaminants through the food chain than are white suckers which are secondary consumers, feeding on invertebrates and detritus. This is further supported by the fact that lake trout from the Lake Ontario drainage basin had levels of mirex 20-100 fold higher than white suckers from the same area (the Lake Ontario drainage basin) (Sergeant et al. 1993).

Concentrations of the organochlorine contaminants in white sucker from the St. Lawrence River were, for the most part, also lower than those reported in white sucker spawning in the Ganaraska River, Lake Ontario (Port Hope, Ontario) (Premdas et al. 1995). This could be a function of our method which may have underestimated some organochlorine concentrations. Even though concentrations of PCBs in the muscle tissue of white suckers from the Ganaraska River were similar to those found in white suckers from the St. Lawrence River, concentrations of total DDT were 5 and 20 fold higher (ΣDDE, DDD, and DDT p, p' isomers only) in Ganaraska River white suckers (females and males, respectively). Concentrations of total HCH (Σa-HCH, b-HCH, g-HCH, and d-HCH) were approximately the same in male white suckers from the Ganaraska River and white suckers from the St. Lawrence River, but concentrations in female white suckers from the Ganaraska River were lower. Concentrations of total chlordanes (Σ*cis*- and *trans*-chlordane, *cis*- and *trans*-nonachlor, oxychlordane and heptachlor) were 16-60 fold higher in Ganaraska River white suckers (females and males respectively). Finally, mirex concentrations were 5 and 18 fold higher in Ganaraska River white suckers (females and males, respectively) (Premdas et al. 1995). The higher concentrations of these organochlorines in white suckers from the Ganaraska River may in part be due to its closer proximity to the Great Lakes.

The results indicating that organochlorine concentrations are lower in white suckers from the St. Lawrence River than in fish from elsewhere in the Great Lakes are somewhat surprising in light of the results from a study by Suns et al. (1993). They analysed PCB concentrations in spottail shiners (*Notropis hudsonius*) (whole fish analysis), during 1990, from 37 sites in the Great Lakes and their connecting channels, including the Welland Canal, Burlington Beach, Etobicoke Creek, Humber River, and Toronto Harbour. Out of these 37 sites, they found the highest concentrations of PCBs in spottail shiners from two sites in the St. Lawrence River; downstream of Reynold's Aluminium and downstream of General Motors on the south shore of the river. In fact, levels of total PCBs in spottail shiners from these two sites in the St. Lawrence

River were 20-33 fold higher than what we observed, in general, in white suckers from downstream. White suckers have a habitat radius of approximately 20 kilometres. We caught white suckers at sites that were approximately 4 kilometres from the outfalls of Reynold's Aluminium and General Motors (Figure 1), and therefore we would assume that if the white suckers were feeding near the outfalls, they would have higher levels of PCB in their tissue. Although, two other sites in the same stretch of the river, just below the Moses-Saunders power dam and Pilon Island, had lower concentrations of total PCBs in spottail shiners than we found in white suckers.

Suns et al. (1993) also analysed total DDT concentrations in spottail shiners from the same 37 sites. The only DDT metabolite present in any of the spottails analysed was p, p' DDE residues (although this may have been a function of their method). These levels were highest in spottail shiners from the Niagara River. DDT levels were approximately 4 times higher in spottail shiners near Reynold's Aluminium and General Motors than we found in white suckers from downstream, although levels below the Moses-Saunders power dam and at Pilon Island were approximately the same in both spottail shiners and white suckers. Reasons for this are unclear, although it is possible that since the outfalls of these two companies are in embayment areas, contaminants are not flushed out as thoroughly. In addition to this, spottail shiners have a habitat radius of approximately 1 km (Scott and Crossman 1973), and are therefore susceptible to local contamination.

In the same study, measurable levels of mirex were only found in fish at five Niagara River sites, at the Credit River (Lake Ontario), and at the Cornwall Marina, Cornwall, Ont. Mirex levels were 22 times higher in spottail shiners from the Cornwall Marina than in white suckers from near the same area. Since no other sites between Lake Ontario and Cornwall had measurable levels of mirex, reasons for high mirex concentrations at Cornwall in this study are unknown (Suns et al. 1993). As previously mentioned, the major sources of mirex in Lake Ontario are the Niagara River and the Oswego River, N.Y., as well as two other small sources. Therefore, these should be the only spots in Lake Ontario where spottail shiners would accumulate mirex. Sergeant et al. (1993) detected levels of mirex in white suckers from Hamilton Harbour, Toronto Harbour, and the Bay of Quinte that were 16, 24, and 38 fold higher, respectively, than those levels that we found in white suckers from the St. Lawrence River.

The IJC Aquatic Life Guidelines for PCBs is 100 ng/g wet weight, the guidelines for mirex = "virtually absent", and the Fish Flesh Criterion for DDT is 200 ng/g wet weight (Suns et al. 1993). In our study, 17.5% of the white suckers downstream, and 20% upstream had levels of PCBs above the IJC guidelines (approximately 400 ng/g dry weight). Mirex was detected in virtually all of the white suckers we sampled from the St. Lawrence River at Cornwall/Massena, therefore exceeding the IJC guidelines in every case. The levels of DDT detected were well below the Fish Flesh Criterion.

The only organochlorine compounds studied that were related to the age of the fish were mirex and DDT. Both of these compounds significantly increased in concentration with the age of the fish. It is uncertain why this relationship only existed with mirex and DDT and should be explored further. It is possible that the high lipophilicity of mirex promotes food chain biomagnification and very slow clearance rates (Skaar et al. 1981). DDT metabolises to DDE in fish very rapidly, and DDE also has a slow clearance rate.

A comparison of PCB homologue distributions between upstream and downstream shows that the pentachloro- and hexachlorobiphenyl homologues made up a greater percentage of total PCBs both upstream and downstream, with tetrachlorobiphenyls coming in a close third (Figure 6). This is similar to the findings of Niimi and Oliver (1989) who found the highest concentrations of PCBs were among the pentachloro- and hexachlorobiphenyl homologues in the muscle tissue of brown, lake, and rainbow trout, and coho salmon from Lake Ontario. The higher percentage of lower chlorinated PCBs in downstream fish compared to those upstream may be related to the PCB inputs at Massena.

SUMMARY AND CONCLUSION

As stated in the introduction, our primary goal in this study was to provide data on the chemical and physical characteristics of white sucker populations that could be used to address ecosystem quality issues in the Cornwall/Massena area of the St. Lawrence River. To achieve this goal we measured population characteristics and contaminant burdens of the white sucker upstream and downstream of the Moses-Saunders power dam. Also, we determined if any effects of contaminant burdens on white sucker populations could be found by measuring a number of population characteristics generally representative of the fish well-being. Although we did not determine all the possible chemical contaminants that probably burden the fish populations in this region, the chemicals we did measure should provide a fair representation of the bioavailability of such materials to fish in the area. Data collected in this study can be used to further monitoring studies for this part of the St. Lawrence River ecosystem.

Our investigation determined that the Moses-Saunders power dam could have an effect on the sedimentation of chemicals in the St. Lawrence River in the vicinity of Cornwall/Massena. We found that out of all the chemicals we analysed in white suckers, concentrations of the parent PAH compounds phenanthrene, anthracene, and fluoranthene and alkylated PAH compounds 2,6 & 2,7-dimethylnapthalene, 2-methylphenanthrene, 1-methylanthracene, 1-methylphenanthrene, and 3,6-dimethylphenanthrene were higher in fish upstream of the dam. This resulted in the concentration of 'total PAH' being significantly higher in fish upstream of the dam. When we compared concentrations of total PCBs and several organochlorine pesticide residues, no difference in burden between upstream and downstream was found, except for total aldrin. We had expected levels of PCB to be higher downstream as a result of known high PCB inputs

(International Joint Commission 1989). This suggests that since the dam has created a slow-current artificial reservoir (Lake St. Lawrence), chemicals flowing into the ecosystem from the Great Lakes may be settling out in the sediments above the dam. This makes it difficult to ascertain the input of chemicals into the downstream area from Cornwall/Massena as the level of sedimentation is likely lower and the flow of water is higher.

The only population characteristic measured that may relate to contaminant levels, was the higher concentrations of PAH and the presence of lip and body papillomas. The occurrence of tumours in the spawning population of white suckers from Hoople Creek (upstream) was similar to the prevalence of tumours in white suckers from highly contaminated areas such as the Grindstone and Oakville Creeks, Hamilton Harbour, and the Ganaraska River. However, it would need to be determined that the contaminant burden observed in individual white suckers from Hoople Creek could promote tumour growth. Premdas et al. (1995) stated that if wild fish health is to be used as a reliable indicator of ecosystem health, baseline studies need to be conducted that determine the prevalence of disease among fish populations and which lip and skin papillomas are related to contaminants present in the environment. One factor that may have a role in the high incidence of papillomas at Hoople Creek is the presence of highway 401. Hoople Creek runs directly underneath the highway and drains the surrounding fields. Spawning white suckers were captured in the creek approximately 500 metres from the highway. A possibility for future research would therefore be to analyse concentrations of contaminants in the sediment of Hoople Creek, above and below the 401 bridge, to determine if their is indeed a local increase.

The differences between upstream and downstream population characteristics could not be linked with the contaminant burden of PAHs in each individual fish. This was to be expected since there is little evidence that clearly establishes a cause-and-effect relationship between a chemical and a fish in natural ecosystems. There are several factors that impede the measurement of such relationships. Chemicals are often present as complex mixtures in natural ecosystems and can act additively, antagonistically, or synergistically (Niimi 1990). Therefore, the effects of one chemical on a fish population in a natural environment is unlikely to cause a detectable difference. Also, *apparent* effects among fish from a contaminated site will depend upon selection of control fish from a non-contaminated reference site. In our study, white suckers in both populations were exposed to the same chemicals, with PAH being accumulated at higher concentrations upstream. Therefore, we were without an adequate control population.

It is likely that many of the differences in population characteristics we noted between upstream and downstream result from the artificial nature of Lake St. Lawrence. Field sampling studies have indicated that fish populations with much higher frequencies of disease, histological, biochemical, and physiological anomalies, and altered population structures strongly suggest a health-related effect. These observations are often reported for sites associated with elevated chemical concentrations, although this effect can be caused by poor physical quality of the environment in which the fish live (Niimi 1990). The Lake St. Lawrence reservoir was created in 1958 and is 136 km^2 in area, of this, 90 km^2 is flooded agricultural land (Efford 1975). Therefore, most of the fish habitat in this area is fairly recent and not very productive as indicated by the lack of food resources (Mercier, unpublished data).

Even though population characteristic differences could not be related to chemical bioaccumulation, the occurrence and concentrations of the chemicals analysed are a cause for concern. Detectable levels for all chemicals, except methoxychlor, were found in virtually all of the white suckers sampled. Approximately 20% of the white suckers had levels of PCB in their muscle tissue that exceeded IJC Aquatic Life Guidelines. In addition, mirex was found in virtually all white suckers sampled, exceeding the Aquatic Life Guideline of "virtually absent", a value below the detection limits of our method. The other chemicals analysed, though present at low concentrations, are ubiquitous and indicate that much work is needed to reduce the introduction of these chemicals to this area.

Although the levels of total PCB exceeded the IJC guidelines in many cases, the concentration of total PCB does not provide any specific information on the overall toxicity to fish. Studies on the sublethal effects of PCBs on fishes in contaminated ecosystems must emphasise the relative concentrations of each congener in order to assess its toxicity. In many studies, congeners 101, 138, 153, and 180 in fish are present at the highest concentrations, at least 3 congeners that include 77, 126, and 169 are known to be highly toxic, and five congeners including 105, 118, 128, 138, and 170 are known to be mixed-function oxidase inducers (Carignan et al. 1994). The concentration of congener 153 is approximately 45-fold higher than congener 77 in Lake Ontario salmonids (Niimi and Oliver 1989), yet comparative enzyme induction studies on mammalian systems suggest congener 77 could be over 10 to 41-fold more toxic than congener 153. Therefore, chemical toxicity, in addition to concentration, is an important consideration for chemical groups with many homologues when issues such as human health and sublethal effects on fishes are being examined (Niimi and Oliver 1989). In addition, Hyatt et al. (1993) stated in reference to the Great Lakes fisheries specimen bank that their "interpretation of the significance of PCBs and related compounds in the environment and potential impact on human health is limited by a lack of data on the temporal, spatial, or trophic trends of specific highly toxic congeners (coplanar PCBs)". A possibility for future study would therefore be to investigate the relative concentrations of specific congeners, found in white suckers from the St. Lawrence River, as well as their toxicity. This would provide better insight into the toxicity of the PCB burden in these fish.

As stated in the introduction, a remedial action plan was initiated in 1986 for the area of the St. Lawrence River surrounding Cornwall/Massena and the area downstream (the AOC). The four roles of remedial action plans are to 1) describe environmental conditions in the AOCs, 2) identify pollution sources in the AOCs, 3) identify remedial options, and 4) recommend preferred remedial options (La Violette 1993). In terms of describing environmental conditions in the AOC, significant data was obtained in this study on white sucker population and contaminant characteristics for the Cornwall/Massena area. The data showed no discernible difference in contaminant concentrations in muscle tissue of these fish with the exception of a few selected PAH and aldrin. Given the type of PAH, their source seems to be petroleum related rather than anthropogenic combustion products. The higher levels in upstream fish could be a function of river hydrology created by the water control and power structures of the dam. Other than this information, we failed to identify pollution sources in the AOC, although the Cornwall/Massena area may be one of the most difficult AOCs to rehabilitate due to the hydrology of the river and political partnerships required.

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APPENDICES

Raw contaminant data for individual fish is available from Sean Backus, Backus Consulting, 39 Puritan Court, Stoney Creek, Ontario, L8E 4K9, or from the Institute for Research on the Environment and the Economy (IREE), 5 Calixa Lavallee St., P.O. Box 450, Stn. A, Ottawa, Ontario, K1N 6N5.

Appendix A - 1. Population characteristics of white suckers caught downstream of the Moses-Saunders power dam in the St. Lawrence River. See Figure 1 for sites.

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
08/02/94	Colquhoun Isl	0.36	35		0				0.84	
08/02/94	Colquhoun Isl	0.24	31		0				0.81	
08/02/94	Colquhoun Isl	0.18	28		0				0.82	
08/02/94	Colquhoun Isl	0.55	37		0				1.09	
08/02/94	Colquhoun Isl	0.53	37		0				1.05	
08/02/94	Colquhoun Isl	0.35	32		0				1.07	
08/02/94	Colquhoun Isl	0.37	33		0				1.03	
08/02/94	Colquhoun Isl	0.2	31		0				0.67	
08/02/94	Colquhoun Isl	0.33	33		0				0.92	
08/02/94	Colquhoun Isl	0.23	30		0				0.85	
08/02/94	Colquhoun Isl	0.41	38		0				0.75	
08/02/94	Colquhoun Isl	0.23	30		0				0.85	
08/02/94	Colquhoun Isl	0.25	33		0				0.70	
08/02/94	Colquhoun Isl	0.21	28		0				0.96	
08/02/94	Colquhoun Isl	0.46	36		0				0.99	
08/02/94	Colquhoun Isl	0.2	28		0				0.91	
08/02/94	Colquhoun Isl	0.28	31		0				0.94	
08/02/94	Colquhoun Isl	0.19	29		0				0.78	
08/02/94	Colquhoun Isl	0.17	27		0				0.86	
08/02/94	Colquhoun Isl	0.18	28		0				0.82	
08/02/94	Colquhoun Isl	0.46	35		0				1.07	
08/02/94	Colquhoun Isl	0.2	30		0				0.74	
08/02/94	Colquhoun Isl	0.26	32		0				0.79	
08/02/94	Colquhoun Isl	0.27	33		0				0.75	
08/02/94	Colquhoun Isl	0.25	31		0				0.84	
08/02/94	Colquhoun Isl	0.17	30		0				0.63	
08/02/94	Colquhoun Isl	0.43	37		0				0.85	
08/02/94	Colquhoun Isl	0.4	36		0				0.86	
08/02/94	Colquhoun Isl	0.31	34		0				0.79	
08/02/94	Colquhoun Isl	0.29	33		0				0.81	
08/02/94	Colquhoun Isl	0.16	29		0				0.66	
08/02/94	Colquhoun Isl	0.52	38		0				0.95	
08/02/94	Colquhoun Isl	0.69	41		0				1.00	
08/02/94	Colquhoun Isl	0.62	41		0				0.90	
08/02/94	Colquhoun Isl	0.44	36		0				0.94	
08/02/94	Colquhoun Isl	2	57		0				1.08	
08/02/94	Colquhoun Isl	0.57	40		0				0.89	
08/02/94	Colquhoun Isl	0.24	31		0				0.81	
08/02/94	Colquhoun Isl	2	61		0				0.88	
08/02/94	Colquhoun Isl	0.35	35		0				0.82	
08/02/94	Colquhoun Isl	0.69	43		0				0.87	
08/02/94	Colquhoun Isl	0.32	32		0				0.98	
08/02/94	Colquhoun Isl	0.3	32		0				0.92	
08/02/94	Colquhoun Isl	0.69	39		0				1.16	
08/02/94	Colquhoun Isl	0.55	37		0				1.09	
08/02/94	Colquhoun Isl	0.35	35		0				0.82	
08/02/94	Colquhoun Isl	0.32	32		0				0.98	
08/02/94	Colquhoun Isl	0.45	36		0				0.96	
08/02/94	Colquhoun Isl	0.41	36		0				0.88	
08/02/94	Colquhoun Isl	0.48	38		0				0.87	
08/02/94	Colquhoun Isl	0.24	29		0				0.98	
08/02/94	Colquhoun Isl	0.66	40		0				1.03	
08/02/94	Colquhoun Isl	0.66	39		0				1.11	
08/02/94	Colquhoun Isl	0.42	38		0				0.77	
08/02/94	Colquhoun Isl	0.62	41		0				0.90	
08/02/94	Colquhoun Isl	0.17	28		0				0.77	
08/02/94	Colquhoun Isl	0.44	37		0				0.87	

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
08/02/94	Colquhoun Isl	0.17	28		0				0.77	
08/02/94	Colquhoun Isl	0.44	37		0				0.87	
08/02/94	Colquhoun Isl	0.9	45		0				0.99	
08/02/94	Colquhoun Isl	0.25	31		0				0.84	
08/02/94	Colquhoun Isl	0.26	31		0				0.87	
08/02/94	Colquhoun Isl	0.23	30		0				0.85	
08/02/94	Colquhoun Isl	0.71	43		0				0.89	
08/02/94	Colquhoun Isl	0.18	27		0				0.91	
08/02/94	Colquhoun Isl	0.25	30		0				0.93	
08/02/94	Colquhoun Isl	0.58	38		0				1.06	
08/02/94	Colquhoun Isl	0.24	28		0				1.09	
08/02/94	Colquhoun Isl	0.66	40		0				1.03	
08/02/94	Colquhoun Isl	0.29	31		0				0.97	
08/02/94	Colquhoun Isl	0.53	37		0				1.05	
08/02/94	Colquhoun Isl	0.25	30		0				0.93	
08/02/94	Colquhoun Isl	0.23	29		0				0.94	
08/02/94	Colquhoun Isl	0.28	31		0				0.94	
08/02/94	Colquhoun Isl	0.29	32		0				0.89	
08/02/94	Colquhoun Isl	0.27	30		0				1.00	
08/02/94	Colquhoun Isl	0.25	31		0				0.84	
08/02/94	Colquhoun Isl	0.2	28		0				0.91	
08/02/94	Colquhoun Isl	0.25	31		0				0.84	
08/02/94	Colquhoun Isl	0.21	28		0				0.96	
08/02/94	Colquhoun Isl	12	105		1				1.04	
08/02/94	Colquhoun Isl	5	83		1				0.87	
08/02/94	Colquhoun Isl	16	112		1				1.14	
08/02/94	Colquhoun Isl	10	98		1				1.06	
08/02/94	Colquhoun Isl	5	80		1				0.98	
08/02/94	Colquhoun Isl	8	90		1				1.10	
08/02/94	Colquhoun Isl	13	102		1				1.23	
08/02/94	Colquhoun Isl	13	106		1				1.09	
08/02/94	Colquhoun Isl	12	106		1				1.01	
08/02/94	Colquhoun Isl	14	107		1				1.14	
08/02/94	Colquhoun Isl	11	98		1				1.17	
08/02/94	Colquhoun Isl	9	96		1				1.02	
08/02/94	Colquhoun Isl	10	97		1				1.10	
08/02/94	Colquhoun Isl	17	115		1				1.12	
08/02/94	Colquhoun Isl	26	131		2				1.16	
08/03/94	Colquhoun Isl	384	323	m	3				1.14	
08/03/94	Colquhoun Isl	490	332	m	4				1.34	
08/03/94	Colquhoun Isl	494	341	m	4				1.25	
08/03/94	Colquhoun Isl	990	432	f	6				1.23	
08/04/94	Colquhoun Isl	954	422	m	6				1.27	
08/03/94	Colquhoun Isl	1034	460	f	7				1.06	
08/04/94	Colquhoun Isl	968	425	m	7				1.26	
08/04/94	Colquhoun Isl	1625	525	f	8				1.12	
08/03/94	Colquhoun Isl	921	420	m	8				1.24	
08/03/94	Colquhoun Isl	826	453	m	8				0.89	
08/03/94	Colquhoun Isl	1288	492	f	9				1.08	
08/03/94	Colquhoun Isl	1112	460	m	10				1.14	
08/17/94	Cornwall Isl	0.77	45		0				0.84	
08/17/94	Cornwall Isl	0.55	39		0				0.93	
08/17/94	Cornwall Isl	2	55		0				1.20	
08/17/94	Cornwall Isl	0.63	42		0				0.85	
08/17/94	Cornwall Isl	0.67	46		0				0.69	
08/17/94	Cornwall Isl	2	60		1				0.93	
08/18/94	Cornwall Isl	937	453	m	9				1.01	

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
08/17/94	Cornwall Isl	1077	489	f	11				0.92	
08/18/94	Cornwall Isl	1470	492	f	11				1.23	
08/16/94	Courtald's	1.65	55		0				0.99	
08/16/94	Courtald's	1.51	54		0				0.96	
08/16/94	Courtald's	1.23	53		0				0.83	
08/16/94	Courtald's	1.87	58		0				0.96	
08/16/94	Courtald's	1.34	52		0				0.95	
08/16/94	Courtald's	1.81	58		0				0.93	
08/16/94	Courtald's	1.51	53		0				1.01	
08/16/94	Courtald's	0.57	41		0				0.83	
08/16/94	Courtald's	0.81	45		0				0.89	
08/16/94	Courtald's	1.32	51		0				1.00	
08/16/94	Courtald's	1.17	50		0				0.94	
08/16/94	Courtald's	0.88	47		0				0.85	
08/15/94	Courtald's	0.82	44		0				0.96	
08/16/94	Courtald's	1.52	59		0				0.74	
08/16/94	Courtald's	1.1	49		0				0.93	
08/16/94	Courtald's	1.15	49		0				0.98	
08/15/94	Courtald's	0.73	45		0				0.80	
08/16/94	Courtald's	1.92	58		0				0.98	
08/16/94	Courtald's	1.68	56		0				0.96	
08/16/94	Courtald's	1.4	53		0				0.94	
08/16/94	Courtald's	1.07	50		0				0.86	
08/16/94	Courtald's	1.19	52		0				0.85	
08/16/94	Courtald's	1.16	50		0				0.93	
08/16/94	Courtald's	1.26	51		0				0.95	
08/16/94	Courtald's	1.49	55		0				0.90	
08/16/94	Courtald's	1.49	56		0				0.85	
08/16/94	Courtald's	1.27	52		0				0.90	
08/16/94	Courtald's	1.09	51		0				0.82	
08/15/94	Courtald's	0.78	43		0				0.98	
08/16/94	Courtald's	3.12	67		1				1.04	
08/16/94	Courtald's	3.25	70		1				0.95	
08/16/94	Courtald's	1033	442	f	5				1.20	
08/16/94	Courtald's	1260	490	f	7				1.07	
08/16/94	Courtald's	900	415	m	9				1.26	
08/16/94	Courtald's	1156	498	m	10				0.94	
06/23/94	Dickerson Isl	0.1	23		0				0.82	
06/23/94	Dickerson Isl	1.65	57		0				0.89	
06/23/94	Dickerson Isl	0.05	20		0				0.63	
06/23/94	Dickerson Isl	0.25	31		0				0.84	
06/23/94	Dickerson Isl	3	69		1				0.91	
06/23/94	Dickerson Isl	2.5	64		1				0.95	
06/22/94	Dickerson Isl	679	385	m	4				1.19	
06/22/94	Dickerson Isl	1518	529	f	7				1.03	
06/22/94	Dickerson Isl	1584	525	f	7				1.09	
06/22/94	Dickerson Isl	1114	474	f	8				1.05	
06/22/94	Dickerson Isl	1880	573	f	9				1.00	
07/27/94	E. St. Regis	0.29	31		0				0.97	
07/27/94	E. St. Regis	0.22	29		0				0.90	
07/27/94	E. St. Regis	1	50		0				0.80	
07/27/94	E. St. Regis	0.41	37		0				0.81	
07/27/94	E. St. Regis	0.27	31		0				0.91	
07/27/94	E. St. Regis	0.81	43		0				1.02	
07/27/94	E. St. Regis	0.85	44		0				1.00	
07/27/94	E. St. Regis	14	110		1				1.05	
07/27/94	E. St. Regis	8	88		1				1.17	

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
07/27/94	E. St. Regis	13	107		1				1.06	
07/27/94	E. St. Regis	7	97		1				0.77	
07/27/94	E. St. Regis	5	81		1				0.94	
07/28/94	E. St. Regis	1006	438	f	5				1.20	
07/28/94	E. St. Regis	989	436	m	7				1.19	
07/28/94	E. St. Regis	902	449	m	9				1.00	
07/28/94	E. St. Regis	1866	515	f	11				1.37	
07/27/94	E. St. Regis	1040	472	m	11				0.99	
07/28/94	E. St. Regis	1470	519	f	12				1.05	
06/09/94	Farlinger's Pt.	117	230	f	3				0.96	
06/09/94	Farlinger's Pt.	895	416	m	4				1.24	
06/09/94	Farlinger's Pt.	1572	473	f	6				1.49	
06/09/94	Farlinger's Pt.	1697	512	f	12				1.26	
06/03/94	Farran Pk.	4	80		1				0.78	
06/03/94	Farran Pk.	7	98		1				0.74	
06/06/94	Flanigan's Pt.	1	58		0				0.51	
06/06/94	Flanigan's Pt.	4	74		1				0.99	
06/06/94	Flanigan's Pt.	19	117		1				1.19	
06/06/94	Flanigan's Pt.	2			1					
06/06/94	Flanigan's Pt.	16	116		1				1.03	
06/06/94	Flanigan's Pt.	3	69		1				0.91	
06/06/94	Flanigan's Pt.	2	62		1				0.84	
06/06/94	Flanigan's Pt.	3	69		1				0.91	
06/06/94	Flanigan's Pt.	3	68		1				0.95	
06/06/94	Flanigan's Pt.	11	92		1				1.41	
06/06/94	Flanigan's Pt.	3	72		1				0.80	
06/06/94	Flanigan's Pt.	2	61		1				0.88	
06/07/94	Flanigan's Pt.	1056	454	m	9				1.13	
06/07/94	Flanigan's Pt.	979	458	m	9				1.02	
06/07/94	Flanigan's Pt.	1663	538	f	11				1.07	
04/21/94	Raisin R.	1378	470	f	5	182	46107	1.73	1.33	no
04/21/94	Raisin R.	1062	437	f	5	126	37825	1.73	1.27	no
04/21/94	Raisin R.	1760	523	f	5	239	71859	1.71	1.23	no
04/21/94	Raisin R.	1562	500	f	5	290	75419	1.89	1.25	no
04/21/94	Raisin R.	1046	442	m	5	69			1.21	no
04/21/94	Raisin R.	1700	495	f	6	264	84110	1.76	1.40	no
04/21/94	Raisin R.	1181	448	f	6	192	51418	1.78	1.31	no
04/21/94	Raisin R.	1313	454	f	6	208	46980	1.92	1.40	no
04/21/94	Raisin R.	1196	452	f	6	165	40040	1.66	1.30	no
04/21/94	Raisin R.	1812	501	f	6	302	62232	2.05	1.44	no
04/21/94	Raisin R.	1843	518	f	6	263	78777	1.81	1.33	no
04/21/94	Raisin R.	1657	500	f	6	237	63010	1.82	1.33	no
04/21/94	Raisin R.	1669	503	f	6	290			1.31	no
04/21/94	Raisin R.	1982	526	f	6	294	79870	1.82	1.36	no
04/21/94	Raisin R.	1315	472	f	6	160	52384	1.47	1.25	no
04/21/94	Raisin R.	1075	448	m	6	48			1.20	no
04/21/94	Raisin R.	1487	489	f	7	279	66309	1.97	1.27	no
04/21/94	Raisin R.	1793	515	f	7	208	78069	1.56	1.31	no
04/21/94	Raisin R.	2087	519	f	7	312			1.49	no
04/21/94	Raisin R.	1592	488	f	7	215	48332	1.81	1.37	no
04/21/94	Raisin R.	1121	443	f	7	172	43849	1.65	1.29	no
04/21/94	Raisin R.	1370	488	f	7	157	50544	1.40	1.18	no
04/21/94	Raisin R.	1700	511	f	7	249	56838	1.90	1.27	no
04/21/94	Raisin R.	1676	512	f	7	252	73886	1.82	1.25	no
04/21/94	Raisin R.	1507	495	f	7	234	57626	1.83	1.24	no
04/21/94	Raisin R.	1857	522	f	7	283			1.31	no
04/21/94	Raisin R.	1546	495	f	7	203	53876	1.66	1.27	no

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
04/21/94	Raisin R.	1561	493	f	7	245			1.30	no
04/21/94	Raisin R.	1600	504	f	8	230	51704	1.73	1.25	no
04/21/94	Raisin R.	2012	523	f	8	330			1.41	no
04/21/94	Raisin R.	1706	533	f	8	144	85488	1.13	1.13	no
04/21/94	Raisin R.	1855	506	f	8	208	53290	1.76	1.43	no
04/21/94	Raisin R.	1760	521	f	8	212	50965	1.66	1.24	no
04/21/94	Raisin R.	1471	498	f	8	167	44144	1.72	1.19	no
04/21/94	Raisin R.	1917	505	f	8	329			1.49	no
04/21/94	Raisin R.	1962	528	f	8	389	79849	2.15	1.33	no
04/21/94	Raisin R.	1805	522	f	8	255	51646	1.87	1.27	no
04/21/94	Raisin R.	2192	563	f	8	300	63860	1.79	1.23	no
04/21/94	Raisin R.	1550	510	f	8	219	54341	1.74	1.17	no
04/21/94	Raisin R.	1582	526	f	8	160	62549	1.72	1.09	no
04/21/94	Raisin R.	2226	565	f	8	294			1.23	no
04/21/94	Raisin R.	1314	478	m	8	50			1.20	no
04/21/94	Raisin R.	2073	567	f	9	265	57470	1.91	1.14	no
04/21/94	Raisin R.	2380	542	f	9	442	98330	2.14	1.49	no
04/21/94	Raisin R.	1086	482	m	9	70			0.97	no
04/21/94	Raisin R.	1004	458	m	9	23			1.05	no
04/21/94	Raisin R.	1378	473	m	9	63			1.30	yes
04/21/94	Raisin R.	2142	547	f	10	355			1.31	no
04/21/94	Raisin R.	1911	535	f	10	276	70214	1.85	1.25	no
04/21/94	Raisin R.	2228	557	f	10	381	85547	1.92	1.29	no
04/21/94	Raisin R.	1733	536	f	10	222			1.13	no
04/21/94	Raisin R.	2038	547	f	10	282	72640	1.57	1.25	no
04/21/94	Raisin R.	1539	500	m	10	100			1.23	no
04/21/94	Raisin R.	1166	467	m	10	47			1.14	no
04/21/94	Raisin R.	2075	545	f	11	297			1.28	no
04/21/94	Raisin R.	1355	487	m	11	94			1.17	no
04/21/94	Raisin R.	1424	478	m	11	95			1.30	no
04/21/94	Raisin R.	1398	503	m	11	59			1.10	no
04/21/94	Raisin R.	1507	503	m	11	84			1.18	no
04/21/94	Raisin R.	2000	572	f	12	295			1.07	no
07/25/94	W. St. Regis	0.52	37		0				1.03	
07/25/94	W. St. Regis	0.26	29		0				1.07	
07/25/94	W. St. Regis	0.19	30		0				0.70	
07/25/94	W. St. Regis	0.28	33		0				0.78	
07/25/94	W. St. Regis	0.25	32		0				0.76	
07/25/94	W. St. Regis	0.22	30		0				0.81	
07/25/94	W. St. Regis	0.24	32		0				0.73	
07/25/94	W. St. Regis	0.23	31		0				0.77	
07/25/94	W. St. Regis	0.29	31		0				0.97	
07/25/94	W. St. Regis	0.25	31		0				0.84	
07/25/94	W. St. Regis	0.26	32		0				0.79	
07/25/94	W. St. Regis	0.21	31		0				0.70	
07/25/94	W. St. Regis	0.25	31		0				0.84	
07/25/94	W. St. Regis	0.27	31		0				0.91	
07/25/94	W. St. Regis	0.28	31		0				0.94	
07/26/94	W. St. Regis	0.47	39		0				0.79	
07/26/94	W. St. Regis	0.84	46		0				0.86	
07/26/94	W. St. Regis	0.37	36		0				0.79	
07/25/94	W. St. Regis	0.51	35		0				1.19	
07/25/94	W. St. Regis	0.13	30		0				0.48	
07/25/94	W. St. Regis	0.15	29		0				0.62	
07/26/94	W. St. Regis	0.31	34		0				0.79	
07/25/94	W. St. Regis	0.23	32		0				0.70	
07/25/94	W. St. Regis	0.14	30		0				0.52	

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
07/25/94	W. St. Regis	0.2	30		0				0.74	
07/25/94	W. St. Regis	0.32	36		0				0.69	
07/25/94	W. St. Regis	0.24	32		0				0.73	
07/25/94	W. St. Regis	0.34	35		0				0.79	
07/25/94	W. St. Regis	0.32	35		0				0.75	
07/25/94	W. St. Regis	0.22	31		0				0.74	
07/25/94	W. St. Regis	0.32	36		0				0.69	
07/25/94	W. St. Regis	0.19	30		0				0.70	
07/25/94	W. St. Regis	0.51	39		0				0.86	
07/25/94	W. St. Regis	0.22	31		0				0.74	
07/25/94	W. St. Regis	0.25	32		0				0.76	
07/25/94	W. St. Regis	0.3	36		0				0.64	
07/25/94	W. St. Regis	0.81	46		0				0.83	
07/25/94	W. St. Regis	0.18	30		0				0.67	
07/25/94	W. St. Regis	0.44	36		0				0.94	
07/25/94	W. St. Regis	0.7	42		0				0.94	
07/25/94	W. St. Regis	0.24	34		0				0.61	
07/25/94	W. St. Regis	0.29	34		0				0.74	
07/25/94	W. St. Regis	0.17	29		0				0.70	
07/25/94	W. St. Regis	0.23	32		0				0.70	
07/25/94	W. St. Regis	0.29	34		0				0.74	
07/25/94	W. St. Regis	0.37	36		0				0.79	
07/25/94	W. St. Regis	0.15	30		0				0.56	
07/25/94	W. St. Regis	0.45	41		0				0.65	
07/25/94	W. St. Regis	0.19	32		0				0.58	
07/25/94	W. St. Regis	0.25	35		0				0.58	
07/25/94	W. St. Regis	0.16	31		0				0.54	
07/25/94	W. St. Regis	0.18	31		0				0.60	
07/26/94	W. St. Regis	0.35	35		0				0.82	
07/26/94	W. St. Regis	0.31	36		0				0.66	
07/26/94	W. St. Regis	0.39	37		0				0.77	
07/26/94	W. St. Regis	0.67	43		0				0.84	
07/26/94	W. St. Regis	0.68	42		0				0.92	
07/25/94	W. St. Regis	0.15	29		0				0.62	
07/25/94	W. St. Regis	0.36	37		0				0.71	
07/25/94	W. St. Regis	0.21	32		0				0.64	
07/25/94	W. St. Regis	0.44	39		0				0.74	
07/25/94	W. St. Regis	0.3	35		0				0.70	
07/25/94	W. St. Regis	0.19	32		0				0.58	
07/25/94	W. St. Regis	0.49	42		0				0.66	
07/25/94	W. St. Regis	0.26	35		0				0.61	
07/25/94	W. St. Regis	0.41	39		0				0.69	
07/25/94	W. St. Regis	0.2	32		0				0.61	
07/25/94	W. St. Regis	0.3	37		0				0.59	
07/26/94	W. St. Regis	0.43	39		0				0.72	
07/26/94	W. St. Regis	0.27	33		0				0.75	
07/26/94	W. St. Regis	0.72	43		0				0.91	
07/26/94	W. St. Regis	0.63	41		0				0.91	
07/26/94	W. St. Regis	0.38	36		0				0.81	
07/26/94	W. St. Regis	0.2	30		0				0.74	
07/26/94	W. St. Regis	0.24	32		0				0.73	
07/26/94	W. St. Regis	0.22	35		0				0.51	
07/26/94	W. St. Regis	0.79	44		0				0.93	
07/26/94	W. St. Regis	0.4	37		0				0.79	
07/26/94	W. St. Regis	0.35	36		0				0.75	
07/26/94	W. St. Regis	0.75	44		0				0.88	
07/26/94	W. St. Regis	0.68	43		0				0.86	

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
07/26/94	W. St. Regis	0.3	35		0				0.70	
07/26/94	W. St. Regis	0.33	36		0				0.71	
07/26/94	W. St. Regis	0.29	35		0				0.68	
07/26/94	W. St. Regis	0.3	37		0				0.59	
07/26/94	W. St. Regis	0.7	44		0				0.82	
07/26/94	W. St. Regis	0.61	41		0				0.89	
07/26/94	W. St. Regis	1.25	53		0				0.84	
07/26/94	W. St. Regis	0.3	35		0				0.70	
07/26/94	W. St. Regis	0.83	46		0				0.85	
07/25/94	W. St. Regis	0.21	31		0				0.70	
07/25/94	W. St. Regis	0.23	30		0				0.85	
07/25/94	W. St. Regis	0.3	30		0				1.11	
07/25/94	W. St. Regis	0.08	25		0				0.51	
07/25/94	W. St. Regis	0.38	33		0				1.06	
07/25/94	W. St. Regis	0.18	31		0				0.60	
07/25/94	W. St. Regis	0.13	28		0				0.59	
07/25/94	W. St. Regis	0.23	32		0				0.70	
07/25/94	W. St. Regis	0.14	28		0				0.64	
07/25/94	W. St. Regis	0.24	33		0				0.67	
07/26/94	W. St. Regis	0.22	31		0				0.74	
07/25/94	W. St. Regis	0.19	31		0				0.64	
07/26/94	W. St. Regis	0.76	44		0				0.89	
07/26/94	W. St. Regis	0.55	40		0				0.86	
07/25/94	W. St. Regis	0.34	32		0				1.04	
07/25/94	W. St. Regis	0.18	31		0				0.60	
07/25/94	W. St. Regis	0.18	30		0				0.67	
07/25/94	W. St. Regis	0.63	44		0				0.74	
07/25/94	W. St. Regis	0.97	43		0				1.22	
07/25/94	W. St. Regis	0.27	34		0				0.69	
07/25/94	W. St. Regis	0.09	23		0				0.74	
07/25/94	W. St. Regis	0.22	29		0				0.90	
07/25/94	W. St. Regis	0.31	35		0				0.72	
07/25/94	W. St. Regis	0.59	43		0				0.74	
07/25/94	W. St. Regis	0.21	27		0				1.07	
07/25/94	W. St. Regis	0.22	31		0				0.74	
07/25/94	W. St. Regis	0.36	32		0				1.10	
07/25/94	W. St. Regis	0.22	28		0				1.00	
07/25/94	W. St. Regis	0.35	32		0				1.07	
07/25/94	W. St. Regis	0.31	35		0				0.72	
07/25/94	W. St. Regis	0.21	31		0				0.70	
07/25/94	W. St. Regis	0.86	43		0				1.08	
07/25/94	W. St. Regis	0.24	33		0				0.67	
07/25/94	W. St. Regis	1.01	50		0				0.81	
07/25/94	W. St. Regis	0.21	30		0				0.78	
07/25/94	W. St. Regis	0.17	30		0				0.63	
07/25/94	W. St. Regis	0.25	32		0				0.76	
07/25/94	W. St. Regis	0.2	30		0				0.74	
07/25/94	W. St. Regis	0.21	29		0				0.86	
07/25/94	W. St. Regis	0.35	31		0				1.17	
07/25/94	W. St. Regis	0.63	41		0				0.91	
07/25/94	W. St. Regis	0.19	31		0				0.64	
07/25/94	V St. Regis	0.25	31		0				0.84	
07/25/94	W 3t. Regis	0.19	31		0				0.64	
07/25/94	W. St. Regis	0.27	31		0				0.91	
07/26/94	W. St. Regis	0.28	34		0				0.71	
07/25/94	W. St. Regis	0.25	32		0				0.76	
07/26/94	W. St. Regis	0.2	31		0				0.67	

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
07/25/94	W. St. Regis	0.7	42		0				0.94	
07/26/94	W. St. Regis	7	90		1				0.96	
07/25/94	W. St. Regis	7	86		1				1.10	
07/26/94	W. St. Regis	6.67	84		1				1.13	
07/26/94	W. St. Regis	146	223	f	4				1.32	
07/26/94	W. St. Regis	1343	497	f	5				1.09	
07/26/94	W. St. Regis	1044	453	f	6				1.12	
07/26/94	W. St. Regis	963	426	f	6				1.25	
07/26/94	W. St. Regis	1544	502	f	8				1.22	
06/28/94	Little Hog Isl	1	53		0				0.67	
06/28/94	Little Hog Isl	19	123		1				1.02	
06/28/94	Little Hog Isl	23	132		1				1.00	
06/28/94	Little Hog Isl	19	125		1				0.97	
06/28/94	Little Hog Isl	13	116		1				0.83	
06/28/94	Little Hog Isl	15	119		1				0.89	
06/28/94	Little Hog Isl	16	116		1				1.03	
06/28/94	Little Hog Isl	6	84		1				1.01	
06/28/94	Little Hog Isl	6	89		1				0.85	
06/28/94	Little Hog Isl	12	111		1				0.88	
06/28/94	Little Hog Isl	8	91		1				1.06	
06/28/94	Little Hog Isl	25	141		1				0.89	
06/28/94	Little Hog Isl	19	125		1				0.97	
06/28/94	Little Hog Isl	35	148		1				1.08	
06/28/94	Little Hog Isl	12	107		1				0.98	
06/28/94	Little Hog Isl	18	125		1				0.92	
06/28/94	Little Hog Isl	33	149		1				1.00	
06/28/94	Little Hog Isl	16	123		1				0.86	
06/28/94	Little Hog Isl	16	121		1				0.90	
06/28/94	Little Hog Isl	13	113		1				0.90	
06/28/94	Little Hog Isl	21	131		1				0.93	
06/28/94	Little Hog Isl	16	120		1				0.93	
06/28/94	Little Hog Isl	22	132		1				0.96	
06/28/94	Little Hog Isl	3	78		1				0.63	
06/28/94	Little Hog Isl	15	120		1				0.87	
06/28/94	Little Hog Isl	8	100		1				0.80	
06/28/94	Little Hog Isl	17	125		1				0.87	
06/28/94	Little Hog Isl	15	120		1				0.87	
06/28/94	Little Hog Isl	12	110		1				0.90	
06/28/94	Little Hog Isl	23	131		1				1.02	
06/28/94	Little Hog Isl	27	141		1				0.96	
06/28/94	Little Hog Isl	23	134		1				0.96	
06/28/94	Little Hog Isl	28	143		1				0.96	
06/28/94	Little Hog Isl	24	137		1				0.93	
06/28/94	Little Hog Isl	6	86		1				0.94	
06/28/94	Little Hog Isl	19	127		1				0.93	
06/28/94	Little Hog Isl	22	130		1				1.00	
06/28/94	Little Hog Isl	48	166		2				1.05	
06/28/94	Little Hog Isl	37	152		2				1.05	
06/28/94	Little Hog Isl	30	143		2				1.03	
06/28/94	Little Hog Isl	29	143		2				0.99	
06/28/94	Little Hog Isl	34	143		2				1.16	
06/28/94	Little Hog Isl	49	171		2				0.98	
06/28/94	Little Hog Isl	31	140		2				1.13	
06/28/94	Little Hog Isl	24	134		2				1.00	
06/28/94	Little Hog Isl	32	146		2				1.03	
06/28/94	Little Hog Isl	31	148		2				0.96	
06/28/94	Little Hog Isl	23	131		2				1.02	

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
06/28/94	Little Hog Isl	33	150		2				0.98	
06/28/94	Little Hog Isl	20	132		2				0.87	
06/28/94	Little Hog Isl	26	140		2				0.95	
06/28/94	Little Hog Isl	33	148		2				1.02	
06/28/94	Little Hog Isl	32	149		2				0.97	
06/28/94	Little Hog Isl	58	166		2				1.27	
06/28/94	Little Hog Isl	28	138		2				1.07	
06/28/94	Little Hog Isl	38	156		2				1.00	
06/28/94	Little Hog Isl	51	167		2				1.10	
06/28/94	Little Hog Isl	36	148		2				1.11	
06/28/94	Little Hog Isl	28	144		2				0.94	
06/28/94	Little Hog Isl	24	136		2				0.95	
06/28/94	Little Hog Isl	31	145		2				1.02	
06/28/94	Little Hog Isl	23	135		2				0.93	
06/28/94	Little Hog Isl	49	167		2				1.05	
06/28/94	Little Hog Isl	50	169		2				1.04	
06/28/94	Little Hog Isl	26	143		2				0.89	
06/28/94	Little Hog Isl	27	144		2				0.90	
06/28/94	Little Hog Isl	47	163		2				1.09	
06/28/94	Little Hog Isl	24	133		2				1.02	
06/28/94	Little Hog Isl	27	141		2				0.96	
06/28/94	Little Hog Isl	24	134		2				1.00	
06/28/94	Little Hog Isl	54	175		2				1.01	
06/28/94	Little Hog Isl	51	171		2				1.02	
06/28/94	Little Hog Isl	41	158		2				1.04	
06/28/94	Little Hog Isl	29	143		2				0.99	
06/28/94	Little Hog Isl	26	143		2				0.89	
06/28/94	Little Hog Isl	33	149		2				1.00	
06/28/94	Little Hog Isl	43	155		2				1.15	
06/28/94	Little Hog Isl	27	142		2				0.94	
06/28/94	Little Hog Isl	55	171		2				1.10	
06/28/94	Little Hog Isl	98	212	f	3				1.03	
06/20/94	W. of Pilon Isl	7	89		1				0.99	
06/20/94	W. of Pilon Isl	3	67		1				1.00	
06/20/94	W. of Pilon Isl	3	68		1				0.95	
06/21/94	W. of Pilon Isl	90	206		2				1.03	
06/21/94	W. of Pilon Isl	950	439	f	11				1.12	

Appendix A - 2. Population characteristics of white suckers caught upstream of the Moses-Saunders power dam in the St. Lawrence River. See Figure 1 for sites.

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
08/09/94	Croil Isl.	0.9	43		0				1.13	
08/09/94	Croil Isl.	0.91	45		0				1.00	
08/09/94	Croil Isl.	0.88	43		0				1.11	
08/08/94	Croil Isl.	0.26	31		0				0.87	
08/08/94	Croil Isl.	0.59	39		0				0.99	
08/09/94	Croil Isl.	1.71	54		0				1.09	
08/09/94	Croil Isl.	0.88	43		0				1.11	
08/09/94	Croil Isl.	1.06	48		0				0.96	
08/09/94	Croil Isl.	1.92	55		0				1.15	
08/09/94	Croil Isl.	0.7	40		0				1.09	
08/09/94	Croil Isl.	1.07	46		0				1.10	
08/09/94	Croil Isl.	0.83	42		0				1.12	
08/09/94	Croil Isl.	1.21	48		0				1.09	
08/09/94	Croil Isl.	0.9	45		0				0.99	
08/09/94	Croil Isl.	1.07	45		0				1.17	
08/09/94	Croil Isl.	1.1	47		0				1.06	
08/09/94	Croil Isl.	0.86	44		0				1.01	
08/09/94	Croil Isl.	1.32	49		0				1.12	
08/09/94	Croil Isl.	0.55	39		0				0.93	
08/09/94	Croil Isl.	0.9	44		0				1.06	
08/09/94	Croil Isl.	1.24	48		0				1.12	
08/09/94	Croil Isl.	0.75	43		0				0.94	
08/09/94	Croil Isl.	1.88	57		0				1.02	
08/09/94	Croil Isl.	0.9	43		0				1.13	
08/09/94	Croil Isl.	1.18	49		0				1.00	
08/09/94	Croil Isl.	0.92	43		0				1.16	
08/09/94	Croil Isl.	1.66	53		0				1.12	
08/09/94	Croil Isl.	0.95	44		0				1.12	
08/09/94	Croil Isl.	2.18	57		0				1.18	
08/09/94	Croil Isl.	2.04	57		0				1.10	
08/09/94	Croil Isl.	0.83	43		0				1.04	
08/09/94	Croil Isl.	0.8	44		0				0.94	
08/09/94	Croil Isl.	0.87	43		0				1.09	
08/09/94	Croil Isl.	1.84	55		0				1.11	
08/09/94	Croil Isl.	1.1	44		0				1.29	
08/09/94	Croil Isl.	2.11	57		0				1.14	
08/09/94	Croil Isl.	1.07	45		0				1.17	
08/09/94	Croil Isl.	1.12	46		0				1.15	
08/09/94	Croil Isl.	0.76	40		0				1.19	
08/09/94	Croil Isl.	1.56	52		0				1.11	
08/09/94	Croil Isl.	0.69	41		0				1.00	
08/09/94	Croil Isl.	0.82	43		0				1.03	
08/09/94	Croil Isl.	0.88	43		0				1.11	
08/09/94	Croil Isl.	1.13	46		0				1.16	
08/09/94	Croil Isl.	1.62	51		0				1.22	
08/09/94	Croil Isl.	0.91	44		0				1.07	
08/09/94	Croil Isl.	1.03	45		0				1.13	
08/09/94	Croil Isl.	0.83	43		0				1.04	
08/09/94	Croil Isl.	0.89	44		0				1.04	
08/09/94	Croil Isl.	1.38	48		0				1.25	
08/09/94	Croil Isl.	1.36	49		0				1.16	
08/09/94	Croil Isl.	0.78	43		0				0.98	
08/09/94	Croil Isl.	0.38	34		0				0.97	
08/09/94	Croil Isl.	1.03	44		0				1.21	
08/09/94	Croil Isl.	0.97	45		0				1.06	

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
08/09/94	Croil Isl.	0.55	39		0				0.93	
08/09/94	Croil Isl.	0.41	36		0				0.88	
08/09/94	Croil Isl.	107	209		2				1.17	
08/09/94	Croil Isl.	321	302	m	3				1.17	
08/09/94	Croil Isl.	694	381	f	4				1.25	
08/09/94	Croil Isl.	540	344	m	4				1.33	
08/09/94	Croil Isl.	639	380	m	4				1.16	
08/09/94	Croil Isl.	843	415	f	6				1.18	
08/09/94	Croil Isl.	672	406	m	6				1.00	
08/09/94	Croil Isl.	627	376	m	9				1.18	
07/19/94	E. Long Sault	0.1	27		0				0.51	
07/19/94	E. Long Sault	111	216		2				1.10	
07/19/94	E. Long Sault	486	352	f	4				1.11	
07/19/94	E. Long Sault	556	362	f	4				1.17	
07/19/94	E. Long Sault	813	418	f	5				1.11	
07/19/94	E. Long Sault	888	427	f	6				1.14	
07/19/94	E. Long Sault	846	432	m	8				1.05	
06/03/94	Farran Pk	4	80		1				0.78	
06/03/94	Farran Pk	7	98		1				0.74	
06/03/94	Farran Pk	749	405	m	6				1.13	
06/03/94	Farran Pk	1058	493	f	8				0.88	
06/03/94	Farran Pk	956	419	m	8				1.30	
06/03/94	Farran Pk	820	425	m	10				1.07	
04/26/94	Hoople Crk	351	308	m	3	7			1.20	no
04/11/95	Hoople Crk	792	397	f	4	108	28670	1.63	1.27	no
04/26/94	Hoople Crk	419	332	m	4	9			1.14	no
04/11/95	Hoople Crk	568	357	m	4	28			1.25	no
04/11/95	Hoople Crk	402	317	m	4	20			1.26	no
04/26/94	Hoople Crk	741	397	f	5				1.18	no
04/11/95	Hoople Crk	928	429	f	5	120	27088	1.60	1.18	no
04/11/95	Hoople Crk	910	413	f	5	134	30874	1.63	1.29	no
04/11/95	Hoople Crk	955	436	m	5	64			1.15	no
04/26/94	Hoople Crk	574	371	m	5	27			1.12	no
04/11/95	Hoople Crk	627	387	m	5	35			1.08	no
04/26/94	Hoople Crk	696	393	m	5	36			1.15	no
04/26/94	Hoople Crk	748	410	f	6				1.09	yes
04/26/94	Hoople Crk	846	452	f	6			1.52	0.92	yes
04/26/94	Hoople Crk	902	439	f	6				1.07	no
04/26/94	Hoople Crk	1052	449	f	6				1.16	yes
04/26/94	Hoople Crk	793	422	f	6	58		1.75	1.06	yes
04/11/95	Hoople Crk	909	429	f	6	145	32528	1.75	1.15	no
04/11/95	Hoople Crk	884	420	f	6	153	30376	1.72	1.19	no
04/26/94	Hoople Crk	870	427	f	6				1.12	no
04/26/94	Hoople Crk	1183	463	f	6	207	37246	1.83	1.19	no
04/11/95	Hoople Crk	783	397	f	6	107	28533	1.52	1.25	no
04/11/95	Hoople Crk	998	433	f	6	171	31133	1.53	1.23	no
04/11/95	Hoople Crk	802	406	f	6	101	25506	1.51	1.20	no
04/26/94	Hoople Crk	688	404	m	6	25			1.04	yes
04/11/95	Hoople Crk	1017	453	f	7			1.56	1.09	yes
04/11/95	Hoople Crk	1120	457	f	7	176	39940	1.91	1.17	no
04/11/95	Hoople Crk	845	433	f	7	113	24860	1.64	1.04	no
04/11/95	Hoople Crk	946	442	f	7	122	23579	1.91	1.10	no
04/11/95	Hoople Crk	974	436	f	7	147	29488	1.81	1.18	no
04/26/94	Hoople Crk	956	448	f	7				1.06	no
04/11/95	Hoople Crk	970	449	f	7	133	32984	1.71	1.07	yes
04/11/95	Hoople Crk	1170	472	f	7			1.77	1.11	no
04/11/95	Hoople Crk	1100	469	f	7	163	38077	1.82	1.07	no

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
04/26/94	Hoople Crk	1178	456	f	7				1.24	no
04/26/94	Hoople Crk	1154	453	f	7	148	30547	1.99	1.24	yes
04/26/94	Hoople Crk	1096	487	f	7				0.95	yes
04/26/94	Hoople Crk	1211	477	f	7	86		1.92	1.12	yes
04/26/94	Hoople Crk	1344	504	f	7				1.05	yes
04/11/95	Hoople Crk	1010	448	f	7	104	23747	1.72	1.12	no
04/11/95	Hoople Crk	909	442	f	7	116	26038	1.58	1.05	no
04/26/94	Hoople Crk	902	416	f	7				1.25	yes
04/11/95	Hoople Crk	1111	458	f	7	116	26201	1.72	1.16	no
04/26/94	Hoople Crk	699	401	m	7	23			1.08	no
04/26/94	Hoople Crk	738	409	m	7				1.08	yes
04/26/94	Hoople Crk	724	398	m	7	18			1.15	no
04/11/95	Hoople Crk	1371	481	f	8	227	45158	1.85	1.23	yes
04/11/95	Hoople Crk	1032	468	f	8			1.75	1.01	no
04/26/94	Hoople Crk	1200	499	f	8	185	33991	2.01	0.97	no
04/11/95	Hoople Crk	1173	462	f	8	156	32292	1.90	1.19	yes
04/11/95	Hoople Crk	972	456	f	8	115	23376	1.77	1.03	yes
04/11/95	Hoople Crk	1173	487	f	8			1.69	1.02	yes
04/11/95	Hoople Crk	1046	455	f	8	166	30057	1.90	1.11	yes
04/11/95	Hoople Crk	1213	467	f	8	188	43390	1.78	1.19	yes
04/26/94	Hoople Crk	753	432	f	8	52		1.63	0.93	no
04/11/95	Hoople Crk	997	450	f	8	116	23788	1.77	1.09	no
04/26/94	Hoople Crk	1298	456	f	8	176	36021	1.92	1.37	yes
04/26/94	Hoople Crk	1114	461	f	8	147	30752	1.98	1.14	yes
04/26/94	Hoople Crk	846	425	f	8				1.10	no
04/26/94	Hoople Crk	994	431	m	8	40			1.24	no
04/11/95	Hoople Crk	657	380	m	8	43			1.20	no
04/11/95	Hoople Crk	688	381	m	8	49			1.24	no
04/11/95	Hoople Crk	805	416	m	8	40			1.12	yes
04/11/95	Hoople Crk	813	411	m	8	45			1.17	no
04/26/94	Hoople Crk	927	434	f	9	93		1.49	1.13	yes
04/11/95	Hoople Crk	1149	483	f	9	146	34057	1.73	1.02	no
04/11/95	Hoople Crk	1167	472	f	9	164	32975	1.66	1.11	yes
04/26/94	Hoople Crk	1301	475	f	9				1.21	yes
04/26/94	Hoople Crk	866	440	m	9	18			1.02	no
04/11/95	Hoople Crk	812	431	m	9	57			1.01	yes
04/26/94	Hoople Crk	669	385	m	9	13			1.17	no
04/26/94	Hoople Crk	812	425	m	9	20			1.06	no
04/26/94	Hoople Crk	786	410	m	9	10			1.14	yes
04/26/94	Hoople Crk	1746	560	f	10	215	62479	1.65	0.99	yes
04/26/94	Hoople Crk	1152	470	f	10				1.11	no
04/26/94	Hoople Crk	1514	510	f	10			1.55	1.14	yes
04/26/94	Hoople Crk	1348	468	f	10	224	49743	1.93	1.32	yes
04/11/95	Hoople Crk	1429	499	f	10	250	47433	1.89	1.15	no
04/26/94	Hoople Crk	735	398	m	10	23			1.17	yes
04/26/94	Hoople Crk	852	434	m	10	27			1.04	yes
04/11/95	Hoople Crk	996	435	m	10	64			1.21	no
04/26/94	Hoople Crk	713	401	m	10	23			1.11	yes
04/11/95	Hoople Crk	1498	514	f	11	236	38248	1.82	1.10	no
04/26/94	Hoople Crk	1154	471	f	11			1.79	1.10	no
04/26/94	Hoople Crk	1699	538	f	11	210	50134	1.74	1.09	yes
04/26/94	Hoople Crk	993	434	m	11	31			1.21	no
04/11/95	Hoople Crk	850	424	m	11	31			1.12	yes
04/26/94	Hoople Crk	799	415	m	12				1.12	no
04/26/94	Hoople Crk	940	427	m	12	54			1.21	no
04/26/94	Hoople Crk	1048	448	m	13	41			1.17	yes
06/02/94	Hoople Isl	4	80		1				0.78	

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06/02/94	Hoople Isl	602	382	f	5				1.08	
06/02/94	Hoople Isl	701	388	m	5				1.20	
06/02/94	Hoople Isl	1663	474	f	8				1.56	
06/02/94	Hoople Isl	1637	510	f	8				1.23	
06/02/94	Hoople Isl	681	417	m	8				0.94	
06/02/94	Hoople Isl	1886	514	f	10				1.39	
06/13/94	Lakeview Hgt	6	90		1				0.82	
06/14/94	Lakeview Hgt	827	428	f	5				1.05	
08/10/94	S.E. Croil Isl	0.39	38		0				0.71	
08/10/94	S.E. Croil Isl	0.51	41		0				0.74	
08/10/94	S.E. Croil Isl	0.32	38		0				0.58	
08/10/94	S.E. Croil Isl	0.33	36		0				0.71	
08/10/94	S.E. Croil Isl	0.49	39		0				0.83	
08/10/94	S.E. Croil Isl	0.34	36		0				0.73	
08/10/94	S.E. Croil Isl	0.27	35		0				0.63	
08/10/94	S.E. Croil Isl	0.41	39		0				0.69	
08/10/94	S.E. Croil Isl	0.2	32		0				0.61	
08/10/94	S.E. Croil Isl	0.78	44		0				0.92	
08/10/94	S.E. Croil Isl	0.32	34		0				0.81	
08/10/94	S.E. Croil Isl	47	161		1				1.13	
08/10/94	S.E. Croil Isl	31	141		1				1.11	
08/10/94	S.E. Croil Isl	20	132		1				0.87	
08/10/94	S.E. Croil Isl	14	113		1				0.97	
08/10/94	S.E. Croil Isl	90	195		2				1.21	
08/10/94	S.E. Croil Isl	131	218		2				1.26	
08/10/94	S.E. Croil Isl	107	202		2				1.30	
08/10/94	S.E. Croil Isl	136	222		2				1.24	
08/10/94	S.E. Croil Isl	147	226		2				1.27	
08/10/94	S.E. Croil Isl	132	218		2				1.27	
08/10/94	S.E. Croil Isl	123	220		2				1.16	
08/10/94	S.E. Croil Isl	103	216		2				1.02	
08/10/94	S.E. Croil Isl	103	205		2				1.20	
08/10/94	S.E. Croil Isl	115	212		2				1.21	
08/11/94	S.E. Croil Isl	150	221		2				1.39	
08/10/94	S.E. Croil Isl	380	312	f	3				1.25	
08/10/94	S.E. Croil Isl	267	283	f	3				1.18	
08/10/94	S.E. Croil Isl	331	306	f	3				1.16	
08/10/94	S.E. Croil Isl	264	275	f	3				1.27	
08/11/94	S.E. Croil Isl	318	302	m	3				1.15	
08/10/94	S.E. Croil Isl	454	331	m	3				1.25	
08/10/94	S.E. Croil Isl	355	300	m	3				1.31	
08/10/94	S.E. Croil Isl	594	378	m	4				1.10	
08/10/94	S.E. Croil Isl	469	343	m	4				1.16	
08/10/94	S.E. Croil Isl	736	425	f	6				0.96	
08/11/94	S.E. Croil Isl	808	423	f	6				1.07	
08/10/94	S.E. Croil Isl	941	478	f	7				0.86	
08/10/94	S.E. Croil Isl	848	427	f	7				1.09	
08/11/94	S.E. Croil Isl	748	410	f	7				1.09	
08/10/94	S.E. Croil Isl	684	406	m	7				1.02	
08/10/94	S.E. Croil Isl	811	447	f	8				0.91	
08/11/94	S.E. Croil Isl	706	402	m	8				1.09	
07/20/94	W. Long Sault	0.19	29		0				0.78	
07/20/94	W. Long Sault	0.16	27		0				0.81	
07/20/94	W. Long Sault	0.15	31		0				0.50	
07/20/94	W. Long Sault	0.21	32		0				0.64	
07/20/94	W. Long Sault	0.25	34		0				0.64	
07/20/94	W. Long Sault	0.14	27		0				0.71	

DATE OF CAPTURE	SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	GONAD WT. (g)	FECUNDITY	EGG DIAM. (mm)	CONDITION FACTOR	TUMOUR
07/20/94	W. Long Sault	0.13	26		0				0.74	
07/20/94	W. Long Sault	0.07	23		0				0.58	
07/20/94	W. Long Sault	0.08	22		0				0.75	
07/20/94	W. Long Sault	0.22	30		0				0.81	
07/20/94	W. Long Sault	0.33	32		0				1.01	
07/20/94	W. Long Sault	0.88	46		0				0.90	
07/20/94	W. Long Sault	0.12	23		0				0.99	
07/20/94	W. Long Sault	0.19	34		0				0.48	
07/20/94	W. Long Sault	0.3	35		0				0.70	
07/20/94	W. Long Sault	0.31	36		0				0.66	
07/20/94	W. Long Sault	0.18	32		0				0.55	
07/20/94	W. Long Sault	0.16	30		0				0.59	
07/20/94	W. Long Sault	0.19	33		0				0.53	
07/20/94	W. Long Sault	0.17	26		0				0.97	
07/20/94	W. Long Sault	1.15	51		0				0.87	
07/20/94	W. Long Sault	0.19	31		0				0.64	
07/20/94	W. Long Sault	0.34	38		0				0.62	
07/20/94	W. Long Sault	0.31	36		0				0.66	
07/20/94	W. Long Sault	0.15	26		0				0.85	
07/20/94	W. Long Sault	0.75	48		0				0.68	
07/20/94	W. Long Sault	0.26	31		0				0.87	
07/20/94	W. Long Sault	0.29	32		0				0.89	
07/20/94	W. Long Sault	0.09	23		0				0.74	
07/20/94	W. Long Sault	0.33	35		0				0.77	
07/20/94	W. Long Sault	0.49	43		0				0.62	
07/20/94	W. Long Sault	18	115		1				1.18	
07/20/94	W. Long Sault	22	127		1				1.07	
07/20/94	W. Long Sault	28	138		1				1.07	
07/20/94	W. Long Sault	22	132		1				0.96	
07/20/94	W. Long Sault	13	110		1				0.98	
07/20/94	W. Long Sault	13	113		1				0.90	
07/20/94	W. Long Sault	20	124		1				1.05	
07/20/94	W. Long Sault	23	131		1				1.02	
07/20/94	W. Long Sault	18	122		1				0.99	
07/20/94	W. Long Sault	34	145		1				1.12	
07/20/94	W. Long Sault	26	134		1				1.08	
07/20/94	W. Long Sault	9	99		1				0.93	
07/20/94	W. Long Sault	14	111		1				1.02	
07/20/94	W. Long Sault	1044	468	f	6				1.02	
07/05/94	Mille Roche	9	100		1				0.90	
07/05/94	Mille Roche	7	94		1				0.84	
07/05/94	Mille Roche	10	105		1				0.86	
07/05/94	Mille Roche	9	102		1				0.85	
07/05/94	Mille Roche	8	101		1				0.78	
07/06/94	Mille Roche	101	209		2				1.11	
07/06/94	Mille Roche	741	390	m	6				1.25	
05/24/94	Wales Isl	892	430	f	7				1.12	

Appendix B. Detection and calibration ions used for GC-MSD analysis

	Reference Surrogate #	Detection Ion m/z
Naphthalene-d8	1	136
1-Methlynaphthalene-d10	2	150
Acenaphthylene-d8	3	160
Acenaphthylene-d10	4	162
Fluorene-d10	5	176
Anthracene-d10	6	188
Pyrene-d10	7	212
Chrysene-d12	8	240
Benzo[a]pyrene-d12	9	264

Compound	Compound #	Detection Ion m/z	Reference Surrogate Used
Naphthalene	1	128	1
Acenaphthylene	2	152	3
Acenaphthene	3	154	4
Fluorene	4	166	5
Phenanthrene	5	178	6
Anthracene	6	178	6
Fluoranthene	7	202	7
Pyrene	8	202	7
Benz[a]anthracene	9	228	8
Chrysene	10	228	8
Benzo[b]fluoranthene	11	252	9
Benzo[k]fluoranthene	12	252	9
Benzo[a] pyrene	13	252	9
Perylene	14	252	9
Indeno[1,2,3-cd]pyrene	15	276	9
Dibenz[a,h]anthracene	16	278	9
Benzo[g,h,i]perylene	17	276	9
2-Methylnaphthalene	18	142	2
1-Methylnaphthalene	19	142	2
2,6 & 2,7-Dimethylnaphthalene	20	156	2
1,6-Dimethylnaphthalene	21	156	2
2,3 & 1,4-Dimethylnaphthalene	22	156	2
1,5-Dimethylnaphthalene	23	156	2
1,2-Dimethylnaphthalene	24	156	2
2,3,6-Trimethylnaphthalene	25	170	2
2,3,5-Trimethylnaphthalene	26	170	2
2-Methylphenanthrene	27	192	6
2-Methylanthracene	28	192	6
1-Methylanthracene	29	192	6
1-Methylphenanthrene	30	192	6
9-Methylanthracene	31	192	6
3,6-Dimethylphenanthrene	32	206	6
9,10-Dimethylanthracene	33	206	6
2-Methylfluoranthene	34	216	7

Compound # = the reference number for each compound used in Figure 4.

Appendix C - 1. Population and contaminant data for individual white suckers from the St. Lawrence River downstream of the Moses-Saunders power dam. See Figure 1 for sites.

SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	PAH ng/g dry wt	PCB ng/g dry wt	CHLOROBENZE ng/g dry wt	CHLORDANE ng/g dry wt	HCH ng/g dry wt	DDT ng/g dry wt	ALDRIN ng/g dry wt	ENDOSULFAN ng/g dry wt	MIREX ng/g dry wt	METHOXYCHLOR ng/g dry wt
Colquhoun Isl.	1288	492	f	9	96	53	13	0.27	0.39	2.1	0.63	0	0.14	0
Colquhoun Isl.	826	453	m	8	34	257	26	0.91	0.51	4	0.51	0.23	0.49	0
Colquhoun Isl.	954	422	m	6	70	255	31	1	0.78	18	1	0.87	1.4	0
Colquhoun Isl.	1112	460	m	10	29	73	100	0	1.7	2.4	0.53	0	0	0
Colquhoun Isl.	968	425	m	7	65	228	33	0.86	0.42	11	0.75	0.38	1.3	0
Colquhoun Isl.	990	432	f	6	50	245	43	0.48	0.86	9.3	0.95	0.85	0.82	0
Colquhoun Isl.	1034	460	f	7	15	131	620	0.83	1	0	8	0	0	0.96
Cornwall Isl.	1077	489	f	11	56	46	18	0.74	1.1	2.8	0.5	0.13	0.34	0
Cornwall Isl.	1470	492	f	11	43	161	39	0.84	0.39	21	0.82	0.66	1.9	0
Courtauld's	1156	498	m	10	87	106	28	0.74	0.66	7.8	0.7	0.17	0.95	0
Courtauld's	1260	490	f	7	100	72	29	0	0.36	0.93	0.63	0.29	0.29	0
Courtauld's	900	415	m	9	92	86	28	0.29	0.36	3.9	0.53	0.17	0.44	0
Courtauld's	1033	442	f	5	30	36	7.7	0	0.055	1.3	0.3	0.12	0.18	0
Dickerson Isl.	1584	525	f	7	21	435	33	1.1	0.7	25	0.91	0.3	1.4	0
Dickerson Isl.	1518	529	f	7	24	216	23	0.53	1	8.4	0.44	0.13	0.86	0.58
Dickerson Isl.	679	385	m	4	0	245	54	1.3	1.3	12	1.2	1.2	1.1	0
Dickerson Isl.	1880	573	f	9		587	33	1.3	0.76	41	1.3	0.27	3	0
Dickerson Isl.	1114	474	f	8	16	214	35	0.43	0.39	6.2	0.53	0.16	0.83	0
E. St. Regis	1470	519	f	12	10	153	38	0.9	0.46	10	0.57	0.15	1.1	0
E. St. Regis	1006	438	m	5	39	135	64	0	1.6	0.29	1.4	0	0.61	0
E. St. Regis	1040	472	m	11	86	478	42	1.1	0.91	53	2.7	0.94	6.7	0
E. St. Regis	1866	515	f	11	56	167	21	1.2	0.56	14	1.5	0.76	1.9	0.64
E. St. Regis	989	436	m	7	15	365	270	0.65	1.2	0.75	1.3	0.13	2.7	0
Farlinger's Pt.	1572	473	f	6	43	673	34	1.7	1.7	38	2.1	0.85	2.3	0.73
Flanigan's Pt.	1056	454	m	9	81	549	30	1.6	1.3	76	2.3	1.5	7.6	0
Flanigan's Pt.	979	458	m	9	91	2702	36	3.1	1.5	90	4.3	0	6.4	1.5
Raisin River	1507	495	f	7	96	217	23	1.3	1	25	1.4	1.1	1.6	0
Raisin River	1700	511	f	7	103	847	58	3.9	2.4	160	16	5.4	8.3	0
Raisin River	1700	495	f	6	94	94	26	1.6	1.7	14	5.1	0.37	0.69	2
Raisin River	1676	512	f	7	51	200	41	1.4	1.7	30	2.9	1.4	2.1	0.87
Raisin River	1760	523	f	5	58	223	30	1.8	1.2	17	2.3	1.2	1.1	1.5
Raisin River	1378	473	m	9	40	278	29	0.42	0.74	30	2.1	0.59	4.6	0
Raisin River	1657	500	f	6	61	232	31	1.5	0.93	19	2.2	1	1.3	0
Raisin River	1812	501	f	6	98	93	21	1.1	0.5	13	0.97	0.75	0.92	0
Raisin River	1004	458	m	9	53	118	30	1.8	1.2	17	2.3	1.2	1.1	1.5
Raisin River	1562	500	f	5	43	380	29	1.1	0.65	25	2.6	1.1	0.95	0
W. St. Regis	1544	502	f	8	21	109	24	0.27	0.36	4.3	0.39	0.18	0.26	0
W. St. Regis	963	426	f	6	35	23	1.1	0.6	0.32	2.6	0.4	0.078	0.18	0
W. St. Regis	1343	497	f	5	30	122	34	0.34	0.47	5.3	0.49	0.12	0.88	0
W. St. Regis	1044	453	f	6	57	102	30	0	0	5.1	0.25	0.032	0.79	0.6

Appendix C - 2. Population and contaminant data for individual white suckers from the St. Lawrence River upstream of the Moses-Saunders power dam. See Figure 1 for sites.

SITE	WEIGHT (g)	TLENGTH (mm)	SEX	AGE	PAH ng/g dry wt	PCB ng/g dry wt	CHLOROBENZE ng/g dry wt	CHLORDANE ng/g dry wt	HCH ng/g dry wt	DDT ng/g dry wt	ALDRIN ng/g dry wt	ENDOSULFAN ng/g dry wt	MIREX ng/g dry wt	METHOXYCHLOR ng/g dry wt
W. Long Sault	1044	468	f	6	20	69	36	0.86	0.44	6.5	1.9	0.12	0.77	0.99
S.E. Croil Isl.	941	478	f	7	75	1357	34	0.87	0.84	4.9	3.5	0.81	1.1	0
S.E. Croil Isl.	736	425	f	6	41	45	22	0.26	0.81	3.1	0.47	0.077	0.42	0.43
Mille Roche	741	390	m	6		121	29	0.95	0.72	19	0.9	0.18	1.7	0
S.E. Croil Isl.	811	447	f	8	74	1061	34	0.65	1.5	0.94	3.9	0.65	1.4	0
S.E. Croil Isl.	684	406	m	7	126	28	1	1.1	0.66	7.3	0.58	0.71	0.39	0.93
S.E. Croil Isl.	706	402	m	8	21	166	155	0	0	14	0.74	0.052	1.3	0.66
S.E. Croil Isl.	355	300	m	3	79	54	37	0	0.068	1.1	0.59	0	0.21	0
S.E. Croil Isl.	808	423	f	6	47	962	20	0.48	0.31	9.7	0.68	0.48	0.99	0.67
S.E. Croil Isl.	748	410	f	7	85	894	22	0.63	0.94	6.9	7.9	0.19	0.64	0
S.E. Croil Isl.	469	343	m	4	38	1352	26	0.77	0.54	16	8.5	0.63	1.2	1
S.E. Croil Isl.	848	427	f	7	64	57	27	0.44	0.84	4.8	0.49	0.087	0.54	0
S.E. Croil Isl.	331	306	f	3	146	390	14	0	0.39	3	2.4	0.2	0.28	0.93
Farran Prov. Pk.	1058	493	f	8	31	26	44	1.1	0.76	0.71	4.6	0.1	0.2	0.76
Farran Prov. Pk.	820	425	m	10	74	130	32	1.3	0.78	19	2.1	0.65	2.3	1.1
E. Long Sault	846	432	m	8	89	43	17	0.43	2.3	2.9	3.3	0	0.39	0
Hoople Creek	1152	470	f	10	53	206	33	2.4	1.6	41	3.2	1.2	3.2	0
Farran Prov. Pk.	749	405	m	6	116	117	28	1.3	1.6	28	3.8	1.3	2.1	0
Farran Prov. Pk.	956	419	m	8	87	450	52	1.7	2.9	71	5.8	0	13	0
E. Long Sault	486	352	f	4	135	132	40	1.5	1.1	3.7	4.1	0.16	1.3	1.2
Croil Isl.	627	376	m	9	114	120	52	1.8	1.1	28	1.1	1.1	2.8	1.5
Croil Isl.	321	302	m	3	58	51	33	1.2	0.68	7.8	0.67	0.66	0.71	0
Croil Isl.	639	380	m	4	99	97	46	1.8	1.2	12	0.91	1	0.87	0
E. Long Sault	556	362	f	4	96	47	32	0.29	0.75	2	3.3	0.02	0.32	0
E. Long Sault	813	418	f	5	62	50	17	0	0.88	1.6	0.48	0	0.42	0
E. Long Sault	888	427	f	6	61	114	11	0.43	0.55	7.6	3	0.09	1.6	0.8
Hoople Creek	902	439	f	6	12	87	18	0.51	0.6	12	1.6	0.1	0.69	0
Hoople Isl.	1663	474	f	8	91	213	28	1.3	1.1	7.5	1.8	0.96	2.2	0
Hoople Isl.	701	388	m	5	81	78	11	1.3	1.2	8.6	1.7	0.14	0.86	0
Hoople Creek	1746	560	f	10	86	96	16	0	0.43	11	0.68	0.16	1.2	0.52
Lakeview Hgts.	827	428	f	5	91	179	43	1.2	0.95	29	1.3	1.2	2.2	0
Hoople Isl.	1637	510	f	8	84	124	11	1.5	0.68	16	11	0.19	1.3	0.85
Hoople Isl.	1886	514	f	10	59	91	33	0.84	1	9.3	2.4	0.14	1.2	0
Hoople Creek	956	448	f	7	64	105	33	0.92	0.98	6.6	4.5	0.99	2.6	0
Hoople Creek	1183	463	f	5	96	68	280	0	1.7	1.2	1.5	0	3	0
Hoople Creek	866	440	m	9	94	486	17	1.1	0.67	110	1.4	1.2	11	0
Hoople Creek	1154	471	f	11	76	148	18	0	0.62	22	1.4	0.14	2.7	0
Hoople Creek	812	425	m	6	67	427	24	1.1	0.88	91	4.2	0	9.2	0
Hoople Creek	846	452	f	6	90	87	38	0	0.98	1.4	9.4	0	0.93	0
Hoople Creek	1211	477	f	7	49	151	23	0.81	0.68	24	22	0.88	2.9	0