Initial Results of an Atlantic Salmon River Acid Mitigation Program

by

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Abstract

Acid precipitation negatively affects Atlantic salmon and other aquatic organisms. As stream acidity has not decreased concurrently with decreasing industrial emissions, immediate mitigation initiatives are required for the persistence of some salmon populations. The West River, Sheet Harbour Acid Mitigation project was designed to treat the once prolific salmon river. A monitoring program was conducted over 2.5 years to assess the early impacts of lime additions to the downstream aquatic communities. While signs of salmon recovery are assumed to require at minimum 3.5 years, preliminary signs of recovery were shown in stream chemistry and aquatic invertebrate communities. Acidity levels were reduced to those conducive to successful juvenile Atlantic salmon survival. Downstream aquatic invertebrate communities increased in abundance and realized shifts in relative dominance of some taxa, with the resurgence of those presumably the most acid sensitive.

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"Scholars have long known that fishing eventually turns men into philosophers. Unfortunately, it is almost impossible to buy decent tackle on a philosopher's salary" **- Patrick McManus**

CHAPTER 1

OVERVIEW OF ACID PRECIPITATION, LIMING AND THE WET RIVER, SHEET HARBOUR ACID MITIGATION PROJECT

General Introduction

Acid precipitation has been linked to severe loss of suitable freshwater habitat for many aquatic organisms (Beamish 1976, Magnuson 1984, Muniz 1984, Rosseland 1986, Ryan and Harvey 1980, Watt et al. 1983). Precipitation that has been artificially acidified, termed acid precipitation, is a result of interaction with sulfuric oxides and nitrous oxides derived from the burning of fossil fuels (Beamish 1976, Cronan and Schofield 1979). The major sources of these noxious gases in North America are the industrial regions of the North Eastern United States and Central Canada.

In 1990, the United States and Canada signed the Clean Air Act in an effort to curtail emissions. This mandated that by the year 2000, a 50% reduction (from 1980 levels) in SO_2 emissions was to be achieved (Watt 2000). The Canada-United States Clean Air Accord, signed in 1991, puts long-term caps on the emissions of both countries. It is anticipated that these efforts to reduce emissions will have positive effects on acidification in areas most affected (Watt 2000).

As Nova Scotia is situated in the unfortunate position of being downwind of the predominating winds of the Northeast US during winter months and of Central Canada during the summer months, this province receives heavy loads of transported air pollutants (Kerekes et al. 1986, Esterby et al. 1989, Jeffries et al. 1995, Anonymous 2004). While areas of Ontario, Quebec and the American Mid-West receive SO_2 and NO_2 loading rates far exceeding that experienced in Nova Scotia (Anonymous 2004), the former areas do not realize significant freshwater acidification due to the buffering capacity of local soils.

In Nova Scotia, acid precipitation affects slightly less than half of the total landmass, due to a divide of geologic characteristics. A lithological formation known as the Southern Upland lies south of a line drawn between Digby, Digby county and Canso, Guysborough county (Figure 1.3, p.27). It is compromised of hard igneous and metamorphic rocks, primarily slates, granites and greywacke, which are slow to degrade and provide few base cations. This area is generally low gradient with altitudes rarely exceeding 140m and is dominated by peat bogs and coniferous forests, which have high rates of release of organic acids. Because of these features, the area is naturally slightly acidic, contains little alkalinity and does not have the ability to buffer the large additions of acid experienced with acid precipitation.

While immediate runoff of acidified precipitation affects rivers, the precipitation also has long-term effects on the soils within rivers' drainage basins. The base cation reserve found in soils, generally calcium, magnesium and potassium carbonates, used to buffer acid water as it percolates through the horizons of soil, becomes depleted. Once this reserve is exhausted, precipitation falling onto that soil does not undergo the significant circumneutralization that would naturally occur. It has been estimated that if all emissions were eliminated within 50 years, the base cations in the basins of the majority of salmon rivers would not achieve pre-acidification levels for 60 to 100 years (Clair 2004). Based on this, it is evident that mitigation is required in addition to emission reductions if river acidity is expected to stabilize at pre-acidification levels in the 21st century.

Acid Precipitation and Aquatic Organisms

Acid precipitation is known to have adverse effects on aquatic organisms (Beamish 1976, MacDonald 1983, Muniz 1984, Gunn 1986, Rosseland 1986, Magnuson 1984, Watt 1987, DFO 2000, Farmer 2000, Ikuta et al. 2001,) and is thought to do so via two distinct mechanisms. The first is from direct toxicity of the high concentrations of H^+ ions and its effect on ion regulation. The second pathway of toxicity results from the change in mobility of metals, especially aluminium at low pH. Aluminium has been shown to be the primary mechanism of lethality for fish and other biota in acidified waters where dissolved organic carbon levels are low (Baker and Scholfield 1982, Baldigo 1997, Calta 1999, Cronan and Schofield 1979, Kroglund et al. 2001, Magee 2001, Peterson et al. 1989). Labile aluminium precipitates onto the gills of fish, decreasing ionoregulatory efficiency and hindering oxygen uptake. This is further complicated by the fishes' response to this stressor, which is to secrete mucus, which in turn compounds the fishes' ability to exchange gases across its gills (Moiseenko and Sharova 2006). Aquatic invertebrates have also been shown to be sensitive to acidification and labile aluminium toxicity associated with decreasing pH (Fjellheim et al. 2001, Fjellheim 2001, Gerhardt 1993, Herrmann 2001, Hopkins 1989, Okland and Okland 1986, Winterbourn 1996) though the majority of studies have been in relation to presence/absence data and few laboratory experiments have been conducted.

Salmon Populations in Nova Scotia

In terms of fish production losses resulting from the negative effects of acid precipitation, no other province has lost a larger proportion than Nova Scotia (DFO 2000). While the decline of salmon in the Southern uplands is a result of a multifaceted problem encompassing at-sea mortality, over fishing and loss of freshwater habitat, it is known that significant losses of salmon production have occurred due to acidification of historical salmon rivers (Anonymous 2000, Watt 1987, Watt et al. 1983).

In all, some 450 rivers in Nova Scotia historically had runs of Atlantic salmon. Of that number, 65 of them lie within the Southern Upland region. In a Department of Fisheries and Oceans report (DFO 2000), it was shown that based on 1980's data, 34 of these 65 Southern Upland rivers exhibited a mean annual pH of less than 5.1, indicating that severe loss and only remnant populations of salmon could persist. Fourteen rivers were below a pH of 4.7 were thought to have extirpated populations. In the last detailed stock status report issued by the Department of Fisheries and Oceans, all monitored salmon rivers within the Southern Upland (with the exception of the LaHave River above Morgan Falls) had adult returns that failed to meet the conservational requirements (DFO 2003).

At-sea mortality appears to be a major factor in the persistence and viability of salmon populations in the Southern Upland as well as other Nova Scotia rivers (Amiro 2000, Anonymous 2004, Marshall et al. 1999). Compounded with reduced freshwater production attributed to acidification, and the potential of reduced marine performance from sub-leathal low-pH effects further loss of salmon populations within the Southern Upland appears likely.

The Acid Mitigation Project

In response to concerns of the state of salmon in the Southern Upland area, an Acid Rain Mitigation Committee (ARMC) was formed in 2000 comprised of members from the Nova Scotia Salmon Association (NSSA), the Atlantic Salmon Federation (ASF), Trout Nova Scotia, Nova Scotia Power, the Department of Fisheries and Oceans and the Nova Scotia Department of Inland Fisheries. The issues facing salmon in this area were discussed and the Nova Scotia Salmon Association decided to initiate an acid mitigation program as a pilot project to investigate and potentially demonstrate the feasibility of liming as a measure to restore freshwater salmon production potential in the Southern Upland salmon rivers.

In 2000, Dr. Atle Hindar of the Norwegian Institute for Water Research, Grimstad, Norway was commissioned to assess the feasibility of liming selected rivers and to recommend an approach towards a mitigation strategy to achieve the goals of the NSSA. Lessons learned in Norway provided valuable insight to design and implementation of the mitigation project as Norway boasts the most active acid mitigation program in the world, with annual operating costs in 1988 exceeding $2.5 M CDN annually (Hindar and Rosseland 1988) and exceeded $16 M CDN annually in 1995 (Sandoy and Romundstad 1995). His report detailed liming strategies for four rivers, the LaHave River, the Medway River, the West River (Sheet Harbour) and the East River (Sheet Harbour). From the Hindar report list, the West River, Sheet Harbour was chosen as a demonstration site for a mitigation program. While lime dosers have been used to treat acid mine drainage systems on a small scale, the use of a doser of this magnitude on a natural salmon river had never been done before in North America. Reasons for choosing the West River, Sheet Harbour as the demonstration river were:

1) It supported a remnant population of Atlantic salmon,
2) It was acidified to the point where it was detrimental to salmon,
3) It was close to a source of lime,
4) Accessibility for electric power was reasonable, and
5) The size of the drainage basin was such that one lime doser would have significant effects.

Liming as a Method of Acid Mitigation

Addition of base materials to acidified waters with the goal of reducing acidity has been studied for over two decades in North American and European countries (Clair 2005). While the effectiveness of this remedial method has been proven, North American liming efforts have largely been accomplished by small localized organizations and community groups, or by treatment of industrial wastes. Large scale governmental acid mitigation programs have yet to happen in either Canada or the United States. By far, the most active acid mitigation programs currently occur in the Scandinavian countries or Norway and Sweden (Clair 2005). As of the year 2005, approximately $170 M US had been spent in Norway on liming projects with even move having been spent in Sweden (Clair 2005).

The most common base material used in "liming" is calcium carbonate ($CaCO_3$) or dolomite limestone ($CaMg(CO_3)_2$). Experimentation with the application of other base materials such as caustic soda, calcined lime, hydrated lime and various sodium products has shown varying degrees of effectiveness and in some cases, threats to human and aquatic health due to their caustic nature (Clair 2005).

Liming is done in two basic manners: continuously with a lime doser, diversions well or rotating drum; or with single applications of coarse or powdered materials that may require reapplication at various time intervals. A detailed review of liming can be found in Hindar (2001). Because of its ability to precisely add lime and its effective treatment of lotic waters (Hindar, 2001), a lime doser was chosen as the mitigation tool for the West River Sheet Harbour.

A lime doser works by mixing river water with crushed limestone to create slurry. The water enters the lime doser building under the power of head and re-enters the river via the same gradient force. Lime is stored in a silo where it is held until it is mixed with river water by an auger situated in a large well. The quantity of lime administered is a function of the discharge rate of the river. A calibrated flow meter and on-site computer continuously adjust rates of mixing. This lime slurry is injected downstream into the river where dissolution occurs. A schematic diagram of a doser can be seen below (Figure 1.1).

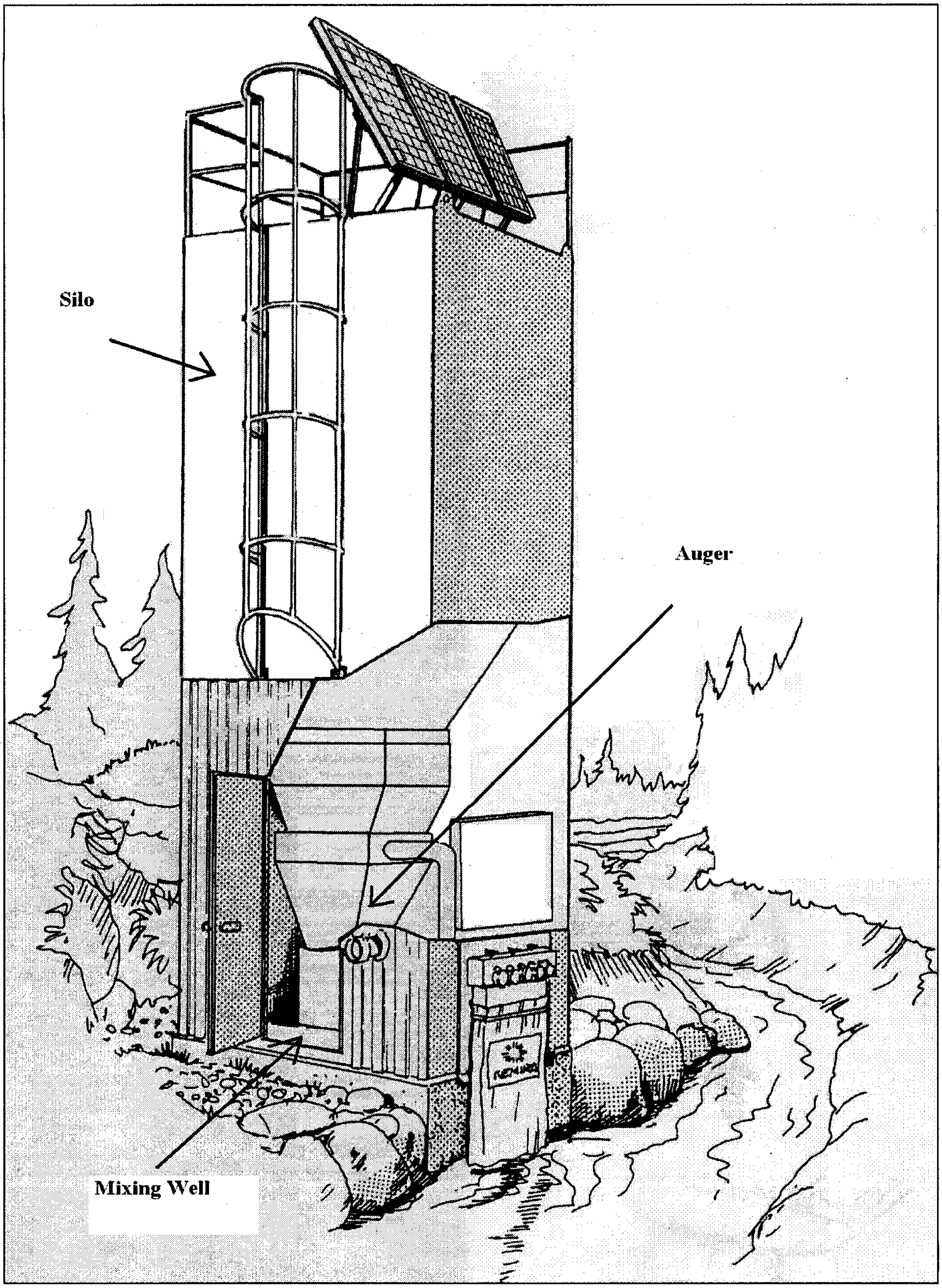

Figure 1.1 Schematic diagram of a typical lime doser. Not illustrated are the underground pipes where water is diverted from the river into a mixing well and then back to the river.

Description of Doser / Liming Project

After exploring the many options outlined in Dr. Hindar's report, a lime doser was deemed the best method to control the pH of river water, in terms of practicality, economy and functionality. Calcium carbonate (limestone) was the base material chosen for liming as it is well tested and available locally, only 40 km's from WRSH. Approximately 98% of the limestone supplied is calcite crushed to < 0.2mm in diameter.

In the spring of 2005, the NSSA acquired land on the upper West River, and preparation of the site commenced, with a gravel road being upgraded and electrical line run to the site. By July of that same year, a platform was constructed to support the lime doser.

A Kemira Kemwater lime system (Fig.1.1 & Fig. 1.2) was installed and became operational on September 21, 2005. This doser works by extracting water from the stream, precisely mixing an electronically controlled dose of crushed lime, and injecting the lime/river water "slurry" back into the river. As lime is added as grams lime per unit volume of water, periods of high flow are sufficiently treated with an increased rate of water intake.

As additional control, dose amounts can be adjusted and system status can checked via modem.

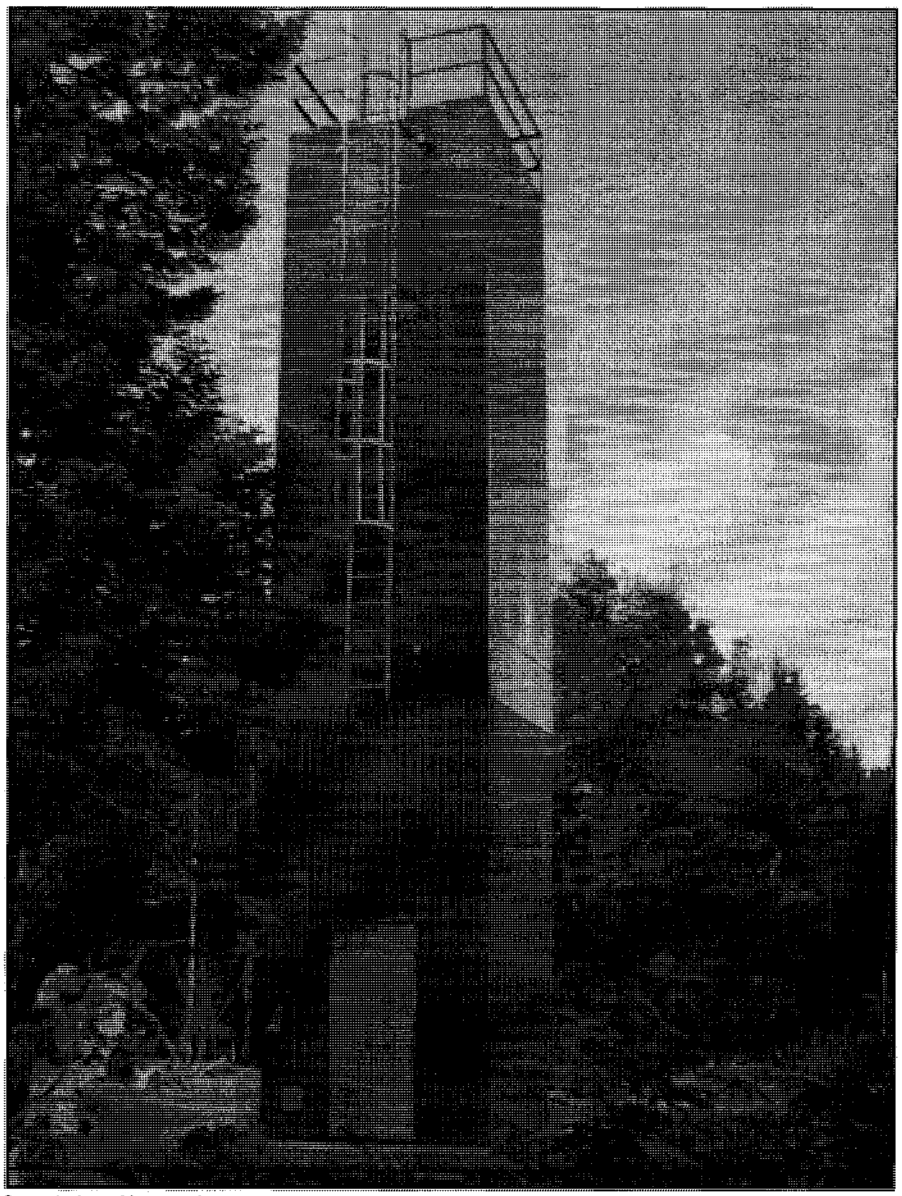

Figure 1.2 – The lime doser at West River Sheet Harbour. For scale, the doser stands 13m in height and the West River is located approximately 3 m to the foreground (not shown).

Funds for ten years of operations have been secured by the NSSA for this liming project, running through to year 2015. At that time, if water chemistry in untreated water has not improved, or if technology dictates, the project term will be extended as needed. Total cost for the ten year commitment was estimated at $599 476 CDN, of which $233 862 was spent during the first year for purchase of the doser, site preparation and initial operating costs.

The lime doser was set up on the upper reach of the main branch of the WRSH (Fig. 1.4), roughly 670m above the impassable set of falls known to historically restrict salmon (Gray 1973). This location allows treatment of approximately 29.9 km of river containing approximately 25% of the historic salmon rearing habitat.

It has been shown that a pH of approximately 5.5 would be sufficient to significantly reduce acid-related mortality in Atlantic salmon (Anonymous 2000, Lacroix and Knox 2005), therefore, a target pH of 5.5 was set for measurement at the river's mouth. Initial dose calculation, as performed by (Hindar 2001) was based on the lime requirement due to H^+, alkalinity, and total organic carbon (TOC). As aluminium was not deemed a sufficient threat, due to complexing with organics (see discussion in Chapter 2) this variable did not factor into the dose calculation.

During the first two months, a limestone dose of $3.5 g \cdot m^{-3}$ was being administered. It was quickly realized that this did not sufficiently decrease acidity in the water at the rivers mouth to the target pH. The dosage was increased to $5.5 g \cdot m^{-3}$ in December 2005 and the target pH was consequently reached. It is thought that error in the estimates of discharge rates lead to under-liming initially.

Description of Study Area

The West River, Sheet Harbour (WRSH) is located on the Eastern Shore of Nova Scotia, approximately one hour north of Halifax (Fig. 1.3). As previously discussed, this area lies within the Southern Uplands and exhibits the geology typical of this area. There does however appear to be small glacial till deposits on the eastern side of the drainage basin, namely within the Little River watershed.

WRSH drains South-Easterly into Sheet Harbour, where it mixes with the East River, Sheet Harbour and the Atlantic Ocean. WRSH is a low-gradient, tannic stained river that drains a narrow basin of approximately 262 km^2 (Hindar 2001) along the approximately 29.9 km main river channel (from lime doser down). The river has two major tributaries, the Killag River to the north and the Little River, anchored by Lake Alma, to the south. Local knowledge suggests that the Killag River contained the majority of historical salmon spawning activity (Ducharme 1972). In all, the West River, Sheet Harbour system contains 20 079 salmon rearing units (100m^2 units)(Amiro 2000, Marshall et al. 2003).

The West River system contains 11 known fish species. Atlantic Salmon (*Salmo salar* L.), Brook trout (*Salvelinus fontinalis* Mitchell) and American eel (*Anguilla rostrata* (Lesueur) are the three species of diadromous fishes. They have also historically been the most important as recreational/commercial species. White sucker (*Catostomus commersoni* (Lacepede)), Yellow perch (*Perca flavescens* (Mitchell)), Brown bullhead (*Ictalurus nebulosus* (Lesueur)), Lake chub (*Couesius plumbeus* (Agassiz)) and banded killifish (*Fundulus diaphanus* (Lesueur)) are also found system wide. Golden shiner (*Notemigonus crysoleucas* (Mitchell)), white perch (M*orone Americana* (Gmelin)) and an unidentified stickleback species (Pungitius spp.) also inhabit some locations within the system.

Amiro (2000) describes the WRSH by gradient classes, with ~24 % of river habitat having a gradient of 0.121%-0.249%, ~41% of habitat having a gradient of 0.25% – 0.49%, ~21% of habitat having a gradient of 0.5% – 0.99%, and the majority of the remainder having gradients above 1. A gradient of 0.5% to 1.49% is considered ideal salmon rearing habitat (Amiro 2000, Elson 1975) as a result of the habitat provided under the accompanying hydrologic conditions. Prior to the consideration of habitat quality and based only on the quantity of available habitat, it was estimated that at the habitats carrying capacity and without complications from acidification, the WRSH could support between 1300 and 1800 returning adult Atlantic salmon (Anonymous 1976).

The local forest type is comprised mainly of mixed Acadian forest dominated by Balsam fir (*Abies balsamea*), Red Spruce (*Picea rubens*), White Spruce (*Picea glauca*), Eastern Hemlock (*Tsuga canadensis*), Yellow birch (*Betula alleghaniensis*) and Sugar Maple (*Acer saccharum*), proving to be lands of value with regards to commercial wood harvest.

Consequently, the drainage basin of the WRSH has been extensively logged and once supported a substantial logging industry, compromising the largest industry in the region. A pulp mill was built at the mouth of the system in the early part of the 20th century by Scott Maritimes Pulp ltd. and remained there until Hurricane Beth destroyed it in 1971 (Anonymous 1972). Many of the harvested logs were driven down the river to the mill and a series of over 30 dams were built to facilitate their movement as well as for water storage. Although log driving stopped in the late 1940's, the dams were maintained until Hurricane Beth destroyed the mill and consequently ended the need for log and water storage (Anonymous 1972). The dams were left to degrade naturally, although reports were produced indicating the need to remove the structures (Anonymous 1973). To date, the remnants of some dams exist and some, such as the lake Alma dam still restrict fish passage.

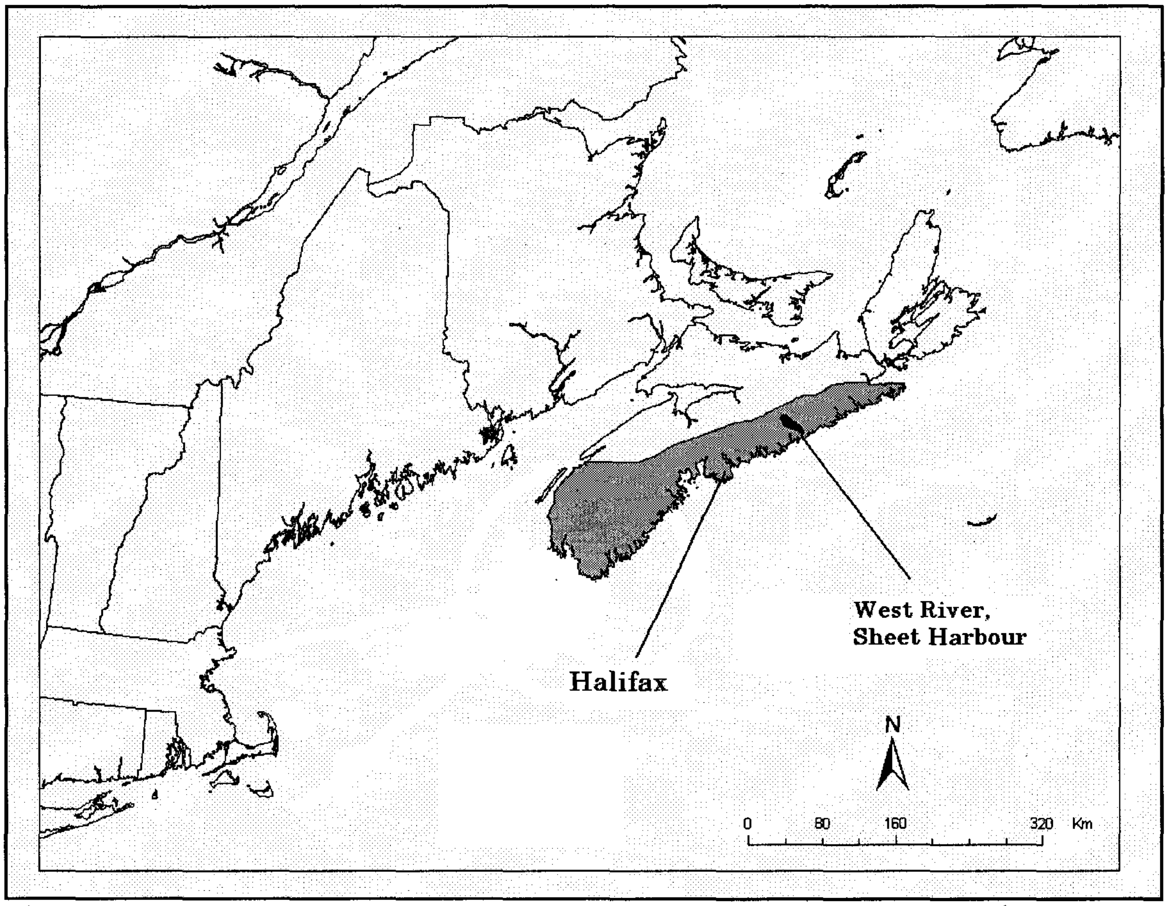

Figure 1.3 - Canadian Maritime provinces / American New England map indicating West River, Sheet Harbour. The light shaded area indicates the Southern upland and the dark shaded area indicates the WRSH drainage basin.

Study Design

While the NSSA was responsible for implementation and operation of the mitigation project, my primary role in the WRSH acid mitigation project was to determine if the addition of lime to the river was having significant effects on aquatic communities downstream. We were in the fortunate position that our research project could begin prior to the commencement of liming. Therefore, our research program entailed a Before-After-Control-Impact (BACI) design. This design permitted examination of the entire river as it existed before liming, and then re-examination of the entire river post-liming, in areas receiving treatment and in areas remaining untreated. Assessment was approached by examining several major parameters. Because anticipated response periods generally exhibit positive correlation with trophic level, I examined biological communities spread across trophic scales in an attempt to provide a better understanding of liming effects within much of the ecosystem, with both a short-term and long-term focus.

Natural inter-annual variability was anticipated to play a large role in dictating the ecological and geophysicochemical state of the river. Therefore, for comparability of treatment/non-treatment years it was important to know what other factors affect each parameter. For example, factors that affect fish communities include: temperature, flow, food availability and oxygen. These parameters, in addition to the parameters expected to change with liming such as pH, calcium and alkalinity, were monitored.

Reference sites were located both above the lime doser on the main branch of the river and within the two major tributaries flowing into the main branch further downstream, the Killag River and Little River. Additionally, five limed treatment sites were located between the doser and the river's mouth at Sheet Harbour (Fig. 1.4 and Table 1.1). Sites were generally chosen if; they were sites historically used by the Department of Inland Fisheries, the Department of Fisheries and Ocean, or other researchers or, they were situated so as to provide spatially important sampling (i.e. immediately above doser & river mouth). Our sampling schedule varied slightly from anticipated timing based on weather condition, however rarely was there a shift of more than 3 weeks. Sampling dates are shown in Table 1.2.

In this study, I collected baseline data of conditions within the West River, Sheet Harbour and assess the early impacts of lime dosing for the 19 months following liming. I tested the suitability of the Scandinavian lime dosing technology in a Nova Scotia salmon river and tested its ability to adequately restore acidity levels to those preferred by Atlantic salmon. I question whether pH can be regulated with a lime doser so that Atlantic salmon mortality associated with low pH is negligible.

Factors affecting salmonid production within the West River, Sheet Harbour may not be limited to high acidity. Therefore, in this study I assessed the potential that other factors, namely temperature and food availability, also limit salmonid production in this river.

Salmonid response as a result of liming may require 3.5 to 5.5 years (typical generation of salmon in WRSH) or more, therefore liming induced change may not be immediately evident. Therefore, I assessed the effects of lime dosing on periphyton and aquatic invertebrate communities, which are expected to respond to liming in a shorter time period.

I use the results of these tests to describe the short term effects of the lime doser and to provide reasonable expectations for the West River, Sheet Harbour acid mitigation project.

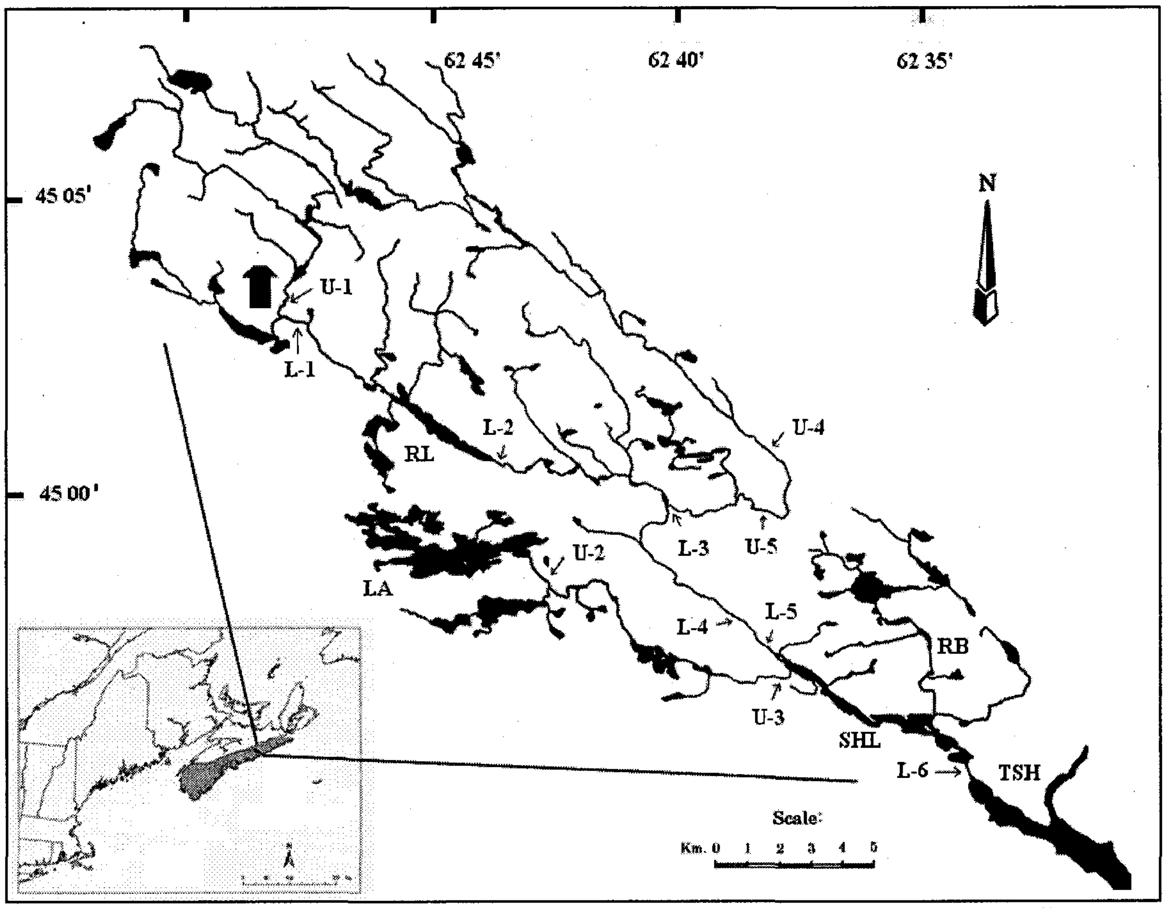

Figure 1.4 – Map of WRSH indicating sampling site locations. Prefix of "U" indicates an un-limed site and a prefix of "L" indicates a limed site. SHL = Sheet Harbour Lake, LA = Lake Alma, RL = River Lake, RB = Rocky Brook and TSH = Town of Sheet Harbour. The doser location is indicated by the letter "D" at coordinates 45° 03' 14" North and 62° 48' 02" West. Impassable falls located 400m downstream of doser. Head of tide located 200m downstream of site L-6. Refer to table 1.1 for more information.

Table 1.1 – Site descriptor for WRSH. Only sites D-1, D-2, D-3, D-4 & D-4 and D-6 (listed in order from the doser to the river's mouth), were treated with lime.

Site	GPS Coordinates	Category
Main Branch, WRSH		
Site U-1 Immediately Above Doser	45° 03' 14" N 62° 48' 02" W	Control
Site D -1 Immediately Below Doser	45° 03' 14" N 62° 48' 02" W	Impact
Site D-2 Below River Lake	45° 00' 32" N 62° 43' 25" W	Impact
Site D-3 Branch Basin	44° 59' 50" 62° 39' 25"	Impact
Site D-4 River Road Run	44° 58' 09" N 62° 38' 05" W	Impact
Site D-5 Iron Bridge Pool	44° 57' 40" N 62° 37' 17" W	Impact
Site D-6 WRSH Mouth	44° 55' 42" N 62° 32' 45" W	Impact
Little River		
Site U-2 Upper Little River	44° 58' 41" N 62° 42' 09" W	Control
Site U-3 Lower Little River	44° 58' 40" N 62° 42' 04" W	Control
Killag River		
Site U-4 Middle Killag River	45° 00' 54" N 62° 37' 44" W	Control
Site U-5 Lower Killag River	44° 59' 41" N 62° 36' 57" W	Control

Table 1.2 – Sampling schedule for West River Sheet Harbour, years 2005 to 2007.

Parameters	**Number of Samples/Year**	**2005 (Pre-liming)**	**2006 (Post-liming)**	**2007 (Post-liming)**
Water Chemistry	N/A	Continuous	Continuous	N/A
Temperature	N/A	Continuous	Continuous	N/A
Fish – Fyke Netting	Dependant on Conditions	May 29th to October 8th	May 4th to September 3rd	April 22nd to May 27th
Fish– Angling	Dependant on Conditions	May 25th to October 8th	April 9th to September 8th	April 7th to May 27th
Fish – Electrofishing	1	September	September	N/A
Invertebrates	2	July & September	July & September	N/A
Periphyton	2	July 6th & September 9th	July 18th & October 21st	N/A
Flow / Discharge	3	July	May, July, Aug	N/A
Refugia	1	N/A	Aug	N/A

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CHAPTER 2

EFFECTS OF LIME DOSING ON WATER CHEMISTRY AND DESCRIPTION OF PHYSICAL HABITAT OF THE WEST RIVER, SHEET HARBOUR

Introduction

The primary goal of liming is to improve water chemistry, specifically to decrease acidity and increase buffering capacity. The desired end results are increased fish abundance and general ecological improvements in aquatic communities. The mechanism to reach these goals is via mitigation of chemical acidity. It is therefore imperative that any liming program should monitor changes in water chemistry. Also, to effectively calculate and administer suitable quantities of lime, a thorough knowledge of the hydrology of the target systems is crucial.

It is known that the pH of acidified waters typically reaches annual lows during the late winter/ early spring and again in the fall of the year (Hesthagen 1986, Lacroix and Knox 2005, Sayer et al. 1993, Watt 1987, Wigington et al. 1992); this is a function of lotic systems being intrinsically linked to cycles of local precipitation as well as snow and ice melt. It therefore is useful to understand the relationship of seasonal flow rates and pH, as an evident inverse relationship exists.

In a survey of the effects of acidification in Canada, Watt (1987) showed that Nova Scotia Rivers with pH > 5.4 showed little reduction in salmon production in 1986 from pre-acidification estimates. Since then, many rivers in the pH range of 5.1 to 5.4 have increased acidity and have been shown to be under acid stress (Lacroix and Knox 2005). For the purpose of the WRSH acid mitigation program, a target pH of 5.5 was chosen based on the known toxicity of acid on various salmon life stages and on the assumption that inorganic aluminium (likely to be the most toxic metal at low pH) is sequestered by organic materials in an organometallic complex over acidity levels relevant to salmon in Nova Scotia (Lacroix 1993, Peterson et al. 1989). Inorganic, labile aluminium has been shown to be toxic to fishes in acidified systems (Cronan and Schofield 1979, Lacroix 1986, Neville 1988) as its affinity for fish gills increases with decreasing pH, binding to the negatively-charged epithelial cells of the fish's gills, reducing ion exchange, promoting mucus secretion and hindering oxygen uptake (Baker and Scholfield 1982, Sayer et al. 1993, Weatherley et al. 1991).

While acidity may be the prime stressor in WRSH, and consequently the major limiting factor during late winter and fall, the high temperatures of summer may also pose a threat.

Temperature is often a contributing factor to habitat selection by fish. As temperature has a negative inverse effect on the amount of oxygen available for respiration, fish tend to choose cooler water where oxygen levels tend to be higher. Salmonid species are particularly sensitive to low oxygen (Armstrong et al. 2003, Gibson 1993) and the interplay of oxygen and temperature is a large part of their habitat selection process. In moving waters, oxygen is readily available for diffusion from the atmosphere to the water. However, as oxygen solubility decreases with increasing water temperature, the absolute amount of oxygen available for fish decreases. As the partial pressure of oxygen controls the rate of oxygen flux across a fish's gill, high temperature, low oxygen and subsequent low partial pressure of oxygen in water induces anoxic stress on fish and other aquatic organisms (Cole 1994, Wurts and Durborow 1992).

The temperature at which Atlantic salmon begin to feel stress, both respiratory and metabolic stress has been shown to be approximately 22.5°C (Armstrong et al. 2003, Caissie 2000, Coutant 1977, Elliott and Hurley 1997, Gibson 1993). In a recent study by Breau et al. (2007), it was suggested that temperature-driven rates of activity was at temperatures above that previously suggested, with young-of-year activity increasing until 23°C and remaining constant from 23°C to 27°C.

Brook trout have a lower tolerance to warm water than salmon at 20°C (Coutant 1977). These values are not the uppermost temperatures at which these fish will survive, but rather the temperature at which some sort of stress is experienced and growth is compromised.

Brook trout in lakes (Biro 1998) and in streams (Baird and Krueger 2003, J. MacMillan, Pers. Comm.) as well as Atlantic salmon parr in streams (Breau et al. 2007) will seek areas of cool water such as a thermocline or springs. Identification of these habitats through careful temperature monitoring is important to sustainable fisheries management. I therefore examined both availability and size of refugia to assess the ability of fish to avoid high temperatures.

The research presented in this chapter is aimed at achieving two goals;

1) Assessing my hypothesis that the high acidity of the West River, Sheet Harbour has limited salmon production and,
2) Assessing the impact of the lime doser on stream acidity.

To do so, I describe a general survey of the West River, Sheet Harbour which explores the potential for chemical (low alkalinity, high dissolved organic carbon, high hydrogen ion concentrations and heavy metal/acidity interaction) and physical (temperature) limitations. Additional abiotic limitations, such as oxygen deficits, cool-water refugia availability and basic hydrography are assessed to reasonably predict limitations of an acid mitigation program.

Through this general survey and the two aforementioned goals, I have attempted to answer three key questions;

a) Does low pH likely limit salmon survival, and consequently production; within the WRSH?

b) Is it probable that variables other than acidity are limiting salmon production within this river? And,

c) Is increased salmon survival within the river is probable following the acid mitigation program?

Methods

Water Chemistry

Water chemistry measurements were taken in three forms: bottle samples (major ion/ trace metals/ nutrients samples), "spot-check" streamside readings and in-situ chemistry logging.

Samples to be sent for comprehensive analysis were taken every six weeks between May 25 to Nov 6 2005, from sites U-1, U-2, U-5, L-2, L-5, & L-6. These samples were processed by the Environment Canada laboratory in Moncton, NB. Samples were also taken on October 19^{th} and December 2^{nd} 2006, and sent to Maxaam Analytical incorporated. All such samples were analyzed for major ions, nutrients, trace metals as well as traditional water chemistry parameters such as conductivity, pH, total organic carbon, alkalinity, color, hardness and turbidity. These samples were taken in 500ml and 250ml acid-washed containers, allowing the containers to overflow three times prior to being filled. Sample lids were attached underwater to minimize atmospheric contamination.

In addition to our bottle samples data, 2003 and 2004 data provided by the Nova Scotia Salmon Association and analyzed by Maxaam Analytical incorporated. (PSC analytics, at the time), were used as a background data set. Additional pH data obtained from Lacroix and Knox (2005), dating from 1996 and 1997, was also used as background information.

In-situ data logging was done using either YSI 600xls Sonde units or a Hydrolab DS5 Sonde unit, measuring pH, conductivity, water temperature and dissolved oxygen. A YSI Sonde was deployed at site U-1 and site L-6 (Fig. 1.3), for the period of April 2nd to November 19th 2006 while the Hydrolab was deployed from February 10th to November 31st 2006. The Hydrolab measured pH, water temperature, dissolved oxygen, conductivity and turbidity.

Finally, periodic "spot-check" streamside measurements were taken throughout the project using a YSI 600qs Sonde unit, measuring pH, conductivity, water temperature and dissolved oxygen. The pH probe was calibrated weekly and the remaining probes were calibrated monthly.

Temperature

Hobo-Onset models ProV2 and pendant data loggers were deployed for the summer months (April to October) in both years with three loggers deployed throughout the winter months (November to March) of 2006/2007. Temperature was recorded every hour. Loggers were placed throughout the system, covering the main branch, Killag and Little Rivers, in both treatment and control areas (see Fig. 0.3). As water levels dropped the loggers were checked to ensure they were covered with a minimum of 15cm of water.

Lake Profiles

In mid-August 2006, Sheet Harbour Lake (refer to Figure 1.3) was surveyed for the presence of stratification and potentially cool water habitat. In areas of deep water (>6m), the YSI probe was lowered to the bottom to measure potential changes in temperature. If a gradient was detected, a complete series of measurements were taken at 0.5m depth intervals.

Flow/Discharge

A staff gauge located at the bridge next to the lime doser was used to measure water level at that location. These readings were used as a proxy for water levels throughout the system by measuring the relationships of relative discharges of most major tributaries. For example, when the doser showed a water level of 1.33m, the discharge at that point was 7% of the total system discharge while the discharge of the Killag River was 19% of the total system discharge. An assumption was made about homogeneous precipitation across the watershed.

Discharge was calculated from a series of flow rate measurements taken in the summer of 2005 and 2006. Flows were measured using one of three velocity meters; a Marsh-McBurney Acoustic Doppler flow probe (July 2005), a Global Water flow probe (May & July 2006) and a SonTek FlowTracker Acoustic Doppler Velicometer (Aug. 2006). Using the USGS $6/10^{th}$ method (Rantz 1982) discharge was calculated by measuring cross section of the river and a suite of mean water velocities. These discharge measurements were taken at various points within the system, including the system's mouth, the water flowing past/through the lime doser site (site U-1), and most major tributaries. A series of measurements were taken on July 27^{th} - 28^{th} 2005, July 5^{th} 2006, May 10^{th} -11^{th} 2006 and August 16^{th} - 17^{th} 2006. Due to unsafe conditions at high water discharge, flow measurements were not conducted at water levels above 1.37m on the doser's staff gauge.

For historical flow rates and discharge, data were obtained from the West River Sheet Harbour hydrology study conducted by the Dept. of Environment (1972).

As a proxy for precipitation, and consequently discharge, meteorological data were obtained from the Environment Canada historical weather database (www.climate.weatheroffice.ec.gc.ca). Malay Falls weather station served as the source for the information, located only 8 kilometers from the village of Sheet Harbour, on the East River, Sheet Harbour

Thermal Refugia

In the third week of July, approximately 21 kms of streambed within the WRSH system were examined for the presence of cool water inputs, namely springs and seeps. Water temperatures of all pools, inlets and steep-sided banks were measured with a traceable handheld thermometer. If a temperature change was observed, measurements of temperature, pH, dissolved oxygen and conductivity were taken with the YSI Sonde. Exact location of each refugium was taken with a handheld Garmin GPS unit. Also, the approximate area of cool water habitat was quantified with respect to availability for fishes.

Statistical Manipulations

As a result of the previously discussed under-dosing during the first three months of treatment, data collected during October, November and December of 2005 were not included in the analysis. The treatment period was therefore from January 2006 onward. A factorial ANOVA and associated Tukey's HSD tests were completed comparing mean pH across sites, time of year (month) and treatment periods.

For the general water chemistry survey, values for parameters at each site were compared pre- and post-treatment with a two-way ANOVA and if warranted, a Tukey's Honest Significant Difference (HSD) test. For data where the values were below the Reportable Detection Limit (RDL) of the specific laboratory which conducted the analysis, values of zero were assigned unless values above the RDL were reported for the same site during the same period, at which point a value of representing the median of the RDL was assigned for analysis.

To compare temperature and precipitation regimes between years, months and sites, factorial ANOVA's, and if warranted, Tukey's Honest Significant Difference (HSD) tests were performed.

Results

Water Chemistry

In the period following adjustment of the lime dosage in late December of 2005, three months following the official start date of the lime doser, mean pH increased between 0.28 to 0.66 units in treated waters, however statistically, not all limed sites were significantly different from pre-treatment pH regimes. Following an Analysis of Variance (ANOVA) that indicated there were some statistically significant changes at some sites (ANOVA, P=0.013)(Table 2.1), Tukey's Honest Significance Difference tests were conducted.

Of the three downstream limed sites with pre-treatment data, two experienced statistically significant acidity decreases, site L-2 (9.8 km downstream from doser)(Tukey HSD, P=0.00) and site L-5 (22.5 km downstream from doser)(Tukey HSD, P=0.00)(Table 2.2). The third treatment site for which direct before and after comparisons were made was the river mouth as site L-6. This site did not experience statistically significant (Tukey HSD, P=0.32)(Table 2.2) decreases in acidity. It is important to note however that the mean pH post treatment was 5.49, very near the project target of 5.5. This is likely biologically significant and should increase survival rates of salmon to desired levels.

Of the control (unlimed) sites, none experienced significant fluctuations in acidity (Tukey HSD, P>0.11) (Table 2.2, Figure 2.2). This indicates the comparability of pre- and post-liming data such that stream acidity was similar between years. I presume that these two years are representative of the river's acidified state.

Because substantial intra-annual variation is apparent in the West River (Fig. 2.2), discrepancies in sampling distributions between years could potentially confound changes in acidity. Fortunately, the distribution of samples prior to this study was similar to the sampling distribution of both pre- and post-liming acidity measurements (Figure 2.1), and the above analysis is adequate.

Increases in pH ranged from 0.28 units to 0.66 units at regularly monitored water chemistry sites though some sections of the river realized substantially greater increases, namely the 4.5 km river section directly below the doser (Fig. 2.3). This section of river is difficult to access, and therefore there were no regularly sampled sites within the section. However, on several occasions water chemistry measurements in this area showed pH values that were slightly below circumneutral at 6.75. This would suggest that a pH change of approximately 2.25 units had occurred at that site.

Of note was the substantial dip in pH during the fall of 2006 (Fig. 2.2). The reason for this dip is unknown, however it is believed that a lime delivery issue resulted in a brief period of little lime being added to the system. If paired with a major rain event at that time, the increase in acidity would have been probable.

Due to the current position of the doser, though treating a large section of the main branch WRSH, the treated water is severely diluted (discussed later in chapter). As a result, pH decreases with distance from the doser (Fig. 2.3). This is opposite of conditions prior to liming, when the influx of the less acidic tributaries raised stream pH.

Water chemistry parameters, as measured from bottle samples, showed no significant changes as a result of liming following ANOVA's and consequent Tukey's HSD tests. While these data are extensive, mean values and standard deviations of the major parameters, both pre- and post-liming are shown in table 2.3. Parameters associated with acidity are briefly described below.

Alkalinity measurements (including total, carbonate and bicarbonate alkalinity) showed no detectable levels of alkalinity (reportable detection limit of 5 mg/l), even with the addition of 5.5g of calcium carbonate per litre. Presumably the site closest to the lime doser, site L-2 (9.8 km below the doser), would be most likely to show a change in alkalinity, however alkalinity did not raise above the reportable detection limit.

Calcium concentrations increased slightly in 2 of 3 control sites and increased slightly in all 3 treatment sites (Table 2.3), however these changes were not statistically significant (Tukey HSD, $P \geq 0.38$). Concentrations were in the range of 0.56 to 1.81mg/L. (Table 2.3).

Measurements of total aluminium were taken, however the resources to measure labile inorganic Al were not available at the time of this study, and no measurements of Al*i* have been made. Total aluminium measurements ranged from 63.7 to 304.9 *u*g/l, with the highest levels of aluminium being found in the lower main branch (Sites L-5 & L-6) following treatment, though again, these sites were not statistically significantly different than pre-liming regimes (Tukey's HSD, P=0.98, P=0.77, respectively).

Total organic carbon is an important determinant of natural acidity and therefore is an important indicator of ambient acidity levels. Total organic carbon was considered high for the system with the exception of Little River. TOC generally ranged between 4.7 to 17.0 $mg \cdot l^{-1}$ with the Little River between 2.7 to 5.3 $mg \cdot l^{-1}$, again, further detail is given in table 2.3. Theses levels however did not significantly alter following liming (Tukey's HSD, $P<0.05$).

Table 2.1 – ANOVA table for pH data to indicate treatment and temporal effects. Year indicates either pre- or post-liming. Treatment Nominal ALPHA = 0.05. df = degrees of freedom, Sum Sq = Total Sum of Squares (total variation), Mean Sq = Mean Sq (sum Sq/df), F-Value = Test Statistic, Pr(>F) = Probability of being greater than F-Value

Analysis of Variance Response: pH					
Source of Variation	Df	Sum Sq	Mean Sq	F-value	Pr (>F)
Site:Year:Month	31	2.745	0.089	1.896	0.013
Residuals	76	3.550	0.047		

Table 2.2 – Tukey Honest Significant Difference test results performed on ANOVA pH data in table 1.1. The test was run for given sites between pre- and post-treatment years. Nominal ALPHA = 0.05. Doser located immediately downstream of site U-1. Sites L-2, L-5 and L-6 lie downstream of doser. For further site description, refer to Figure 1.3 and Table 1.1.

Test	Difference	Lower	Upper	Adjusted P-Value
Site U-1 (Pre-Post) (Control)	0.1486	-0.1343	0.4616	0.9585
Site U-2 (Pre-Post) (Control)	-0.1773	-0.5263	0.1718	0.9274
Site U-5 (Pre-Post) (Control)	0.3250	-0.0319	0.6818	0.1176
Site L-2 (Pre-Post) (Treatment)	-0.7277	-1.0172	-0.4383	**0.0000**
Site L-5 (Pre-Post) (Treatment)	-0.3124	-0.5100	-0.1148	**0.0000**
Site L-6 (Pre-Post) (Treatment)	-0.2469	-0.5640	0.0702	0.3296

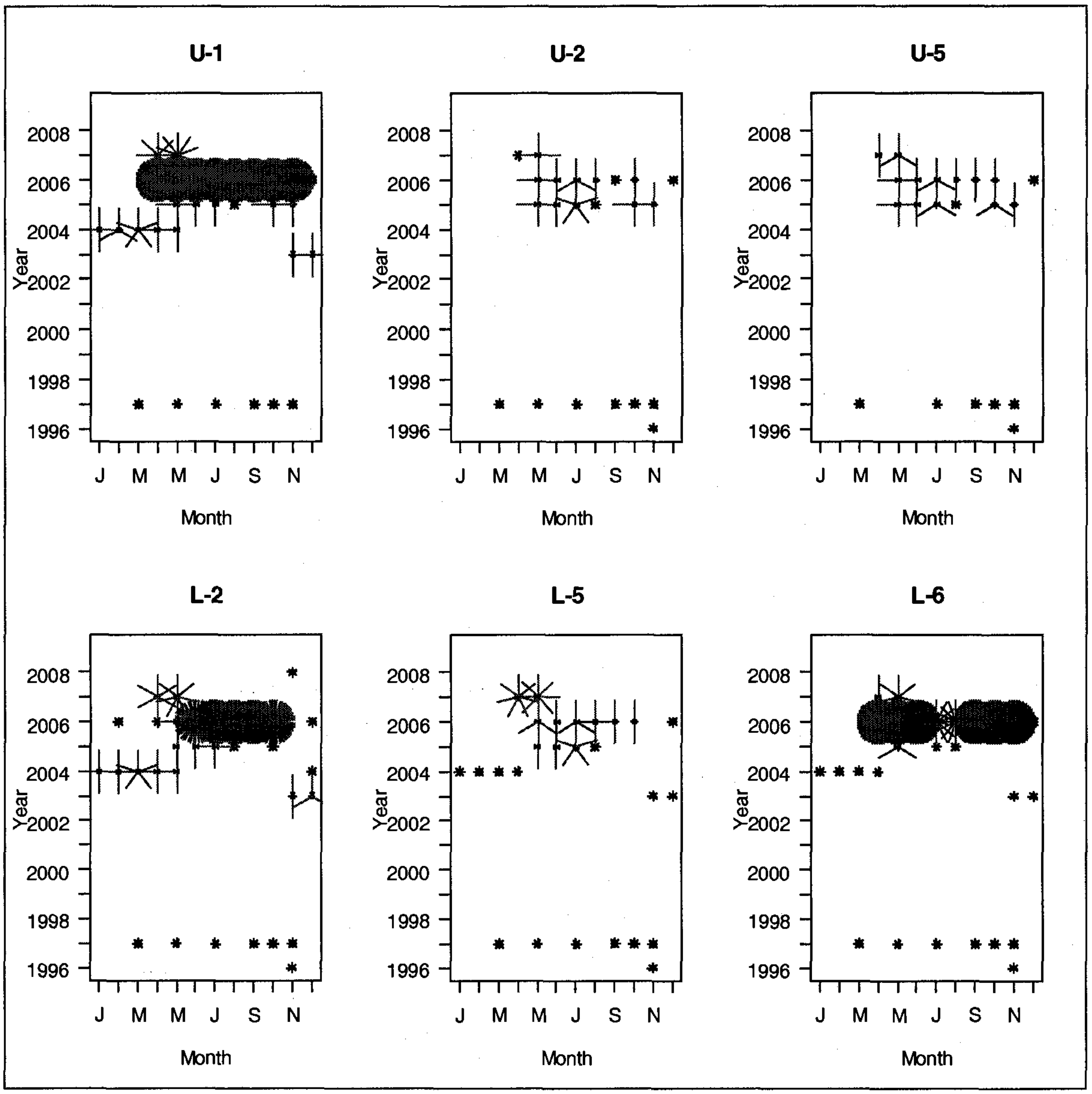

Figure 2.1 – Sunflower plot of temporal distribution of pH data used for analysis at control and impact sites. An asterisk indicates one sample per month and each additional branch off of each asterisk indicates an additional sample, for example, January of 2004 at site U-1 indicates 5 samples. Sites U-3, U-4, D-1, D-3 & D-4 not shown as a result of limited pH data.

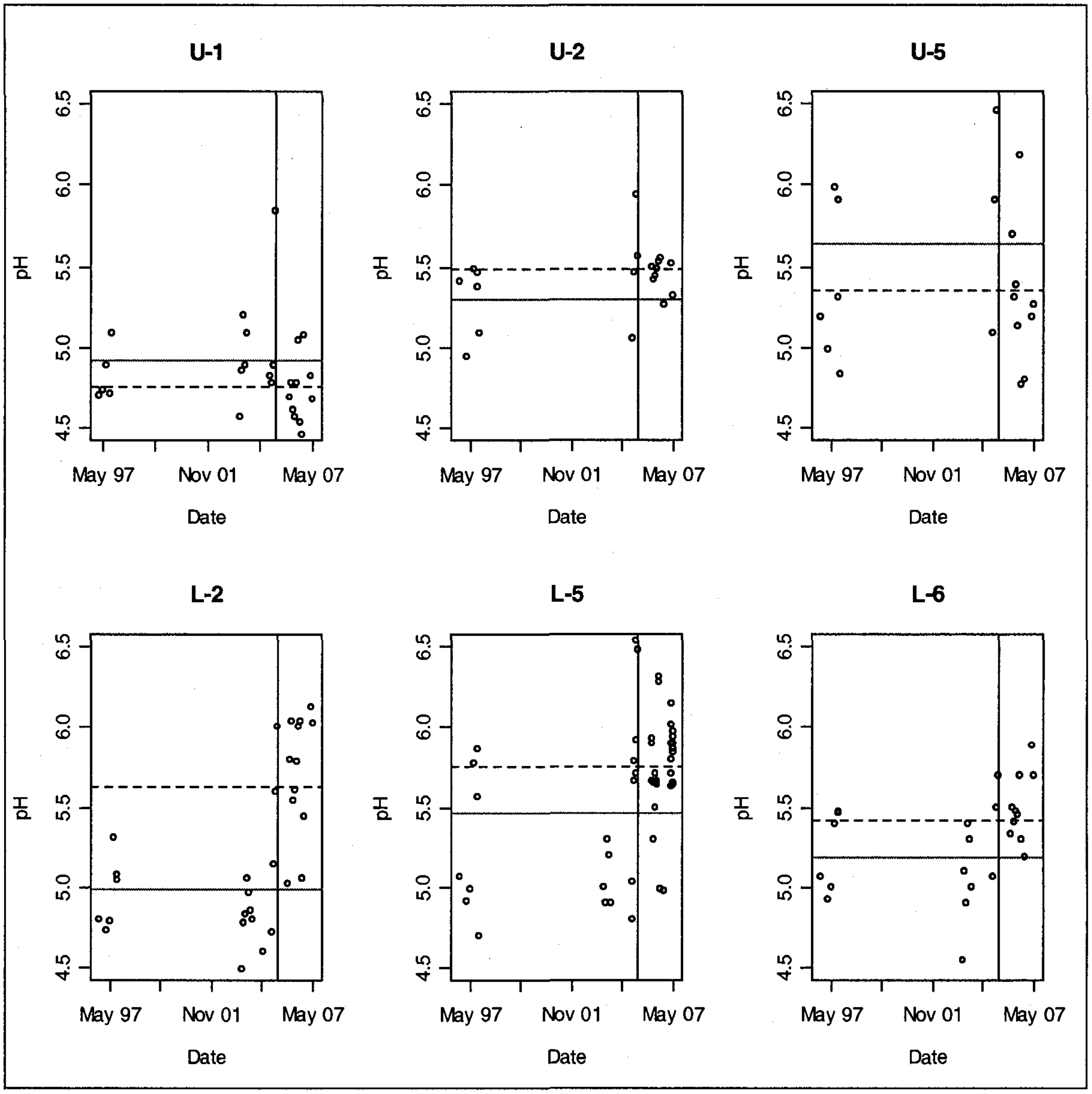

Figure 2.2 – Mean monthly pH values at control and treatment sites during pre-treatment (left side of vertical line) and post treatment (right side of vertical line). Treatment period, as indicated by vertical line used only as temporal reference point, control sites were not limed. The solid line (red in .pdf) represents the total mean pH during the pre-liming period, and the dotted line (green in .pdf) indicates total mean pH in the post-liming period. Elevated pH values immediately prior to liming were a result of drought conditions (refer to Figure 2.11). Sites U-3, U-4, D-1, D-3 & D-4 not shown as a result of limited pH data.

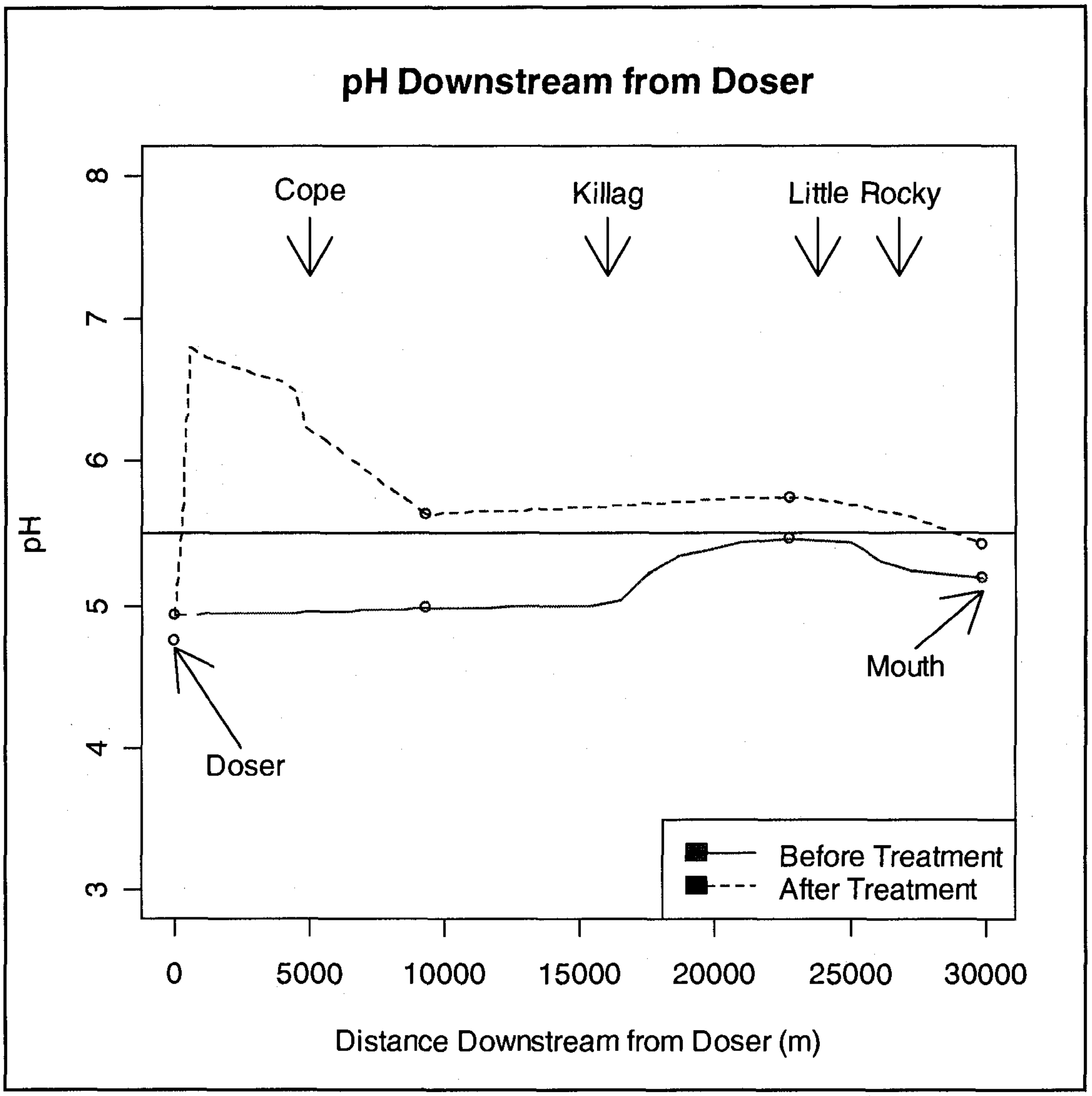

Figure 2.3 – Theoretical plot of pH on the main WRSH during a longitudinal survey from the lime doser (0m) to the rivers mouth (30000m). Circled data points indicate mean annual pH as determined from actual data. Other shorter data time series used to construct interstitial data points.

Table 2.3 – Summary of mean values for selected water quality parameters. Standard deviation in brackets. Sample size as indicated below site names unless otherwise noted. NM = Not Measured, ND = Not Detected. Data from external laboratories only (i.e. Bottle sample data).

Parameter	**Units**	**Pre-Treatment Sites**					
		U-1 (N=26)	U-2 (N=3)	U-5 (N=3)	L-2 (N=27)	L-5 (N=8)	L-6 (N=8)
Bicarbonate Alkalinity	mg/L	NM	NM	NM	NM	NM	NM
Carbonate Alkalinity	mg/L	ND	ND	ND	ND	ND	ND
Total Alkalinity	mg/L	ND	ND	ND	ND	ND	ND
Dissolved Sulfate	mg/L	2.25 (0.87)	1.81 (0.10)	2.11 (0.29)	2.08 (0.87)	1.69 (0.75)	2.07 (0.80)
Calcium	mg/L	0.82 (0.21)	0.56 (0.07)	1.81 (1.16)	0.85 (0.16)	1.08 (0.37)	0.96 (0.18)
Magnesium	mg/L	0.43 (0.10)	0.37 (0.01)	0.43 (0.10)	0.43 (0.09)	0.44 (0.10)	0.42 (0.07)
Total Organics	mg/L	6.97 (1.98)	4.37 (0.80)	6.97 (0.90)	7.02 (1.65)	6.71 (1.68)	6.21 (1.35)
Conductivity	μS/cm	31.80 (5.50)	23.50 (0.30)	32.00 (6.40)	36.50 (5.30)	33.60 (5.90)	31.60 (5.30)
Total Aluminium	μg/L	117.30 (46.60) *N=4	170.30 (85.90) *N=3	178.20 (33.20) *N=32	145.00 (70.70) *N=3	165.80 (49.90) *N=3	147.80 (90.00) *N=4
Turbidity	NTU	0.70 (0.30) *N=23	NM	NM	0.50 (0.30) *N=24	0.70 (0.80) *N=5	0.50 (0.20) *N=5
Parameter	**Units**	**Post-Treatment Sites**					
		U-1 (N=4)	U-2 (N=4)	U-5 (N=4)	L-2 (N=8)	L-5 (N=4)	L-6 (N=4)
Bicarbonate Alkalinity	mg/L	ND	ND	ND	ND	ND	ND
Carbonate Alkalinity	mg/L	ND	ND	ND	ND	ND	ND
Total Alkalinity	mg/L	ND	ND	ND	ND	ND	ND
Dissolved Sulfate	mg/L	2.62 (2.37)	1.58 (0.67)	2.18 (1.42)	2.05 (0.66)	1.96 (1.12)	1.85 (0.99)
Calcium	mg/L	0.97 (0.27)	0.61 (0.20)	1.23 (0.18)	1.13 (0.36)	1.28 (0.20)	1.32 (0.28)
Magnesium	mg/L	0.53 (0.12)	0.41 (0.07)	0.54 (0.08)	0.46 (0.07)	0.53 (0.08)	0.56 (0.11)
Total Organics	mg/L	10.67 (2.36)	4.00 (1.21)	11.53 (3.95)	10.53 (4.19)	10.90 (3.75)	10.85 (4.60)
Conductivity	μS/cm	33.7 (6.40)	24.4 (1.10)	31.8 (0.80)	32.50 (2.20)	33.20 (0.90)	34.50 (0.90)
Total Aluminium	μg/L	235.80 (5.30)	215.30 (102.70)	112.20 (56.80) *N=2	233.90 (63.20) *N=6	257.50 (67.10) *N=2	257.10 (10.60) *N=2
Turbidity	NTU	1.30 (1.13) *N=2)	0.50 (0.10) *N=3	0.90 (0.50) *N=2	0.70 (0.30) *N=23	0.90 (0.40) *N=2	0.80 (0.10) *N=2

Temperature

As a result of equipment malfunction, no data was collected during the months of July, August and part of September 2006 at Site L-6 (river's mouth)(Figs. 2.4, 2.5 & 2.6). Although this data was not included in temperature analysis, the data presented below represents four monitoring stations is though to be sufficient to provide a general overview of thermal conditions within the system.

Water temperature in the pre-treatment and post-treatment years was statistically similar ($P>0.05$) only during June at Site U-2 and Site L-6, during June & July at Site U-5 and during September at Site U-1. Temperature discrepancies in other months were in general a warmer month of May and a slightly cooler fall (Fig. 2.6).

Temperature frequently exceeded the 20°C threshold (that preferred by brook trout) during the period of May 1st through to September 30th. The months of July and August were the warmest months with temperature exceeding 20°C an average of 61.0% of the time in July (range, 48.7% - 100%) and 53.3% of the time in August (range, 28.5% - 100%) (Fig. 2.4).

Conversely, temperature rose above the 23.0°C threshold (that preferred by juvenile Atlantic salmon) less frequently. In the month of July, the threshold was breached 29.1% of the time (range, 9.8% - 68.1%), and in August was breached 8.6% of the time (range, 1.2% - 12.8%) (Fig. 2.5).

As stated, July and August were the hottest months in both years (Figs. 2.4 and 2.5), as would be expected. Sites located downstream of lentic habitat (Sites U-1, U-2 and L-6) tended to be the warmest during June, July, August and September, relative to sites with a more lotic environment upstream (Site U-5) (Figs. 2.4 & 2.5). The month of May was significantly warmer across all sites (ANOVA, $P<0.05$), though May temperatures infrequently rose above the 20°C threshold (mean, 0.9% of time (Fig. 2.4).

Maximum temperatures for the sampling sites in the Main branch WRSH, Killag River and Little River were 30°C, 29°C and 30°C, respectively, all of which occurred on August 10th 2005. This high temperature coincided with extreme low flow that lasted through to mid-September of the same year.

Interesting also was the daily range in temperatures. Diel fluctuations as large as 9.5°C were observed, with a range of 6°C or 7°C common.

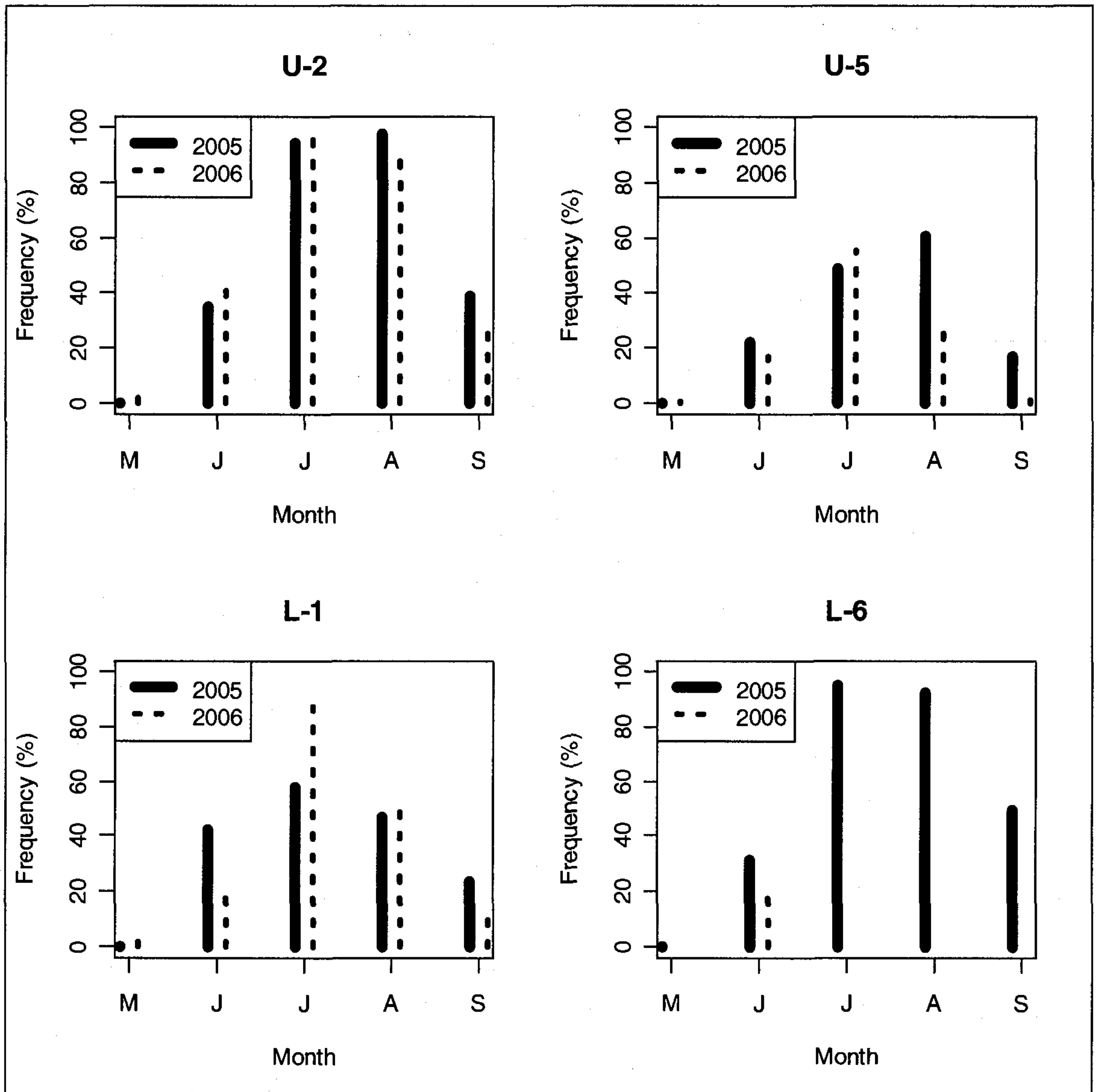

Figure 2.4 – Percentage of time from May 1st to September 30th where temperatures exceeded 20°C for 4 sites on the WRSH. Temperature data collection intervals were one hour. As a result of equipment malfunction, no data is represented in the months of July, August nor part of September 2006 at site L-6. All other "0"-values represent 0% of time above threshold.

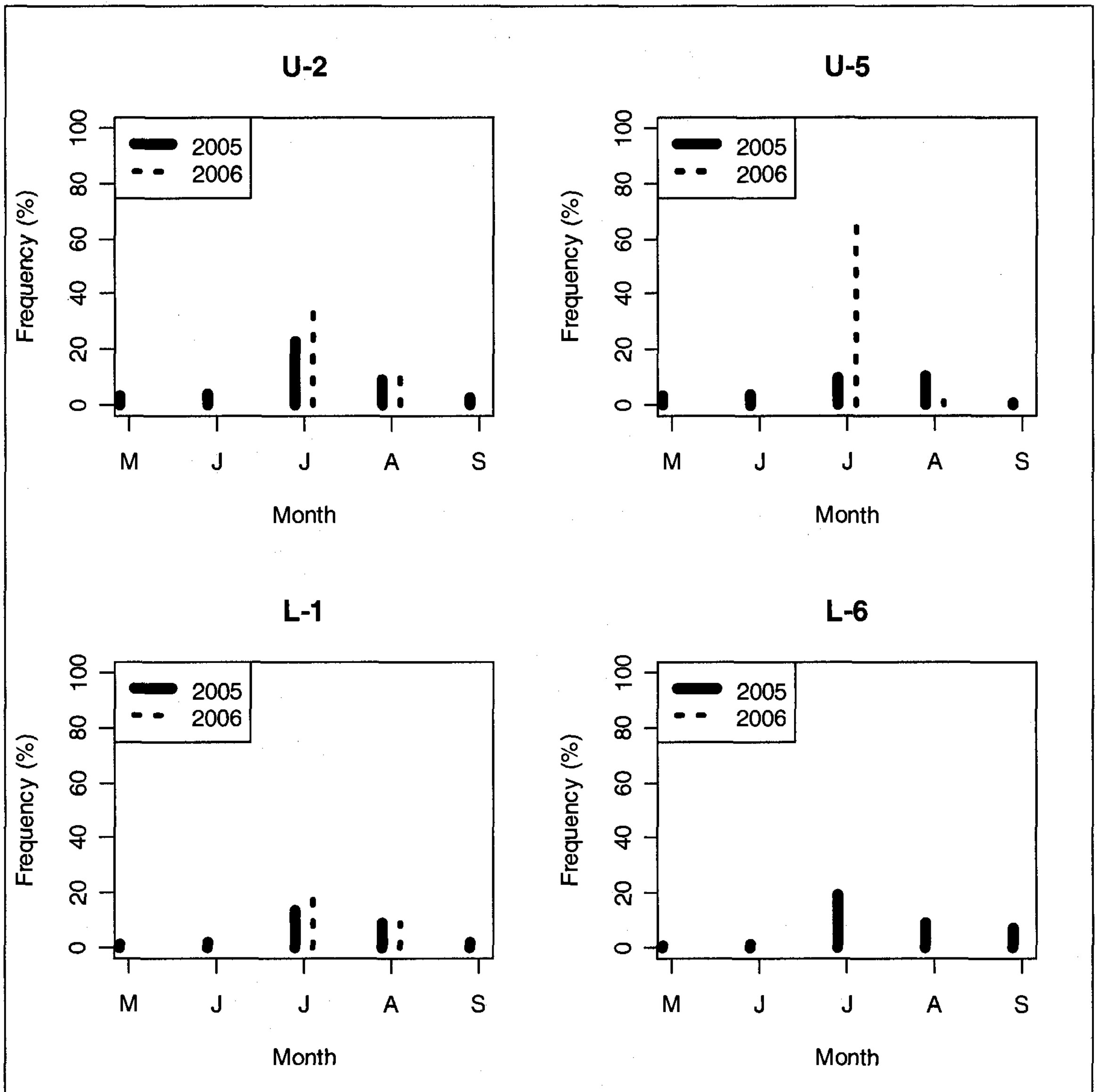

Figure 2.5 – Percentage of time from May 1st to September 30th where temperatures exceeded 23°C for 4 sites on the WRSH. Temperature data collection intervals were one hour. As a result of equipment malfunction, no data is represented in the months of July, August nor part of September 2006 at site L-6. All other "0"-values represent 0% of time above threshold.

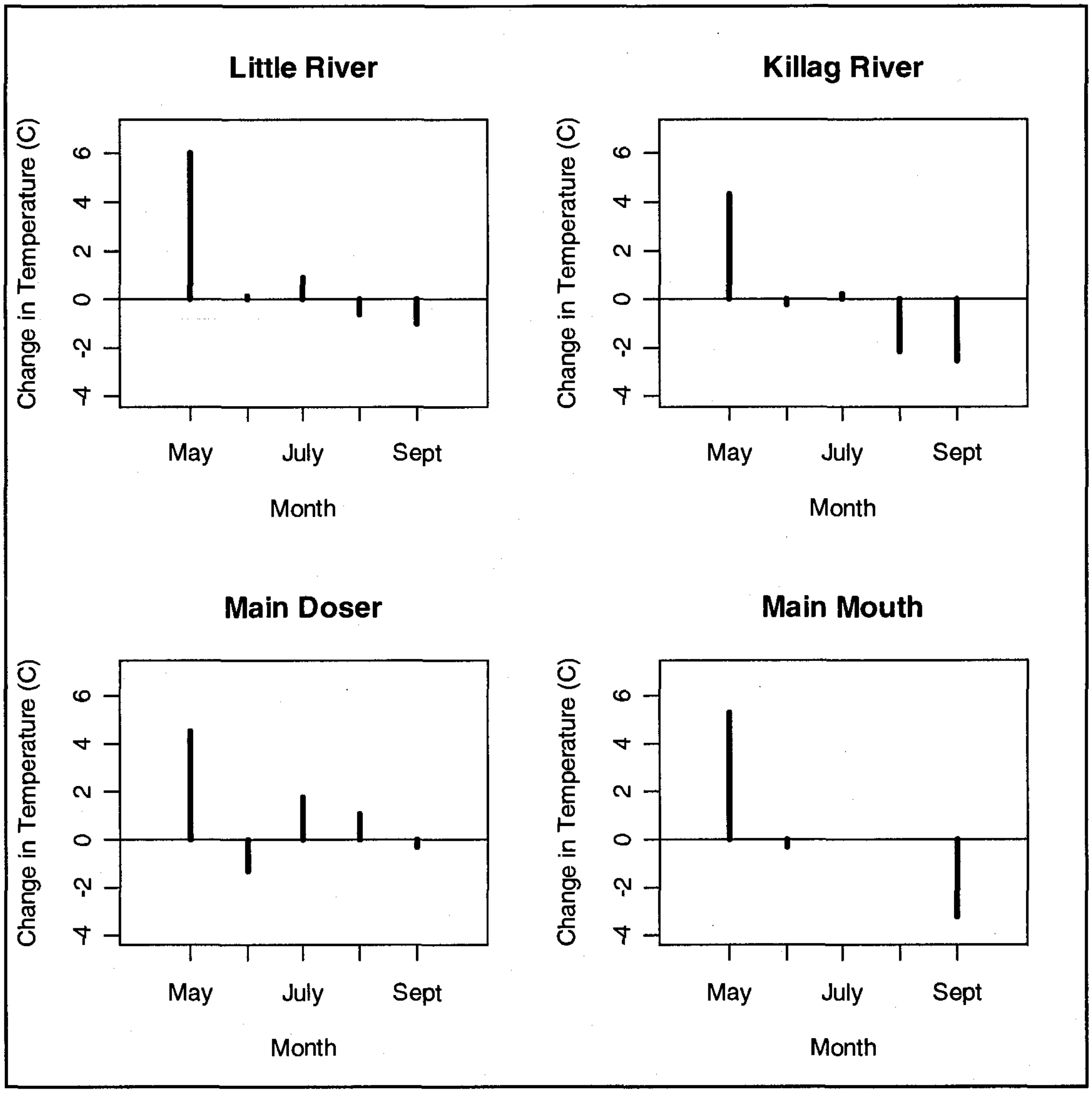

Figure 2.6 – Change in water temperature from 2005 to 2006 at four sites in the WRSH. Positive numbers indicates an increase in mean monthly temperature. July and August values at the Main Mouth site are absent due to equipment failure.

Lake Profiles

Although 5 sites were examined for stratification within Sheet Harbour Lake, only one site showed strong temperature stratification. This location was 11.97m deep and was located just off of the confluence with Rocky brook (Figure 1.3). Only the profile of the stratified site is shown (Figure 1.11), as other sites exhibited complete mixing and profiles would consist of vertical lines depicting constant dissolved oxygen and temperature

At the stratified site, water temperature dropped from 19.5 °C to approx. 12.5 °C, at a depth of approximately 9.5m. Conductivity also increased from 28 $mS \cdot cm^{-1}$ in the hyperlimnion to 70 $mS \cdot cm^{-1}$ in the hypolimnion. Furthermore, dissolved oxygen was depleted from slight supersaturation in the hyperlimnion, to near anoxia below the metalimnion. This sharp decline in DO commenced at a shallower depth than the reduction in temperature, thus offering little habitat for salmonids seeking cool temperatures and high oxygen saturation.

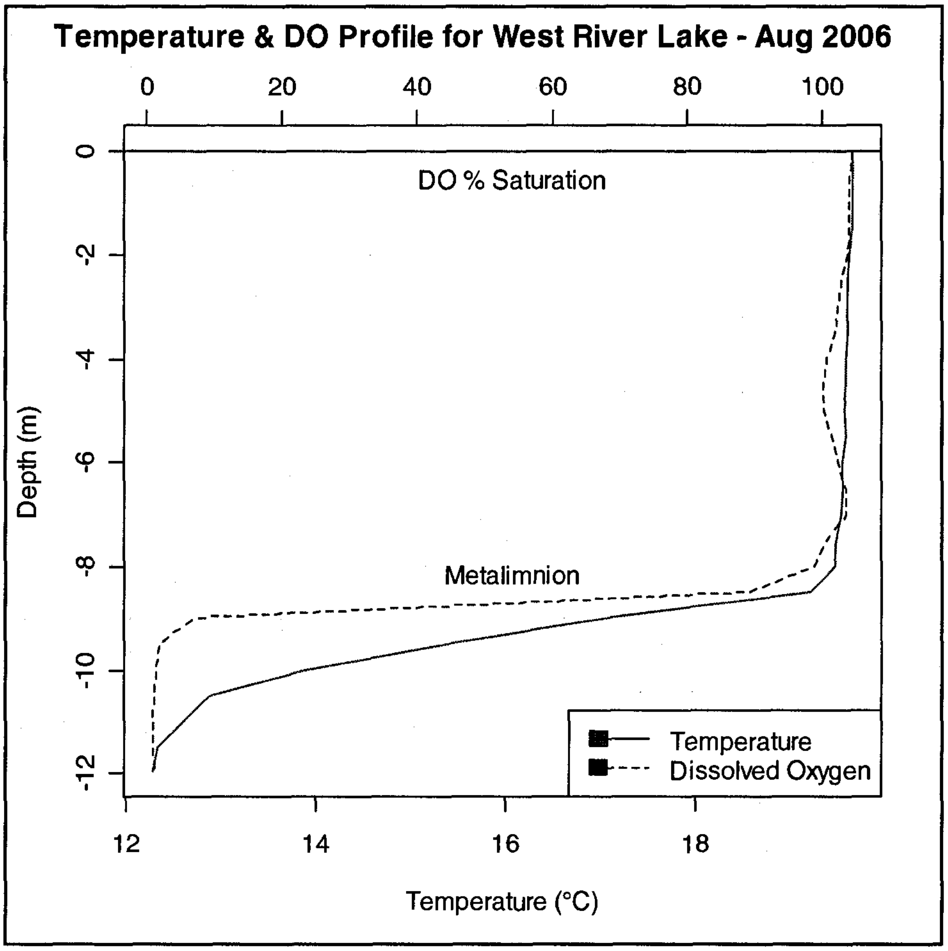

Figure 2.7 – Temperature and dissolved oxygen profile for the deepest section of Sheet Harbour Lake, WRSH, August 2006.

Flow/Discharge

The percent of total system discharge being treated with lime is quite low. Over the four data sets, the doser water (initial treated water) represented between 6.0% and 8.1% of the total discharge of the system, with a mean value of 6.7% (Table. 1.3).

At the Beaver Dam Mines road (site L-2), some 8900m downstream, the treated water is diluted by a factor of between 3.42 and 3.91 with a mean of 3.69. By the time the water has reached the Iron Bridge Pool (site L-5), the treated water has been diluted by a factor of 6.03 and 8.75 with a mean of 7.49.

Site	Percent (%) of Total Discharge			
	July 11 2005	May 16 2006	July 5 2006	August 17 2006
Doser	6.0	08.1	6.0	6.8
Upper Rocky	2.8	6.2	5.5	5.6
Beaver Brook	1.8	1.5	3.5	1.2
Killag River	1.5	19.9	15.0	14.6
Little River	1.3	17.2	14.8	21.8
Lower Rocky	15.3	13.9	15.3	6.4
Other Sources	46.1	33.2	39.9	43.6
Mouth Discharge	7.98 $m^{3}\cdot s^{-1}$	6.63 $m^{3}\cdot s^{-1}$	3.99 $m^{3}\cdot s^{-1}$	4.86 $m^{3}\cdot s^{-1}$

Table 2.4 – Discharge summaries (as percent total discharge) for various sites within or entering the Main WRSH. Rivers are listed in order from the most upstream location to the most downstream location. Doser=Site U-1, Little River = Site U-3 and Mouth = Site L-6.Upper Rocky and Beaver Brook located between Site L-1 and L2. Killag River measured at confluence with Site L-3. Lower Rocky located 1.8 km upstream from Site L-6 (Figure 1.3). The amount of discharge attributed to "other sources" was the total difference between the discharge at the systems mouth and the sum total of al measured discharges.

A comparison of monthly precipitation between the pre-treatment year of 2005 and the post-treatment year of 2006 (Figure 2.12) revealed that the summer of 2006 was considerably wetter than the summer of 2005, though this difference was not statistically significant (ANOVA, P>0.38) (Table 2.4). Figure 2.11 also shows the general relationship between precipitation and stream pH, where drought conditions, such as that of the 2005 summer months, correlates with elevated stream pH. This elevations in stream pH can also be seen in Figure 2.4.

Compared to historical monthly means (1940-1971), the discharges calculated at the rivers mouth were higher than expected (Figure 2.11). No data exists on the standard deviations of discharges nor does information exist detailing the methods used to calculate the discharge calculations of the 40's to 70's, making absolute comparison difficult. Additionally, flows measured in the mid to late 1900's reflect a flow regime dominated by dams. At one point, over 30 dams were located on the river, used mainly as water storage for log driving to the mill at the base of the system (Anonymous 1973). These structures were maintained until Hurricane Beth came ashore in August of 1971. This storm dumped approximately 254 mm of rain on the basin, flooding the river and destroying a lumber mill located in Sheet Harbour as well as damaging many of the dams (Anonymous 1973). With an estimated cost of rebuilding of approximately one million dollars , the Scott Paper Co. discontinued lumber processing in the area and the series of dams were no longer required (Anonymous 1972). Their remnants still remain and thier legacy of stream channel modifications continues to alter the available fish habitat.

In addition to direct measurements of discharge, precipitation data was used as a proxy for discharge, and to a degree, river acidity. Figure 1.13 shows a general relationship of higher pH values following long periods of drought and decreased pH following large rain events. This chart also affirms the observation that the summer of 2006 was wetter than the summer of 2005.

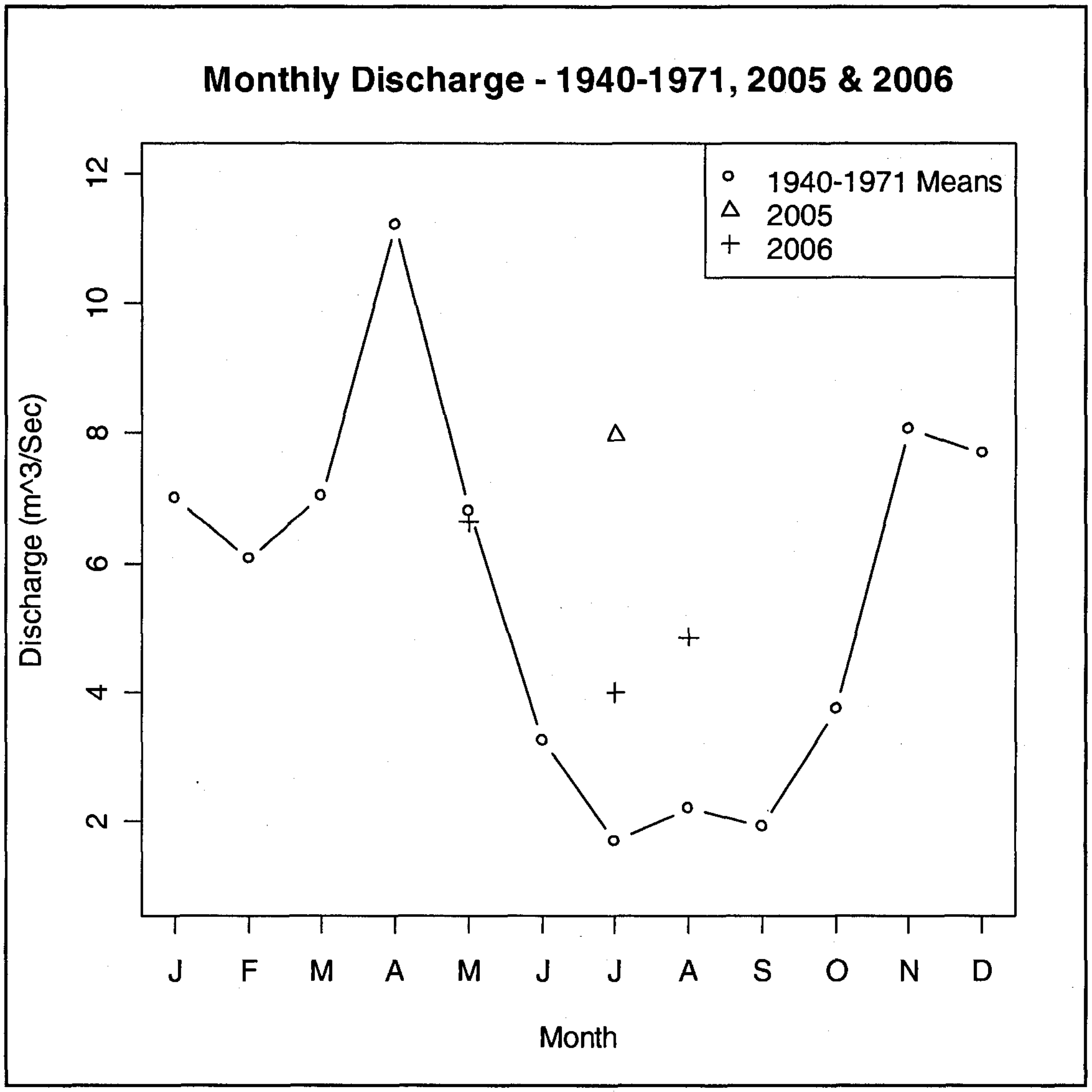

Figure 2.8 – Historical and recent discharges at the mouth (Site L-6) of WRSH. The lack of data post-1971 is due in part to a loss of equipment during Hurricane Beth (1971).

Table 2.5 – ANOVA table for total precipitation at Malay Falls, NS, March 1st 2005 to Sept. 1st 2006. df = degrees of freedom, Sum Sq = Total Sum of Squares (total variation), Mean Sq = Mean Sq (sum Sq/df), F-Value = Test Statistic, Pr(>F) = Probability of being greater than F-Value.

Source of Variation	df	SS	MSS	F-Value	Pr(>F)
Year	1	63	63	0.7708	0.38039
Month	11	1747	159	1.9288	**0.03370**
Year:Month	5	439	88	1.0675	0.37748
Residuals	508	41828	82		

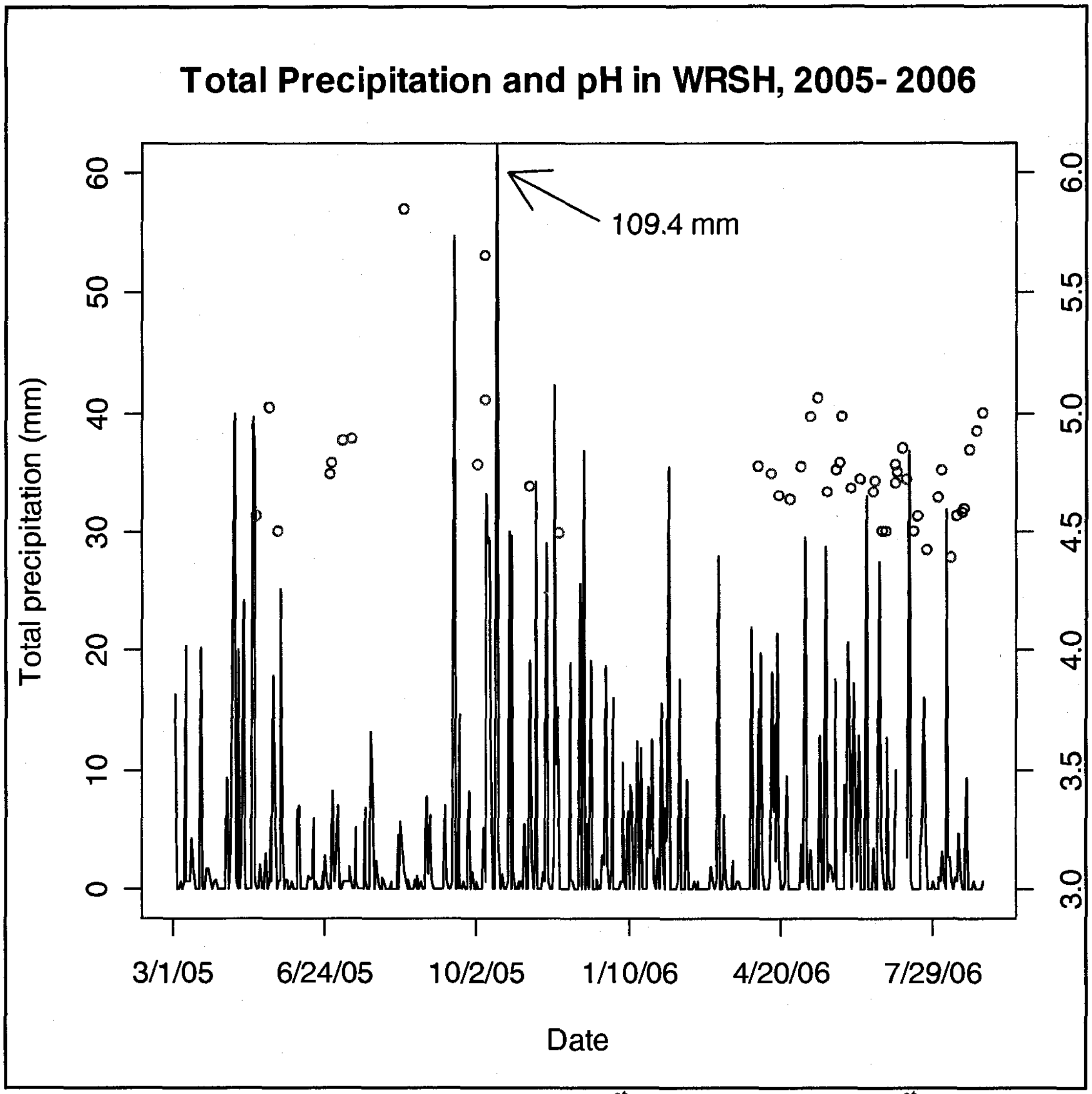

Figure 2.9 – Precipitation record from March 1st 2005 to September 1st 2006 as seen at Malay Falls, NS. Measured pH values from the lime doser (site 1) at corresponding times are represented by the circle data points. Scale on the right side represents pH values.

Thermal refugia

On the Killag, Little and Main branch WRSH, a total of 6800, 5500 and 8700 linear meters of river, respectively, were examined for the presence of coolwater refugia. A total of 13 significant springs / seeps were identified. They range in surface area from 2 m^2 to approximately 60 m^2 and have water temperature that in mid-summer averages approximately 14.5 °C. Two of the most important springs, as presumed from the number of trout observed congregating there during periods of high river temperature, are both located in tributaries, one in the Killag River and one in the Little River. The Killag spring has a relatively high midsummer pH (5.43), a temperature of approximately 15°C, dissolved oxygen of approximately 100 % saturation and a conductivity of 28 $mS \cdot cm^{-1}$, which is similar to the main channel of the Killag River. The Little River spring had slightly lower pH of 5.0 compared to the main channel, a temperature of approximately 15.0 °C, dissolved oxygen of only 70 % saturation and a conductivity of representative of the channel at approximately 40 $mS \cdot cm^{-1}$. The above data indicated that the springs are short-pathway springs, draining the adjacent hillsides and entering the rivers via slow creeks approximately 1m in width. The two springs differ by the area into which they pour.

The main Killag spring empties into a small stillwater where depths average only 0.5-1m and the spring water is quickly mixed. The Little River spring emptied into a large bowl-shaped basin, with minimal flow and depths of up to 7m.

Discussion

Water Chemistry

Lacroix and Knox (2005) considered the West River to be suitable for salmon rearing in 20% of the habitat sampled, based on observed minimum pH values. They also stated that even habitat with the relatively higher pH, in the range of 5.0 to 5.5, would cause some loss of salmon production. Therefore, the target pH for the system was set at 5.5 or above.

The pH target of 5.5 was set for river mouth, however the most downstream area providing typical lotic salmon parr rearing habitat, was Iron Bridge Pool (Site L-5). Below this, pH is important mainly to smolts en route to the estuary, and potentially as lentic habitat for parr. Consequently, arguably the most important section in which to closely regulate pH is from site L-5 upstream. During the smolt emigration period, the dose was increased to ensure a pH of 5.5 at the point where the fresh and saltwater mix and high acidity is no longer a threat due to the buffering ability of sea water. The target pH was met at most locations in the treated river.

The addition of lime by the doser is governed by flow and episodes of high acidity during spring and fall flushing events should be dampened in treated waters. This may be extremely important as even relatively short episodes of acidification (days to hours) may be as detrimental as chronic acidification to many salmonid species (Baker et al. 1996, Gunn 1986, Lacroix and Korman 1996, Lacroix 1987b, Magee 2003). The West River is thought to be episodically acidic (Hindar 2001, Lacroix and Knox 2005). These minima generally occurred between November and March (Lacroix and Knox 2005). Coincidentally, the most sensitive life stages of many salmonid fishes also occurs at this time, namely as pre-smolts during March. During the months of November through March, pH was recorded on data loggers (as described above) or during monthly trips to the system. There were issues of ice formation that made data logging unsafe and impractical, therefore it is possible that absolute minimum pH values were under sampled or missed all together. This was not considered a major issue for this study, as pre- and post-liming data follows similar temporal patterns.

Historically, pre-liming minima were shown to be in the range of 4.0 to 4.5 (Lacroix and Knox 2005) however recent pre-liming data, collected by the NSSA and for this study, showed considerably higher minima values, with the majority in the pH class of 4.5 to 5.0 (Figure 2.2). Following commencement of treatment, minima in treated waters reached only 4.97 during this study, which is considered to pose a problem to only a small proportion of salmon during specific life stages, namely as swim-up fry and during smoltification (Lacroix and Knox 2005). It is important to note that this minima coincided with the previously mentioned lime doser malfunction in the fall of 2006. This is of concern and steps have been implemented to reduce the likelihood of reoccurrence. It is therefore reasonable to assume that the pH minima would have been even higher under flawless operation.

Indices of the state of acidification and its effects on the biota of the West River were also examined by assessing aspects of the river's water chemistry other then pH.

The ability to buffer against further inputs of acidity is an important part of steam water chemistry. Without buffering ability, a stream may be highly volatile and any input of acidity, from the atmosphere or otherwise, would translate increased stream acidity. Throughout the West River, alkalinity was low. In control sections of the river, this reflects the thin soils that have been stripped of their acid neutralizing capacity and consequent alkalinity. In treated sections, this lack of alkalinity demonstrated the solubility of lime in the acidic water, and the deep deficit of buffering materials throughout the system.

As discussed earlier in this chapter, aluminium in acidified waters is thought to be the major physiological hurdle facing aquatic organisms (Baker and Scholfield 1982, Baldigo 1997, Cronan and Schofield 1979, Herrmann 2001, Lacroix 1986, McCahon et al. 1989, Winter et al. 2005). In many systems, biological acid thresholds are masked by the interactions with labile aluminium. In organic-rich waters however, aluminium may not pose such a threat, and it has been shown that organic carbon complex with free aluminium, rendering it unavailable for bio-uptake, effectively shielding fish from the toxicity of aluminium (Lacroix 1986, Peterson et al. 1989). While the West River, Sheet Harbour does contain substantial quantities of total aluminium (63 to 304 $mg \cdot l^{-1}$), labile aluminium levels are unknown. These levels of total aluminium are consistent with other rivers in the southern upland (DFO 2000).

In effort to discern anthropogenic acidity from natural acidity and as a proxy for color, total organic carbon (of which the majority will be dissolved organic carbon) was measured. Like total organic carbon (TOC), dissolved organic carbon (DOC) is shown to strongly correlate with pH (Lacroix and Knox 2005), with increasing levels of DOC leading to decreasing pH. The West River naturally contains high levels of fulvic and humic acids, derived from peat bogs and conifer forests, contributing to its dark color and high DOC/TOC. Though this may naturally drive pH downwards, anthropogenic acidification has likely resulted in further increases in acidity.

Knowing the high levels of DOC that exist in the West River, it may be reasonable to assume that the labile aluminium present in the West River would be sequestered by the DOC complexing, thus protecting fish from its potentially harmful effects. Further investigation of the aluminium speciation and DOC/aluminium interactions of the West River is advisable.

In summary, liming has had significant positive effects on stream pH in the WRSH. The target mean pH of 5.5 has been met (or very nearly met) at all sections of the treated stream and pH minima are nearing biologically acceptable levels. However, if the acidity of the West River has been decreased, but alkalinity has not increased, the pH of the water in treated sections is very much a function of lime dosage and no surplus of lime is being administered. That is, the water is being sufficiently treated, but the current liming regime leaves little room for error as a decrease in lime would result in a change in pH. Furthermore, alkalinity levels in control sections also remain below detectable levels, indicating that natural buffering capacity remains critically low or even non-existent. If liming on the West River is terminated, the pH of treated waters would presumably return to a pre-liming state.

Temperature

In an extensive temperature survey of Nova Scotian rivers, MacMillan and Crandlemere (2004) showed little correlation between Atlantic salmon densities and temperature in many Nova Scotia streams, while brook trout densities and biomass decreased with increasing temperature. It is therefore reasonable to assume that based on the higher than optimal temperatures observed in the West River, Atlantic salmon are most likely threatened, but perhaps affecting growth more so than survival. Compounded annually, long-term population viability may be affected.

Temperature limitations on brook trout populations are also likely, but direct mortality may be more significant than that experienced by salmon, as the trout's lower preferred temperature was exceeded more frequently. Consequently, a relationship between the amount of coolwater refugia and the standing crop of brook trout should exist within this system.

The temperature of the West River, Sheet Harbour showed substantial inter-annual, monthly (Figures 2.7 & 2.8) and daily temperature variation. Diel temperature fluctuations of up to 9.5 °C are likely a function of wide shallow sections of river and the waters low albedo produced by the high organic carbon content.

The Killag River temperature loggers showed the coolest stream water of the system while the Upper Little River and the Mouth of the Main West River showed the warmest (Figure 1.7). A probable reason for these sites being warm is that these sites are located below large lakes, Lake Alma and Sheet Harbour Lake that have large surface areas (3.84 and 1.59 km^2, respectively) that absorb heat energy from the sun.

Given the long duration of high temperatures above that preferred by both salmon and trout, it would be reasonable to expect that Atlantic salmon and brook trout production may be limited by temperature, and that these fish need seek areas of thermal refugia. The degree to which salmonid populations would be affected is largely unknown, and the importance of temperature-induced salmon production limitations, relative to limitations imposed by low pH, has not been explored.

Lake profiles

The survey performed in August 2006 indicated that there was no cool water habitat provided by Sheet Harbour Lake. Both oxygen and temperature began decreasing at approximately 9m however oxygen decreased at a much more rapid rate than did temperature. Therefore, at depths where temperature began to reach suitable levels for fish comfort, the oxygen was at critical levels. As the lake has extensive macrophyte growth, accumulated logs from the historic lumber industry and high rates of detritus settling, high biological oxygen demand at depth could be expected and consequent anoxia would result.

Conductivity measurements made during the profile indicated that specific conductance increased rapidly below the metalimnion, to values of 70 *u*S/cm, approximately twice that of the hyperlimnetic waters. These values were not seen elsewhere in the system. As groundwater tends to be cool, oxygen poor and relatively higher in conductivity, it may be reasonable to suspect that the cool water of the hypolimnion is derived from aquifers. The stratification would therefore not have been derived in a traditional fashion where warming surface water segregates from cool benthic water, but rather represents the pooling of groundwater in a bathymetric depression. Also, the lack of oxygen may therefore be explained by insufficient mixing across the metalimnion as opposed to biological oxygen demand by benthic sediment/detritus.

After talking with homeowners on the shores of the lake, it was discovered that the average depth of their wells was 8 to 9m, further supporting the hypothesis of groundwater infusion into the lake. Further investigation of surface lithology and stratigraphy would clarify this phenomenon.

It is obviously therefore that Sheet Harbour lake offers little thermal refugia for salmonids attempting to escape the high temperature of summer, and that crenon spring habitat is likely the most important refugia.

Flow/Discharge

The weather data collected from the Malay Falls weather station showed statistically similar total precipitation during the months of March through to the first of September during the pre- and post-treatment years (P=0.38)(Table 1.4). It is therefore assumed that the two years are comparable in terms of flow regimes.

We were consistent with both method and site selection during all flow calculation forays however we were forced, due to technical problems, to use three separate flow meters. The issue of comparability between meters was considered to be small and we directly compared results derived from all flow meters.

While every effort was made to calculate discharge from all the major tributaries, due to access issues and time constraints, not all inputs could be measured. Other sources contributed for up to 46.1% of the total discharge for the system. These "other" sources can be explained from both inputs such as Cope Brook, Paul Brook, Keef Brook, Tent Brook and a myriad of other small brooks. Also, direct inputs from proximal riparian zones likely contribute significantly to the systems water supply.

Due to its relatively high position within the watershed, the lime doser treats only a small portion of the total water discharged at he rivers mouth, ranging from 6.8 to 8.1%. As pH of the entire treated section of river has improved, this location maximizes the length of treatable River, though it does have implications on the effectiveness of liming. At this point, a dose of $5.5 g \cdot m^{-3}$ is near the saturation point for waters flowing by the doser location, and as previously stated, alkalinity in treated water remains critically low. Therefore, the doser does sufficiently treat the system below, but deviations from current flow regimes and/or a decrease in stream pH across the system may reduce the effectiveness of the lime doser.

Thermal Refugia

The sites we identified were the most evident (due to size and location) and were presumably the most important for trout. Salmon however may relate to smaller springs located in riffle sections, as none were observed in the larger springs. During our survey, these micro-springs may have been easily overlooked due to their small size and quick mixing.

Of concern are the effects of forestry on these important refugia. Rates and manner of interaction between surface water and ground water, in the hyporheic zone, are known to change with cutting of the drainage basin (Curry et al. 2002). Some portion of the Killag river's major spring has been recently cut and many of the smaller springs lay within large areas of clear-cutting. This is of concern as it has been shown that stream temperature (Corbett et al. 1978) and dissolved nutrient/ion/metal leaching into nearby streams (Dahlgren and Driscoll 1994, Hornbeck et al. 1986) may increase as a result of clear-cutting practices.

As a large number of mature trout use these springs during the high-temperature months of summer, altered spring habitat may have immense effects on the quantity and quality of trout within the river. The importance of these springs for salmon parr remains unknown fort the West River, Sheet Harbour as no observations of salmon within spring habitats occurred. Given current hydrology of the system, presumably sufficient thermal refugia exists to support the current salmonid populations, however this may limit further production. Again, the role of temperature-induced limitations, relative to low pH-induced limitations is unknown.

Conclusions

Assessment of the conditions of the West River prior to treatment showed that acidic conditions in the river limited salmon survival. As a result, it is logical to assume that the river's salmon smolt production was also affected.

Effects of acid mitigation are that a decrease in mean acidity (increase in mean pH), and as a result, salmon survival in treated sections of the river should increase. In the uppermost treated sections of river, acid-related mortality is likely to be zero. It is also the upper section of the river where some of the best habitat, recently un-inhabited by juvenile salmon as a result of low pH, stands to realize the largest gains in salmon production.

The survey of chemical and physical habitat within the river showed that factors unrelated to acidity may also limit salmon production. Stream temperature of the main branch West River was above that preferred by both brook trout and Atlantic salmon. Areas of thermal refuge in the form of macro-springs were identified, and their use by brook trout was evident, indicating that brook trout production within the river is likely limited by temperature, and as a result, the availability of spring habitat. Atlantic salmon production may be limited, though I observed little evidence of spring usage by salmon parr.

Therefore, knowing the conditions that now exist in the West River under a newly limed state, it is reasonable to assume that Atlantic salmon production will likely increase. An increase in brook trout production is not as predictable as high temperature limitations may superseded limitations imposed by high acidity

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CHAPTER 3

EFFECTS OF LIME DOSING ON PERIPHYTON AND AQUATIC INVERTEBRATE COMMUNITIES

Introduction

Aquatic invertebrates are as equally well suited to serve as indicators of impacts of acidification as are fish. Acid sensitive taxa tend to be those with external gills such as the Ephemeroptera, Plecoptera and some Trichoptera, though some taxa within the family Chironomidae are also rather acid sensitive (Okland and Okland 1986). These taxa are usually the first to be affected by acid deposition (Courtney 2000, Fjellheim and Raddum 1995, Fjellheim 2001). Unlike fish however, for most invertebrate taxa, a generation consists of one year or less, which facilitates potentially faster response to environmental change. For these reasons, the study of macroinvertebrate assemblages should be an integral part of any acid mitigation assessment program.

Invertebrate densities (abundances) have been shown to decrease and relative dominance of taxa (or groupings such as grazers, collectors and predators) has been shown to shift following acidification (Hall et al. 1980, Magnuson 1984). It is therefore logical that opposite trends would be observed following acid mitigation, provided sufficient seeding from neighbouring areas. Increases in abundance, shifting relative dominance of benthic communities and the reappearance of acid sensitive species have been observed post-liming on several occasions (Fjellheim et al. 2001, Lingdell and Engblom 1995). In a study of acid stressed lake communities, Locke (1996) also found that food web complexity and food chain length increased with pH, while invertebrate richness varied with pH, peaking at values of 5.5 to 6.0.

Shifts in total abundance as well as abundance of feeding guilds (grazers, collectors and predators) also stimulates "ripple effects" for other trophic levels, namely fish which feed upon the invertebrates (discussed in chapter 3) and the periphyton community (Bowlby and Roff 1986).

Following acidification, and a consequent decrease in abundance of grazing invertebrate consumers, periphyton biomass may increase. The opposite has been observed following liming where decreases in biomass following liming was attributed to the rebound of acid sensitive herbivore invertebrates (Magnuson 1984). Therefore, as an adjunct to benthic macroinvertebrate monitoring, periphyton biomass monitoring may be suitable to assess the effects of liming. However, as periphyton communities are prone to strong trophic interactions, results are often difficult to interpret.

For the WRSH acid mitigation project, both aquatic macro-invertebrates and epilithic periphyton have been assessed as lower trophic level communities may indicate change at a timeline compatible with the duration of this study. The primary objective of this chapter was to determine if liming has imposed changes in the aquatic insect and periphyton communities. I hypothesize that both aquatic invertebrate and periphyton abundance and community composition would shift as a result of liming. Furthermore, the implications of this monitoring may extend past evidence of change, as invertebrate abundance, as the primary food source for salmonids, may directly affect the condition, growth and abundance of insectivorous fishes. I hypothesize that increased invertebrate abundance and would result in increased condition and growth of brook trout and juvenile Atlantic salmon.

Methods

Periphyton Field Procedures

At each site, three sample replicates were taken, each from separate rocks, located on the right, center and left side of the channel within a given sampling site. Rocks were chosen at random by blindly traversing the streambed in a bank-to-bank, zigzag motion. A second researcher on the River's bank indicated random stopping points while blindfolded, at which time, the researcher in the water picked up the rock nearest to their right foot that had a maximum dimension between 15 cm and 50 cm - a size suited for transport to the rivers bank. A 4 cm^2 flexible template was pseudorandomly laid upon the rock so that the non-embedded surface (as originally oriented in-situ) was sampled. A round Dremel brand 442 carbon steel brush (www.Dremel.com), affixed to a 12v cordless drill, was used to scrape the area inside the template. Cleaning duration generally lasted from 10-20 seconds, or until the sample area was deemed clean. The removed substance was washed into a container pre-rinsed with river water, using a 500 ml wash bottle. The contents of the container were then rinsed into a 500ml Nalgene filter unit attached to a Nalgene hand operated vacuum pump with vacuum gauge. The sample was pre-filtered using Whatman GF/D filter and the filtered sample was then filtered again using a Whatman GF/C filter. Both filters were folded, inserted into a folded Whatman qualitative paper filter, then labeled and stored in a zip-top plastic bag in a -20°C freezer. Total time from field to freezer was generally less than 48 hours.

Total quantity of water used to wash the sample through the filter was also recorded. Because the water used for washing came from the river, and potentially held ambient chlorophyll, via phytoplankton, a 500 ml sample was taken mid-water column and also filtered. This was the first task at each site, and was done prior to entering the water, minimizing the risk of introducing additional chlorophyll to the water through disturbance of periphyton.

The sampling schedule consisted of two sampling periods in both the pre- and post-treatment year. Sampling took place on July 6 and September 9 in 2005 and July 18 and October 21 in 2006. On each date, 8 sites were sampled, 4 of which were control (U-1, U-2, U-4 & U-5) and 4 of which were impact sites (L-1, L-2, L-4, L-5).

Periphyton Laboratory Procedures

In the laboratory, the frozen periphyton samples were removed from the freezer. The sample glass fiber filter was removed from the protective paper filter covering and using tweezers, placed in a centrifuge vial, along with 10 ml of reagent grade (99+%) acetone. The vials were then placed in a refrigeration unit and left for 24 hours. Following the 24 hour period, samples were removed from cold storage and allowed to equilibrate to room temperature. Samples were then centrifuged for 15 minutes. The top supernatant was decanted, so as to prevent the entry of filter particles into the sample. The sample was placed in a cuvette and the acetone/periphyton aliquot was processed with a Turner designs fluorometer. If need be, the samples were diluted with known quantities of 99+% acetone to assure the sample would fall with the detection range of the fluorometer.

The concentration given by the fluorometer, in mg/ml was correlated for dilution and represented as milligrams chlorophyll *a* per 2 cm by 2 cm sample. This again was converted into a milligram chlorophyll *a* per square centimetre of streambed.

Periphyton Statistical Analysis

One-way ANOVA's were performed for chlorophyll concentrations between sites, treatments, years and sampling dates, using RGUI v. 2.3.1 (R development core team, 2005.). If the ANOVA showed a significant difference, a Tukey's Honest Significant Difference (HSD) post-hoc test was conducted.

Aquatic Invertebrate Field Procedures

All procedures, both field and laboratory, followed the Canadian Aquatic Biomonitoring Protocol (Reynoldson et al. 1997). Six sites were chosen, three of which were in treated sections of the river (Sites L-2, L-4 & L-5), while three were in untreated or reference sections of the river (Sites U-1, U-2 & U-5)(Table 0.1). Site L-6 was not sampled due to the bedrock nature of that section. All sites were in third order or higher stream sections to maintain consistency and to coincide with areas frequented by salmonids. Sites were sampled twice a year, during July and September. At each site, a sampling section was chosen such that its length was 6 times the bankfull width. In this way, at least one pool-riffle sequence was sampled. Using a triangular framed kick-net (mesh size 400μm), three replicate transects were taken at each site, moving from bank to bank in an upstream zigzagging motion. Each replicates consisted of a one minute kick sample, covering the streambed at a constant pace. Invertebrates captured in the net were placed in a 500ml glass mason jar with a solution of 10% buffered formalin. Care was exercised to ensure that no invertebrates were left in the net. The samples were left to sit for one to three days and then transferred to a solution of 70% ethanol.

Aquatic Invertebrate Laboratory Procedures

Within the first week post-collection, all samples underwent an initial sorting process. First, any large or irregular materials included in the sample, such as large twigs or rocks, were thoroughly rinsed over a 500 μm mesh sieve and discarded. Secondly, if a sample contained a large amount of sand and/or gravel, the sample was elutriated and the lighter organics were washed into the sieve. The elutriated sand/gravel portion of the sample was inspected for invertebrates and those found were added to the materials in the sieve. The remaining sand/gravel from the elutriated sample was preserved with 70% ethanol and labelled. All invertebrates and detritus remaining in the sieve were again placed in 70% ethanol and stored for further processing.

Initially, sample sorting was done without the use of a microscope. Samples were rinsed with tap water to remove all ethanol. The sample was placed in an enamel sorting tray and the whole sample was picked, with all invertebrates counted and separated into vials for each family, preserved in 70% ethanol and labeled. After processing only 11 samples, it was determined that this was not a sufficient manner of processing.

Samples were then processed by using a 100-cell subsampler. This involved rinsing all invertebrates and organics in a 500 μm sieve and this was washed with tap water and placed in a beaker. Using a 100-cell Plexiglas sub-sampler, the sample was split into 100 sub-samples, from which cells were selected using a random number generator (www.random.org). Cells were placed into petri dishes and analyzed under a 6.4 power dissecting microscope, identifying invertebrates to order. Consecutive cells were processed until a minimum of 300 invertebrates had been picked. The sample remaining in the sub-sampler was preserved in 70% ethanol and labeled, as was the remaining detritus from the sorted petri dishes. Finally, all invertebrates were counted, separated into vials for each family, preserved in 70% ethanol and labelled.

Finally, small samples were whole counted using the microscope. This method was both more accurate and saved time as often nearly all of the 100 cells in the subsampler would need to be picked in order to reach our mandatory 300 individuals.

Because those 11 samples which were whole-sampled would not be truly representative, a correction factor was devised to compensate for invertebrates found by microscope that were originally overlooked when picking by eye. This was accomplished by randomly picking three 2005 samples that had only part of them removed for the sub-sampling process. The remaining sample was processed with the original whole-sampling, no-microscope technique. Invertebrates were identified and tallied, much the way the original 11 samples were done. The leftovers from that process were then subjected to examination under the microscope. Invertebrates were again identified and tallied. The quotient of the number in a given taxa from the microscope count divided by the number of the same taxa counted in the first step was used as the correction factor.

Aquatic Invertebrate Statistical Analysis

Community composition was assessed using multivariate statistics. Analysis was completed using the statistical program Primer v.6. Following construction of a Bray-Curtis similarity matrix, SIMPER (Similarity percentages) tests and ANOSIM (Analysis of similarity) tests were conducted to assess the spatial distribution of reduced data.

Due to the effects of life history, samples based on month (July or September) were analyzed separately, is it was thought that data collected in the same month would group together. This was observed in through preliminary ordination analysis.

Ordination analysis is the distance-based analysis of data across two or three planes, where dimensional planes represent scales of variance between actual data points within a group and those of randomized data.

Results

Periphyton

The analysis of periphyton samples, using Chlorophyll *a* concentrations, showed significant seasonal effects (ANOVA, P=0.001), and a site effect (ANOVA, P=0.03), but no significant treatment effects (ANOVA, P=0.47)(Figures 3.1). The fall sample of 2006 was showed significantly lower chlorophyll *a* concentrations than the other samples (Tukey HSD, P<0.01). The lowest single measurement of chlorophyll *a* was that taken at site U-1 in the fall of 2006 (5.34mg/cm^2) and the highest single measurement (91.79 mg/cm^2) was taken at site L-4 in August of 2005.

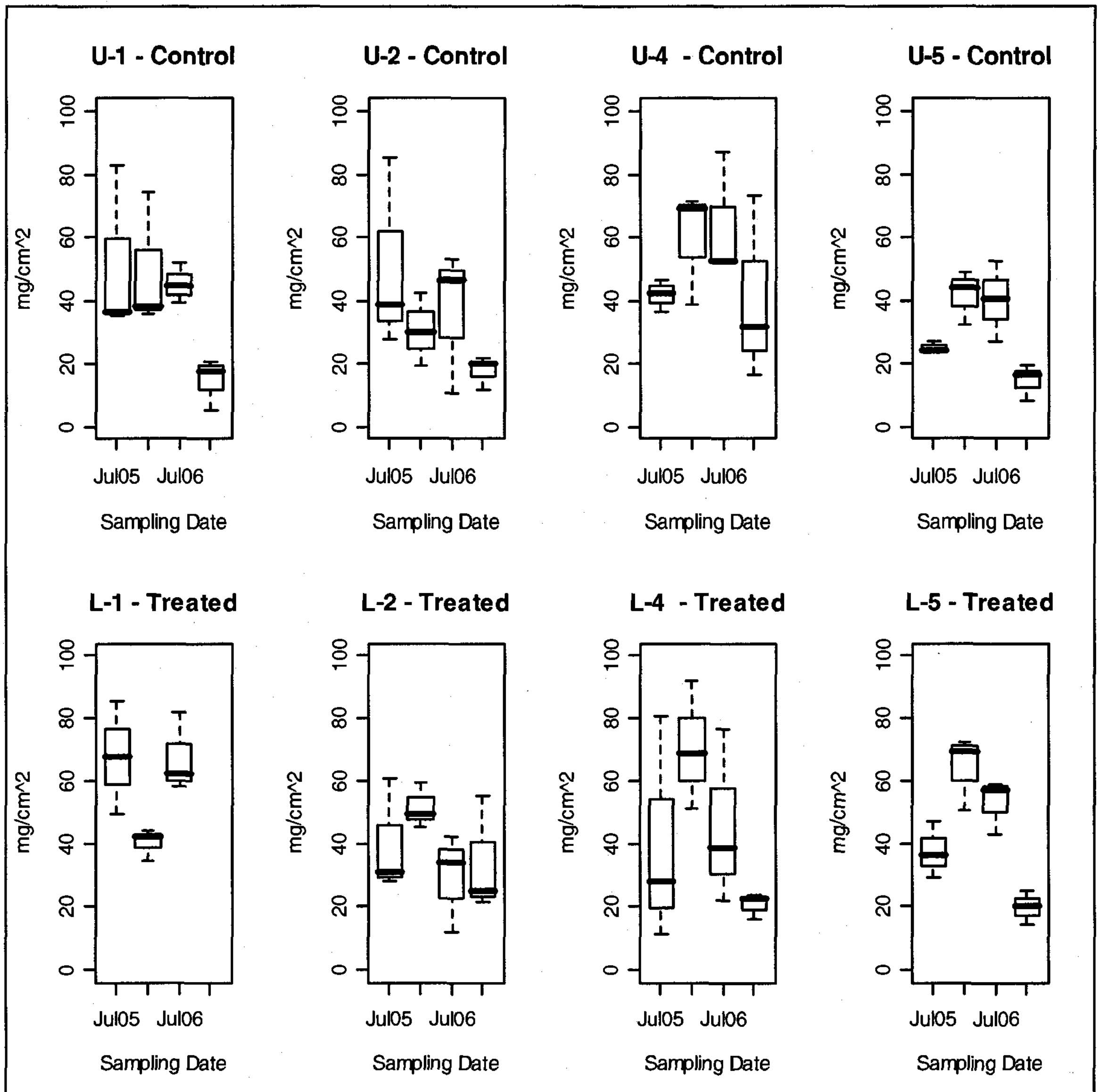

Figure 3.1 – Boxplots of chlorophyll concentrations (expressed as mg·cm^{-2} of rock surface) for all sites in WRSH, across the four sampling dates. N=3 for all sites and dates.

Table 3.1 – ANOVA table for periphyton (mg chlorophyll a/ cm^2). Year indicates either pre- or post-liming. Treatment indicates a control or impact site. Nominal ALPHA = 0.05. df = degrees of freedom, Sum Sq = Total Sum of Squares (total variation), Mean Sq = Mean Sq (sum Sq/df), F-Value = Test Statistic, Pr(>F) = Probability of being greater than F-Value.

Analysis of Variance Response: mg chlorophyll/cm^2					
Source of Variation	df	Sum Sq	Mean Sq	F-Value	Pr (>F)
Year	1	16054114	16054114	7.5618	0.0078
Site	6	31555815	5259302	2.4772	0.0327
Year : Site	6	12067562	2011260	0.9473	0.4682
Year : Treatment	1	832648	832648	0.3922	0.5334
Residuals	62	131629512	2123057		

Aquatic Invertebrates

A total of 15 orders and 28 families of invertebrates were identified (Table 3.2). At least 9 additional families were not identified, in invertebrate orders outside the class Insecta. The order Trichoptera had the largest diversity of families with 8 families present, followed by Diptera with 6 families and Plecoptera with 4 families.

To describe the data, only samples collected in the same month, either July or September, were compared. This was thought prudent as invertebrates represented in July samples could possibly be in larval form, yet by September largely be in adult form and thus unrepresented in aquatic benthic samples.

July

Invertebrate abundance at control sites increase from a mean of 1751 organisms in 2005 to 3708 organisms in 2006, however this increase was not significant (Tukey HSD, P=0.07) (Fig. 3.2). Likewise, organism abundance also increased at treated sites from 1408 in 2005 to 2883 in 2006, but again this was not significant (Tukey HSD, P=0.26) (Fig. 3.2).

Based on multivariate Analysis of Similarity (ANOSIM) and Similiarity Percentages (SIMPER) analysis, July samples were significantly different between 2005 and 2006 for control sites (P=0.004) and treatment sites (P=0.017) (Table 3.3). However, there was no significant difference between control and treatment sites in either year (Table 3.3), that is, control and treatment sites were similar both before and after liming. These results indicate that there is no liming-induced effect on either abundance or taxa dominance. Cluster analysis visually depicts these same trends (Fig. 3.3 & 3.4).

September

During September sampling, invertebrate abundance at control sites increase from a mean of 2108 organisms in 2005 to 3731 organisms in 2006, however this increase was not significant, however close (Tukey HSD, P=0.06) (Fig. 3.2). In limed (treatment) sites, organism abundance increased significantly (Tukey HSD, P=0.00) from 1726 in 2005 to 4397 in 2006 (Fig. 3.2). This represents the first observed significant increase in invertebrate abundance.

Based on multivariate Analysis of Similarity (ANOSIM) and Similiarity Percentages (SIMPER) analysis, September samples were again significantly different between 2005 and 2006 for control sites (P=0.001) and treatment sites (P=0.004) (Table 3.4). Unlike the July samples however, there was some divergence between control and treatment sites following liming. Prior to liming, September sampled control sites were similar to treatment sites in taxa dominance and abundance, however following liming, limed sites significantly diverged from unlimed sites (P=0.01)(Table 3.4), indicating that while an overall increase occurred, the scale of change was greater in samples from limed sections of the river. Unlike the July samples, these results indicate that there is indeed liming-induced effects taxa dominance and abundance. Cluster analysis visually depicts the divergence in treated areas following liming (Fig. 3.5 & 3.6).

In summary, a general taxa abundance increase was observed across all sites, though this increase was significant only in treated sections of the river for September-collected samples. During the treatment year, differences in abundance and taxa dominance were observed across all sites, and both sampling months. However, for July samples in 2005 and 2006, as well as September samples in 2005, both treatment and control sites were statistically similar, yet by September 2006, a shift had occurred and control and treatment areas were now statistically different. In all, abundance has significantly increased and taxa dominance has significant altered as a result of liming.

Table 3.2 – A list of aquatic invertebrates sampled from the WRSH. All invertebrates were identified to order and the major orders were identified to family. N/A indicates that family level identifications were not performed.

Orders represented	**Families represented**
Amphipoda	*N/A*
Coleoptera	
	Elmidae
	Psephinidae
Diptera	
	Athericidae
	Ceratopogonadae
	Chironomidae
	Empidiade
	Simulidae
	Tipulidae
Ephemeroptera	
	Baetidae
	Ephemerellidae
	Heptagenidae
Hemiptera	*N/A*
Hydracarina	*N/A*
Lepidoptera	*N/A*
Megaloptera	
	Corydalidae
	Sialidae
Mollusca	*N/A*
Nematoda	*N/A*
Odonata	
	Coenagrionidae
	Gomphidae
	Libellulidae
Oligochaeta	*N/A*
Platyhelminthes	*N/A*
Plecoptera	
	Chloroperlidae
	Leuctridae
	Perlidae
	Perlodidae
Trichoptera	
	Brachycentridae
	Helicopsychidae
	Hydropsychidae
	Hydroptilidae
	Lepidostomatidae
	Leptoceridae
	Philopotamidae
	Polycentripodidae

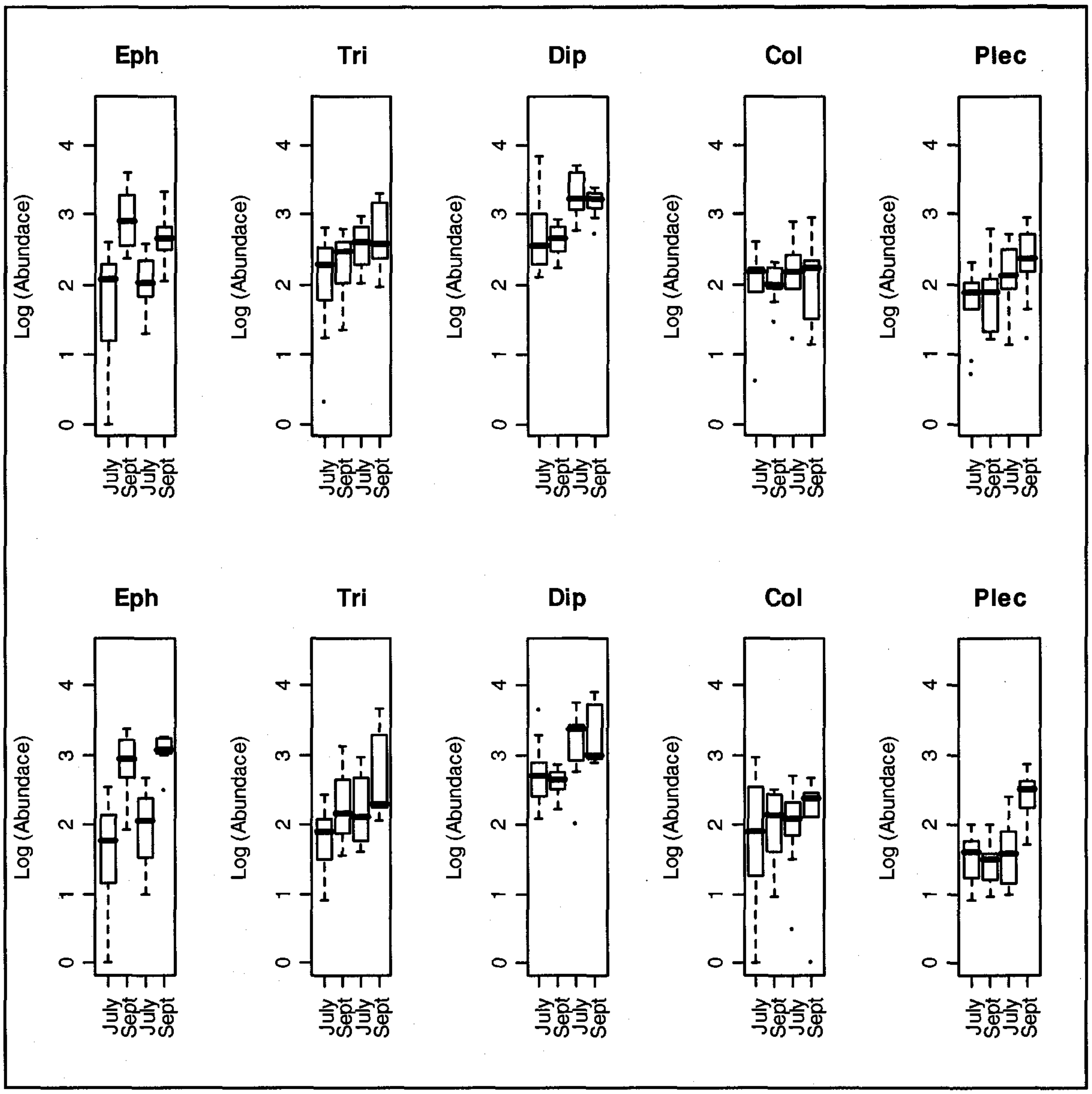

Figure 3.2 – Boxplots of log transformed abundance for the top five taxa in unlimed areas (**top row**) and for limed areas (**bottom row**) of the WRSH. The first set of July and September samples were pre-liming (top row) and the second set of July and September samples were post liming (bottom row). Eph = Ephemeroptera, Tri = Trichoptera, Dip = Diptera, Col = Coleoptera and Plec = Plecoptera.

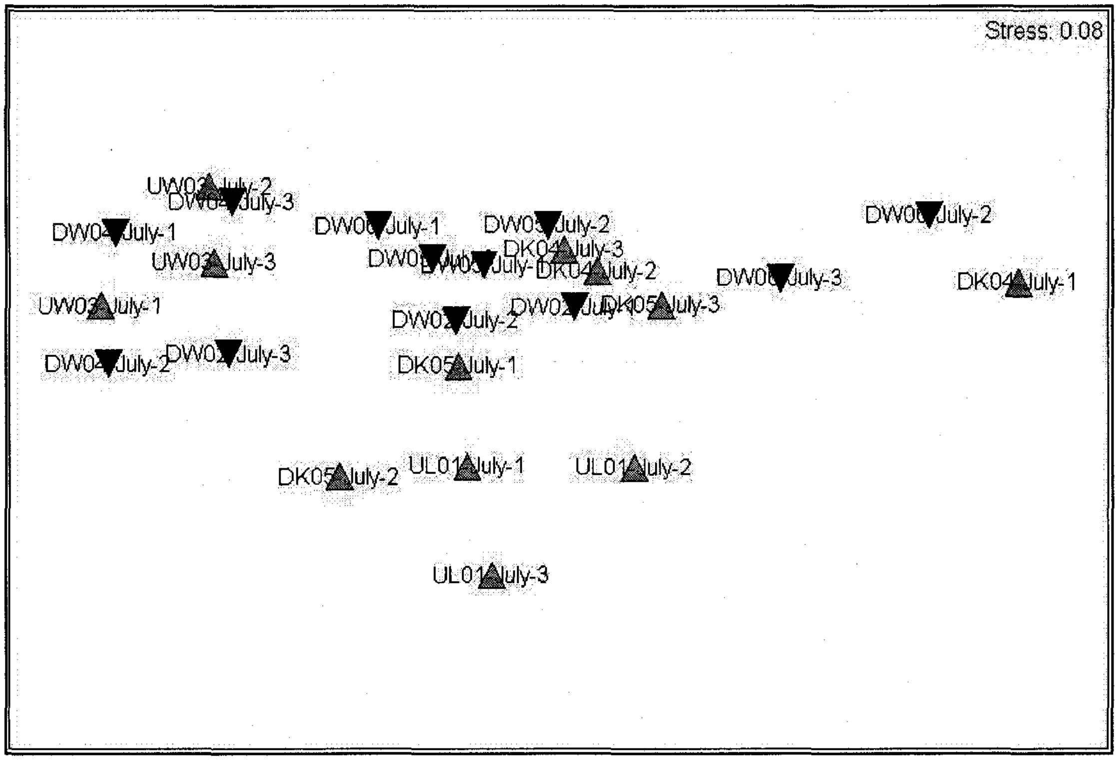

Figure 3.3 – Ordination analysis of sites sampled in July 2005 (Pre-liming) in treatment and control areas of the WRSH. Green (upwards pointing) triangles indicate control sites and blue (downwards pointing) triangles indicate treatment sites.

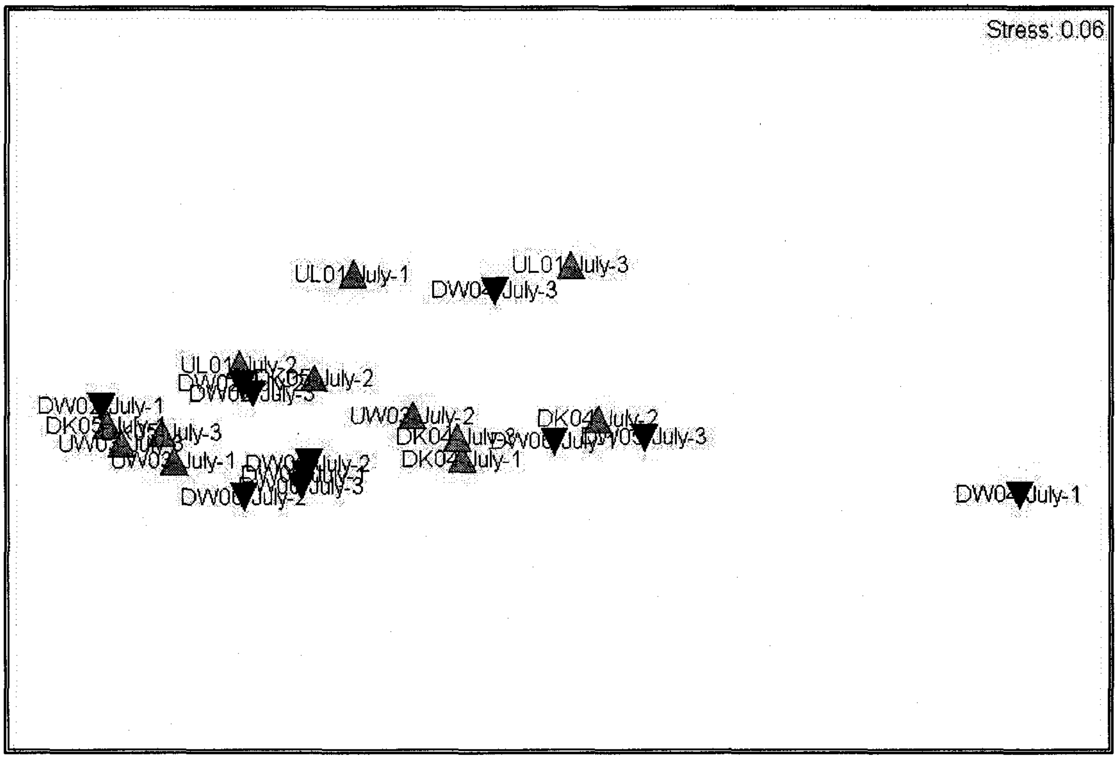

Figure 3.4– Ordination analysis of sites sampled in July 2006 (Post-liming) in treatment and control areas. Green (upwards pointing) triangles indicate control sites and blue (downwards pointing) triangles indicate treatment sites.

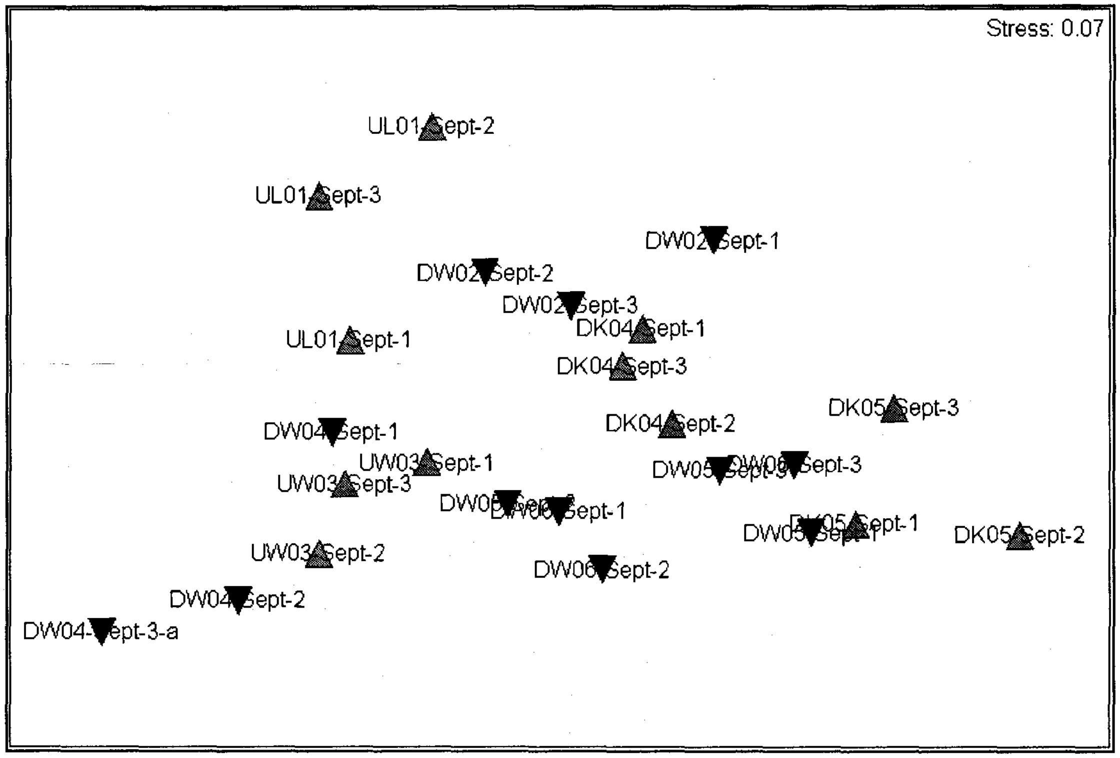

Figure 3.5 – Ordination analysis of sites sampled in September of 2005 (Pre-liming) in treatment and control areas. Green (upwards pointing) triangles indicate control sites and blue (downwards pointing) triangles indicate treatment sites.

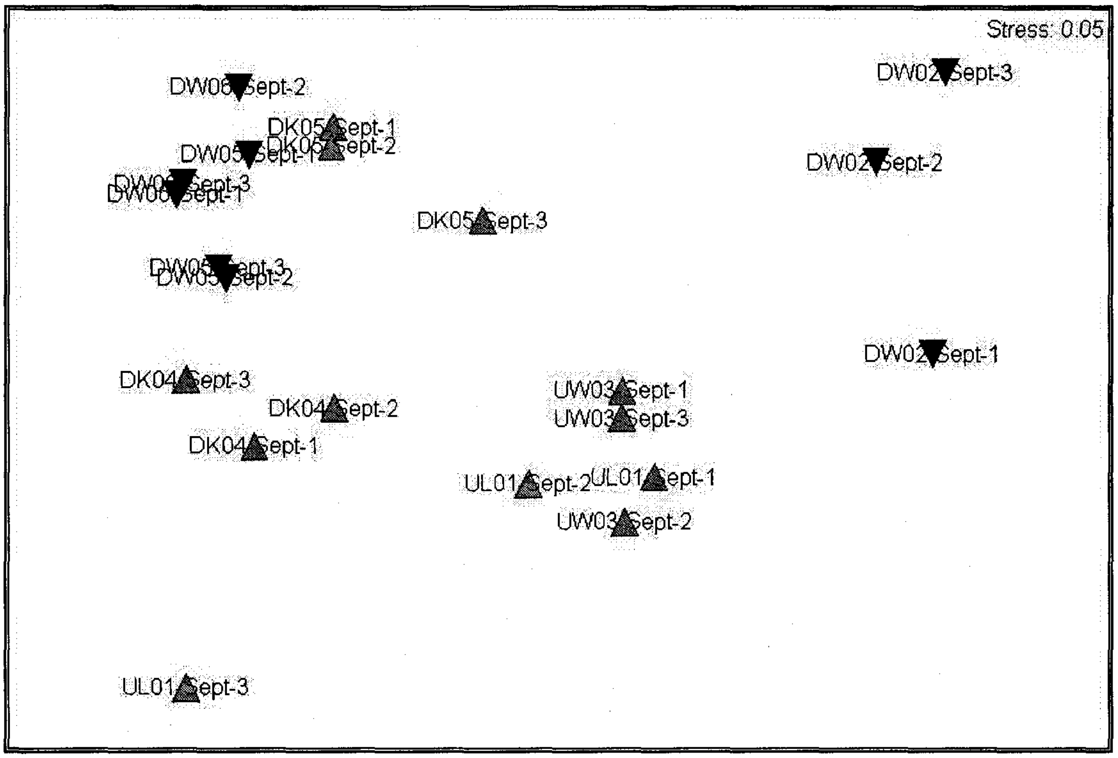

Figure 3.6 – Ordination analysis of sites sampled in September 2006 (Post-liming) in treatment and control areas. Green (upwards pointing) triangles indicate control sites and blue (downwards pointing) triangles indicate treatment sites.

Table 3.3 – July sampling effects and associated R and P values in control and treatment sites over both years. Sp = Spatial effects (control/treatment), Ti = Temporal effects and Tr = Liming effects.

July Samples				
	Pre Control	**Pre Treatment**	**Post Control**	**Post Treatment**
Pre Control		Sp No effect r =0.008	Ti Effect r = 0.244 P = 0.004	N/A
Pre Treatment			N/A	Ti / Tr Effect r = 0.217 P = 0.017
Post Control				Sp / Tr No Effect r = 0.014

Table 3.4 – September sampling effects and associated R and P values in control and treatment sites over both years. Sp = Spatial effects (control/treatment), Ti = Temporal effects and Tr = Liming effects.

September Samples				
	Pre Control	**Pre Treatment**	**Post Control**	**Post Treatment**
Pre Control		Sp No effect r = -0.008	Ti Effect r = 0.397 P = 0.001	N/A
Pre Treatment			N/A	Ti / Tr Effect r = 0.285 P = 0.004
Post Control				Sp / Tr Effect r = 0.242 P = 0.01

Discussion

Periphyton

There was little evidence of a treatment level effect on the quantity of periphyton present The autumn sample in the fall of 2006 had a statistically significant reduction in total chlorophyll concentrations. This was assumed to be a result of the seasonal sampling effect as instream flow prevented sampling during September and the sample was delayed a month until October. In association with the shortened photoperiod and reduced water temperatures of fall, algal growth was assumed to have decreased, resulting in the decreased chlorophyll concentrations. Though Magnuson (1984) noted decreases in periphyton biomass following liming as a result of increased grazing by invertebrates, this was not considered the case in the WRSH, as the severe drop in biomass was realized in both treatment and control areas.

There may have been shifts in the relative contributions of important taxa towards total biomass of the aufwuchs community, post liming, but taxonomic analysis is required for proper assessment. Furthermore, periphyton communities, as expressed by total chlorophyll are largely regulated by environmental conditions and are therefore highly variable. A lengthier time series of measurements may be required to assess the impacts of liming on the periphyton community. These data suggest that the acidic conditions of the West River, Sheet Harbour did not adversely affect the biomass of the aufwuchs community.

Aquatic Invertebrates

As no differences were observed between control and treatment sites during July and September sampling in 2005 (pre-liming) and during July of 2006, habitat variables were not thought to significantly influence species composition or abundance, and there was sufficient evidence to allow direct comparison of control and treatment sites. The statistically significant divergence of taxa dominance and abundance in September of 2006 (treatment year) should therefore be considered a real indication of liming induced change. This observation of a significant increase in overall abundance for the benthic macroinvertebrate community is consistent with the literature on post-liming effects (Fjellheim and Raddum 1995, Magnuson 1984, Raddum 1995). This increase in abundance may potentially positively affect fish in the WRSH through increased feeding opportunities.

Reasons for the overall increase in abundance across sites, though not significant for any month or sites other than September of 2006 (treatment year) in limed sections, are largely unknown. Naturally inter-annual variation may be largely responsible for this increase, however without a longer time series of data, this cannot be confirmed. Non-significant differences in flow, timing of flow, temperature (Chapter 2) or other factors may have also contributed to this general increase. It is however reasonably to assume that the significant increase in abundance at limed sites is in part a function of decreased acidity.

While no effects were observed in the July samples as a result of liming, the increase in abundance and the shift in dominant taxa observed in September samples suggests that a "temporal lag" occurred where survival and colonization was undetectable until later in the mitigation process. Presumably, those taxa responding to liming were limited by the acidic condition pre-liming. Similar trends are described by Hall et al. (1980).

Of the limited toxicity testing performed on aquatic invertebrates, focus has primarily been on individual species, with little examination of higher taxonomic groupings (Fjellheim et al. 2001, Hopkins 1989, McCahon and Pascoe 1989, Okland and Okland 1986, Raddum 1995). Therefore, the presence or absence of acid-sensitive species at WRSH is unknown until samples are processed with refined taxonomic precision. For the scope of this project, only comments on general acid sensitive taxa according to family groupings were made. Though not entirely comprehensive, this data is useful as the presence of groups such as Mollusca provide valuable insights on the benthic communities present in the WRSH. Surveys of Mollusca taxa in Scandinavia have determined that waters of low calcium and of high acidity are generally not suitable for their persistence (Okland and Okland 1986).

The occurrence of Mollusca primarily occurred at one site, the upper Little River, which is a control site, but was also one of the least acid impacted sites in the WRSH for which invertebrates were sampled. This may indicate the presence of acid refugia, where acid sensitive species of invertebrates and other organisms may have persisted in sufficient numbers to provide a bank from which colonization in limed areas can occur.

These results indicate that there were liming-induced effects on the aquatic invertebrate community. Given time, the community may undergo even greater shifts, becoming more representative of those in non-acid stressed systems.

Conclusions

While I found little evidence of increased periphyton abundance as a result of liming, there was an indication of change within the invertebrate community. Without a longer time series of abundance data for the system, we can only assume that the significant increase in invertebrate abundance was a result of liming and did significantly deviated from "normal" variance under acidified conditions. As is often the case with such studies, further investigation is necessary to distil these initial observations.

As previously discussed, changes observed in the invertebrate community may be a sentinel of liming-induced changes in the fish community, as the relatively shorter life cycles of invertebrates are likely to respond more rapidly to acid mitigation.

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Chapter 4 – Fish and Fish Community Monitoring

Introduction

The effect of acidification on fish and fish populations is a well studied subject. In general, losses of fish at the population level due to acidification are thought to be as a result of recruitment failure (Beggs and Gunn 1986, Sayer et al. 1993) as early life stages of fish, such as egg, fry and alevin, are the most sensitive to acidification (Atland and Barlaup 1996, Muniz 1984, Sayer et al. 1993). Furthermore, spawning activity in salmonids is known to be compromised with exposure to low pH waters (Ikuta and Kitamura 1995, Ikuta 2003, Schofield 1996). Other studies have indicated additional consequences of acidification on fish populations, such as changes in growth, distribution, altered age classes and abundance (Barlaup et al. 1994, Beamish 1976, Holmgren 2001, Lacroix 1987, Lacroix 1985, Ryan and Harvey 1980, Schindler 1988).

In addition to salmonid fishes, many other fish species are sensitive to acidification (Beamish 1976, Lacroix 1987, Ryan and Harvey 1980). However, some fish species are more sensitive to acidification than others, resulting in shifts in community structure following acidification. Lacroix (1987) indicated that in Southeastern Nova Scotia, Atlantic salmon and cyprinid species dominated the least acidic streams while American eels dominated the most acidic streams.

The primary goal of the WRSH liming initiative is to increase the freshwater survival, and consequently production, of Atlantic salmon (*Salmo salar* L.). This is a reasonable goal as Atlantic salmon in Nova Scotia are known to have been affected by acidification (Clair 2004, Lacroix and Knox 2005, Lacroix and Korman 1996, Power 1998, Watt 1987, Watt et al. 1983) and salmon are known to positively respond to acid mitigation programs involving liming. Acid mitigation efforts in Norway have resulted in substantial gains in salmonid fish abundance (Eriksson 1983, Rosseland and Hindar 1988, Saksgard 1995, Sandoy 2001, Weatherley 1988). The River Mandal of Southern Norway, a once prolific Atlantic salmon river, was considered to have an extirpated salmon population by the mid-1900's. Following an extensive liming program starting in 1996, catches increased to 2 tonnes·year^{-1} after only 2 years of liming and to 10 tonnes·year^{-1} after 5 years (Aas 2002). Artificial augmentation of juvenile salmon, in the form of stocking of fry and fingerlings, usually complements liming strategies in Norway, as was the case with the Mandal River (Aas 2002, Sandoy 2001). Similarly, on the River Bjerkreim, parr densities rose from 1 salmon parr·100m^{-2} to between 15 and 40 parr·100m^{-2} (Aas 2002).

While Norwegian studies showed rapid response of salmonids, for the relatively short duration of this Canadian study, several fish parameters were assessed with three main objectives;

1) To investigate salmonid growth, condition, abundance and distribution for potential liming-induced shifts,
2) To examine the status of Atlantic salmon for future comparison, and
3) To assess potential liming-induced shifts in fish community structure.

As salmon survival has been shown to be affected by acidity (Lacroix and Gordon 1985, Atland and Barlaup 1996), I hypothesized that salmon densities would increase with increasing pH. Furthermore, Lacroix (1987) showed that species richness increased with increasing pH, therefore I also hypothesize that with acid mitigation, richness of fish species in treated waters would occur.

As the mitigation program is a long-term commitment and signs of recovery may not be realized during the first years of the project, information collected for future comparison is of utmost importance. Some data presented in this chapter may facilitate little immediate statistical/hypothesis testing, however its role in the future assessment of this demonstrative project may be substantial.

Methods

The WRSH acid mitigation project may affect fish on a community, population or individual level. Consequently, to assess effects of liming on the rivers fish, comprehensive population parameters and basic fisheries variables were monitored for the salmonid fishes (Atlantic salmon and brook trout) and total fish community composition was monitored. Fish in both control and treatment areas, pre- and post liming, were assessed as a temporal and spatial reference. This is the only method of assuring proper interpretation of results due to liming (Lacroix 1996).

Trapping

Fyke nets and trap nets were used as the primary method of capturing fish in 2005, as our secondary method of catching fish in 2006 with angling directed towards salmonids dominating. Additionally, fyke netting was a supplemental method of catching fish in 2007 in conjunction with the Nova Scotia Salmon Association smolt wheel project (Halfyard 2007). Two sizes of nets were used. The large fyke (trap) nets had a 1.5m opening, two 7.62m side wings with a 30.48m center lead net. The smaller fyke nets had 0.7m openings with two 7.62m side wings. Nets were anchored in place using rebar that had been pounded into the streambed. Traps were set to capture upstream or downstream migrating fish depending on seasonal movements of fish. At all times, the holding section of the nets was placed in water of low velocities to reduce stress on captive fish. In general, nets were checked every morning, although at times of high catch rates the nets were checked in the mornings and evenings. At the time of checking, all debris was removed from the nets and all holes were repaired. Nets were set intermittently from May 25^{th} to October 8^{th} 2005, from May 4^{th} to July 11^{th} in 2006 and from April 23^{rd} to May 30^{th} in 2007. In general, nets were set from Monday to Friday of each week (Mon. – Thurs. night), but this was always the case as dictated by water conditions. Nets were set at sites U-1, U-2, U-3, U-4, U-5, L-2, L-4 and L-5, though not all sites were fished simultaneously.

In addition to the fyke and trap nets, fish were also trapped in a 1.5 m diameter, rotary screw trap (a.k.a. smolt wheel) as part of a salmon smolt estimation project of the Nova Scotia Salmon Association (NSSA). These fish were also used in this study. The trap was secured in place using 1.59 cm polypropylene rope and secured to the bridge on the Killag road, which is located at site L-5. The smolt wheel was installed on Saturday, April 21^{st} 2007 and began fishing on Sunday, April 22^{nd} 2007. The trap was checked twice daily, once at approximately 0800h and again at approximately 1900h, until the project was completed on May 29^{th} 2007 (Halfyard 2007).

Angling

Angling proved to be an important part of the fish sampling regime. While the nets provided a representative sample of the fish community that was migrating past a sampling area, angling allowed active sampling of stationary fish that may not be intercepted with the nets. Equipment used for angling consisted of #5 or #7 weight fly rods and associated equipment, 1.81kg (4lb) test tippet material, and an assortment of flies ranging from size #8 to #20. Conditions dictated which flies were used, however, at times when two anglers were covering the same water, two different patterns were fished, and generally two separate fly categories (i.e. dry fly, wet fly, streamer or nymph patterns). Angling took place from June 14^{th} to October 8^{th} in 2005, from April 9^{th} to September 8^{th} in 2006 and from April 23^{rd} to May 30^{th} in 2007.

Electrofishing

Electrofishing was conducted during late September or early October of both the pre-treatment year (2005) and the first treatment year (2006). A Smith-Root model 11-A backpack electrofisher was used in all electrofishing surveys, using a three-sweep depletion method without barrier netting. All sites were approximately 6 times longer than they were wide (6 bankfull widths) so as to encompass a series of pool, riffle & run habitats. The boundaries of each site were clearly marked for future surveys. Voltage, duty cycle operating time (sweep duration) and all other parameters pertaining to the operation of the machine was recorded to ensure consistency. Furthermore, a full description of the site was recorded including representative mean depths, water velocity, water temperature, dominate substrate, macrophyte cover, canopy cover and weather conditions. All captured fish were anaesthetized with Clove oil prior to processing. Fish were identified, measured and weighed to the nearest gram or 1/10th gram, depending on the year. Also, scale samples were taken from all salmonids deemed older than young-of-the-year.

Historical electrofishing density data for years 1966-1968, 1973-1977 and 1994 to 2000 were provided by the Nova Scotia Department of Inland Fisheries and the Department. of Fisheries and Oceans, Dartmouth.

Fish Processing

To assess growth, movement and abundance through a mark/recapture design, fish were either marked with a series of fin clips, denoting various locations, or tagged with a plastic Carlin tag, onto which a 5-digit code had been printed. Fish receiving the Carlin tags were also fin clipped to assess tag loss. To reduce stress and speed processing time, all fish were anaesthetized prior to tag application by placing the fish in a solution of clove oil (approx. 25mg.L) and stream water (Taylor and Roberts 1999). Using a double surgical needle tag injector, the nylon lines were inserted just ventrally and posterior to the dorsal fin, being sure to thread through the pterygiophores.

Length to the nearest mm was taken on all captured salmonid fishes using a standard measuring board. Fish jaws were pinched together so as to ensure consistent measurements. Weight was also measured on all salmonid fishes Using a wetted plastic bag attached to a Pesola brand 300g or 1000g spring scale, fish were weighed by first weighing the empty wetted bag and then weighing the same set-up with the fish in the bag. This configuration allowed for easy and accurate reading of weight as fish remained calm, and total time out of water was generally no longer then 15 seconds. It also is considered to be accurate (Jennings 1989). Finally, fish were examined for the presence of any unusual or irregular marks such as predator marks as well as fin clips, tags or tagging scars resulting from tag loss.

Aging

On all captured non-anadromous brook trout as well as all life stages of juvenile salmon, a small sample of scales were removed for later age determination. In general, scales were removed with a small pocket knife, scraping an area no greater that 0.25 cm^2. The scales were placed between two small pieces of paper, placed inside a coin envelope, and the envelope was labeled. On brook trout, scales were removed from the flank of the fish, starting roughly 3-7 scales above the lateral line and just below the posterior edge of the dorsal fin. For salmon, scales were removed from the flank of the fish, roughly 3-7 scales above the lateral line and just below the adipose fin.

At the laboratory, scales were scraped from the envelope papers, placed under the microscope at 6.4x power, and 3-6 high quality scales were chosen to be mounted. High quality scales were the largest of those not showing signs of regeneration around the focus of the scale. The reading scales were pressed between a standard microscope slide and a glass slip cover, and the slip cover fastened with either acrylic adhesive or clear scotch tape. These slides were read with a standard scale projector. Using a micrometer, projected scale total length (from focus to outside edge, along the major axis) was measured as well as the length from the focus to each annulus, again along the major axis.

In this study, age is designated as age+. It is presumed that eggs hatch in early spring, but for simplicity, I assumed a birth date of January 1st. Thus, a fish born in the spring of 2004, is a 0+ (first year of life) until Jan. 1st 2005. If captured in May of 2005, it is deemed a 1+ (second year of life).

Condition Factor/ Relative Weight Calculations

A standard Fulton's condition factor was used to calculate condition or "plumpness" of Atlantic salmon parr and smolts over 130mm fork length (Barnham and Baxter 1998, Fulton 1902).

Weight-length relationships of fish are generally curvilinear (Murphy and Willis 1996) and expressing this relationship is generally done for two reasons (as expressed by LeCren (1951)): for conversion between length and weight measurements and, as a means of describing deviation of an individual fish or grouping of fish from the expected (average) "condition" or "plumpness" for that species.

While weight increases with length, and length being the primary determinate of weight, different species gain weight at different rates and at different life stages, generally a function of body shape and feeding or growth (Le Cren 1951). For this reason, fish of different species, and at times, fish of the same species but residing in dramatically different environments cannot always be directly compared. Therefore, the relative weight equation was used for calculation of condition in brook trout. Due to the fact that a standard weight formula has not been described for juvenile Atlantic salmon, it was not used for salmon.

The relative weight equation, as described by (Wege and Anderson 1978), is

$$W_r = W / (W_s \cdot 100),$$

where W_s is the length-specific standard weight equation, as determined via length-weight regression representing the species over its entire range (Murphy 1991). Standard weight equations have been derived for many species across their range (Murphy and Willis 1996, Murphy 1991) including the brook trout. Unfortunately, for various reasons, this has never been completed for juvenile Atlantic salmon.

Only brook trout over 130mm fork length were used in the relative weight calculations(Murphy et al. 1990, Murphy 1991) and parameters used in the standard weight equation were an intercept of -5.085 and a slope of 3.043.

Condition factor was calculated using the Fulton (1902) method where;

$$K = (W/L^3) \times 100\,000,$$

Where W = weight in grams and L = length in millimeters. The constant of 100 000 is used as a method of scaling to make calculated K values easier to read.

Population Density Calculations

A Zippens depletion method was used to estimate densities of fish in a given electrofishing site (Zippen 1956), incorporated in the statistical program "popden v.1.3", as issued by DFO (Gulf Region). Also, a Leslie population estimator (Ricker 1975) was used to compare estimates between the two methods. Population densities were calculated for all captured fish species when possible.

Aging Calculations

Fish lengths at past ages were back-calculated with the Fraser-Lee back-calculation equation as described by Murphy and Willis (1996).

The age proportion of smolt for the smolt run of 2007 were determined by extrapolating the mean fork lengths for each cohort. A mid-point value between each mean was determined and all smolts between midpoint values - with an assumed mean of the cohort mean - was deemed a single age class.

Finally, calculation of annual growth from back-calculated length-at-age values was determined for each age of fish at each year. Thus, the growth of an individual could be determined during all past growing seasons. By separating fish by age at any given year, it was possible to assess growth of age one, two and three trout for 4 years prior to liming and one year following liming.

Results

Fish Community Assessment

A total of 10 fish species were captured including: Atlantic salmon (*Salmo salar* L.), brook trout (*Salvelinus fontinalis* Mitchell), white sucker (*Catostomus commersoni* (Lacepede)), American eel (*Anguilla rostrata* (Lesueur)), yellow perch (*Perca flavescens* (Mitchell)), brown bullhead (*Ictalurus nebulosus* (Lesueur)), lake chub (*Couesius plumbeus* (Agassiz)), banded killifish (*Fundulus diaphanus* (Lesueur)), ninespine stickleback (*Pungitius pungitius* L.) and golden shiner (*Notemigonus crysoleucas* (Mitchell)). Also, white perch (*Morone Americana* (Gmelin)) are known to exist in some lakes within the watershed (Rocky Brook Lake), but were not sampled in this study.

In 2005, a total of 105 net nights produced a total of 3513 fish. White suckers comprised the majority of the catch with 2787 captured. American eel (N=293) and yellow perch (N=144) were the next most common species. Of the target species, a total of 92 brook trout and only 21 salmon parr were captured in the fyke nets (Appendix A).

In 2006, netting effort was reduced to 81 net nights, but produced a total of 4448 fish. Again, white sucker was by far the most common fish with 3052 being captured. Yellow perch (N=952) were the second most commonly captured fish. American Eel (N=106) were again common, but in fact trailed Atlantic salmon smolt (N=196). The vast majority (all but 5 smolts) were captured in fyke nets set for downstream migrants. No such downstream set nets were placed in 2005. A total of only 77 brook trout were captured in the fyke nets in 2006 (Appendix A).

Tests about the location of the mean CPUE would be heavily influenced small sample sizes and by flow and temperature variances between similar months over each sampling year. Also because netting methods and temporal sampling schedule between years was inconsistent, direct comparison of community composition was restricted to data obtained from electrofishing. However, to describe general abundance, some catch-per-unit-effort (CPUE) data from 2005 and 2006 was useful (Appendix A). These data suggest that diversity was similar between years at any given sampling site. Also, at any given site, and for any given species, CPUE was generally similar when comparing similar months (i.e. June CPUE for white sucker at site L-2) and similar directional sets (i.e. upstream) (Appendix A).

Though there was no formal examination of population parameters for fish species other than the salmonids, the yellow perch population appeared to be stunted.

Typical fork lengths for perch were approximately 8 to 12 cm with very few fish over 15cm. Also, based on anecdotal evidence of large quantities of large white suckers, it is assumed that there is considerable biomass associated with the white sucker population, though no formal measurements of biomass were made. Of note is that during the spawning run of white sucker, catches in excess of 400 fish per net-night occurred. Typical fork length of white suckers was 20cm to 25cm.

In 1956, brown trout (*Salmo trutta*) were introduced to the East River Sheet Harbour (Ducharme 1972) and are thought to persist today. There have been unofficial reports of brown trout in the WRSH, but after our extensive sampling we found no evidence of brown trout in the system.

Species Diversity

Diversity of all species captured during electrofishing was monitored. A total of 7 different species were encountered in the electrofishing sites, including Atlantic salmon, brook trout, American eel, white suckers, lake chub, 9-spine stickleback, banded killifish and brown bullhead. Diversity at each site during each year did not change drastically, from 4.50 in 2005 to 4.17 in 2006, and only species in low abundance were responsible for most of the change between years (Table 4.1). In the 8 cases where a species was represented in one survey yet not the other, 7 of the species were represented by 4 individuals or less. Only Atlantic salmon at site L-5 provided a species change (addition in treatment year) where the number of individuals was potentially significant (N=8) (Table 4.1).

The only two sites where no salmon were sampled in the two years combined were sites U-1 and L-2, both of which are in the upper Main branch WRSH and were two of the most acidic sites, as discussed in chapter 2. Site U-1 however is above the falls thought to be impassable (Figure 1.4).

Table 4.1 – Total number of fish species captured at each site during electrofishing surveys, 2005 and 2006 in the WRSH. S= Atlantic Salmon, T= Brook Trout, W = White Sucker, E = American Eel, K= Banded Killifish, L= Lake Chub, 9S= 9-Spine Stickleback, B= Brown Bullhead. The change in species is shown in the far right hand column. A - sign indicated that the species was found in 2005 and not in 2006, and a + sign indicates the opposite. The number in parentheses () indicate the number of individual fish found or lost. For example, -K (3) for site U-2 indicates that in 2005, 3 banded killifish were found, but in 2006, no banded killifish were found. For further site descriptions, refer to site description in chapter 1 (Table 1.1).

	2005		2006		Species Change
Site	No. Spp.	Spp.	No. Spp.	Spp.	
U-1 – Control	3	W, E, L	2	W,E	- L (1)
U-2 – Control	6	S,T,W,E,K,L	5	S,T,W,E,L	- K (3)
U-5 – Control	4	S,W,E,L	5	S,T,W,E,L	+ T(1)
L-2 – Treatment	4	W,E,K,L	3	E,K,L	- W (4)
L-4 – Treatment	4	W,E,K,L	4	S,W,E,K	-B(1) +S(**8**)
L-5 - Treatment	6	S,W,E,K,9S,B	6	S,W,E,K,L,9S	- B (1) + L (1)
Mean	**4.50**		**4.17**		

Salmon Densities

Salmon densities showed some variation across the system, though in general, densities were low (Table 4.2). Salmon were found in 3 out of 6 sites in 2005 and in 4 out of 6 sites in 2006. Densities were estimated to be as low as 0.27 parr (+young-of-year)/ 100m^2, and as high as 3.89/100m^2 (Table 4.2). Using a three sweep depletion method, the number of salmon in consecutive sweeps was low (N=0 to 6). With such low numbers, the regression equations used in a Zippen's depleation method estimate at times have perfect regression, therefore no estimate of standard error. Consequently, confidence intervals could not be calculated. Furthermore, confidence intervals were not available for historic data.

Densities over the two years increased at limed sites and decreased at control sites. However, in a 12-year perspective, the 2005 and 2006 estimated densities were similar to other years (Figure 4.1). At some sites, such as site 5, a cohort of salmon parr were observed moving through the population, so that presumably the same fish were counted in consecutive years (Table 4.2). There were no fish of the following cohort present in 2006 at this site.

Table 4.2 – WRSH salmon parr (all ages) densities (per 100m^2), at all 6 electrofishing sites. Proportion of young-of-year (YOY) in sample shows # YOY / total # all salmon. N/C = No Change. Confidence intervals not calculated due to low sample sizes in successive sweeps.

Site	**2005 Parr·100m^{-2}**	**Proportion YOY in Sample**	**2006 Parr·100m^{-2}**	**Proportion YOY in Sample**	**Trend**
U-1 – Above Doser Main	0	N/A	0	N/A	N/C
U-2 – Up. Little River	3.36	1 / 14 (0.071)	2.82	0 / 11 (0.000)	Decrease
U-5 – Lower Killag River	3.89	19 / 19 (1.000)	1.35	0 / 4 (0.000)	Decrease
L-2 – Upper Main	0	N/A	0	N/A	N/C
L-4 – Lower Main	0	N/A	0.96	5 / 8 (0.625)	Increase
L-5 – Lower Main	0.27	2 / 2 (1.000)	0.72	3 / 9 (0.333)	Increase

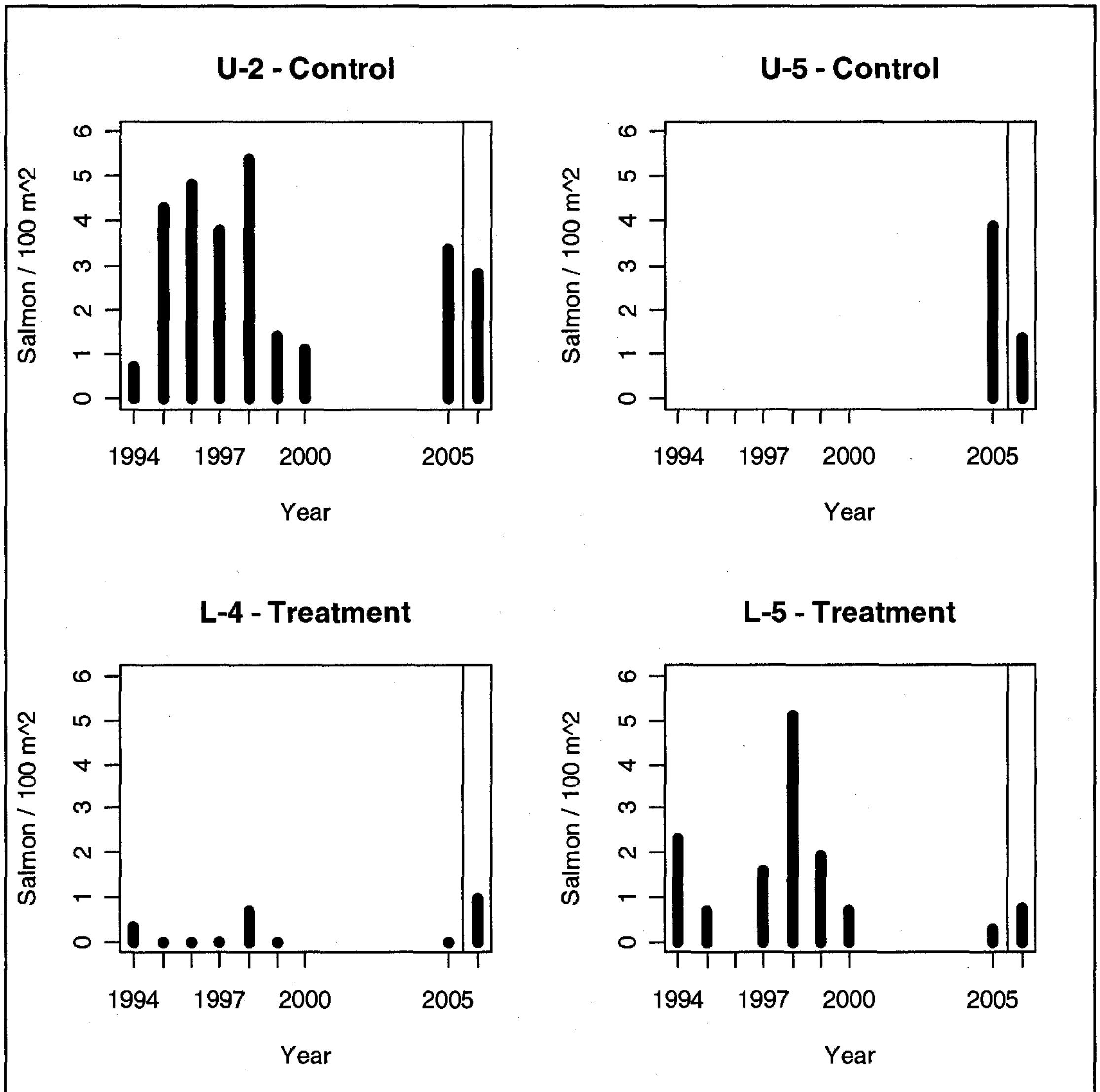

Figure 4.1 – WRSH salmon parr (all ages) densities (per $100m^2$), from 1994 to 2006. 1994 to 2000 data provided by NS Dept. of Fisheries and Aquaculture and DFO. Confidence intervals not provided for 1994-2000 data.

Fish Movement and Tagging

Salmon movement was based on captured and recaptured fin clipped fish with a total of 20 salmon parr clipped in 2005 and 126 salmon parr clipped in 2006. No recaptures occurred in 2005 however 15 parr were recaptured in 2006. Of these recaptures, all were recaptured at the same site where originally marked.

For salmon, no major movements other than the spring emigration of smolts were observed; though in the spring of 2007, several salmon smolt (N=3) were recovered leaving the Little River that had fin clips from the main river and from the previous season. The site of origin was site L-4, River Road Run on the main branch WRSH, some 3100m away, indicating previous movement between branches of the system. No salmon were captured or recaptured in the coolwater spring habitats.

Trout movement was assessed based on recaptured tags with a total of 103 brook trout marked with fin clips in 2005 and another 380 trout marked with fin clips in 2006. Additional, 219 trout were tagged with Carlin tags in 2006. Recaptured tags in 2005 and 2006 were 3 (2.9%) trout and 88 (14.7%) trout, respectively. The majority of the trout marked or tagged were captured via angling.

Tag recapture prior to the water reaching 20°C was evenly spread throughout the system with many trout being recaptured very near to the same area they were initially tagged. One trout was recaptured three times from behind the very rock where it was initially captured and tagged. After river temperatures climbed above the 20°C threshold, trout became scarce in many areas (Figure 4.2). Large congregations of fish were found in the spring areas discussed in chapter one. Within these springs, many tagged fish were recovered during July and August (N=46 or 52% of seasons recaptures).

Some trout were captured numerous times (up to 4 times in 36 days), some fish were captured soon after being tagged (approx. 25 minutes post fin clipping) and some were captured far from their initial tagging location (more than 12 500m).

In 2005, only 20 salmon parr were marked with no recaptures. In 2006, 123 parr were marked with just 1 being recovered. No salmon smolts were captured in 2005 as nets were not set specifically for downward migration during April and May. In the post-treatment year of 2006, two nets were placed for smolts, capturing 229 smolts and recapturing 6 at a downstream location.

A population estimate was attempted for the tagging program using a Jolly-Seber population estimator, however due to major violations in assumptions, the estimate was assumed to be inaccurate. Violations were primarily the infusion of untagged anadromous trout and non-random mixing associated with angled trout exhibiting high site fidelity.

At the Killag spring, the total number of trout captured in 2006 was 172, of which 32 (18.6%) were recaptures. Of those trout recaptured in the Killag spring, 75% were locally tagged fish (i.e. fish marked in the same river). An additional 12.5% were of site L-3 (Branch basin) origin, 9.4% were tagged at Iron Bridge pool (Site L-5) and 3.1% were tagged at the site U-3 (Lower Little River) (Figure 1.4). At the Little River spring, only 4 trout were recaptures, representing 11.7% of the 34 trout captured at that location in 2006. Of the trout recaptured at the spring, one of the four came from site L-5 (Iron Bridge pool) on the main branch, while the other 75% were again tagged locally (Little River).

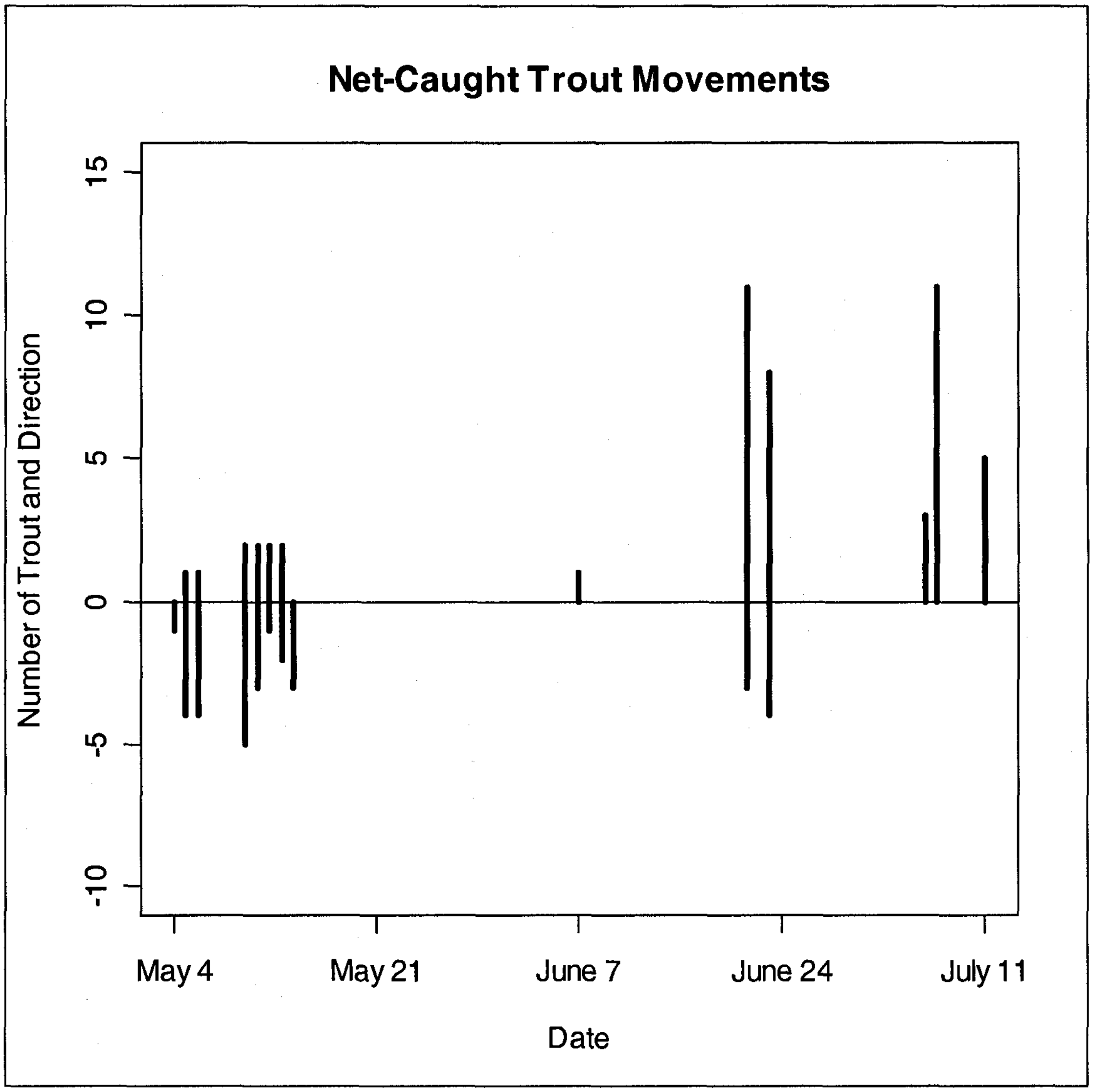

Figure 4.2 – Brook trout movement observed in 2006 based on frequency and direction of net caught trout. Negative numbers indicate downstream moving trout. Proportion of downstream nets to upstream nets remained constant throughout period. In general, temperature exceeded 20°C by the second week of June.

Age and Growth

There were few aged three trout represented in the back calculated sample and no aged 4 trout, though there have been trout aged as 4+ fish within the WRSH (Halfyard 2007). Likewise, no aged 4+ salmon parr or smolt were sampled. The vast majority of salmon parr smolted in their third year (2 year old), and therefore most parr sampled were age 1+. This was observed in the spring smolt run of 2007, where approximately 80.9% of the run was comprised of fish aged 2+ while the remainder was aged 3+ (Halfyard, 2007).

To assess inter-site differences in growth, back-calculated length at age was compared for salmon parr and salmon smolt (combined) as well as brook trout, between river branch and between pre-treatment and post-treatment years.

However, as back-calculated length-at-age data shows the length of any given fish at the start of past growing years, environmental conditions in any given year may skew the results of comparisons of growth derived from simple back-calculation. For example, if 1+, 2+ and 3+ fish are sampled, the back-calculated ages at 1 year shows the growing conditions in the year t-1, t-2 and t-3, respectively. Therefore to assess fish growth for any given age of fish at any given year, compensating for the sinusoidal growth pattern of fish, year- and age-specific growth was calculated.

Salmon smolt collection occurred at sites L-4 and L-5 and U-3 in 2005 and 2006. The fish collected at the main branch sites (L-4, L-5) were therefore a mixture of Main WRSH and Killag River smolts as a result of the Killag entering upstream of those collection points. For this reason, comparisons could only be made between the Little River smolts and the Main+Killag smolts. This likely confounded any possible effect of liming in 2006. Plots of year-specific growth for salmon smolts showed significant deviation (ANOVA, P=0.04) in growth between the Little River and combined Main WRSH + Killag River sites (Figure 4.3), with Main + Killag fish growing faster (Figure 4.3). Tukey's HSD tests indicated that these significant differences in growth between the two groups occurred for YOY salmon in year 2004 (Tukey HSD, Main+Killag >Little, P=0.00) and 1 year old parr in 2005 (Tukey HSD, Little>Main+Killag, P=0.00).

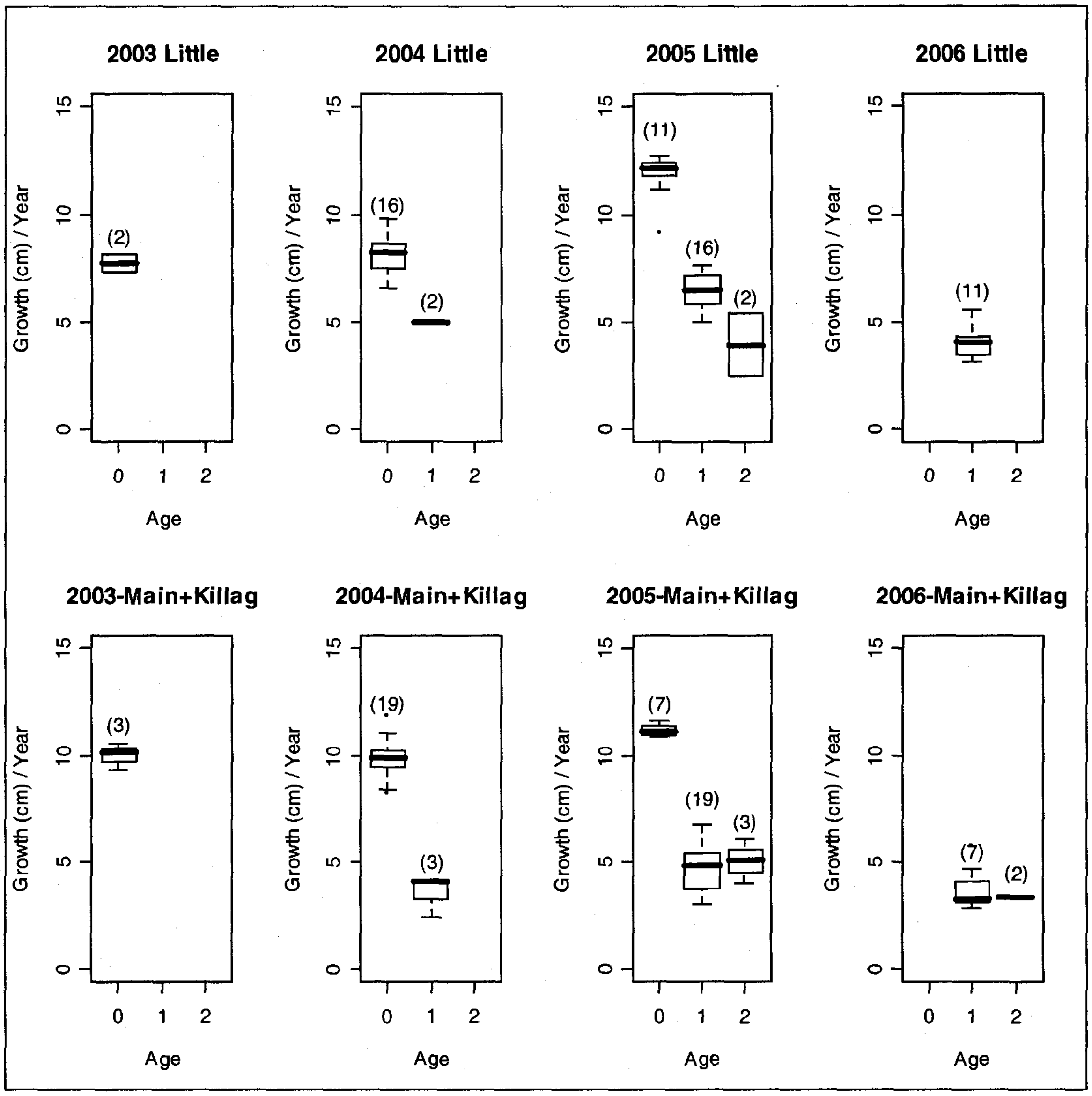

Figure 4.3 – Boxplots of specific growth for all ages of WRSH salmon smolt in each year from 2003 to 2005 in pre-treatment and in the post-treatment year of 2006. Growth determined by back-calculated lengths-at-age. Plots on the top line represent the control sites and the bottom row of plots represents limed (test) sites.

A plot similar to that for salmon smolts was constructed for back-calculated brook trout growth. Unlike smolts however, trout were sampled at each site of each branch of the system, therefore growth should be specific to branch. Of course, the findings of major movements may confound river branch differences in environmental conditions..

The plots of yearly specific growth for brook trout showed a slight increase in growth for 1 year old trout during the treatment year of 2006 (Figure 4.4), however ANOVA analysis showed that this was not significant (ANOVA, P=0.62) and provided little evidence of liming-induced effects on growth.

Mean growth rate for trout from unlimed waters in the first year (age 0), second year and third year of growth was 95.7mm (sd=25.6, N=75), 59.9mm (sd=17.2, N=59) and 55.5mm (sd=14.3, n=15), respectively. Conversely, annual trout growth in limed waters for the first, second and third year was 86.8mm (sd=24.7, N=69), 65.8mm (sd=19.3, N=49) and 59.8mm (sd=17.9, N=22), respectively.

These growth rates were slightly below those reported for brook trout in regionally close Southern Upland lakes (MacMillan and Lablanc 2002) where trout grew a mean of 116mm in their first year (age 0), 66mm in thier second year and 71mm in their third year. When compared to regionally close Southern Upland river systems, trout growth was similar (Hastey 2007), though varying proportions of each rivers anadromous component may skew growth rates.

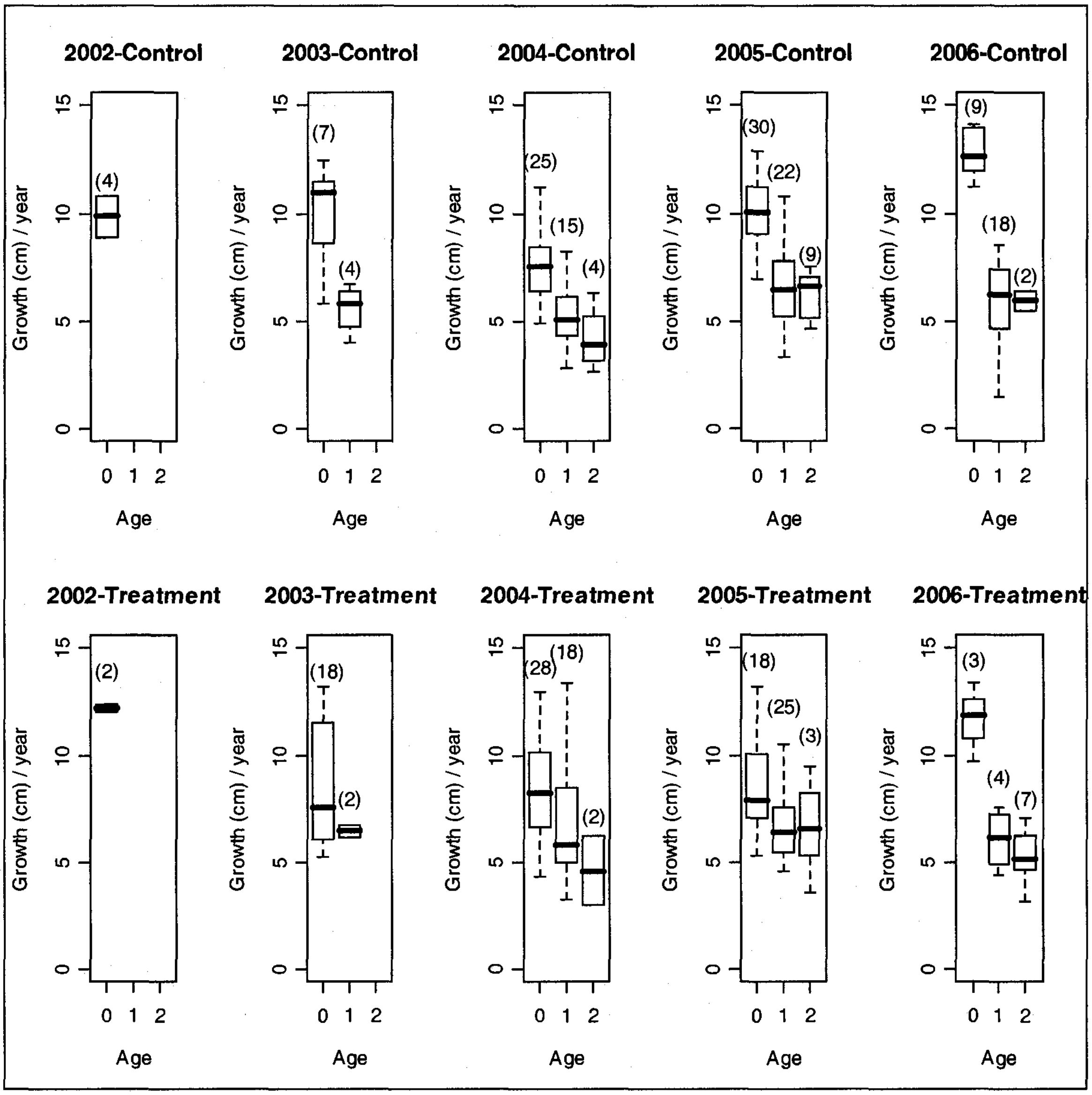

Figure 4.4 – Box plots of annual growth for all ages of WRSH brook trout in each year from 2002 to 2005 in pre-treatment and in the post-treatment year of 2006. For example, a three year old trout, captured in 2006, had its first year of growth (as a young-of-year) in 2003. Its first year of growth (in cm)(labelled 0) is plotted in 2003. Growth was determined by back-calculation. Plots on the top row represent all control sites pooled and the bottom row of plots represents all limed sites (pooled).

Fish Condition

When relative weights are well below a value of 100, feeding conditions or food supply are thought to be insufficient. On the contrary, when relative weight values are consistently well above 100, the fish in question may not be utilizing their resources to its potential (Murphy and Willis 1996).

The condition of the trout in the WRSH system was deemed moderate, with relative weights below those exhibited in brook trout populations in other parts of their range. Brook trout generally had relative weight values between 80 and 85, below the expected mean value of 100. Mean relative weight and range for brook trout (over all years) in the Main WRSH, Little River and Killag was 85.9 (62.2, 107.6), 79.7 (53.3, 101.8) and 83.8 (67.7, 114.2), respectively. However, as I am assessing potential changes in relative weight as a result of liming, it was important to compare river branch-specific relative weight over time.

While river branches consistently exhibited differing mean relative weights among years (Figure 4.5), there was only one year instance where this difference was significant. In 2006, the main branch trout had significantly higher relative weight than those of the Little River (Tukey's HSD. P=0.000). As shown in Figure 4.5, the sampling distribution of trout was not similar with respect season between these two years. When comparing years, the 2005 samples were significantly lower than those of 2006 for the Little, Main and Killag Rivers (Tukey's HSD, P=0.0006, P=0.020 and P=0.023, respectively)(Figure 4.5). Relative weight was also significantly lower in 2005 than in 2007 for the Little River and Main WRSH (Tukey's HSD, P=0.000 and P=0.030, respectively) (Figure 4.5). The only other significant difference between years or branch, which did not involve the 2005 samples was the Main WRSH, where relative weight in 2006 was significantly higher than those of 2007(Tukey's HSD, P=0.030)(Figure 4.5).

To test the potential for a seasonal effect on relative weight, as displayed in Figure 4.5, I plotted mean monthly relative for each year (Figure 4.6). Though sample distribution did not allow branch specific analysis of variance, comparison of month with all years pooled showed no significant seasonal variation (ANOVA, P=0.169).

Also, to investigate potential bias as a result of capture method (selectivity), displayed indirectly via fork lengths, I regressed relative weight on fork length. This regression showed a non- significant relationship ($R^2 \leq 0.095$) between relative weight and fork length (Figure 4.7).

Unlike trout, juvenile salmon (parr and smolts) have not had a standard weight equation calculated across all populations, therefore is was impossible to calculate relative weight for the WRSH salmon. I therefore calculated Fulton's condition factor (K). Condition factor of salmon parr was quite good, with condition values generally between 1.2 and 1.4, indicating good health and ample food supply (Figure 4.8). Smolt K-values were less than parr, as expected, but generally remained between 1.0 and 1.2 (Figure 4.8).

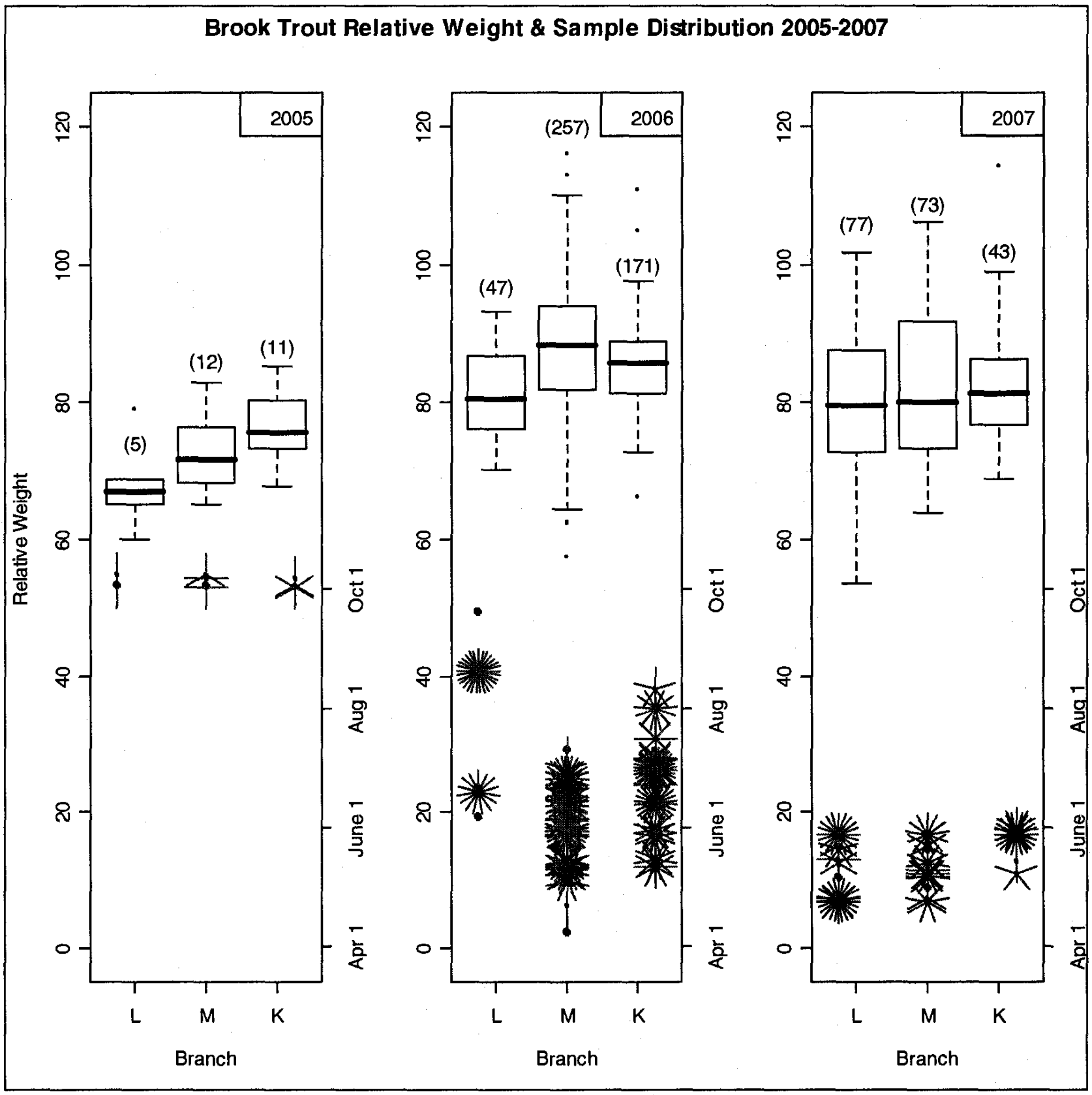

Figure 4.5 – Box plots of relative weight and sunflower plots of sampling distributions of WRSH brook trout by branch over each sampling year. The box plots show relative weight (left hand scale) and sunflower plots show sampling dates and sample size (date scale on right). L = Little River, M = Main branch WRSH and K = Killag River. Sunflower plot represents each sample with a black dot. If more than one trout was sampled at any given site on the same date, a "petal" is added to the dot (i.e. Little River, Oct. 2005 show 3 dots, one dot with two "petals", therefore 5 samples were taken).

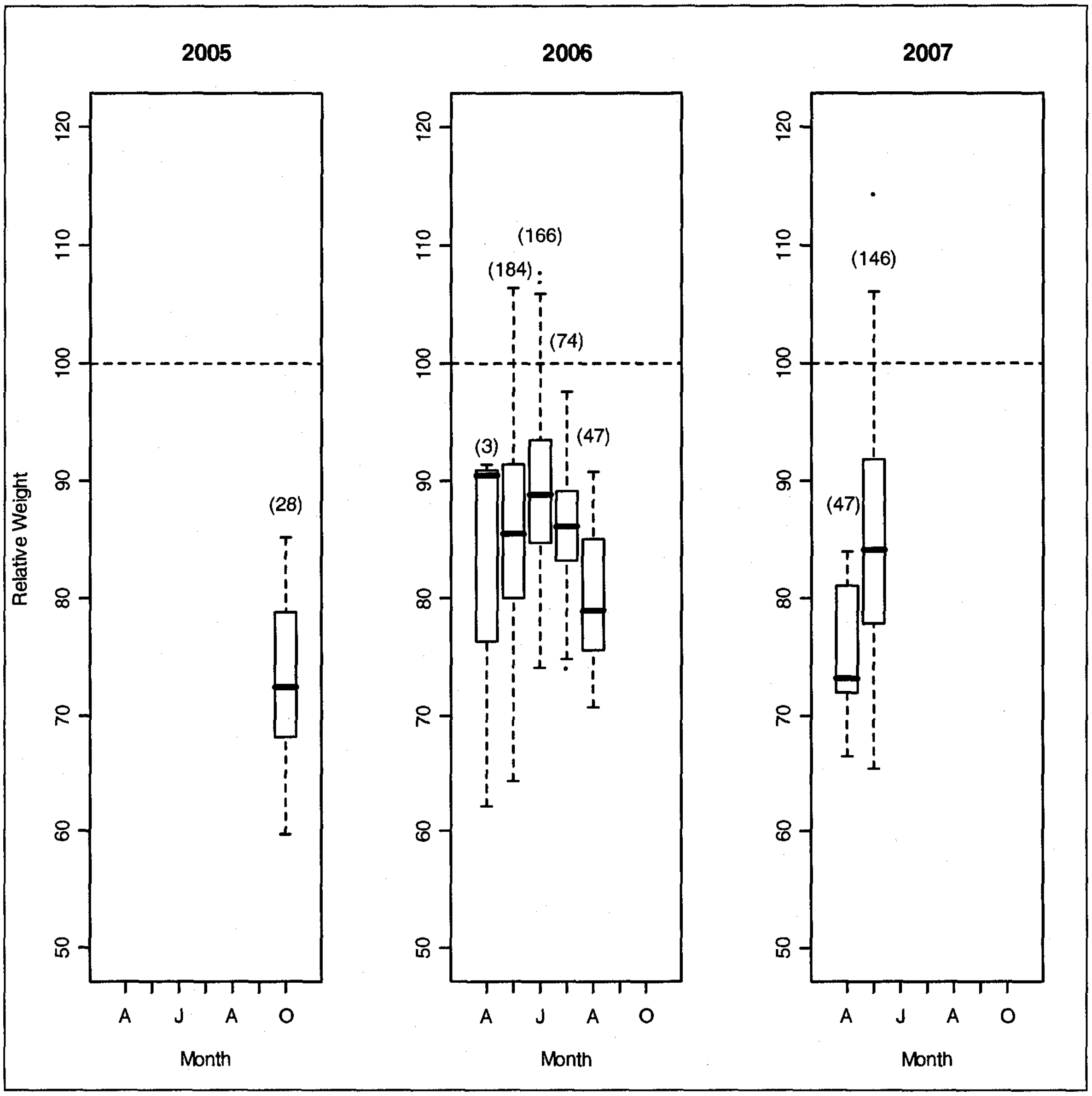

Figure 4.6 – WRSH brook trout relative weight annual trends, by month as shown by boxplots. All three years of the study are represented. Numbers in parentheses () are the sample size each month.

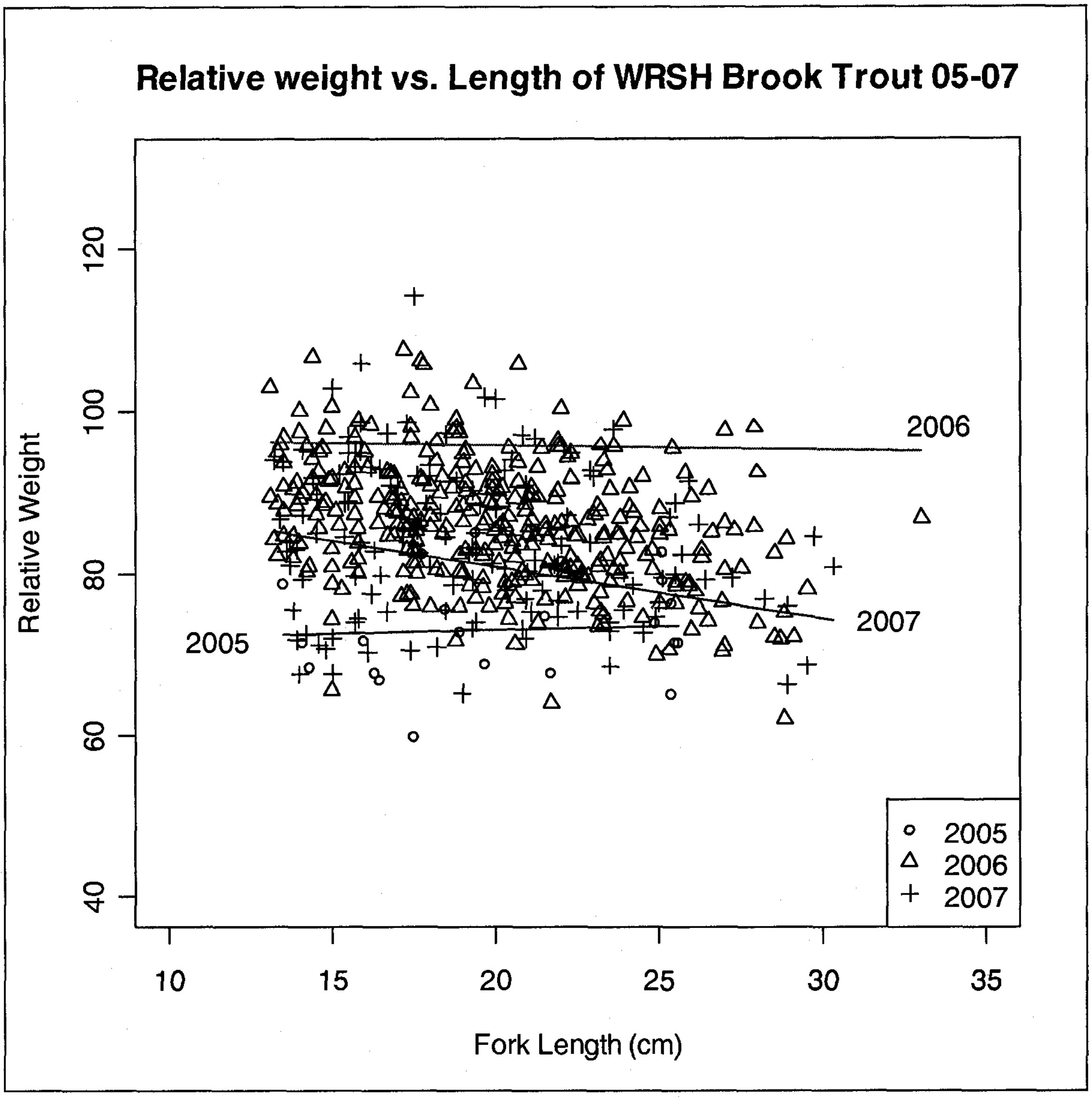

Figure 4.7 – WRSH brook trout relative weight versus fork length for all three study years. Regression lines indicate expected Wr at given length for each dataset (year). Pearson correlation coefficients for 2005, 2006 and 2007 were 0.004, 0.095 and 0.087, respectively.

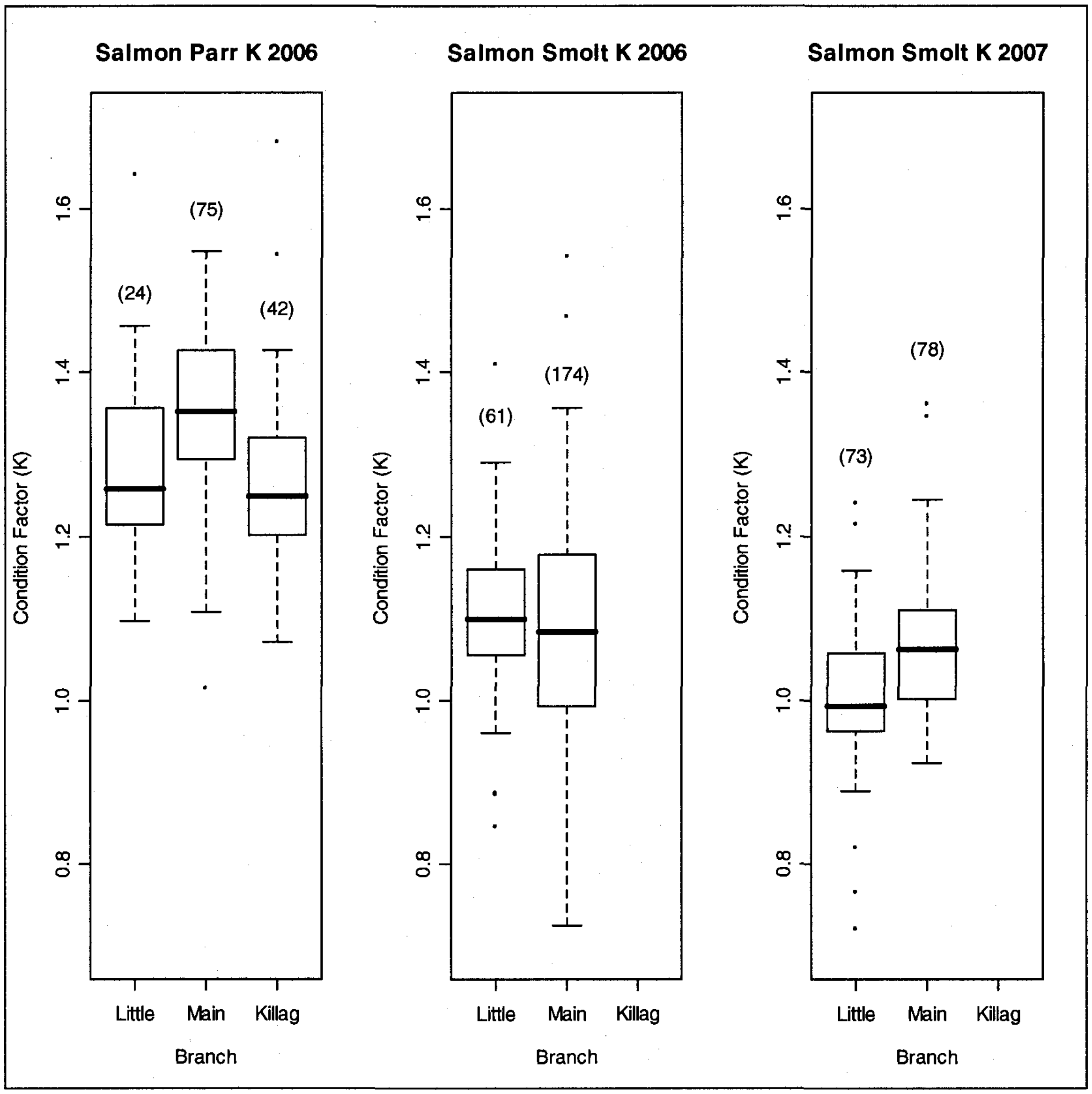

Figure 4.8 – Boxplots of WRSH salmon parr and smolt condition factor (K) in 2006 and 2007. Condition factor calculated using fork length.

Discussion

Fish Community and Species Diversity

In an electrofishing survey of acidified rivers of eastern NS, Shaw et. al (1995) indicate that in rivers with pH < 5.0, mean species diversity was 2.3 species · site^{-1}, and in river with mean pH >5.0, the mean species diversity was 5.1 species · site^{-1}. My electrofishing data indicates that the mean number of fish taxa captured in 2005 and 2006 was 4.50 and 4.17 species respectively, which closely correlates to values given by Shaw et al (1995). As changes in species diversity between years was largely driven by the presence/absence of species represented by only a few individuals (generally less than 4 fish), the changes were not thought to be of importance nor significant.

The increase in salmon smolt numbers from 2005 (0 smolt) to 2006 (196 smolt) is the result of netting effort directed at downstream movement in 2006 but not in 2005. Therefore, comparisons of smolt CPUE could not be compared and provide little insight as to their abundance.

These data do not suggest that any liming-induced change in species composition has occurred, though this was expected as the single year of treatment would likely be insufficient time to allow for community-level shifts resulting from individual-level benefits of liming.

As a side note, the apparently large population of potentially stunted yellow perch may contribute to heavy predation of young-of-the-year trout and salmon in the lower sections of the system, specifically around Sheet Harbour Lake. Further study investigating the influence of these competitors on salmonids, and the potential for retardation of recovery of salmon in that part of the system, may be warranted.

Salmon Densities

When compared to historical data from the late 20th century (1994 to present), salmon densities of 2005 and 2006 were visually well within recent inter-annual variation and are not thought to be significantly different. However, electrofishing surveys from 1965-1968 indicate that salmon densities were likely significantly higher. Ducharme (1972) reported YOY densities averaging 50.4 fry per $100m^2$ and 6.3 parr per $100m^2$ (Ducharme 1972). Conversely, in a similar paper it was reported that mean density of fry from 1967-1970 was 9.1 fry per $100m^2$ and 1.77 parr per $100m^2$ (Anonymous 1975). As the reports outlined severe differences in densities, it is unclear to what degree densities have declined. However, based on adequate spawning escapements, it was estimated that densities should be approximately 30.3 fry and 15.1 parr per $100m^2$ (Anonymous 1975), therefore I contend that indeed juvenile salmon densities have suffered declines.

With assumed low returns of salmon to the WRSH, juvenile salmon densities should be patchy based on redd site selection of adults during the two preceding autumns. Presumably then, density of young-of-year and parr should largely be a function of egg deposition in the two years prior to sampling. For this reason, only two years of data are overly prone to inaccuracy and a longer time series would solidify observations of density. Supporting this patchy theory was the movement of YOY salmon through the population at site U-5. Where all salmon in 2005 were YOY and all salmon in 2006 were parr, it is reasonable to assume that the same cohort of fish were sampled each year without replacement by an younger cohort.

The potentially significant increase in salmon numbers at site L-4 is interesting. The reason no salmon were sampled in 2005 at site L-4 is unknown as the fish sampled in

2006 at that site were a mix of YOY (5) and parr (3). Presumably, if parr (1+ or older) were present in the 2006 sample, they should have been present during 2005 sampling, baring immigration during the winter as YOY or as 1+ parr in the spring/summer.

The fact that the Killag River traditionally supported approximately 50% of the salmon spawning habitat in the system and the majority of the spawning activity (Ducharme 1972), we would expect the Killag to have the highest densities. This however was not evident as densities at the upper Little River site were similar to the Killag. Once more, the patchy nature of egg deposition by the small number of salmon assumed to return to the river each year, and the small number of electrofishing sites likely "muddies" these observations.

The absence of salmon YOY and parr, as determined by electrofishing, netting and angling at sites U-1 and L-2 indicates the large area (min. 9.8km of river) at the upper Main branch, WRSH that is apparently void of salmon. This section of river offers a significant amount of salmon spawning and rearing habitat. As discussed in chapter 2, this area was one of the most acidic sections of the watershed, with mean pH at approximately 4.75 to 5.00. As Lacroix and Knox (2005) suggested, survival of salmon acidity levels of 4.5 to 5.0 is likely low, and therefore the lack of long term persistence of salmon is this area is expected to be as a result of this low pH. With the significant increases in pH as a result of liming, the areas below the doser (and impassable falls) should now facilitate juvenile salmon survival. Presumably, recolonization of this area would provide some of the largest liming-influenced increases in salmon smolt production provided sufficient egg deposition occurs.

In all, salmon densities were low as expected and did not drastically change as a result of liming. Our surveys showed that salmon densities are likely highly controlled by egg deposition as a result of few adult spawners and densities may not be a great indicator of liming success if egg deposition does not increase. Finally, the absence of salmon in some areas indicates the potential for major gains in smolt production provided eggs are deposited in these areas.

Fish Movement and Tagging

Fish movement as determined by tagging indicated the extensive use of the spring habitat within the system. As indicated by the temperature surveys (Chapter 2), not all parts of the system provide year-round habitat for brook trout, thus migration to find these cool-water refugia follows periods of warm weather. This observation is consistent with the finding of many researchers that brook trout seek coolwater refugia (Gibson, 1966, Fry 1951, Biro 1998, MacMillan and Crandlemere 2005,). This may confound any deductions of brook trout growth and density as sub-units of trout in any given river branch may not be as segregated as necessary.

There may be some movement of salmon, as late as the pre-smolt stage, between rearing areas as juvenile salmon have been shown to move not only within their natal stream section, but also to adjacent rearing sites (McCormick et. al 1998). The recapture of salmon smolts (N= 3) in the Little River that were original marked in the Main branch WRSH indicates some movement of parr or potentially pre-smolts.

Some degree of avoidance of low pH has been shown in laboratory settings (Atland and Barlaup 1996) but little information exists on in-stream active migration to areas of favourable pH. The purpose of these movements therefore is largely unknown and may be spurred by several factors, and cannot be attributed to a preference for less acidic water.

Pre-liming (pre Oct. 2005), the Little River would have offered the least acidic over wintering habitat in the system (Chapter 2 - Figure 2.2), and if parr were selecting habitat based on pH, it stands to reason that parr would move to this area. However, following liming, the Main branch maintained a minimum pH equal to or greater than that of the Little River (Chapter 2 - Figure 2.2), Therefore following the acid-avoidance movement theory, parr would not be prompted to relocate. As this was the only observation of parr movement, further investigation of the environmental cues spurring parr migration may prove useful.

In the 1960's, a counting fence was in operation on the WRSH, near Iron Bridge Pool (Site 4). In the years of 1966 and 1967, aged 1+ and 2+ salmon parr were reported migrating downstream, presumably to the lake habitat below, at a similar time to the spring smolt run (Ducharme 1972). In the present study, few parr (N= 2, CPUE = 0.13) were observed moving downstream at this time and it was assumed that this movement was small scale in nature. Reasons for this difference in the movement patterns of parr may be density-driven, where the low densities presently observed do not "force" parr to disperse in search of new habitat.

Without thorough investigation of the lentic habitats, their relative importance as rearing habitat in this system is unknown. Atlantic salmon parr are known to rear in lentic habitats where competition (both intraspecific and interspecies) and predation may be decreased (Gibson 1993).

As it relates to the long term liming project, the finding of little movement of juvenile salmon reinforces the assumption that juvenile density, as a proxy for survival (with allowance for egg deposition) can be used as a monitoring tool to assess the impacts of the acid mitigation program. Conversely, the confirmation of large scale trout movements indicates that attempts to quantify liming-induced effects based on trout response in treated and untreated areas may not be an adequate indicator success for the acid mitigation program.

Finally, the findings of major trout congregations within spring habitats exemplify the need for protection of critical areas within the larger habitat complexes. It therefore cannot be assumed that seemingly small areas of the West River are insignificant, as the loss of just a few of these spring habitats would likely result in a severe reduction of the standing crop of trout. While no such areas were identified for juvenile salmon, additional surveys of potential spawning and parr habitat, especially within the upper reaches of the main branch, should be conducted to identify areas offering the greatest potential for salmon recolonization.

Age and Growth

Annual growth analysis showed no consistent trends in growth among branches of the river, representing treated and untreated sections of river. This is to be expected as back-calculated length-at-age represents past growth, and in this case, growth prior to liming.

For the assessment of environmental stress and the resultant growing conditions, annual age-specific growth of individuals is likely a superior index than strict back-calculation of age at length, as the latter is dominated by past growth. The increase in young-of-year growth in brook trout at control sites is likely a function of better flow conditions. Trout residing in the Main WRSH may be less affected by periods of low precipitation during the core growing months of May and June, due to its relatively higher stream order and the availability of deeper water in large pools and lakes. Intra-site migration, specifically fish moving from limed waters to tributaries in search of springs, may potentially account for some portion of the interplay of growth between control and treatment sites.

Very few trout reached age 4 in the WRSH. This is consistent with trout ages in similar, regionally close systems (MacMillan and Crandlemere 2005, Hastey 2007), with trout aged 4+ and 5+ rare and generally represented in anadromous individuals.

The age composition of smolt for the 2007 smolt run was 80.9% 2+ smolts with the remainder 3+ fish. This contrasts data from 1965 to 1968 where the proportion of smolts aged 2+ and 3+ was 48.7% and 50.8% respectively (Ducharme 1972). A potential reason for this is the possibility of a shift in the thermal regime of the river as mean age of smoltification has been shown to increase with latitude, and consequently stream temperature (Metcalfe and Thorpe 1990). In a study of the nearby Moser River, data suggested that mean air temperature has increased over the last 65 years (MacMillan, *unpublished data*). Assuming a relationship between mean air temperature and mean river temperature, exaggerated by past riparian zone tree harvesting and the channel widening effects of log driving leading to increased solar influx to the river, mean river temperature has likely increased since the middle of the last century. However, insufficient historic temperature data exists for the West River to empirically demonstrate this theory.

While these data provide little evidence of liming induced changes in the growth pattern of salmon or trout within the system, the data collected is a good representation of the conditions prior to, and immediately following, the start of the mitigation program. The effect of liming on fish condition, and the interplay of density, temperature and competitor species may, in the future, provide valuable information as to the effects of this program.

Fish Condition

The relative weight of WRSH trout appeared to be stable at a level below what would be expected based on trout from other areas of the brook trout North American geographical range. This may indicate a paucity of resources, likely as a result of density-dependant competition. Also, the high temperatures (chapter 2) may create a bottleneck of resources/habitat at the times when trout seek cool water springs, negatively affecting condition.

The significant difference in relative weight observed between the Main branch WRSH and the Little River in 2006 may reflect the discrepancy in sampling distribution, namely the time of year samples were taken, though date was shown to not significantly alter relative weight in this system.

The condition of salmon parr and smolts indicated that there is sufficient prey availability and that local habitat is suitable. This would be expected as densities are low and competition with other salmon should be low. While many other species that feed on invertebrates are present within the system (white sucker, brook trout etc.), apparently either little niche overlap occurs or the total biomass of all fish within that feeding guild is below the production potential.

Salmon condition factor for parr was similar to those reported by Ducharme (1972) for the WRSH (1+ parr, mean K=1.07, N=19), suggesting that a long term change may have occurred. The discrepancies between densities from nearly 35 years prior (mean 50.4 YOY and 6.3 parr per $100m^2$) and the present, may have a large effect on parr condition, potentially due to reduced intra-specific competition for prey.

Smolt condition was slightly less than the parr condition, however was anticipated as smoltification generally entails an elongation of the body (McCormick 1998), that would decrease relative weight.

Though these data provide little evidence of a liming induced effect on both trout and salmon condition, the data set again provides a reference from which future monitoring can be compared. Also, evidence of above average condition for salmon parr indicates that prey resources are not limiting under current densities. While this would seem intuitive at such low salmon densities, it may be useful to track as a proxy for general densities.

Conclusions

In summary, the fish community (as a whole), fish species diversity, salmonid densities, salmonid growth, and salmon condition have not yet shown a response to liming. The life history of fish, and salmonids in particular, suggest that the response to liming is likely to require a longer time period following liming, in the range of 3-5 years at minimum. Therefore, the data collected to describe general fish population parameters for this system should prove useful for re-assessment of the acid mitigation program several years in the future.

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GENERAL CONCLUSIONS

As a result of liming, the WRSH has realized significant decreases in acidity, to pH levels that are biologically acceptable to many aquatic organisms, including our target species of Atlantic salmon. Mean pH of the river water at the system's mouth is approximately 5.5, the predetermined target value, while most sites upstream of the mouth are in the 5.5 to 6.0 range. Maintenance of this water chemistry goal is paramount to the success of this project.

Aquatic invertebrate communities have also shown indications of change, with an overall abundance increase and a shift of dominant taxa within the treated section of river. This is encouraging as it indicates a less acid stressed invertebrate community and provides increased feeding opportunities for salmonid fishes.

Other biological signs of change are less evident, though given the relatively short duration of this project, this was anticipated and it is believed that further detectable biological shifts will occur in time. Hence, reasonable timelines associated with recovery are important to this project. Most salmon in the WRSH emigrate as smolts aged 2+ and 3+, and spend 1 or 2 winters at sea. Thusly, it may take between 3.5 and 5.5 years for a single egg to adult to egg cycle to be completed. With such a timeframe, the first salmon that will have realized the full benefit of liming (as swim-up fry through to smolt) will return to the river in the summers of 2008 – 2009. Densities of salmon therefore are not likely to show significant increases other than that provided directly by improved egg-smolt survival.

Also important was the identification of key components to restoration and healthy aquatic communities. Areas of refuge have been identified for acid sensitive invertebrate taxa, primarily in sections of tributaries. These areas should serve as remnant populations from which adjacent, newly treated areas can be seeded. Mobile taxa with aerial adult stages such as Ephemeroptera, Trichoptera, Plecoptera, Diptera and Odonata taxa should colonize new areas at a faster rate than more sedentary organisms such as Mollusca.

Concerns of other environmental variables potentially affecting aquatic communities in the WRSH have also been identified, such as altered river morphology from historical logging activities and drainage basin land use practices (specifically "clear-cut" wood harvesting in sensitive spring recharge areas). Though these factors could potentially limit the absolute salmon production in the river, it is unlikely that they would hinder a recovery program such as the Acid Mitigation Program.

Finally, through investigation of fish and fish communities, the salmonids of the WRSH appear to be in good physical condition, and are neither severely food-limited nor crowded. Furthermore, habitat suitable for salmon has been identified, including the acceptable stream pH that now exists throughout treated sections of the river. It is therefore reasonable to assume that this river is a strong candidate for salmon enhancement through combined of liming and stocking initiatives.

Lingdell (1995) showed that liming of 12 Swedish rivers returned the benthic invertebrate community to a "pristine state" compared to regionally close, non acidified systems. While that conclusion may be accurate for central Sweden, on a larger spatial scale and considering the entire aquatic community, this is likely not the case for all liming projects. In a recent review, Clair and Hindar (2005) concluded that while water chemistry parameters may be restored to levels suitable for aquatic life, aquatic communities will likely not be returned to pre-acidification states, further indicating that target fish species can be restored using active management approaches. Consequently, the need to define expected outcomes for the WRSH acid mitigation project is essential to the assessment of its success. A target aquatic community must be identified which would signify a return to a non-acid stressed community. The presence and abundance of acid-sensitive species will ultimately affect perception of the effectiveness of lime treatment of this system.

While acid sensitive epilithic periphyton species and Chironomidae species may require similar environmental chemical requirements to more prevalent organisms, the Atlantic salmon will ultimately bare the scrutiny of assessment and consequently play the role of barometer for the WRSH project. Caution is essential while evaluating the restoration of salmon as there are a multitude of factors controlling the abundance and distribution of juvenile Atlantic salmon within the WRSH. Of these factors, two major divisions can be made, mirroring the major divisions in the life history of Atlantic salmon, where factors affecting salmon are derived from freshwater or saltwater environments. Liming will address the juvenile stages of salmon life, from egg to smolt, but the smolt to adult cycle must not be ruled out as an equally weighted factor controlling salmon population in the WRSH.

While juvenile production in the WRSH and other Southern Upland rivers has been lowered and is below conservation requirements due to acidification (Lacroix and Knox 2005, O'Neil 1998), without improved at-sea survival, salmon populations may not persist (Amiro and Gibson 2005) without artificial supplementation. An important potential delayed effect of acidification, one that is not often considered, is the effect of decreased marine performance, and consequently survival, as a result of acid exposure during early life stages (Kroglund and Staurnes 1999, Staurnes et al. 1996, Staurnes et al. 1995).

In summary, three actions are required for a significant increase in both population size and the prospect of persistence for WRSH salmon; an increase in egg deposition, increased survival leading to increased production of smolt and finally, increased marine survival rates. Positive effects on instream juvenile salmon survival and consequent production of smolts should result from the active liming program. This is a significant hurdle and one step closer to achieving the goal of once again having a sizable salmon population in the West River. However, without complimentary actions of "active management approaches" as described by Clair and Hindar (2005), this effort may not be enough. Realizing this, the Nova Scotia Salmon Association in partnership with the Department of Fisheries and Oceans implemented a Live Gene Banking (LGB) program for the WRSH. In the spring of 2007, 113 seaward migrating salmon smolts were intercepted and brought to DFO's Coldbrook biodiversity facility. These salmon will be raised and released back to the WRSH as ripe adults where the fish will be left to spawn naturally, circumventing the issues of low marine survival and contributing to increased egg seeding. The second cohort of LGB smolts will be collected in the spring of 2008.

In all, the West River, Sheet Harbour acid mitigation project has reached all goals expected within the short timeframe of this study. Decreased acidity levels and changing invertebrate communities should therefore be considered indicators of success thus far. Important however, is the continued support of this project to ensure auxiliary initiatives such as the Live Gene Bank augmentation program continue as well as the fundamental mitigation of acids.

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APPENDIX

	Site U-1																	
	Salmon Parr		Brook Trout		White Sucker		American Eel		Yellow Perch		Brn Bullhead		Lake Chub		B. Killifish		Total	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
May	NS	0 (1)	NS	0 (1)	NS	36 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	2 (1)	NS	0 (1)	NS	38 (1)
June	0 (8)	NS	0 (8)	NS	14.25 (8)	NS	0.50 (8)	NS	1.38 (8)	NS	1.00 (8)	NS	0 (8)	NS	0 (8)	NS	17.13 (8)	NS
July	0 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	2 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS
Aug.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Oct.	0 (3)	NS	0 (3)	NS	0.33 (3)	NS	0.33 (3)	NS	1.00 (3)	NS	0.67 (3)	NS	0.33 (3)	NS	0 (3)	NS	2.67 (3)	NS
Mean	0 (12)	0 (1)	0 (12)	0 (1)	9.58 (12)	36 (1)	0.42 (12)	0 (1)	1.33 (12)	0 (1)	0.83 (12)	0 (1)	0.08 (12)	2 (2)	0 (12)	0 (1)	12.25 (12)	38 (1)

Figure X – Catch-per-unit-effort (CPUE) data for upstream migrating fishes at site U-1 in 2005 and 2006. A unit effort = 1 net night = 24h. Number of net nights indicated in parentheses (). NS= Not sampled.

	Site U-2																	
	Salmon Parr		Brook Trout		White Sucker		American Eel		Yellow Perch		Brn Bullhead		Lake Chub		B. Killifish		Total	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
May	NS	0.40 (5)	NS	0 (5)	NS	131.60 (5)	NS	0 (5)	NS	0 (5)	NS	0 (5)	NS	0 (5)	NS	0 (5)	NS	132.00 (5)
June	0.75 (4)	0.33 (3)	1.00 (4)	0.67 (3)	6.25 (4)	29.00 (3)	0 (4)	0 (3)	0.25 (4)	0 (3)	0.25 (4)	0 (3)	0 (4)	0 (3)	0 (4)	0 (3)	8.5 (4)	30.00 (3)
July	0.67 (3)	0 (3)	2.33 (3)	0 (3)	5.33 (3)	2.67 (3)	0 (3)	0.67 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)	8.33 (3)	3.33 (3)
Aug.	0 (3)	NS	1.00 (3)	NS	2.00 (3)	NS	0 (3)	NS	0 (3)	NS	0 (3)	NS	0 (3)	NS	0 (3)	NS	3.00 (3)	NS
Oct.	0 (2)	NS	2.00 (2)	NS	1.00 (2)	NS	0 (2)	NS	0 (2)	NS	0 (2)	NS	0 (2)	NS	0 (2)	NS	3.00 (2)	NS
Mean	0.42 (12)	0.27 (11)	1.50 (12)	0.18 (11)	4.08 (12)	68.45 (11)	0 (12)	0.18 (11)	0.08 (12)	0 (11)	0.08 (12)	0 (11)	0.08 (12)	0 (11)	0 (12)	0 (11)	6.17 (12)	69.09 (11)

Figure X – Catch-per-unit-effort (CPUE) data for upstream migrating fishes at site U-2 in 2005 and 2006. A unit effort = 1 net night = 24h. Number of net nights indicated in parentheses (). NS= Not sampled.

Site U-3

	Salmon Parr		Brook Trout		White Sucker		American Eel		Yellow Perch		Brn Bullhead		Lake Chub		B. Killifish		Total	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
May	0 (1)	0.14 (7)	0 (1)	0.86 (7)	0 (1)	16.57 (7)	2 (1)	2.57 (7)	1 (1)	100.00 (7)	0 (1)	0 (7)	0 (1)	0.43 (7)	0 (1)	0 (7)	3 (1)	124.71 (7)
June	1 (1)	0 (2)	0 (1)	1.00 (2)	1 (1)	2.00 (2)	1 (1)	2.00 (2)	0 (1)	0 (2)	0 (1)	0.5 (2)	0 (1)	0 (2)	0 (1)	0 (2)	3 (1)	5.50 (2)
July	0 (3)	0.33 (3)	0.67 (3)	1.00 (3)	1.33 (3)	2.67 (3)	2.33 (3)	1.00 (3)	0 (3)	0.33 (3)	0 (3)	0.67 (3)	0.33 (3)	0 (3)	0 (3)	0 (3)	4.67 (3)	6.00 (3)
Aug.	0 (2)	NS	0.50 (2)	NS	0.50 (2)	NS	0 (2)	NS	0 (2)	NS	0 (2)	NS	0 (2)	NS	0 (2)	NS	1.00 (2)	NS
Oct.	0 (1)	NS	1 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	1 (1)	NS
Mean	0.13 (8)	0.17 (12)	0.50 (8)	0.92 (12)	1.00 (8)	10.67 (12)	1.13 (8)	2.08 (12)	0 (8)	58.42 (12)	0 (8)	0.25 (12)	0.13 (8)	0.25 (12)	0 (8)	0 (12)	2.88 (8)	75.17 (12)

Site U-5

	Salmon Parr		Brook Trout		White Sucker		American Eel		Yellow Perch		Brn Bullhead		Lake Chub		B. Killifish		Total	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
May	NS	0 (6)	NS	0.50 (6)	NS	62.00 (6)	NS	0.17 (6)	NS	0.17 (6)	NS	0 (6)	NS	0.17 (6)	NS	0 (6)	NS	63.00 (6)
June	0.13 (8)	0 (2)	2.25 (8)	4.50 (2)	57.88 (8)	5.00 (2)	3.00 (8)	0 (2)	0.25 (8)	0 (2)	0 (8)	0.50 (2)	0.50 (8)	0 (2)	0 (8)	0 (2)	64.00 (8)	10.00 (2)
July	0 (2)	0.67 (3)	0.50 (2)	6.00 (3)	4.00 (2)	2.67 (3)	1.00 (2)	0 (3)	0 (2)	0 (3)	0 (2)	0 (3)	0 (2)	0 (3)	0 (2)	0 (3)	5.50 (2)	9.33 (3)
Aug.	0 (3)	NS	0.33 (3)	NS	(0.67) (3)	NS	1.00 (3)	NS	0.13 (3)	NS	0 (3)	NS	0.27 (3)	NS	0 (3)	NS	35.73 (3)	NS
Oct.	0 (3)	NS	2.50 (3)	NS	0.50 (3)	NS	0.50 (3)	NS	0 (3)	NS	0 (3)	NS	0 (3)	NS	0 (3)	NS	3.50 (3)	NS
Mean	0.07 (15)	0.18 (11)	1.67 (15)	2.73 (11)	31.60 (15)	35.45 (11)	2.00 (15)	0.09 (11)	0.13 (15)	0.09 (11)	0 (15)	0.09 (11)	0.27 (15)	0.09 (11)	0 (15)	0 (11)	35.73 (15)	38.73 (11)

Site L-2

	Salmon Parr		Brook Trout		White Sucker		American Eel		Yellow Perch		Brn Bullhead		Lake Chub		B. Killifish		Total	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
May	NS	0 (4)	NS	0.75 (4)	NS	56.60 (4)	NS	0 (4)	NS	0.75 (4)	NS	0 (4)	NS	0.25 (4)	NS	0 (4)	NS	58.25 (4)
June	0 (8)	0 (1)	0.13 (8)	0 (1)	33.63 (8)	0 (1)	0.50 (8)	2 (1)	0.38 (8)	0 (1)	0.25 (8)	0 (1)	1.00 (8)	0 (1)	0 (8)	0 (1)	35.88 (8)	2 (1)
July	0 (3)	0 (2)	0 (3)	0 (2)	16.00 (3)	1.00 (2)	0.33 (3)	2.00 (2)	2.67 (3)	2.00 (2)	0 (3)	1.5 (2)	0 (3)	0 (2)	0 (3)	0 (2)	19.00 (3)	7.00 (2)
Aug.	0 (3)	NS	0 (3)	NS	1.00 (3)	NS	0 (3)	NS	0.67 (3)	NS	0 (3)	NS	0 (3)	NS	0 (3)	NS	1.67 (3)	NS
Oct.	0 (3)	NS	0 (3)	NS	4.67 (3)	NS	0 (3)	NS	0 (3)	NS	0 (3)	NS	0 (3)	NS	0 (3)	NS	4.67 (3)	NS
Mean	0 (17)	0 (7)	0.06 (17)	0.43 (7)	19.65 (17)	32.57 (7)	0.29 (17)	1.00 (7)	0.76 (17)	1.00 (7)	0.12 (17)	0.43 (7)	0.47 (17)	0.14 (7)	0 (317)	0 (7)	21.35 (17)	35.57 (7)

Site L-4

	Salmon Parr		Brook Trout		White Sucker		American Eel		Yellow Perch		Brn Bullhead		Lake Chub		B. Killifish		Total	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
May	NS	0 (7)	NS	0 (7)	NS	5.14 (7)	NS	0.43 (7)	NS	2.00 (7)	NS	0 (7)	NS	0 (7)	NS	0 (7)	NS	7.71 (7)
June	0 (2)	0.50 (2)	1.50 (2)	5.50 (2)	0 (2)	5.50 (2)	0 (2)	4.50 (2)	1.00 (2)	0.50 (2)	0 (2)	0.50 (2)	0 (2)	0.50 (2)	0 (2)	0 (2)	2.5 (0)	18.00 (2)
July	0 (3)	0 (1)	0 (3)	0 (1)	0 (3)	1 (1)	1.00 (3)	6 (1)	0 (3)	0 (1)	0 (3)	0 (1)	0 (3)	0 (1)	0.33 (3)	0 (1)	1.33 (3)	7 (1)
Aug.	0 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	0 (1)	NS	1 (1)	NS	1 (1)	NS
Oct.	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	0 (6)	0.10 (10)	0.50 (6)	1.10 (10)	0 (6)	4.80 (10)	0.50 (6)	1.80 (10)	0.33 (6)	1.50 (10)	0 (6)	0.10 (10)	0 (6)	0.10 (10)	0.33 (6)	0 (10)	1.67 (6)	9.70 (10)

Site L-5

	Salmon Parr		Brook Trout		White Sucker		American Eel		Yellow Perch		Brn Bullhead		Lake Chub		B. Killifish		Total	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
May		0 (6)		0.17 (6)		209.17 (6)		1.83 (6)		4.33 (6)		0 (6)		0.17 (6)		0.17 (6)		216.33 (6)
June	0.25 (8)	0 (1)	2.88 (8)	2 (1)	181.88 (8)	0 (1)	7.38 (8)	22 (1)	7.75 (8)	1 (1)	0.25 (8)	1 (1)	2.50 (8)	0 (1)	10.25 (8)	0 (1)	213.13 (8)	26 (1)
July	0 (4)	NS	0.50 (4)	NS	18.50 (4)	NS	3.75 (4)	NS	4.50 (4)	NS	0.25 (4)	NS	0.50 (4)	NS	0.75 (4)	NS	28.75 (4)	NS
Aug.	0 (4)	NS	0 (4)	NS	4.75 (4)	NS	5.50 (4)	NS	4.75 (4)	NS	1.00 (4)	NS	0.75 (4)	NS	0 (4)	NS	16.75 (4)	NS
Oct.	0 (3)	NS	1.67 (3)	NS	40.33 (3)	NS	2.67 (3)	NS	0.33 (3)	NS	0.33 (3)	NS	0 (3)	NS	0 (3)	NS	45.33 (3)	NS
Mean	0.11 (19)	0 (7)	1.67 (19)	0.43 (7)	92.72 (19)	179.29 (7)	5.78 (19)	4.71 (7)	5.56 (19)	3.86 (7)	0.44 (19)	0.14 (7)	1.39 (19)	0.14 (7)	4.72 (19)	0.14 (7)	112.39 (19)	189.14 (7)

-trap net

Site L-4 Downstream

	Salmon Smolt	Salmon Parr	Brook Trout	White Sucker	American Eel	Yellow Perch	Brown Bullhead	Lake Chub	Banded Killifish	Total
May	16.38 (8)	0.13 (8)	0.75 (8)	11.13 (8)	1.63 (8)	12.63 (8)	0.00 (8)	0.50 (8)	0.00 (8)	43.13 (8)
June	0.50 (2)	0.50 (2)	5.00 (2)	5.50 (2)	2.00 (2)	2.00 (2)	2.00 (2)	1.50 (2)	0.00 (2)	19.00 (2)
July	0.00 (2)	0.50 (2)	0.00 (2)	2.50 (2)	1.00 (2)	0.50 (2)	0.50 (2)	0.00 (2)	0.00 (2)	5.00 (2)

Figure X – Catch-per-unit-effort (CPUE) data for downstream migrating fishes at site L-4 in 2006. A unit effort = 1 net night = 24h. Number of net nights indicated in parentheses (). NS= Not sampled.

				Site L-5 Downstream						
	Salmon Smolt	Salmon Parr	Brook Trout	White Sucker	American Eel	Yellow Perch	Brown Bullhead	Lake Chub	Banded Killifish	Total
May	4.43 (7)	0.14 (7)	0.14 (7)	8.29 (7)	0.00 (7)	13.57 (7)	0.14 (7)	0.43 (7)	2.29 (7)	29.43 (7)

Figure X – Catch-per-unit-effort (CPUE) data for downstream migrating fishes at site L-5 in 2006. A unit effort = 1 net night = 24h. Number of net nights indicated in parentheses (). NS= Not sampled.

				Site L-4 Downstream						
	Salmon Smolt	Salmon Parr	Brook Trout	White Sucker	American Eel	Yellow Perch	Brown Bullhead	Lake Chub	Banded Killifish	Total
May										
June										
July										

Figure X – Catch-per-unit-effort (CPUE) data for downstream migrating fishes at site L-4 in 2007. A unit effort = 1 net night = 24h. Number of net nights indicated in parentheses (). NS= Not sampled.

				Site L-5 Downstream						
	Salmon Smolt	Salmon Parr	Brook Trout	White Sucker	American Eel	Yellow Perch	Brown Bullhead	Lake Chub	Banded Killifish	Total
May										
June										
July										

Figure X – Catch-per-unit-effort (CPUE) data for downstream migrating fishes at site L-5 in 2007. A unit effort = 1 net night = 24h. Number of net nights indicated in parentheses (). NS= Not sampled.