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Relative Activity of Brook Trout and Walleyes in Response to Flow in a Regulated River

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Abstract.—Coded electromyogram telemetry transmitters were used to examine the effects of varying flows on the relative activity of brook trout *Salvelinus fontinalis* and walleye *Sander vitreus* in a regulated river. The relative activity levels of two brook trout and two walleyes were continuously monitored for a minimum of 24 h, and measurements were compared with river flow values logged at nearby gauging stations. Generally, fish relative activity levels mimicked patterns of flow change, peaks in activity level corresponding to peaks in flow. Mean relative activity was generally greatest at extreme high (≥25-m^3/s) and low (<15-m^3/s) flows. High flows may have elicited hyperactivity (increased activity) as fish sought suitable refugia, increased activity to hold position in the water column, or increased feeding activity on increased levels of drifting invertebrates. Hyperactivity at low flows may have been caused by relocation due to habitat loss or ease of movement at lower flow regimes. Physiological telemetry provides researchers with a method of quantifying the immediate effects of flow changes on fish. Increasing our knowledge of the effects of river regulation on fish is essential to the development of more effective management strategies that balance ecology and economics.

Rivers regulated for hydropower generation are frequently subject to significant deviations from the natural flow regime (Poff et al. 1997), and reviews of the effects of this have demonstrated negative impacts on fish community structure (e.g., Bain et al. 1988), population abundance (e.g., Cowx and Gould 1989), and numerous other ecological variables (e.g., Cushman 1985; Steele and Smokorowski 2000; Bunn and Arthington 2002). Although some relationships between flow change and biotic response have been determined (Bain et al. 1988; Hunter 1992; Valentin et al. 1994), efforts to quantify potential impacts are often limited by the time-lag required to observe changes (Bunn and Arthington 2002). Efforts aimed at modeling the effect of regulated flow on fish habitat have been hampered by the validity of the assumptions used in the models (Mathur et al. 1985), as well as by the level of biological understanding underlying observed fish habitat preferences (Heggenes 1988). Such inherent time constraints and modeling uncertainties may lead to management decisions being made with limited information, potentially to the detriment of river ecology and power generation. As a result, attempts to quantify immediate biotic response to flow modifications should be made when possible.

Electromyogram (EMG) telemetry is one method for obtaining the immediate responses of free-swimming fish to different environmental stressors (e.g., Cooke and Schreer 2003). Radio transmitters equipped with two electrodes and an antenna allow muscle contraction rates to be monitored, while concurrently fixing a fish's position via conventional tracking methods (Weatherley et al. 1996). Changes in fish relative activity levels can be linked to changes in the environmental parameters under study (Cooke and Schreer 2003), or further related to swimming speed and estimates of oxygen consumption as determined by laboratory calibrations (Weatherley et al. 1982; Hinch et al. 1996; Geist et al. 2002). Relationships between hydroriver flow and fish relative activity (EMG) have not been previously examined to our knowledge (see Cooke et al. 2004).

The objective of this study was to examine the relative activity levels of brook trout *Salvelinus fontinalis* and walleye *Sander vitreus* (formerly *Stizostedion vitreum*) with flow changes in a regulated river. The results of the study are discussed in the context of fish ecology, while evaluating the use of electromyogram telemetry in influencing water allocation management decisions.

Methods

Study site.—The Magpie River, which flows through Wawa, Ontario, (47°57′6″N, 84°49′8″W), has been part of an ongoing adaptive management experiment designed to determine whether ecological benefits result from restricting the rate of change of flow (i.e., the ramping rate [$m^3 \cdot s^{-1} \cdot h^{-1}$]) on the river. Developed in the late 1980s for hydroelectric power generation, the Magpie River has three generating stations and four dams; the most upstream generating station dam is located

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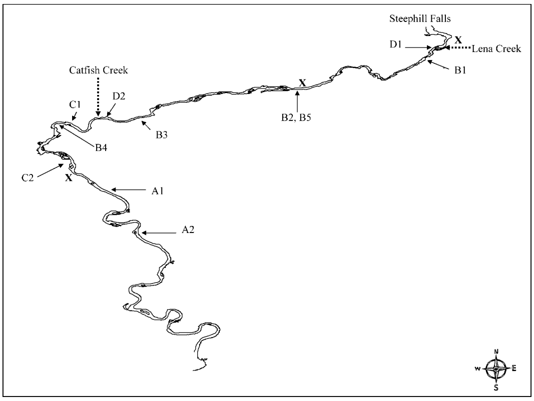

FIGURE 1.—The 20-km section of the Magpie River, Wawa, Ontario, below Steephill Falls. Locations and chronological order of movement of the tagged fish are as follows: (1) brook trout 1 (A1 = July 10–12, 2002 [release location]; A2 = July 13–September 3, 2002 [location of logged activity]); (2) brook trout 2 (B1 = June 23–July 7, 2002 [release location and location of logged activity]; B2 = July 7–July 16, 2002; B3 = July 17, 2002; B4 = July 18, 2002; B5 = July 19–September 3, 2002); (3) walleye 5 (C1 = July 7, 2002 [release location]; C2 = July 8–September 27, 2002 [location of logged activity]); (4) walleye 6 (D1 = July 6–11, 2002 [release location]; D2 = July 12–August 2, 2002 [location of logged activity]). Flow gauging stations are represented by *X*s.

at Steephill Falls, approximately 13 km north of Wawa. The study area included the 20-km stretch of the river below Steephill Falls (Figure 1).

The current lease agreement for the Steephill Falls Generating Station stipulates a minimum discharge of 7.5 m^3/s. The maximum flow that can pass through the turbines is 44.5 m^3/s, for a generating capacity of approximately 16 MW. During the study period of June to October 2002, ramping rates were restricted to 25% of the previous hour's discharge. Due to these restrictions, the Steephill Falls Generating Station operates in a modified peaking manner, usually reaching lowest flows at night and on weekends, and ramping up slowly to generate maximum possible power during the day. Flow regimes are determined by restrictions imposed on the water lease, water availability, hydro demand, purchase and sale agreements, and a myriad of other factors caused by a deregulated electricity marketplace.

Species of sport fish common to the Magpie River include brook trout, walleye, yellow perch *Perca flavescens*, northern pike *Esox lucius*, and lake whitefish *Coregonus clupeaformis*. Brook trout and walleye were chosen as the study species as they are the most commonly sought after by anglers, and both species are found throughout the study area.

Tagging procedure.—In this study, coded EMG (CEMG-R11–18) transmitters (Lotek Engineering, Inc., Newmarket, Ontario) measuring 11 mm × 54 mm, weighing 10 g in air, and having frequencies in the 149–150-MHz range, were used. The cylindrical tags consisted of electronics packaged in a polytube and filled with resin, a single trailing Teflon-sheathed antenna, and two Teflon-sheathed electrode wires. The antennas, made with 6-gauge spring wire, were 44 cm long, and the electrode wires (made of the same material) were tipped with 14-karat gold sensors (8.0 mm × 0.9 mm).

The CEMG tags work similarly to the EMG*i* transmitters described by Kaseloo et al. (1992), Beddow and McKinley (1999), Cooke et al. (2002), and others, except that pulse intervals (ms) normally transmitted and recorded by the receiver are now first translated into a measure of relative activity level (ranging between 0 and 50). Lower pulse intervals, reflecting increased muscle activity, are assigned a higher value. Thus, in theory, an EMG relative activity level of 50 corresponds to an approximate pulse interval of 800 ms, whereas an EMG reading of 0 corresponds to an approximate value of 2,300 ms (Larry Egan, Lotek Engineering, Inc., personal communication).

Three brook trout were angled with either fly-fishing or casting gear, and one brook trout and four walleyes were electrofished with a Smith-Root boat electrofishing unit (settings = DC at 60 Hz, 2.8 A, and 750 V) between June 18 and July 10, 2002. Following capture, fish were held in an aerated, 20-L bucket containing fresh river water until an anesthetic bath was prepared. Fish were anesthetized in a 40-mg/L induction bath of clove oil and ethanol (Anderson et al. 1997) until regular opercular movement ceased. Once anesthetized, fork length (cm) and weight (kg) of the fish were recorded, and the fish were placed ventral side up on a piece of foam on a surgery table. A maintenance dose of anesthetic (10 mg/L) continuously irrigated the fish's gills during surgery. As the maintenance bath was depleted, freshwater was added, thus diluting the anesthetic. The surgical procedure began with a 3-cm incision to one side of the ventral midline, posterior to the pelvic girdle. The transmitter head was inserted and gently guided to the front of the pelvic girdle. A 16-gauge, ½-in needle was used to provide an exit for the antenna, following which the gold tips of the electrodes were positioned 10 mm apart in the ax-

TABLE 1.—Characteristics of the tagged fish in a study of relative activity responses to flow in the Magpie River, Ontario.

Fish tag number	Species	Fork length (cm)	Weight (kg)	Date tagged	Date last tracked
1	Brook trout	30.5	0.5	Jul 10	Sep 3
2	Brook trout	38.3	0.97	Jun 23	Sep 3
3	Brook trout	40.8	1.25	Jun 18	Jun 20
4	Brook trout	33.8	0.6	Jun 23	Jul 26
5	Walleye	46.5	1.4	Jul 7	Sep 27
6	Walleye	57.5	1.9	Jul 6	Aug 2
7	Walleye	50.0	1.5	Jul 6	Jul 15
8	Walleye	36.0	0.7	Jul 6	Aug 27

ial musculature, below the lateral line. A tool similar to the one described by Bunt (1999) was used to inject the electrodes on the left side of the fish and ensure equal distance between the electrodes in all tagged fish (Beddow and McKinley 1999). Electrode wires were tucked into the body cavity and the incision was closed by four interrupted, 3–0 Monocryl monofilament sutures. The fish were then placed in a fresh, aerated, 20-L recovery bucket where they were kept for approximately 30 min, then released. The duration of the surgery—from the time the fish left the anesthetic until they were placed in the recovery bucket—was less than 7 min. All surgeries were conducted by the same experienced surgeon. Tag weight represented 2% or less of the weight of the fish in air, in all cases.

Tracking and EMG monitoring.—Fish were manually tracked by canoe 24 h after tagging using an SRX-400 W32C receiver and a handheld, three-element Yagi antenna (Lotek Engineering, Inc.). Fish position was marked by means of a handheld global positioning system (GPS) unit (Garmin GPS 12 XL), and general habitat information was recorded. Manual tracking occurred almost daily from June 19 to August 2, 2002, then less frequently until September 27, 2002, usually between 0730 and 1600 hours. After fish positions were recorded, a fixed station (SRX-400 W32C in a waterproof housing, mounted on a tripod with a four-element yagi antenna) was set up to log continuous EMG data from one or more fish. Our results focus on the four fish (two brook trout and two walleyes) for which continuous, 24-h data were collected. The remaining tagged fish were suspected to have fallen subject to human or animal predation before the fixed station could monitor their activity (Table 1).

Flow readings.—Hourly flow readings were logged at three stations approximately 2.5, 7.5, and 13.5 km below Steephill Falls (Figure 1). The upper two stations were outfitted with Campbell Scientific data loggers (CR10X) equipped with Keller pressure transducers (173-L; Geo Scientific) and were maintained by the Watershed Science Center (Peterborough, Ontario), who developed rating curves and provided the hourly discharge data (m^3/s) for periods during which EMG data were recorded (R. Metcalfe and C. Krezek, Watershed Science Center, unpublished data). The most downstream station was maintained by the Water Survey of Canada and was equipped with a Valcom VEDAS II data logger and a Sutron Accubar pressure sensor.

Data analysis.—A range of 267–436 EMG readings/h were recorded for the four fish for which continuous data were gathered. Each fish's data were matched with flow data from the closest gauging station on the river, with the maximum distance between fish and station being 7.5 km. The maximum time-lag between that station and the fish was estimated to be 2 h, when upramping occurred (C. Krezek, Watershed Science Center, personal communication). Average hourly EMG values and corresponding flow data were plotted against time for observation of any patterns, and the variability of hourly EMG data was examined by means of average coefficient of variation calculations (± 1 SD). Subsequently, scatterplots of EMG versus flow were examined for relationships. To distinguish potential differences in fish relative activity with certain flow characteristics, flow values were categorized by magnitude (''high'' = ≥ 25 m^3/s; ''medium'' = <25 and ≥ 15 m^3/s; and ''low'' = <15 m^3/s), and variability (''fluctuating'' or ''stable''). Flow was considered fluctuating when a continual increase or decrease of a minimum 0.05 m^3/s occurred over 3 h.

All statistical analyses were completed using Microsoft Excel (Microsoft Corp., Redmond, Washington) with additional PopTools software or STATISTICA 6.1 (StatSoft, Inc. 2002). Each fish was analyzed separately as fish EMG relative activity was recorded individually under unique flow

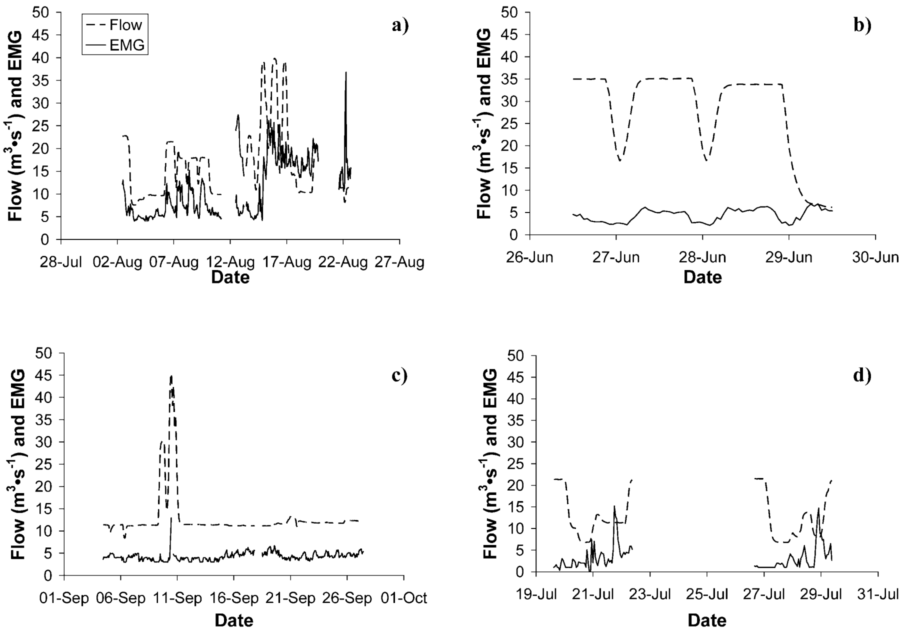

FIGURE 2.—Hourly flow and electromyogram (EMG) data (2002) for **(a)** brook trout 1, **(b)** brook trout 2, **(c)** walleye 5, and **(d)** walleye 6. Flow data were recorded at a gauging station approximately 7.5 km upstream of where fish 1 was located, 0.5 km upstream of fish 2, 1 km downstream of fish 5, and 2 km upstream of fish 6. The average coefficients of variation (CV = 100 × SD/mean) of EMG for brook trout 1 and 2 were 0.171 (SD, 0.102) and 0.41 (SD, 0.088), respectively. The average CVs of EMG for walleyes 5 and 6 were 0.106 (SD, 0.063) and 0.427 (SD, 0.888), respectively.

regimes. Since comparisons of individual fish relative activity over time were desired, the use of a standard parametric analysis of variance (ANOVA) was not possible as data were not independent. Thus, a randomized complete block ANOVA test (Manly 1997) was used to generate a test statistic and significance level. The sample size in each test was limited by the smallest available n per flow category; therefore, to ensure the test statistic was unbiased by the smallest sample size, we randomized all the data within each flow category and used 5,000 Monte Carlo simulations to generate a mean F-value. The EMG data were then completely randomized across flow categories, and an additional 5,000 Monte Carlo simulations were conducted to generate a randomization distribution against which the significance level of the mean F-value was assessed. Results were compared to a Bonferroni-adjusted α of 0.006.

Results

Meristic and tagging data for all fish are presented in Table 1. Positional data for the four fish in which 24-h data were collected are illustrated in Figure 1 and shows that movements were generally limited to one large-scale shift downstream posttagging, following which they remained in a relatively defined area. Brook trout 1 was an exception to this trend as it made both upstream and downstream movements. Fish were generally found in habitats characterized by cobble substrate (see substrate classification in Bain and Stevenson 1999), with an average depth of 1 m when flows averaged 20 m^3/s.

The monitoring of brook trout 1 lasted 21 d (Figure 2a). Flow levels recorded in the vicinity of the fish fluctuated daily, with peaks recorded between 0900 and 1100 hours, August 6–10, 2002. High flows stabilized until 0000 hours during this time period, following which flow subsided to a minimum at approximately 0400 hours. Fish EMG values mimicked the pattern of flow changes, increased flows resulting in hyperactivity (increased activity) and peaks in EMG values corresponding to peaks in flows. However, once flow stabilized, EMG values slowly declined prior to the decrease in flow. During August 13–17, 2002, a marked increase in flow levels resulted in hyperactivity for this fish.

For brook trout 2, 24-h data were collected dur-

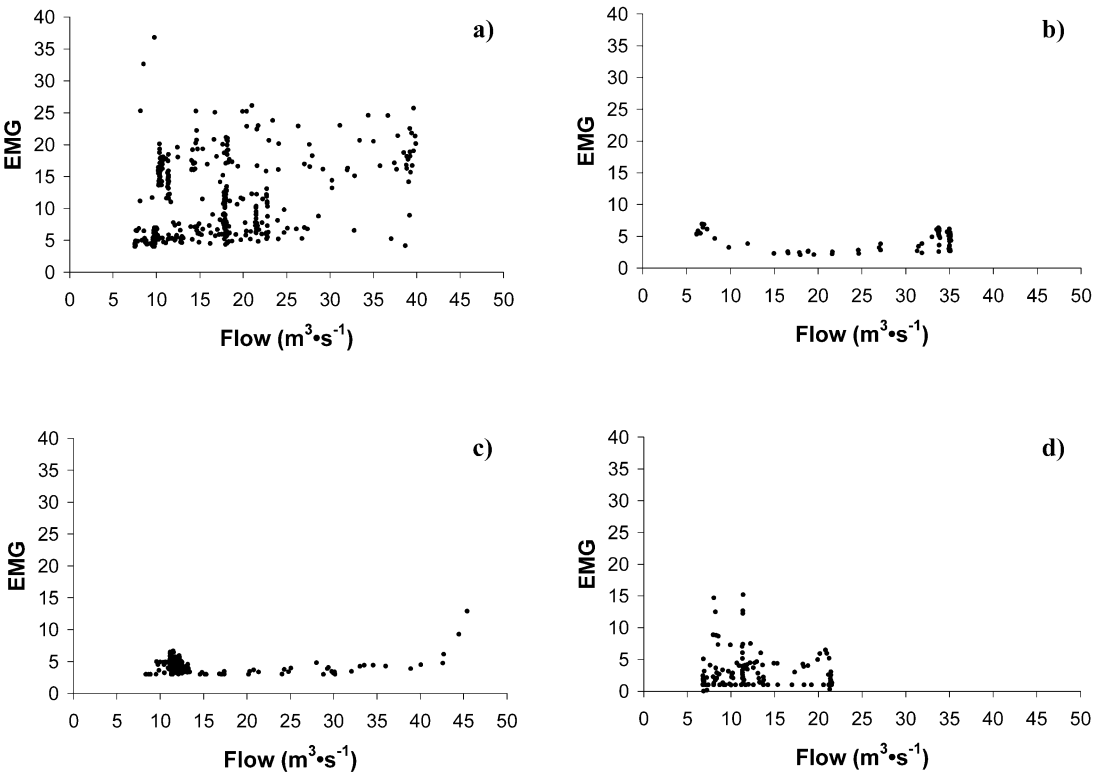

FIGURE 3.—Scatterplots of electromyogram (EMG) data versus flow for **(a)** brook trout 1, **(b)** brook trout 2, **(c)** walleye 5, and **(d)** walleye 6.

ing June 26–29, 2002 (Figure 2b). Flow patterns were cyclical in nature, with peak flows attained at 0800 hours, stabilizing until 2100 hours, then decreasing to a minimum at 0100 hours. Peaks in relative activity corresponded exactly to the peaks in flow, and stabilization periods in relative activity harmonized with those in flow.

The flow patterns in September 2002 were consistently more stable than in previous months (Figure 2c). For most of September, flow was consistently 11 ± 1 m^3/s and the EMG levels of walleye 5 remained relatively stable, displaying what appeared to be a regular diurnal pattern. The largest peak in relative activity for walleye 5 corresponded with the largest flow fluctuation.

Two periods of 24-h data were collected for walleye 6 (Figure 2d). EMG patterns did not appear to follow changes in flow patterns.

An examination of EMG versus flow data (Figure 3) showed no consistent pattern between fish,

TABLE 2.—Summary statistics of fish electromyogram data for the various flow categories (described in the text); *n* is the number of samples; CV is the coefficient of variation (100 · SD/mean). A randomized complete-block ANOVA and numerous Monte Carlo simulations were used to examine potential differences in fish activity level among the flow categories. A Bonferroni adjustment was made to the type I error, such that α was set to 0.006.

	Brook trout							
	Fish 1				Fish 2			
Flow type	*n*	Mean	CV	*P*	*n*	Mean	CV	*P*
Fluctuating	176	11.62	0.6	0.025	32	3.79	0.41	<0.006
Stable	233	10.13	0.52		41	4.8	0.24	
High	34	17.26	0.3	<0.006	47	4.66	0.25	<0.006
Medium	174	10.85	0.5		14	2.62	0.18	
Low	201	9.6	0.63		12	5.21	0.28	

within—or among—species. Attempts to fit models to the data resulted in low explanatory power for all cases. Thus, attempts to relate changes in EMG to categorized flow types were made. Table 2 provides summary statistics of fish relative activity levels for the various flow categories. Generally, no significant difference in fish relative activity was found between periods of stable versus fluctuating flow, and medium flows generally resulted in the lowest relative activity recorded.

Discussion

In this study we found that brook trout and walleye relative activity levels generally mimicked patterns of flow in a regulated river, indicating that fish respond directly and immediately to flow change within a localized reach of river. These results are unique in that, to our knowledge, no study to date has attempted to characterize brook trout or walleye relative activity responses to hourly changes in regulated flow regimes.

Once fish were tagged, fish movement was usually limited to one downstream shift in habitat (occurring 1 d–2 weeks posttagging), followed by apparent site fidelity. Our observations of minimal walleye movements are supported by Paragamian (1989) who found walleye movement to be less extensive during summer months relative to spring and autumn on the Cedar River, Iowa, and McConville and Fossum (1981) who found walleyes to have a small home range on the Mississippi River. While one brook trout exhibited limited habitat shifts, the other brook trout made both downstream and upstream movements. Variability in fish movements within a species is not uncommon (e.g., Bunt et al. 1999) as active fish are often active in both diurnal and nocturnal hours, and sedentary fish remain so for entire days (see McConville and Fossum 1981). Reasons for this variability may be caused by the habitat in which the fish live. If all life requirements can be met in one area, movement will be minimal (see Leclerc and Power 1980).

Suitable refugia within a habitat are a key requirement for fish to be able to withstand increasing flows. High flows did not result in downstream displacement of our tagged fish, suggesting that large substrates, backwater areas, or pools were present in the areas we monitored. The use of such refugia during high flow levels is likely responsible for activity observations seen for brook trout 1. Peaks in flow elicited increased fish relative activity (hyperactivity), but as suitable refuge was found, the EMG values decreased over time despite maintained high flows. Hyperactivity at high flows may also be a result of increasing amounts of drifting invertebrates (Minshall and Winger 1968; Pearson and Franklin 1968). This feeding activity may be responsible for the observations seen for brook trout 2. Increased activity corresponded with increased flow, and EMG values remained high as high flow levels were maintained. Increased activity at low flows may have been the result of fish opportunistically relocating when velocity was not a deterrent to movement, or simply because the habitat became unsuitable.

Generally, there was no significant difference in fish EMG levels between stable versus fluctuating flow periods. The imposed restrictions on flow changes on the Magpie River (i.e., 25% of the previous hour's flow) may have affected the results. We would expect that unrestricted, peaking hydropower operations would likely show a difference.

Although the apparent ''mimicking'' behavior of fish activity to flow changes was observed, statistical relationships between the two variables could not be made. It has been suggested by Dudgeon (1991) that biotic interactions are enhanced by more predictable flow regimes. A lack of con-

TABLE 2.—Extended.

	Walleyes							
	Fish 5				Fish 6			
Flow type	*n*	Mean	CV	*P*	*n*	Mean	CV	*P*
Fluctuating	102	4.11	0.30	0.02	72	3.47	0.81	0.12
Stable	431	4.33	0.18		61	2.69	1.06	
High	16	4.9	0.54	0.049				0.048
Medium	20	3.45	0.14		36	2.29	0.77	
Low	497	4.29	0.18		97	3.42	0.9	

sistent daily flow patterns may explain why plots of EMG versus flow appeared to demonstrate such poor relationships. Other variables that may covary with flow, such as temperature (Cushman 1985), may also contribute to changes in relative activity levels, and thus a multiple parameter model may have had more explanatory power.

Walleye 5 demonstrated regular cycles of daily activity during consistent periods of flow, a peak in its activity corresponding to a major increase in flow. Day period would likely explain changes in activity level more successfully than flow changes in this instance, and the quantification of this variable in future studies should also be considered.

Measures of relative activity levels provided by CEMG tags do not actually quantify the amount of energy used by the fish (Geist et al. 2002), yet energetic costs associated with changes in relative activity may be one of the more important sources of variation in fish growth rates (Boisclair and Leggett 1989). The only way to quantify energy expenditure is to calibrate the EMG readings with a measure of the swimming speed and oxygen consumption of the fish (see Økland et al. 1997). Due to portability limitations of a swim chamber (Geist et al. 2002) and other problems, such as subjecting fish to added stressors (Standen et al. 2002), calibrating tagged fish before their release in the field is not always an option. Laboratory calibrations on a separate group of fish can be conducted and used (e.g., Hinch and Bratty 2000), yet Geist et al. (2002) found that a single radio transmitter did not produce similar results every time in different fish due to individual fish differences in swim performance, or inconsistencies in the placement or function of the tag. However, to answer energetics-related questions, swim tube calibrations are essential, yet the field component is equally essential to quantify relative activity levels in free-living fish (Cooke et al. 2001).

In this study we have begun to quantify the effect of flow changes on the relative activity of brook trout and walleyes on a regulated river. The continual collection of flow data from gauging stations and EMG data from fixed stations allowed for a snapshot of immediate biotic responses, which is paramount to understanding the effects of river regulation on the fish community (Valentin et al. 1994; Bunn and Arthington 2002). While it appears that changes in flow elicit an activity response in brook trout and walleyes, the response is variable in magnitude and direction, and, from this study, unpredictable. The collection of other physical variables discussed (e.g., temperature and day period) and the examination of EMG activity on an unregulated river will further increase our understanding of the mechanism of response and also the potential energetic cost of varying flow regimes. Increasing our knowledge of the effects of river regulation on fish is essential to allowing the development of more effective management strategies that find a balance between ecology and economics.

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