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Performance of White Sucker Populations along the Saint John River Main Stem, New Brunswick, Canada: An Example of Effects-Based Cumulative Effects Assessment

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White sucker (*Catostomus commersoni*) are widely distributed in North America and are often used in environmental monitoring. Whole organism characteristics of three white sucker populations determined to be resident (outside of spawning) within small sections of the Saint John River, New Brunswick, were studied in 2001 and 2002. Significant differences in performance characteristics were present among sites. The differences can be interpreted as either improved sucker performance at Florenceville (upstream site), or decreased performance at Woodstock. Without further investigation it is difficult to identify whether the apparent improved performance is a response to nutrient enrichment, or increased mortality associated with the recent prevalence of lesions. Confounding factors are also present. Daily water level fluctuations resulting from an upstream dam discharge may change habitat availability and/or diversity, thereby altering the fish community. Liver sizes in Saint John River white sucker are considerably larger than in fish collected in Ontario, but are not relative to nearby New Brunswick river populations. This has implications for the importance of reference site selection and understanding the natural variability within a species (intra-specific variation) on multiple spatial scales.

Key words: **white sucker, performance, monitoring, Saint John River**

Introduction

A survey of the Saint John River system was initiated in 1999 to identify areas of concern throughout the basin. The survey was initiated in the upper part of the basin, near the Canada–U.S. border (Galloway et al. 2003) and has since been continuing down river. The survey is following an effects-based approach to cumulative effects assessment (Munkittrick et al. 2000) that uses the performance characteristics of resident fish populations to identify sites showing impacts that warrant further investigation. The collections focus on whether fish populations show differences in whole organism characteristics reflective of performance (growth, reproduction, energy storage, age distributions) (Munkittrick et al. 2000; Lowell et al. 2003). When sites with altered performance are detected, detailed follow-up studies are initiated to determine whether the causes can be detected (Hewitt et al. 2003).

Preliminary work identified a number of areas in the upper reach of the Saint John River requiring additional study, including sites near a poultry processing plant, a sewage treatment facility and pulp and paper mills (Galloway et al. 2003), and in tributaries with large-scale potato agriculture (Gray et al. 2002, 2005; Gray and Munkittrick 2005). A fish community survey was conducted to identify the potential sentinel species in the freshwater portion of the Saint John River (Curry and Munkittrick 2005) and reported the presence of 35 fish species. During this community survey, a significant number of white sucker (*Catostomus commersoni*) were captured with external lesions (4–12% occurrence in adults), identifying a potential area of concern in the river reach near the Beechwood hydroelectric facility, as lesions in the species are rarely reported (Munkittrick, Unpublished data).

Before follow-up studies were initiated on the potential relevance and causes of these lesions, it was necessary to determine whether the white sucker inhabiting the area are mobile or resident. The middle reach of the Saint John River downstream of the Beechwood hydroelectric facility receives a number of effluents, including those from food processing plants and sewage treatment facilities. Initial studies examined site fidelity and movement patterns of white sucker in the Saint John River using radio and acoustic tracking assessments of their movements (Doherty 2004; Doherty et al. 2004). Those studies demonstrated that fish collected during the mid to late fall period had spent considerable periods of time

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in small reaches of the river, and that it was uncommon for fish to move among river sections (i.e., sites with identified point source discharges) except during the spawning period. These movement studies increased the level of confidence that white sucker performance characteristics would reflect local conditions associated with the areas in which they were captured (i.e., reside) during non-spawning seasons (Doherty 2004).

White sucker were collected from three areas progressively further downstream from the Beechwood hydroelectric facility to determine whether the white sucker were showing responses in terms of their growth, reproductive investments or energy storage. Information on these characteristics can be used to indicate potential response patterns of the population to local stresses. The main objective of this work was to evaluate and compare adult white sucker at sites within the Saint John River on issues related to performance and its use as a monitoring organism in Atlantic Canada. Within this context, evaluation of lesion frequency in white sucker, determination of the potential consequences and correlating stresses with lesions and/or decreases in performance were goals of this study.

Methods

Fish were collected downstream of point source inputs at three sites (Florenceville, Hartland and Woodstock, N.B.) in October 2001, using short-set experimental gill nets, and during the spawning run in May 2002 using hoop nets (Fig. 1). Fall sucker collections were repeated at the same main river sites in 2002 during the same week, with the addition of a site on a connected tributary (Tobique) and a neighbouring watershed (Miramichi) (Fig. 1).

The Saint John River has a length of almost 660 km and a basin of 55,110 km², of which portions are located in Maine, Quebec and New Brunswick (>50%) (Dominy 1973; Cunjak and Newbury 2005; Fig. 1). Natural river conditions have changed as the result of multiple hydroelectric facilities, industrial and municipal development (i.e., effluent discharges), agricultural runoff and other non-point source inputs (Dominy 1973; Curry and Munkittrick 2005).

The middle reach of the river consists of two reservoirs created by hydroelectric dams. The Beechwood hydroelectric facility (113MW; river km 295; 1957) is

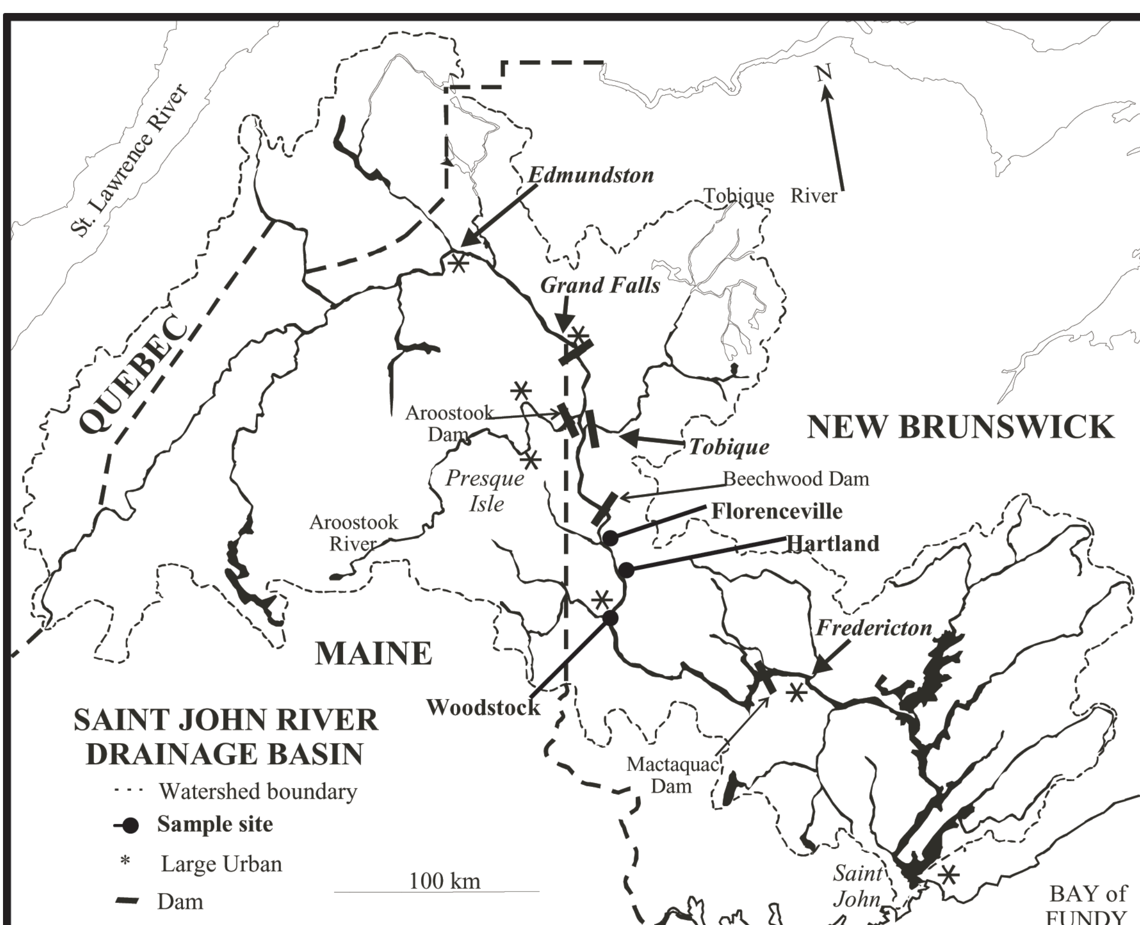

Fig. 1. Map of the Saint John River basin (adapted from Curry and Munkittrick [2005] with permission).

located approximately 20 km upstream of Florenceville and is a peaking station with a daily cycle throughout the entire year (i.e., low discharge overnight and high during the day) dictated by the seasons. It has an inefficient fishway that is only seasonally operated for selected fish species. The bottom end of the reach is completed by the Mactaquac hydroelectric facility (653MW; river km 135; 1968), located approximately 19 km west of Fredericton. It is the largest dam on the river, generates a reservoir >60 km in length, flooding an area of approximately 87 km^2, and has only an elevator-truck method for fish passage (e.g., no fishway). During spawning runs in the spring, various species of fish are trapped below the dam and trucked upstream, around the dams.

Within the river reach, the river flows by Perth-Andover (pop. = 1980; 9.27 km^2), Florenceville (pop. = 762; 7.17 km^2), Hartland (pop. = 902; 9.32 km^2) and Woodstock (pop. = 5,198; 13.26 km^2). The Maqtaquac headpond starts downstream of Woodstock near Nackawick, N.B. (Fig. 1). Interactions of effluent discharges and fluctuating water levels, which alter their dilution, have not been investigated. In Florenceville, the river receives effluent from a food processing plant that has been in operation since 1957. Potato processing for the production of French fries is the primary focus of the plant with supplemental processing of other crops during summer months (Jacques Whitford Environment Limited 1996). The processing plant, as of 1996, had a tertiary waste treatment system with a retention time of ~15 days and discharge volume of 7000 to 10,000 m^3/d (Jacques Whitford Environment Limited 1996).

Hartland's wastewater facility consists of an aerated lagoon with maximum design capacity of 1260 people (discharge 573 m^3/d), while the Woodstock system consists of an oxidation ditch designed for 6000 people (discharge 2717 m^3/d). The Meduxnekeag River, a major tributary to the Saint John River, is located approximately 500 m upstream of the Woodstock sewage effluent discharge. Agricultural runoff and a single sewage effluent discharge are present along this tributary (Sheryl Johnstone, New Brunswick Department of the Environment and Local Government, pers. comm.). Both the Hartland and Woodstock facilities are operating at full capacity and experience periodic episodes of raw sewage discharge into the aquatic environment of the Saint John River (Sheryl Johnstone, New Brunswick Department of the Environment and Local Government, pers. comm.).

Fish Collections

Lethal sampling of adult white sucker was conducted at each site to assess performance parameters. Two periods of lethal sampling were conducted: fall sampling and spring sampling. Fall sampling was repeated in consecutive years (2001 and 2002) with temporal consistency being maintained (i.e., week of October 13) at the main stem areas of concern to look at differences among sites and annual variation within a site. Spring sampling occurred in four Saint John River tributaries to compare reproductive performance of white sucker populations just prior to spawning in 2002. Tributaries sampled were based on spawning movements and observations made in 2001 (Doherty 2004) (Fig. 2).

Standard capture methods were used to limit the catch of non-target species and to select for white sucker within a desired size range in efforts to reduce variability within a site. In the fall, short-set experimental gill nets with mesh sizes ranging between 64 to 89 mm were typically set for 15 to 30 min and on-site presence was maintained. During the spring, a variety of gear types including hoop, fyke and gill nets were used to target migrating suckers. Non-target species were counted and returned to the river as quickly as possible.

Weight (nearest 0.1 g), length (nearest mm), condition factor, liver and gonad size (nearest 0.01 g) were measured or calculated as endpoints of energy storage and reproductive condition to assess performance (Munkittrick et al. 2000). Age structures (opercula) were collected to determine size-at-age as a measure of growth for fish collected in 2002. Estimated ages were read two to three times, randomly and blind (sex, size and previous age estimate were unknown to the reader). Samples for biochemical analysis (blood, bile and liver) and histology (liver, spleen and kidney) were catalogued for subsequent analysis. To meet statistical requirements for the characterization/comparison of these parameters, efforts were made to obtain 20 adult white suckers of each gender from each site (Environment Canada 1997).

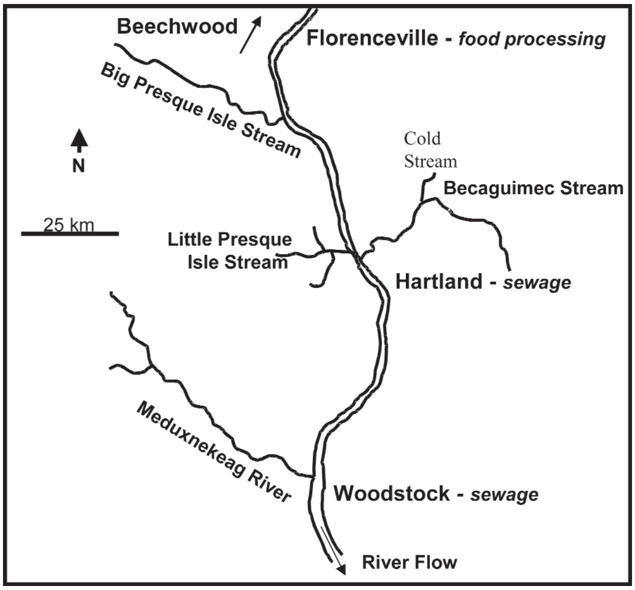

Fig. 2. Middle reach of the Saint John River, extending downstream of the Beechwood run-of-the-river peaking hydroelectric facility to the head of the Mactaquac Reservoir at Woodstock, N.B.

Data Analysis

The biological fish data (i.e., length, weight and organ size) was assessed in terms of normality and equality of variances, prior to statistical comparisons. When determined to be appropriate, log_{10} transformation of the biological data was performed before further analysis was conducted. Differences in the energy requirements between male and female fish may result in differences in the endpoints measured. Thus, data were analyzed for each sex separately.

To test for differences in length, weight and age of adult white sucker among sites within a year, analysis of variance (ANOVA) with post-hoc multiple comparisons were used. Generalized linear models (GLM) were used to analyze other supporting response variables including condition (relationship between fish length and weight), size-at-age and organ size for both liver and gonad. In the GLM, adjusted body weight (wet total weight – organ weight) was used as the covariate. For females, an additional GLM was conducted using fork length as the covariate instead of adjusted weight. For graphical representation and summary, condition factor (K) was calculated as: $K = 100*[\text{wet total weight}/(\text{length}^3)]$, while organ sizes were expressed as indices: gonadosomatic index, $GSI = 100*[\text{gonad weight}/(\text{adjusted body weight})]$ and liver-somatic index, $LSI = 100*[\text{liver weight}/(\text{adjusted body weight})]$.

Annual variation of adult white sucker performance parameters within a site was analyzed using the same analyses and comparisons. White sucker performance parameters from the identified area of concern were compared and analyzed in an expanded data set in 2002 with the addition of two upper main stem Saint John River sites (Galloway et al. 2004), the Tobique tributary, and the neighboring Miramichi River (MSW branch). Statistical analyses were done using the software package SYSTAT (SPSS, SYSTAT, Chicago, Ill., U.S.).

Results

From the short-set gill netting, more suckers were caught in Hartland (n = 56) but it had the lowest catch per unit effort (CPUE) of the three sites, approximately three suckers per net hour, while Florenceville (n = 38) and Woodstock (n = 45) were both over 6 fish per gill net-$hour^{-1}$ in 2001. White sucker represented a high proportion of the total CPUE, as by-catch of non-target species was very limited. A limited standardized gill net fish community survey conducted in the summer of 2002, showed that white sucker account for much less of the total catch in Hartland and Woodstock relative to Florenceville. Fish species richness was lowest in Florenceville with only two species, white sucker and smallmouth bass, followed by Hartland (3) and Woodstock (6). Smallmouth bass was the only other species caught at all three sites. Of the suckers collected in the fall, >95% were considered to be adult based on visual secondary sexual characteristics and a criterion of having a GSI ≥1% (Munkittrick et al. 2000).

Fall 2001

Male and female sucker size (length and weight) and size-at-age were larger at the farthest upstream site, Florenceville. There were no significant site differences in female condition factor in 2001 ($p = 0.50$; Table 1). However, male condition factor was significantly lower in Woodstock ($p = 0.03$; 7.9%) compared to Florenceville (Table 2). Female liver size was significantly elevated in Hartland by almost 23% ($p < 0.001$) relative to Florenceville. In comparison, Woodstock female liver size was significantly smaller ($p = 0.05$) than Florenceville, but did not differ significantly from Hartland (Table 1). Males showed a larger increase in liver size for a given body weight (GLM interaction $p = 0.002$), with almost a 75% increase in Hartland and a 5.3% decrease in Woodstock relative to Florenceville (Table 3). Male gonad size regression lines had significantly differing slopes as determined by a significant GLM interaction (male $p = 0.008$). Hartland and Woodstock male gonad regressions had a decreased slope of 41.5 and 50.3%, respectively, when compared to Florenceville. No significant interactions were present when female gonad size was analyzed using either length or weight as the covariate. However, site was determined not to be a significant factor upon removal of the interaction term.

Fall 2002

In 2002, using secondary sexual characteristics of anal fin morphology (male—fin extends beyond margin of caudal peduncle; female—shorter, does not extend past caudal peduncle) and the presence/absence of tubercles it was possible to externally identify gender of individual fish. Correct identification resulted 98% of the time, with misidentification of a single male and single female from Florenceville.

Sizes of both male and female white sucker were significantly smaller at Hartland and Woodstock relative to Florenceville. Female length decreased by 10% in Hartland ($p < 0.001$) and 8.6% in Woodstock ($p < 0.001$). Florenceville females were over 30% heavier than fish collected at Hartland ($p < 0.001$) and Woodstock ($p < 0.041$). This pattern was mirrored in male suckers with Hartland (FL and Wt $p < 0.001$) or Woodstock (FL and Wt $p < 0.001$) having significantly shorter and lighter fish than Florenceville (Table 2).

Male condition factor was significantly lower both in Hartland ($p < 0.01$, 6.3%) and Woodstock ($p < 0.001$, 14.8%) compared to Florenceville. Woodstock males had the lowest condition (1.26 ± 0.01), which was

TABLE 1. Length, weight, condition factor, gonadosomatic and liver-somatic indices of adult female white sucker[a] from the identified area of concern collected during October 2001 and 2002[b]

		Study site		
Year	*Fish performance endpoint (mean ± SE)*	*Florenceville*	*Hartland*	*Woodstock*
2001	Sample size	19	25	17
	Fork length (cm)	43.5 ± 0.58 A	41.1 ± 0.79 A	36.1 ± 0.65 B
	Weight (g)	1138.8 ± 50.4 A	963.7 ± 65.2 A	640.3 ± 35.8 B
	Condition factor (K)[c]	1.37 ± 0.03	1.34 ± 0.02	1.34 ± 0.03
	LSI %[d]	1.70 ± 0.07 A	2.09 ± 0.08 B	1.60 ± 0.05 B
	GSI %[e]	7.44 ± 0.42	6.63 ± 0.29	5.66 ± 0.41
2002	Sample size	20	16	18
	Fork length (cm)	43.7 ± 0.60 A	39.0 ± 0.68 B	39.9 ± 0.56 B
	Weight (g)	1197.7 ± 48.7 A	816.5 ± 55.7 B	822.6 ± 31.2 B
	Age (y)[a]	5.9 ± 0.31 A	4.7 ± 0.23 B	5.4 ± 0.28 A
	Condition factor (K)[c]	1.43 ± 0.02[f]	1.35 ± 0.03[f]	1.29 ± 0.02[f]
	LSI %[d]	1.88 ± 0.05 AB	2.04 ± 0.10 A	1.57 ± 0.06 B
	GSI %[e]	7.58 ± 0.33 A	5.78 ± 0.37 AB	5.31 ± 0.31 B

[a]Fish with GSI >1% considered adult.
[b]Numbers within a row with different letters are statistically different ($p < 0.05$).
[c]Condition factor (K) = 100[body weight/(fork length3)].
[d]Liver-somatic index (LSI) = 100[liver weight/(body weight – liver weight)].
[e]Gonadosomatic index (GSI) = 100[gonad weight/(body weight – gonad weight)].
[f]Indicates significant interaction ($p < 0.05$).

significantly different from Hartland ($p < 0.001$). The slope of regression lines for female condition factor in 2002 was significantly different (GLM interaction $p = 0.008$). Hartland had the highest slope, which decreased by 36% in Woodstock and was over 20% higher than that of Florenceville females (Table 3).

Differences in white sucker age structure were also present, with Florenceville males being significantly older than Woodstock males, while Hartland females were younger than either Florenceville or Woodstock females (Tables 1 and 2). No significant differences in male or female growth were apparent among sites in

TABLE 2. Length, weight, condition factor, gonadosomatic and liver-somatic indices of adult male white sucker[a] from the identified area of concern collected during October 2001 and 2002[b]

		Study site		
Year	*Parameter*	*Florenceville*	*Hartland*	*Woodstock*
2001	Sample size	18	18	22
	Fork length (cm)	38.6 ± 0.82 A	35.9 ± 0.65 B	34.7 ± 0.44 B
	Weight (g)	830.8 ± 52.3 A	622.7 ± 40.4 B	547.7 ± 22.7 B
	Condition factor (K)[c]	1.41 ± 0.03 A	1.31 ± 0.02 B	1.30 ± 0.02 B
	GSI %[e]	5.74 ± 0.36[f]	4.85 ± 0.19[f]	5.30 ± 0.19[f]
	LSI %[d]	1.60 ± 0.07[f]	1.62 ± 0.13[f]	1.18 ± 0.03[f]
2002	Sample size	19	20	14
	Fork length (cm)	39.4 ± 0.56 A	36.3 ± 0.46 B	36.1 ± 0.60 B
	Weight (g)	907.7 ± 34.7 A	663.5 ± 26.7 B	596.4 ± 27.0 C
	Age (y)	5.0 ± 0.23A	4.4 ± 0.22 AB	4.1 ± 0.26 B
	Condition factor (K)[c]	1.48 ± 0.03 A	1.38 ± 0.03 B	1.26 ± 0.01 C
	GSI %[e]	5.66 ± 0.15	5.25 ± 0.12	5.49 ± 0.17
	LSI %[d]	1.69 ± 0.08 AB	1.81 ± 0.11 A	1.29 ± 0.07 B

[a]Fish with GSI >1% considered adult.
[b]Numbers within a row with different letters are statistically different ($p < 0.05$).
[c]Condition factor (K) = 100[body weight/(fork length3)].
[d]Liver-somatic index (LSI) = 100[liver weight/(body weight – liver weight)].
[e]Gonadosomatic index (GSI) = 100[gonad weight/(body weight – gonad weight)].
[f]Indicates significant interaction ($p < 0.05$).

TABLE 3. Regression analysis of weight, gonad and liver size of adult male and female white sucker collected from sites on the Saint John River during October 2001 and 2002

			Female					Male				
Endpoint	*Year*	*Site*	*Slope*	*Intercept*	*N*	*P*	R^2	*Slope*	*Intercept*	*N*	*p*	R^2
Weight	2001	Florenceville	3.42	-2.55	19	<0.001	0.85	3.07	-1.96	18	<0.001	0.87
	2001	Hartland	3.35	-2.44	25	<0.001	0.96	3.20	-2.20	18	<0.001	0.93
	2001	Woodstock	2.90	-1.72	17	<0.001	0.87	2.94	-1.80	22	<0.001	0.89
	2002	Edmundston	2.45	-1.00	26	<0.001	0.85	2.56	-1.19	19	<0.001	0.75
	2002	St. Hilaire	2.29	-0.72	22	<0.001	0.73	2.54	-1.15	13	<0.001	0.92
	2002	Florenceville	2.80	-1.52	20	<0.001	0.89	2.41	-0.89	19	<0.001	0.83
	2002	Hartland	3.65	-2.91	16	<0.001	0.89	2.57	-1.19	20	<0.001	0.76
	2002	Woodstock	2.34	-0.83	18	<0.001	0.80	2.74	-1.50	14	<0.001	0.93
Gonad size	2001	Florenceville	1.90	-3.86	19	<0.001	0.81	1.64	-3.09	18	<0.001	0.74
	2001	Hartland	1.52	-2.70	25	<0.001	0.92	0.94	-1.15	18	<0.001	0.62
	2001	Woodstock	1.36	-2.26	17	<0.001	0.59	0.80	-0.75	22	<0.001	0.47
	2002	Edmundston	2.30	-5.06	26	<0.001	0.73	1.29	-2.13	19	<0.001	0.59
	2002	St. Hilaire	2.15	-4.60	22	<0.001	0.58	1.44	-2.55	13	0.002	0.62
	2002	Florenceville	1.62	-3.00	20	<0.001	0.72	0.98	-1.20	19	<0.001	0.65
	2002	Hartland	1.81	-3.59	16	<0.001	0.86	0.89	-0.98	20	<0.001	0.73
	2002	Woodstock	1.75	-3.45	18	<0.001	0.56	1.23	-1.89	14	<0.001	0.79
Liver size	2001	Florenceville	1.28	-2.64	19	<0.001	0.70	1.08	-2.04	18	<0.001	0.78
	2001	Hartland	1.44	-2.99	25	<0.001	0.92	1.89	-4.27	18	<0.001	0.79
	2001	Woodstock	1.28	-2.57	17	<0.001	0.84	1.03	-2.02	22	<0.001	0.70
	2002	Edmundston	1.39	-2.89	26	<0.001	0.76	1.98	-4.69	19	0.008	0.29
	2002	St. Hilaire	0.89	-1.31	22	<0.001	0.49	1.63	-3.54	13	0.001	0.58
	2002	Florenceville	1.10	-2.04	20	<0.001	0.73	0.92	-1.53	19	0.004	0.36
	2002	Hartland	1.13	-2.06	16	<0.001	0.66	1.67	-3.63	20	<0.001	0.63
	2002	Woodstock	1.46	-3.15	18	<0.001	0.62	1.24	-2.55	14	0.004	0.47

2002 (i.e., slopes were parallel; interactions for length $p_{female} = 0.40$, $p_{male} = 0.65$ and weight $p_{female} = 0.73$, $p_{male} = 0.94$), however size at a given age (i.e., intercept) differed significantly among sites ($p < 0.01$), with male and female sucker in Florenceville larger at any given age.

In 2002, female liver size was not significantly larger in Hartland ($p = 0.24$) relative to Florenceville; however, livers were significantly larger than those in Woodstock ($p < 0.001$, 23%) (Table 1). This pattern of no significant difference in liver size at Florenceville was also present in males. The difference in male liver size between Hartland and Woodstock was significant ($p = 0.001$) and represented a decrease in Woodstock by 28.8% (Table 2). There was a significant decrease in female gonad size between Florenceville and Woodstock ($p_{FL} < 0.05$, 29.9%).

Spawning 2002

In the spring of 2002, female weight was greater in the two smaller tributaries, the Little Presque Isle ($p = 0.004$) and Becaguimec Stream ($p = 0.007$), when compared to the Meduxnekeag (Table 4). There were no significant differences in female length between tributaries. Male white sucker size differed significantly in terms of both weight and length among tributaries. The Little Presque Isle had significantly longer and heavier males, in comparison to the three other tributaries (Table 4). Males from the Becaguimec were significantly smaller than those from either the Big Presque Isle or Meduxnekeag, which did not differ. Female condition factor was significantly lower in the Meduxnekeag compared to the three other tributaries ($p < 0.01$). Meduxnekeag males had the lowest condition (1.32 ± 0.02), which was significantly different from Big Presque Isle males ($p = 0.002$).

The regression lines for male liver size versus body weight were significantly different (GLM interaction $p = 0.010$). Big Presque Isle Stream had the highest slope (1.445, $r^2 = 0.745$, $p < 0.001$), while the Meduxnekeag River had the lowest (0.414, $r^2 = 0.185$, $p < 0.001$), representing a difference of >70%. Female liver size differed significantly between multiple tributaries; Becaguimec fish had the largest LSI (2.19 ± 0.08) and the Meduxnekeag had the smallest (1.49 ± 0.04) (Table 4). No significant difference in male gonad size was present between the four tributaries sampled ($p = 0.254$). Unlike males, female white suckers had significant differences in gonad size. Both significant differences involve comparisons with Becaguimec females, which had smaller gonads (GSI = 14.64 ± 0.69) than those from the Big Presque Isle (17.07 ± 0.70; $p = 0.001$) and the Little Presque Isle (17.50 ± 0.63, $p = 0.005$).

TABLE 4. Length, weight, condition factor, gonadosomatic and liver-somatic indices of migrating adult white sucker collected during May 2002[a,b]

Sex	Fish performance (mean ± SE)	Big Presque Isle (BPI)	Little Presque Isle (LPI)	Becaguimec Stream (BS)	Meduxnekeag River (MR)
Male	Sample size (n)	20	8	20	20
	Fork length (cm)	37.2 ± 0.51 A	41.2 ± 0.75 C	31.9 ± 0.47 B	36.7 ± 0.49 A
	Weight (g)	762.5 ± 32.4 A	985.8 ± 36.6 C	453.3 ± 23.2 B	655.4 ± 30.9 A
	Age (y)	4.9 ± 0.31 AB (14)	6.7 ± 0.40 C (8)	4.4 ± 0.19 B (19)	5.6 ± 0.35 AC (13)
	K[c]	1.47 ± 0.36 A	1.41 ± 0.03 AB	1.38 ± 0.04 AB	1.31 ± 0.03 B
	GSI[d]	3.61 ± 0.35 A	2.28 ± 0.54 AC	3.53 ± 0.14 B	3.81 ± 0.35 BC
	LSI[e]	1.73 ± 0.07[g]	2.01 ± 0.21[g]	2.10 ± 0.08[g]	1.56 ± 0.13[g]
Female	Sample size (n)	19	19	20	20
	Fork length (cm)	39.6 ± 0.67 A	41.8 ± 0.87 A	41.4 ± 0.79 A	39.3 ± 0.57 A
	Weight (g)	1011.8 ± 56.1 AB	1169.2 ± 64.4 A	1143.1 ± 60.8 A	879.41 ± 44.6 B
	Age (y)[f]	5.6 ± 0.31 (18)	6.4 ± 0.39 (14)	6.5 ± 0.42 (12)	5.9 ± 0.30 (20)
	K[c]	1.59 ± 0.02 A	1.57 ± 0.02 A	1.59 ± 0.04 A	1.43 ± 0.03 B
	GSI[d]	17.07 ± 0.69 A	17.52 ± 0.16 AC	14.64 ± 0.68 B	14.28 ± 0.66 BC
	LSI[e]	1.70 ± 0.05 A	1.66 ± 0.08 AB	2.18 ± 0.07 C	1.48 ± 0.04 B

[a]Numbers within a row with different letters are statistically different ($p < 0.05$) and the number in parentheses for age parameter indicates sample size, as not all structures collected were readable.
[b]Fish with GSI ±1% considered to be adult.
[c]Condition factor = 100[body weight/(fork length3)].
[d]Gonadosomatic index = 100[gonad weight/(body weight – gonad weight)].
[e]Liver-somatic index = 100[liver weight/(body weight – liver weight)].
[f]Indicates age-tributary analysis was not significant ($p > 0.5$).
[g]Indicates significant interaction ($p < 0.05$).

Annual Variation within a Site

No significant differences were present in male length, weight, condition or liver size within a site across years. In Woodstock, male gonad regression lines from the two years had significantly different slopes (GLM interaction $p < 0.01$), decreasing by 6.6% in 2002. The only significant difference in females was in relation to size (length and weight $p < 0.001$) and was limited to the Woodstock site. In 2002, female length increased by 10.6% and weight by 28.4% in comparison to 2001 at Woodstock.

Discussion

The lesions that were seen during 1999 and 2000 were not observed during the sampling periods of 2001 and 2002. However, there were significant differences in the characteristics of white sucker among sites. It is clear from the radio tracking and movement information that the fish are resident in small river-sections (except during spawning), where they were caught during fall sampling (Doherty 2004). The differences between sites were consistent between years, with white sucker consistently showing decreases in body length, weight and condition, as distance downstream progressed from Florenceville to Woodstock. In females, the liver size followed the same general trend in both 2001 and 2002 (Table 5).

Fish that have increased food resources have been shown to respond by increasing size, condition, liver size and gonad size (Gibbons and Munkittrick 1994; Munkittrick et al. 2000). The difference in fish characteristics between responses could be interpreted as either improved performance at Florenceville (site furthest upstream), or decreased performance at Woodstock. It is difficult in a river system to understand what the reference site should be, although the stimulus for examining the system was an increased presence of lesions near Florenceville. Interpretation of the data requires a study design that has multiple reference sites on the same river or adjacent rivers (Environment Canada 2000), or has a range of reference sites available (Bailey et al. 2004). While additional study sites were not collected as part of this study, additional regional data are available from a variety of ongoing comparable studies. Galloway et al. (2003, 2004) collected white sucker performance data on the Saint John River near Edmundston, upstream of two hydroelectric facilities at Beechwood and Grand Falls. These fish were collected during the same time period as the middle reach. By expanding the analysis, fish can be compared with sites further upstream on the Saint John River, as well as with fish collected on several nearby rivers in New Brunswick.

Male white sucker collected during this study from Florenceville had a condition factor significantly higher in comparison to sites further upriver, both upstream (St. Hilaire) and downstream from an Edmundston pulp mill, as well as two other New Brunswick rivers, the Tobique and Miramichi (Fig. 3). Similar increases were seen in female gonad size relative to upstream Saint John River

TABLE 5. Summary of significant differences in adult white sucker performance parameters collected in the middle reach of the Saint John River[a,b]

			Pairwise site comparisons		
Sex	*Year*	*Parameter*	*Hartland compared to Florenceville*	*Woodstock compared to Florenceville*	*Woodstock compared to Hartland*
Male	2001	Fork length	-	-	0
	2002	Fork length	-	-	0
	2001	Weight	-	-	0
	2002	Weight	-	-	-
	2001	K[c]	-	-	-
	2002	K[c]	-	-	-
	2002	LSI[e]	0	0	-
Female	2001	Fork length	0	-	-
	2002	Fork length	-	-	0
	2001	Weight	0	-	-
	2002	Weight	-	-	0
	2001	LSI[e]	+	-	0
	2002	LSI[e]	0	0	-
	2002	GSI[d]	0	-	0

[a]Fish with GSI >1% considered to be adult.
[b](0) = no significant difference; (+) = significant increase; (-) = significant decrease.
[c]Condition factor = 100[body weight/(fork length3)].
[d]Gonadosomatic index = 100[gonad weight/(body weight – gonad weight)].
[e]Liver-somatic index = 100[liver weight/(body weight – liver weight)].

sites (Fig. 5). Liver sizes in both male and female white sucker from the Saint John River are considerably larger than in white sucker collected in other rivers in Ontario (Munkittrick et al. 1994, 2000) and larger than in New Brunswick lakes in the region (Galloway et al. 2003). However, the liver sizes are not larger than those present in the Tobique (a tributary of the Saint John) and the Miramichi (just east of the Saint John River) (Fig. 4).

Although the differences are consistent, and suggest that fish have improved performance at Florenceville, the ecological relevance of changes in these parameters is a matter of debate. Munkittrick et al. (2002) reviewed changes in endpoints such as gonad size, liver size and condition factor from pulp mill monitoring studies and concluded that changes outside of 25% in gonad size and liver size, and 10% in condition, were important. Similar conclusions have been made in Lowell et al. (2003, In press). The changes seen in this part of the basin exceed the size differences expected from yearly variation within this system as well as others, and would be interpreted as ecologically relevant.

The effects-based approach operates on a series of iterative studies to progressively isolate the causative agents responsible for the changes (Hewitt et al. 2003). Improved performance of fish at Florenceville can be associated with either an increase in food availability associated with nutrient enrichment, or a decrease in the abundance of fish with a stable food resource (Munkittrick et al. 2000). Past studies involving benthic invertebrates suggested that effluent discharge from the food processing plant in Florenceville was having a nutrient enrichment effect (Jacques Whitford Environment Limited 1996).

Significant differences were present in the population age structure between sites, with Florenceville having the oldest average age for both male and female white sucker. At all three sites, females averaged older than males by 0.5 to 1.3 years, as expected. Male white sucker age declined with downstream progression, with Woodstock fish being almost one year younger than Florenceville fish, potentially suggesting male sexual maturation at an earlier age. Fish of both sexes were also significantly larger at a given age in Florenceville, in terms of length and weight, relative to Hartland and Woodstock. At the same time, total catch success was reduced in Florenceville and Hartland relative to Woodstock during the summer fish community survey. White sucker catch rates in the fall varied considerably on multiple temporal scales (within a day, and between years).

The response patterns observed can be separated based on a difference in abundance—nutrient enrichment would be expected to increase the abundance of fish and decrease the mean age, whereas increased mortality may not change the mean age, and should decrease abundance (Munkittrick et al. 2000). It is difficult without further sampling to identify whether the apparent improved performance is a response to the nutrient enrichment, or a response to increased mortality associated with the lesions that had been prevalent in recent years. However, the food processing plant at Florenceville is a major contributor of nutrients to the river, and follow-up studies will investigate the nutrient issues in the area.

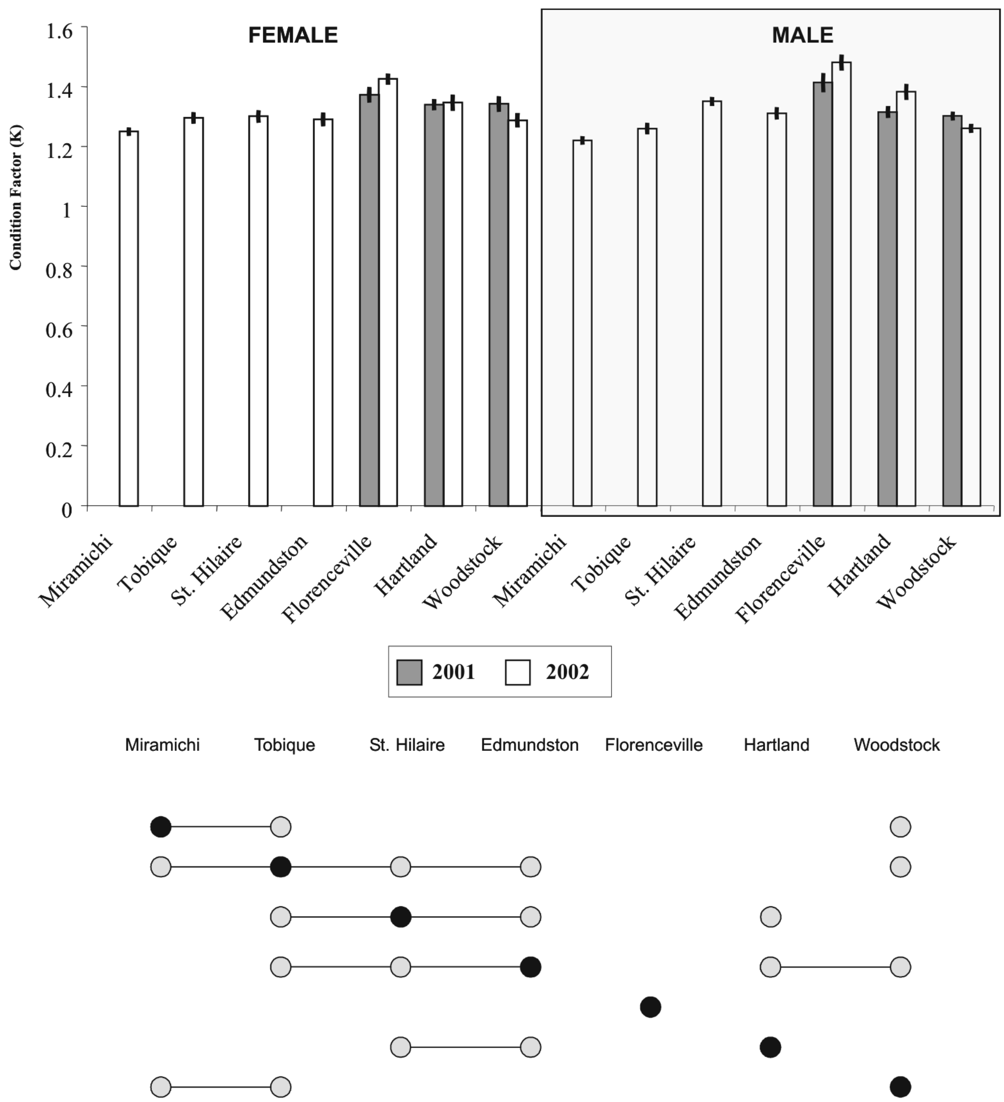

Fig. 3. Adult male and female white sucker condition factor from the Saint John River (2001 and 2002), a connected tributary and a neighbouring watershed (mean ±1 SE), plus multiple comparisons among sites (2002) for males provided below.

There are confounding factors associated with the fluctuating water levels downstream of the peaking facility at Beechwood. Daily, cyclical changes in water levels of 2 m or more may reduce habitat availability and/or diversity, as well as alter fish community composition as supported by observed differences in species richness. In Florenceville, and to a lesser degree Hartland, fish species (including small-bodied species) may be absent or present in relatively small numbers as the lack of persisting shallow water habitats and high flows restrict their establishment. In 1996, a lack of fish population establishment in Florenceville was reported, when only a single fallfish was caught in an adult fish survey, which consisted of seining and baited longlines (Jacques Whitford Environment Limited 1996). However, Curry and Munkittrick (2005) reported the presence of 11 species in Florenceville including low numbers of bullhead and multiple salmonid species: Atlantic salmon (*Salmo salar*), brook charr (*Salvelinus fontinalis*) and the introduced rainbow trout (*Oncorhynchus mykiss*). This increased species richness in Florenceville resulted from a standard sampling protocol involving night seines, either boat or backpack electrofishing at night, and short-set evening gill netting. Although other small-bodied species were caught in the survey, their population levels were considered low. Smallmouth bass is essentially the only other species that is abundant in Florenceville, and smallmouth bass generally occupy a different feeding niche than white sucker. In addition, riverine populations of smallmouth bass are known to make significant seasonal movements, typically in the fall when they move to deeper water for overwintering. Such behaviour has been observed in the downstream movement of Saint John River smallmouth bass tagged with acoustic transmitters (Doherty and Curry, Unpublished data). Algae and benthic macro-invertebrate communities may have sufficient water between rocks and in isolated pools to persist along shoreline reaches during periods of low water. As a result, when river water levels rise, "new" previously unexploited benthic feeding resources are available to

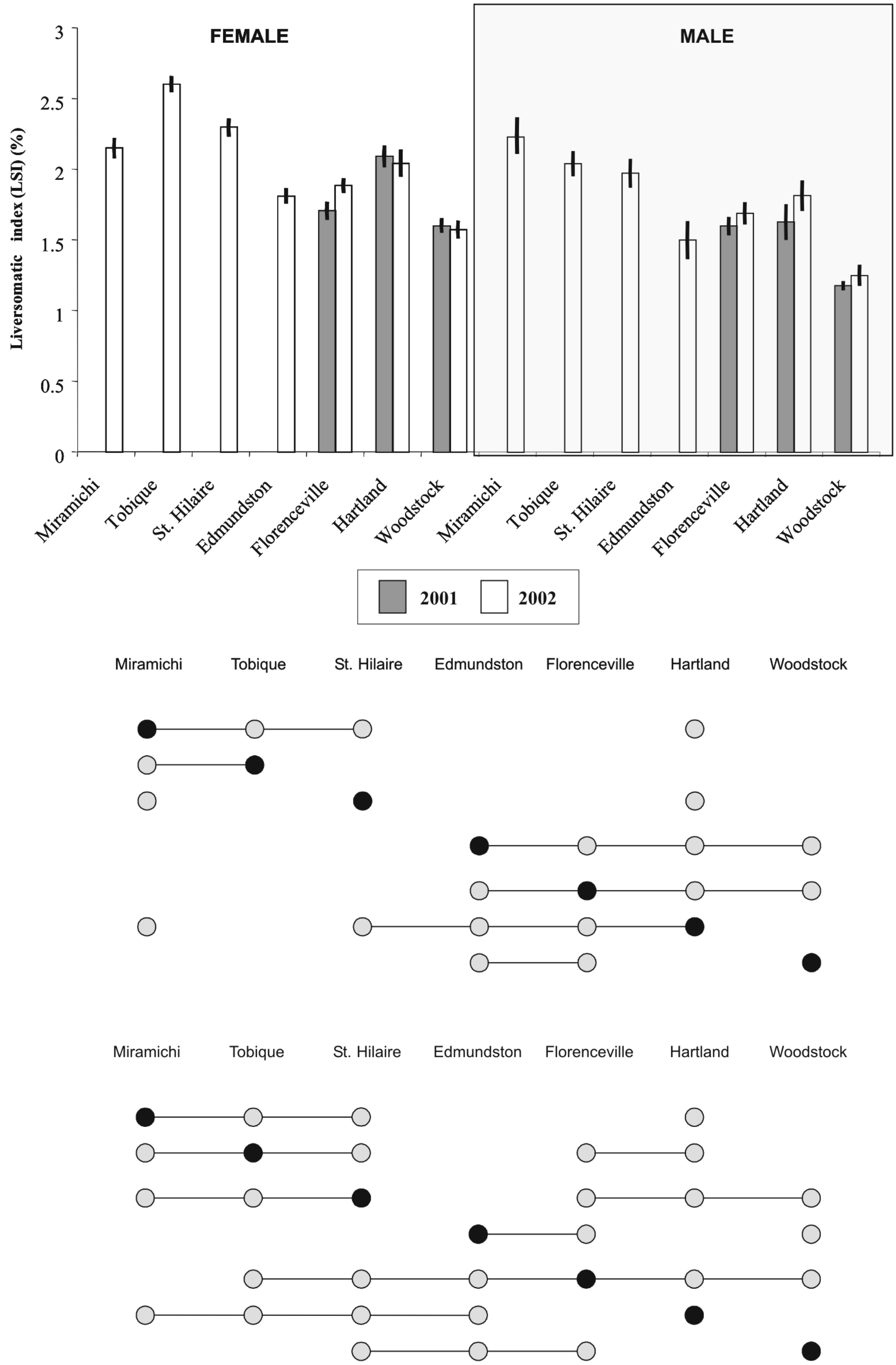

Fig. 4. Adult male and female white sucker gonadosomatic index from the Saint John River (2001 and 2002), a connected tributary and a neighbouring watershed (mean ±1 SE), with multiple comparisons among sites (2002) for females: length (top) and weight (bottom) used as a covariate.

Florenceville white sucker, possibly contributing to the increased size-at-age and condition.

Significant differences in gonad size were present in both male and female white sucker within the middle reach in 2002 that were not apparent in 2001. Male gonad size was elevated in Hartland compared to Woodstock, while female gonad size was larger in Florenceville relative to Woodstock (29.9%). This finding is unlike Galloway et al. (2004), who reported no significant differences in gonad size between white sucker collected downstream of a pulp mill and at a reference site in the Saint John River upper reach. Excluding major storm events in 2002, flows in the Saint John River were below the 75-year mean, but typical to those present in 2001 especially during the period from

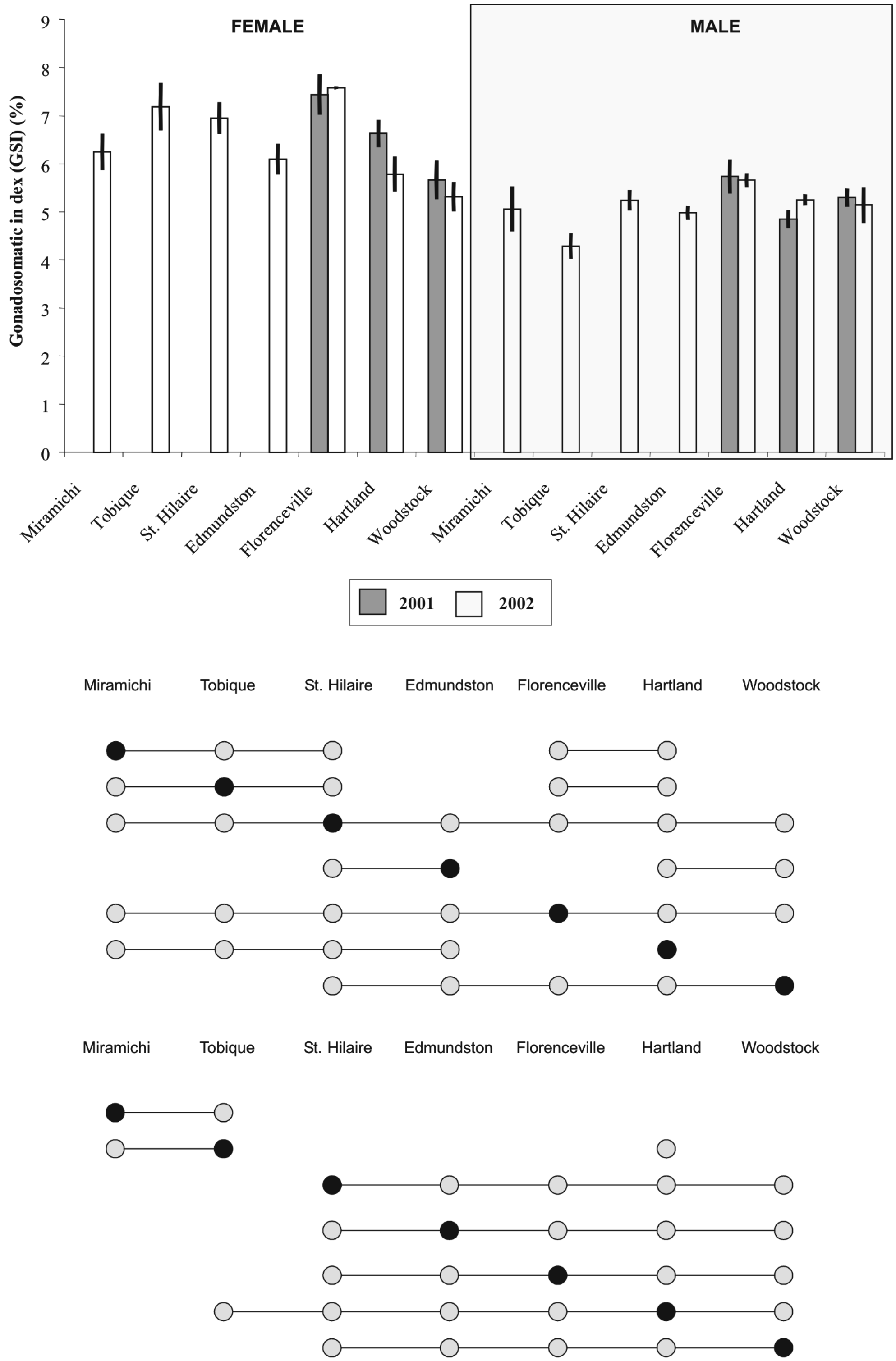

Fig. 5. Adult male and female white sucker liver-somatic index from the Saint John River (2001 and 2002), a connected tributary and a neighbouring watershed (mean ±1 SE), with multiple comparisons among sites (2002): female (top) and male (bottom).

August to October. The significant increases in condition factor and gonad size suggest a potential interaction of nutrient enrichment, Saint John River water levels, altered flow regime from dam discharge and other factors.

Liver size deviated from the declining pattern with downstream progression, for both sexes. In 2001, instead of a decline there was a significant increase in LSI of female suckers collected from Hartland, downstream of the wastewater treatment plant, in comparison to Florenceville (Table 3). From the 2002 expanded analysis of liver size, both sexes in Woodstock had significantly smaller livers than all other sites excluding Florenceville. Furthermore, St. Hilaire, the most upstream reference site within the Saint John River, as well as fish from reference sites on the Miramichi and Tobique rivers had females with significantly larger livers than Florenceville. Sample sites on the Miramichi and Tobique rivers have minimal human development upstream, consisting primarily of forestry operations.

No clear patterns emerged from the performance and reproductive parameters among the four tributaries in the middle reach that were sampled in the spring of 2002. This corresponds to a period of time in which white sucker were determined to have significant movements, increasing the probability of mixing of fish with different exposure histories. The upstream site was the location of the largest fish during the fall; however the spawning site furthest upstream did not have the largest fish during the spawning run. Stock mixing of white sucker populations from multiple main river locations during migrations to spawning tributaries may result in increased variability in whole organism characteristics, lowering the ability to detect effects or follow any differences back to a causative source.

Summary and Conclusions

The patterns observed in five white sucker endpoints in the fall of 2001 were shown to be repeatable in the fall of 2002 for three sites in a previously identified area of concern. It has been shown both in this study and by Galloway et al. (2003) that Saint John River white sucker populations have larger livers than those in water bodies of other geographical regions. Underlying background ecosystem differences in geology, hydrology, physical structure, local climate, water chemistry and biota can affect energy sources and flows, as well as other factors, and may result in larger liver size (Environment Canada 2000; Munkittrick et al. 2000). Genetic differences or predisposition for a particular organ size range may also exist not only between isolated systems, but also within a system consisting of barriers to fish movement that prevent gene flow. This may have contributed to differences observed in the expanded analysis. If a population of Saint John River white sucker were compared only to a reference site outside the system or in an isolated river reach (i.e., upstream of a dam), false conclusions of whether an effect was present or not may result. This has implications for the importance of reference site selection and understanding the natural variability within a species on a broader spatial scale.

Saint John River Recommendations

- Comparison of white sucker population characteristics upstream and downstream of the food processing discharge is required in an attempt to isolate confounding factors and determine if nutrient enrichment is in fact present.
- Confirmation or validation of nutrient enrichment through a second sentinel fish species would be unlikely due to the interactions among habitat fluctuations, Beechwood dam discharge and fish community composition. An alternative option may be a benthic invertebrate community assessment.
- Assessment and application of modelling to investigate the interaction among dam discharge, altered flow regime and changes in river habitat availability, composition (i.e., persistence of shallow water) and their effects on aquatic flora/fauna communities along a river gradient. This modelling should be applied to the areas below hydroelectric facilities at Grand Falls, Tobique, Aroostook and Beechwood.

General Recommendations

- From the seasonal movement and residency patterns reported in the Saint John River, assessment of white sucker population characteristics (level of exposure, length, weight, condition, organ size and population estimates) should be assessed in the fall; with late winter to early summer sampling being avoided.
- Based on the expanded analysis showing a pattern of larger livers in Saint John River white sucker, reference sites should come from within the same system (i.e., river reach) as exposed sites whenever possible. If it is not possible, assessment of the natural system-to-system variability among reference sites must be considered in order to interpret population characteristics and detect effects resulting from stressors. This may not be limited to white sucker and should be considered with other sentinel species.

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References

Bailey RC, Norris T, Reynoldson T. 2004. Bioassessment of freshwater ecosystems: using the reference condition approach. Kluwer Academic Publ., Boston, Ma.

Cunjak RA, Newbury RW. 2005. Atlantic coast rivers of Canada, chapter 21, p. 938–981. *In* Benke AC, Cushing CE (ed.), Rivers of North America. Academic Press, San Diego, Ca.

Curry RA, Munkittrick KR. 2005. Fish community responses to multiple stressors along the Saint John River, New Brunswick, Canada. *In* Rinne JN, Calamusso R, Hughes R (ed.), Changes in large river fish assemblages in North America: implications for management and sustainability of native species. American Fisheries Society.

Doherty CA. 2004. Movement patterns and biology of white sucker in a riverine environment exposed to multiple stresses. M.Sc. thesis, Department of Biology, University of New Brunswick, Fredericton, N.B.

Doherty CA, Curry RA. Unpublished data.

Doherty CA, Curry RA, Munkittrick KM. 2004. Adult white sucker show limited mobility near point source discharges in a large Canadian river. *In* Borton DL, Hall TJ, Fisher RP, Thomas JF (ed.), Pulp and paper mill effluent environmental fate and effects. DEStech Publication, Lancaster, Pa.

Dominy CL. 1973. Recent changes in Atlantic salmon (*Salmo salar*) runs in the light of environmental changes in the Saint John River, New Brunswick, Canada. Biol. Conserv. **5**:105–113.

Environment Canada. 1997. Fish survey expert working group: recommendations from Cycle 1 review. EEM/1997/6, Environment Canada, Ottawa, Ont.

Environment Canada. 2000. Technical guidance documents for metal mining EEM program. Environment Canada, Ottawa, Ont.

Galloway BJ, Munkittrick KR, Curry RA, Wood CS, Dunn S. 2004. Identifying a suitable fish species for monitoring multiple effluents in the Upper Saint John River, Canada. *In* Borton DL, Hall TJ, Fisher RP, Thomas JF (ed.), Pulp and paper mill effluent environmental fate and effects. DEStech Publication, Lancaster, Pa.

Galloway BJ, Munkittrick KR, Currie S, Gray M, Curry RA, Wood CS. 2003. Examination of the responses of slimy sculpin (*Cottus cognatus*) and white sucker (*Catostomus commersoni*) collected on the Saint John River (Canada) downstream of pulp mill, paper mill, and sewage discharges. Environ. Toxicol. Chem. **22**:2898–2907.

Gibbons WN, Munkittrick KR. 1994. A sentinel monitoring framework for identifying fish population responses to industrial discharges. J. Aquat. Ecosys. Health **3**:227–237.

Gray MA, Curry RA, Munkittrick KR. 2002. Non-lethal sampling methods for assessing environmental impacts using a small-bodied sentinel fish species. Water Qual. Res. J. Canada **37**:195–211.

Gray MA, Curry RA, Munkittrick KR. 2005. Impacts of nonpoint inputs from potato farming on populations of slimy sculpin (*Cottus cognatus*). Environ. Toxicol. Chem. **24**:2291–2298.

Gray MA, Munkittrick KR. 2005. An effects-based assessment of slimy sculpin (*Cottus cognatus*) populations in agricultural regions of northwestern New Brunswick. Water Qual. Res. J. Canada **40(1)**:16–27.

Hewitt LM, Dubé MG, Culp JM, MacLatchy D, Munkittrick KR. 2003. A proposed framework for investigation of cause in environmental effects monitoring. Hum. Ecol. Risk Assess. **9**:195–211.

Jacques Whitford Environment Limited. 1996. Final report McCains Foods Limited: environmental effects monitoring – 1995 Florenceville. Project No. 7354.

Johnstone S (New Brunswick Department of the Environment and Local Government). Personal communication.

Lowell RB, Ribey SC, Ellis IK, Porter EL, Culp JM, Grapentine LC, McMaster ME, Munkittrick KR, Scroggins RP. 2003. National assessment of the pulp and paper environmental effects monitoring data. Environment Canada, National Water Research Institute, Burlington/Saskatoon, NWRI Contribution No. 03-521.

Munkittrick KR. Unpublished data.

Munkittrick KR, McGeachy SA, McMaster ME, Courtney SC. 2002. Overview of freshwater fish studies from pulp and paper environmental effects monitoring program. Water Qual. Res. J. Canada **37**:49–77.

Munkittrick KR, McMaster ME, Van Der Kraak G, Portt C, Gibbons WN, Farwell A, Gray M. 2000. Development of methods for effects-driven cumulative effects assessment using fish populations: Moose River project. Society of Environmental Toxicology and Chemistry (SETAC).

Munkittrick KR, Van Der Kraak GJ, McMaster ME, Portt CB, van den Heuvel MR, Servous MR. 1994. Survey of receiving-water environmental impacts associated with discharges from pulp mills: gonad size, liver size, hepatic EROD activity and plasma sex steroid levels in white sucker. Environ. Toxicol. Chem. **13**:1089–1101.

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