Ecological Effects of Road De-icing Salt on Adirondack Forests and Headwater Streams

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Abstract

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Water samples from upstream and downstream sites on eighteen study streams in the Adirondacks, New York State, were collected over three years and analyzed for the presence of road salt runoff as measured by chloride ion content. Streams crossed by state roads receive more road salt runoff than streams crossed by county roads. High levels of road salt runoff were not associated with lower levels of Plecoptera or Trichoptera in headwater streams in the Adirondacks. However, Ephemeroptera were affected by high levels of road salt runoff. Forest composition in ten transects above and below state roads was analyzed by point-centered quarter method. Trees in the lowest quartile of circumference in each transect, representing recruitment, were further analyzed by point-centered quarter method. Transects were centered on study streams. Mean chloride ion content of study streams, indicating forest exposure to road salt runoff, was seen to favor recruitment of balsam, *Abies balsamea*.

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1.1: Introduction:

Ecological Effects of Road Salt

1.1: Roads

Paved roads are a major feature of the modern landscape and a ubiquitous element of human presence in the industrialized world. Roads are also the first sign of new development. New road construction begins a process of urbanization or suburban sprawl (Angermeier *et al.* 2004).

In the US and elsewhere, roads are flanked by mown or otherwise maintained strips, creating a corridor that has been called the "road-effect zone" (Forman 2000). The ecological influence of these constructions radiates outward beyond the parallel strips. The road-effect zone may provide ecological benefit (it may be the most diverse area in an intensively farmed landscape) but road-effect zones have various ecologically detrimental effects as well (Forman 2000). Traffic noise alters avian community composition; roads may block wildlife corridors; collisions with wildlife can affect local species demography, and roads bring more light and heat into forests, creating edge effect. There are other detrimental effects that impact freshwater: roads impede wetland drainage; they often require sections of streams to be channelized, they can hinder fish passage, and in cold climates they deliver road salt runoff to adjacent waterbodies (Forman 2000, Trombulak and Frissell 2000).

A study that took into account four broad road types: primary roads in urban areas, primary roads (under state control) in rural areas, and secondary roads in urban and rural areas concluded that 18 to 19% of the total area of the United States is affected by roads, excluding indirect effects such as atmospheric pollution (Forman 2000). One potential effect of roads is runoff of de-icing salt.

1.2: Road Salt

During the 1950s the use of rock salt as a winter road deicer became popular in the United States (Godwin *et al.* 2003). The New York State Department of Transportation still favors NaCl as a deicing chemical, as it is the least expensive of available de-icers. In fact, New York State mines 4.3 million metric tons of rock salt (halite) per year (DuChene and Reed 2009). About 950,000 tons of road salt, 22 tons per lane mile, are applied yearly to New York State roads by NYSDOT (Kelting and Laxson 2010). The United States as a whole uses over 23 million tons of rock salt for road de-icing (Novotny *et al.* 2007).

By weight, road salt is about 40% sodium and 60% chloride, with up to 5% trace elements or possible contaminants. It can contain trace amounts of phosphorus, sulfur, nitrogen, copper, or zinc (Environment Canada 2001). Ferrocyanides such as sodium ferrocyanide $Na_4Fe(CN)_6{\cdot}10H_20$ are used as road salt anti-caking agents. If ferrocyanides are exposed to light while in solution, they will dissociate to form cyanide ions, CN^-, which then hydrolyze to HCN and volatilize. Ferrocyanides have “limited solubility,” however, and generally remain stable in the environment (Environment Canada 2001).

Once road salt goes into solution as runoff, its two major components have different fates. The sodium ion tends to bind to soil particles (PMRA 2006), whereas chloride ions move with the water, persisting and accumulating in the aquatic environment (PMRA 2006). In addition to adhering to substrates, sodium can be taken up by organisms in freshwater streams. Aquatic insect larvae in acidic environments use Na^+/H^+ exchangers to substitute sodium for hydrogen ions and thereby maintain acid/base homeostasis, as do amphibians (Clark *et al*. 2004, Harvey 1992, Marshall 2002). In general, aquatic insects would have less tolerance to low pH in a sodium-poor environment (Clark *et al*. 2004). For these reasons studies of road salt contamination have often measured Cl^- in the environment or its effect on aquatic organisms, rather than measuring the amount or effect of Na^+, or NaCl or total salts.

Even if concentrations of chloride ion and changes in aquatic community composition correlate, observed changes need not be due to chloride ion. Road salt can affect the chemical composition of receiving soils and waters in other ways besides simple delivery of sodium and chloride. In a study that compared highway runoff from four sites upgradient and downgradient of a six-lane highway as it passed through a forest in southeastern Massachussetts, with no possible additional source of contamination other than road salt, it was found that when chloride concentrations were high in downgradient groundwater, that water also contained significantly more sodium, calcium, magnesium, potassium, barium, strontium, copper, iron, and zinc than upgradient water (Granato *et al*. 1995). This is apparently an effect of sodium ions being exchanged for calcium and other cations in the soil, increasing the mobility of these cations and causing them to be detectable in downgradient groundwater (Granato *et al*. 1995). Clay and organic matter in soil have negative surface charges which attract groundwater cations. Normally Na^+ cannot out-compete ions such as Ca^{2+} or Mg^{2+}, which are more positively charged, or K^+ , a smaller cation than sodium (smaller atoms outcompete larger ones for exchange sites). However, sodium becomes a much better competitor when its concentration relative to other ions is increased, as when an area receives road salt runoff (Kelting and Laxson 2010).

1.3: Road Salt and Groundwater

Groundwater is water that has percolated past the unconsolidated sediments where spaces between soil particles are filled mostly with air, and reached the zone where spaces and cracks in rock are filled with water. The top of this zone is the water table. Streams can be replenished by baseflow, water that seeps into the streams either from unconsolidated sediments or from groundwater. The speed of groundwater can vary from a few feet to a few hundred feet per year (Pollack 1992). Pollutants that enter groundwater may take years to resurface due to baseflow discharge (Environment Canada 2001).

When surface waters are road salt-impacted, it’s possible to infer whether the NaCl entered the waterbody from direct runoff or from groundwater by checking the ratio of sodium to chloride ion. If the ratio is 1:1, it was direct surface runoff. If there is less sodium, the route taken was through soil and groundwater, leaving some sodium bound to substrate.

Wells are supplied by groundwater. Well water contamination, especially by sodium, is a health issue. Drinking water guidelines for sodium and chloride concentrations in Canada are based on the levels at which they are perceived by taste: 250 mg/L chloride, 200 mg/L sodium (Environment Canada 2001). The New York State Department of Health does not specify a sodium limit for drinking water, but cautions that “water containing more than 20 mg/L of sodium should not be used for drinking by people on severely restricted sodium diets. Water containing more than 270 mg/L of sodium should not be used by people on moderately restricted sodium diets” (NYSDOH 2006). In Massachusetts, 20 mg/L is the sodium standard for drinking water (MA DEP 2006).

Between 1973 and 1983 seven wells on either side of Route 9 in Goshen Massachusetts averaged 79 mg/L sodium, while Route 9 received an average of 14.3 tons road salt per lane mile (Pollack 1992). In 1983 this was reduced to 3.3 tons per lane mile, and two years later the wells averaged 52 mg/L. Five years after the change the wells averaged 36 mg/L sodium (Pollack 1992).

Some sodium is naturally present in groundwater, although its concentration can vary widely, from 6 to 130 mg/L, even where soil is not saline (Jones *et al.* 1992). Sometimes the sodium concentration is not known because chloride ion has been measured instead. Where chloride ion is over 100 mg/L in a well, the water is found to be hard due to magnesium and calcium ions liberated by sodium exchange (Jones *et al.* 1992).

Chloride is naturally present in groundwater as well, from a variety of sources. It may derive from sedimentary rock that was once an ocean floor (Jones *et al.* 1992. See saline lakes, below). Chloride can also come from animal sources, raw sewage, and agricultural fertilizers.

In metropolitan Toronto chloride concentrations as high as 14,000 mg/L have been measured in shallow sub-surface water (Howard and Haynes 1993). It can be much harder to measure the chemistry of groundwater, unless a well is present in the desired study area. One solution is to monitor groundwater quality by sampling freshwater springs. Springs are upwellings of groundwater, and they contain invertebrate fauna which can provide information on the combined effects of any groundwater pollution that may be present (Williams *et al.* 1999).

Chloride ion concentrations in springs in and around Toronto were found to reflect the extent to which the area was urbanized. At an urbanized site next to a bridge and highway the spring had a maximum 1324 mg/L Cl^-, with a mean of 1092 mg/L. In contrast, a spring in the Glen Majors Conservation Area had a mean of 2.1 mg/L Cl^- (Williams *et al.* 1999). An interesting point was that whereas the streams showed seasonal variations, spikes and troughs of chloride concentration, Cl^- in springs was much more stable throughout the year (Williams *et al.* 1999). This shows that ions in the enclosed groundwater environment change and migrate according to much slower timeframes than they do in the comparatively chaotic outdoor world.

Another way to monitor groundwater, and to gauge the chloride input to groundwater from road salting, is to use the mass balance method in which the amount of chloride from road salt used within a watershed or catchment is compared to the amount of chloride in the catchment streams. (Total salt could be compared instead, or conductivity). The chloride that is missing is presumed to be in the groundwater. As years pass, chloride input to the stream will increase to more nearly match the chloride input from road salt to groundwater, until finally a steady state is achieved with chloride inflow to surface water matching chloride outflow from groundwater.

In a study of the Highland Creek Basin in the Metropolitan Toronto and Region Watershed, Howard and Haynes (1993) installed a probe and data logger to measure conductivity at 15-minute intervals in a stream which received the waters of all the lower-order streams in the basin, just before the water entered Lake Ontario. Water samples were taken regularly for chloride ion concentration and conductivity, so that conductivity could be used as a measure of chloride ion concentration. Data was gathered for approximately 2 ½ years. The basin is crossed by a 12-lane highway and a network of arterial and secondary roads, and receives about 10,000 tons of chloride annually in the form of NaCl road salt. The basin does not receive significant fertilizer input. Calculations included correcting for chloride entering streams from baseflow, as almost none of this chloride would have come from the previous winter's road salting.

This study showed that only 45% of the chloride deposited onto the basin by road salting was removed by overland flow into streams and transported with the stream water out of the basin (Howard and Haynes 1993). For example, in 1989-90, 3427 tons of chloride (31%) left the basin in streamwater before the end of April. Another 1609 tons (14 %) exited during summer rains before the end of October (Howard and Haynes 1993).

If only 45% of chloride applied in a year exits from a catchment, 55% is being stored in groundwater. Eventually the amount of chloride entering the basin subsurface waters would match the amount leaving by baseflow. Hydrological calculations indicated that that steady state would be reached in the basin in 20 years (Howard and Haynes 1993). At that time, the average groundwater chloride concentration discharging as baseflow would be 426 +/- 50 mg/L, almost twice the maximum acceptable drinking water chloride concentration (Howard and Haynes 1993).

1.4: Road Salt and Surface Waters

Surface waters in some areas naturally have more chloride ion. Saline lakes are found worldwide and have important ecological roles, often supporting migratory birds. The arid Canadian prairie provinces of Alberta, Saskatchewan and Manitoba have lakes with higher salinity waters due to concentration of salts by evaporation (Environment Canada 2001). Southern Alberta and Saskatchewan have saline lakes due to underlying shale and sandstone.

Saline waters have 3000 mg/L or higher total salts (Environment Canada 2001). In contrast, a survey of 417 lakes in non-saline non-urbanized areas of Canada in Labrador, Newfoundland, Nova Scotia and New Brunswick found median chloride ion concentrations between 0.3 and 4.5 mg/L. Rain contains 0.1 mg/L chloride ion (Novotny *et al.* 2007).

Large chloride ion inputs to lakes can interfere with normal seasonal mixing of lake waters, causing a chemical form of stratification. Thermal stratification much more familiar: warmer water is less dense than cooler water, and in many temperate lakes will form a top layer during summer months. As the weather cools in the fall and winds pick up, the lower cooler layer typically gets thinner and then breaks up entirely as wind propels mixing of the entire lake water. This lake turnover occurs because in cooler weather there is less temperature difference for the force of wind to overcome. The same turnover, "complete vertical mixing" (Novotny *et al.* 2007), usually occurs again in the spring. Such a lake is dimictic.

"Density stratification caused by salt can be much stronger than that caused by temperature" (Novotny *et al.* 2007). A salt addition of 10 mg/L produces as much stratification in a lake as a temperature increase of one degree Celsius (Novotny *et al.* 2007). The salt runoff from the winter season can prevent the spring turnover. A lake may become monomictic, mixing layers once instead of twice, or meromictic, going all year without mixing. This has been observed to happen irregularly in the Twin Cities area of Minnesota, with normally dimictic lakes occasionally having a monomictic, heavily chloride stratified year (Novotny *et al.* 2007). Low dissolved oxygen in the hypolimnion can kill or stress aquatic life, and will make it easier for heavy metals and phosphorus to come out of the bottom lake sediments into solution (Novotny *et al.* 2007).

In the Twin Cities area of Minnesota (The TCMA), nine urban lakes showed significant differences in concentrations of Na^+ and Cl^- between surface and bottom waters, but non-significant differences between surface and bottom concentrations for all other ions tested. Median sodium and chloride concentrations were 73 and 132 mg/L surface, 105 and 186 mg/L bottom, respectively (Novotny *et al.* 2007). There are no geological sources of chloride ion in the TCMA, and in the geologically similar Wisconsin North Temperate Lakes Region, chloride concentrations of 4-10 mg/L are found (Novotny *et al.* 2007). Paleontological work on diatom assemblages in sediment cores from TCMA lakes calculated that chloride concentrations in 1750-1800 A.D. were approximately 3 mg/L (Ramstack *et al.* 2004).

Road salt pollution can be measured in feeder streams that supply lakes, as was seen in four headwater streams that descend from Goodnow Mountain and surrounding uplands in the central Adirondacks, northern New York State. One site above and two sites below the state road that crosses all four streams were tested for chloride concentration (Demers and Sage 1990). At each study stream a significant difference in chloride concentration was found between sites 100 m upstream and downstream. Mean upstream concentrations at the four streams ranged from 0.51 – 1.35 mg/L Cl^-, while downstream concentrations at 50 m below the road ranged from 1.70 to 17.05 mg/L Cl^-. No significant difference was seen between the two downstream sites 50 and 100 m below the road, indicating that “these elevated chloride levels were not just an immediate roadside phenomenon” (Demers and Sage 1990). This study also demonstrated persistence of chloride runoff over time, months after road salt application. Sampling took place at least monthly between April – July 1987 and December 1987 – September 1988, and elevated chloride concentrations persisted at all downstream stations (Demers and Sage 1990).

Trends in road salt contamination of surface waters can be observed where the same waterbody or watershed has been sampled for chloride ion successively over a span of decades. First Sister Lake in Ann Arbor, Michigan was first sampled from 1965 to 1967, during which time Cl^- concentrations increased from 33 to 79 mg/L. The same lake was sampled again in 1973 and 74, when Cl^- concentrations of 63 to 116 mg/L were recorded. In 1994 and 95 the lake contained 243 to 289 mg/L Cl^-, and in 2002 First Sister Lake had 295 mg/L Cl^- (Benbow and Merritt 2004).

The Mohawk River in New York State was sampled for various ions in the nineteen fifties, seventies, and nineties. Between 1952 and 1953 chloride ion concentrations in the Mohawk River averaged 7.7 mg/L (maximum 16 mg/L). Between 1971 and 1974 they averaged 13.5 mg/L (maximum 28 mg/L). Between 1990 and 1998 the river averaged 20.4 mg/L Cl^- (maximum 47 mg/L). All sampling in all years was from the same USGS gauging station at Cohoes, NY (Godwin *et al.* 2003). Estimated mean daily yields of ions in the Mohawk River during these periods were calculated by using monthly mean discharge and monthly mean concentrations. The change in estimated mean daily yield of chloride ion from the 1950s to the 1990s was 19.93 mg/L, or 243.02%. Sodium ion also showed a large increase during these periods. From the 1950s to the 1990s Na^+ in the river increased by 10.10 mg/L, or 129.96% (Godwin *et al.* 2003).

That these chloride and sodium increases came from road salt is inescapable. In the same studies, mean daily yields of potassium, magnesium, calcium and sulfate ions were also calculated. Potassium, magnesium and calcium all increased by less than 10% between the 1950s and 1990s, whereas sulfate decreased by 22.77% (Godwin *et al.* 2003). The Mohawk River Basin that drains into the Mohawk River was less than 6% urbanized at the time of the

Godwin *et al.* study (2003), yet 288 wells and springs within the watershed had been found to have chloride contamination averaging 62.12 mg/L, maximum 10,800 mg/L (Godwin *et al.* 2003).

Long-term increases in chloride ion pollution are not limited to traditional snow belt areas. Kaushal *et al.* (2005) found significant increases in chloride ion concentrations over a thirty-year period in Baltimore County, Maryland, the Hudson River Valley, New York, and the White Mountains of New Hampshire (numbers not supplied). Rural streams in the White Mountains sometimes contained more than 100 mg/L Cl^-, which the authors point out is "similar to the salt front of the Hudson River Estuary" (Kaushal *et al.* 2005). In streams flowing through urban and suburban Baltimore, winter chloride ion spikes approached 5000 mg/L (Kaushal *et al.* 2005). Typical mean annual snowfall in the mid-Atlantic region is 46 cm, and yet 82,000 metric tons of deicing salt were applied in Baltimore during the study period 1986—2000 (Kaushal *et al.* 2005). The authors note that during this same period impervious surface in and around Baltimore increased by 39%. They believe that increasing construction of roadways and parking lots is associated with rising chloride ion pollution and can affect many northern areas of the United States (Kaushal *et al.* 2005).

"The surface waters most sensitive to road-salt impacts are low-dilution environments such as wetlands" (Environment Canada 2001). Wetlands typically drain slowly, and chloride ion is transported or flushed by flowing water. Since the 1970s, new regulatory definitions of wetlands have been developed by the Fish and Wildlife Service, National Research Council, Army Corps of Engineers, and various state and local governments (Tiner 2005), activity that reflects growing understanding of the ecological contributions made by wetlands. Definitions have to allow for complex variation between wetlands. For example, the 1979 FWS definition specifies that a wetland have at least one of three characteristics, relating to hydrophytic plants, soil type, or water saturation (Tiner 2005). Wetlands can be permanent features of the landscape or they can be seasonal (ephemeral, vernal). Wetlands can also be man-made, as in roadside ditches (Tiner 2005).

When wetlands are relatively small and inconspicuous, and especially when they are manmade, there may be a tendency to discount anthropogenic damage to them without awareness of their contribution to ecosystem productivity. “Studies have largely ignored small seasonal wetlands such as fens, vernal pools, and flooded roadside ditches. These habitats are usually fish-free and support unique faunas that are vulnerable to salt contamination” (Petranka and Doyle 2010).

1.5: Road Salt and Plants

Challenges to roadside vegetation from road salt include aerial deposition, changes in soil ion content, changes in soil nitrogen cycling, and changes in physical soil structure. When a new highway was being planned adjacent to the Morton Arboretum in Illinois, a testing scheme was put in place to measure how far road salt would penetrate into the park. This included transects with sampling buckets open to the atmosphere, examination of white pines (a salt-sensitive species on which salt damage is visually obvious), some planting of test white pines, and construction of earthen berms intended to protect the park from salt deposition. The highway was built in 1989, and testing took place at the Arboretum during winters from 1984 to 1987 and 1990 to 1991. Tests concluded that “the aerial sodium chloride plume is at least 15m high within 67m” of the highway, and may have achieved that height because winds were guided upwards by the earthen berms (Kelsey and Hootman 1992). Damage to white pines included needle necrosis and tree death (Kelsey and Hootman 1992). Another study found that the sodium chloride plume from a deiced highway can deposit salt up to 500m away (Jones *et al*. 1992).

Organic and clay particles in soil have a negative surface charge. Cations in the liquid in soil pores form electrostatic attractions, weak bonds, to these soil particles. Under normal circumstances, several common soil ions bond more strongly to soil particles than sodium: hydrogen and aluminum ions are each more strongly bound to clays and organics than calcium or magnesium ions, which in turn are each more strongly bound to the soil than potassium, and finally potassium trumps sodium (Kelting and Laxson 2010). Sodium is out-competed for bonding sites by these other ions because sodium has only one positive charge, and it is relatively large. Smaller cations bond to exchange sites on soil more readily than large cations. However when the supply of sodium is greatly increased, as when road salt runoff seeps into soil, sodium displaces other cations (Kelting and Laxson 2010).

Plant cation macronutrients calcium, magnesium, and potassium and micronutrients copper, zinc, manganese and molybdenum are available to plants when electrostatically bound to clay and organic soil particles. When cations are unbound because they have been out-competed for binding sites by sodium, they may leach out of the soil, depriving plants of these nutrients (Kelting and Laxson 2010). Sodium also out-competes hydrogen ion, freeing the H^+ and making the soil less acidic. Road salt runoff would have one positive effect on very acidic soil, since pH lower than 5 decreases the action of soil nitrifying bacteria and raising pH may increase nitrate (NO_3^-) levels in the soil. However, soil nitrifying bacteria are sensitive to salinity, and their activity is significantly reduced at NaCl concentrations ≥ 0.25 mg/L (Green *et al.* 2008). Ammonium ions (NH_4^+) are displaced from their soil binding sites by sodium, and can leach out of soil (Green *et al.* 2008), decreasing soil fertility.

Roadside vegetation and surface waterbodies are both vulnerable to changes in soil structure that result from road salt. Calcium ions structure soil by bridging negatively-charged clay particles, holding them together. This “cation bridging” saves clay particles from being leached into surface waters, and allows the soil to absorb more water. The sodium cation, with its large size and single positive charge, does not bridge clay particles. Loading soil with sodium can therefore increase runoff of rain into local waterbodies along with increased sediment load with rain runoff (Kelting and Laxson 2010).

1.6: Road Salt and Vertebrates

De-icing salt attracts some mammals to roadsides, and contributes to car accidents. Mammals that seek salt at roadsides and are often struck by cars include moose, white-tailed deer, mule deer, bighorn sheep, woodchucks, porcupines, snowshoe hares, and cottontail rabbits (Environment Canada 2001, Kelting and Laxson 2010). Radio-collared moose in New Hampshire “extended their range to include pools heavily contaminated by road salt . . . there were twice as many moose-vehicle collisions per kilometer where roadside pools were present than where there were no pools“ (Kelting and Laxson 2010). In spring, male moose are growing antlers and females are lactating. At this time their sodium hunger is greatest, and the frequency of moose-vehicle collisions is greatest as well, although it is not the heaviest season for car traffic (Kelting and Laxson 2010).

Birds are also attracted to road salt, probably both as a source of sodium and for its resemblance to the pebbles that birds use to aid in digestion. Bird vehicle strikes are unlikely to be reported; however Mineau and Brownlee (2005) found twelve published reports of bird strikes by vehicles. Species included bobwhite quail, ring-necked pheasants, white-winged crossbills, common crossbills, red crossbills, evening grossbeaks, and pine siskins. Several of these bird kills were obviously reported because of the large numbers involved, for example approximately 1000 evening grossbeaks killed in British Columbia over a period of two weeks in 1980 after feeding on road salt (Mineau and Brownlee 2005). Grossbeaks, crossbills and siskins are collectively called "winter finches" because they often move south out of boreal forest in winter when conifer seeds are less available. In some areas the winter finches are called "grill birds" because they are so often hit by cars (Mineau and Brownlee 2005).

In one case from the 1950s, the road salt had been stained blue, and the bird gut contents were also blue. While the kidneys of mammals have the ability for precise regulation of sodium and chloride retention or excretion, avian kidneys are not as well equipped for this task. And while marine birds have nasal glands that excrete excess salt, non-marine birds do not have this mechanism. Often winter finches appeared sick or unnaturally fearless after feeding on road salt. Symptoms of salt toxicosis include partial paralysis, tremors, inability to fly or perch, and "retropulsion" (involuntary backwards movements) (Mineau and Brownlee 2005).

Toxicity testing was carried out using the house sparrow as a model. This common alien invader is the same approximate size as winter finches, however, house sparrows come originally from the middle east. In that arid environment they may be exposed to more salt, and may be more salt tolerant than winter finches (Mineau and Brownlee 2005). In toxicity tests water was withheld for 6 hours after salt ingestion to replicate winter conditions. Overt signs of toxicity and first mortality were recorded at 1,500 mg/kg road salt, or two and a half 2.4-mm-diameter road salt particles. The median lethal dose was 3,000 mg/kg road salt, or 5.2 particles of that size (Mineau and Brownlee 2005).

Amphibians of many different species are in decline worldwide, and efforts are ongoing to find which environmental stressors are affecting them. Amphibians may be especially vulnerable to water pollution because their egg and larval life stages are spent in water. Amphibian eggs are water permeable and depend on water to carry oxygen through the innermost egg membrane to the embryo. Amphibians also typically have permeable skin (an adaptation for gas exchange and water intake) so adult stages may also be vulnerable to water pollution. A few studies have addressed amphibians and road salt.

Wood frog (*Rana sylvatica*) eggs from Canadian wetlands were reared in water containing different concentrations of sodium chloride that reflected salt concentrations that had been measured in the field. Field concentrations of 0.39, 77.5, and 1,030 mg/L NaCl were measured in northwestern Ontario, and the same concentrations were used in testing the chronic effects of salt on wood frogs. Chronically salt-exposed wood frog tadpoles at all treatment levels had significantly decreased survivorship. Significantly fewer of the treated tadpoles underwent metamorphosis, with the fewest in the highest treatment level. At 77.5 and 1,030 mg/L NaCl, developmental or behavioral abnormalities were often observed, such as bent tails or swimming in circles (Sanzo and Hecnar 2006).

Chloride ion concentrations appear to structure amphibian assemblages in roadside ponds. In a study of 26 ponds within 60 m of roads in Nova Scotia, ponds averaged 118.5

mg/L chloride ion in spring, 82.3 mg/L in early summer, and 97.1 mg/L in late summer. These concentrations represent a salt pulse at spring snow melt, dilution of ponds by spring and early summer rains, and then concentration of pond water by evaporation in summer heat. Eight amphibian species were found in these ponds. Species richness of amphibians declined significantly with increasing chloride concentration. In ponds with the higher Cl^- concentrations no spotted salamanders (*Ambystoma maculatum*) or wood frogs (*Rana sylvatica*) were found, whereas no pattern was seen regarding study pond Cl^- concentration and presence/absence of spring peepers (*Pseudacris crucifer*), green frogs (*Rana clamitans*), or American toads (*Bufo americanus*) (Collins and Russell 2009).

Acute toxicity testing of tadpoles or salamander larvae of these same species showed that spotted salamander larvae and wood frog tadpoles had the lowest median lethal chloride ion concentrations: 1178.2 mg/L and 1721.4 mg/L respectively. The other three species listed above all had higher median lethal chloride ion concentrations: 2830.4, 3109.3, and 3925.8 mg/L respectively (Collins and Russell 2009). The more-sensitive spotted salamanders and wood frogs breed early in the year, around the time of spring runoff and high Cl^- concentrations. In contrast, the salt-tolerant American toad lays its eggs in vernal pools (ephemeral ponds), which gradually evaporate and increase in salinity (Collins and Russell 2009).

Another study demonstrated relative salt-tolerance of green frogs *Rana clamitans* compared to that of the spotted salamander *Ambystoma maculatum.* Eggs of both species were gathered from vernal pools or beaver-created wetlands in the central Adirondacks, New York State, and in laboratory experiments they were hatched and grown at chloride ion concentrations that had been observed in similar local waterbodies. Embryonic survivorship and incidences of malformations were recorded. Very different results were obtained from spotted salamander and green frog experiments. For spotted salamanders, survivorship at control (1 mg/L Cl^-) and 33 mg/L Cl^- was the same, but survivorship "significantly declined . . . with increasing chloride concentration" (Karraker and Ruthig 2009) of 145, 465, and 945 mg/L Cl^- . At the highest chloride ion concentration the incidence of malformed individuals was also significantly higher. In contrast, none of these chloride ion concentrations significantly increased mortalitity or malformation of green frogs (Karraker and Ruthig 2009). In an earlier study the lead author similarly concluded that green frogs are relatively insensitive to road salt, although that study reported significantly more green frog embryo malformation at 945 mg/L Cl^- (Karraker 2007).

Why would one amphibian handle road salt easily and another not? Amphibian embryos develop inside the innermost membranous chamber of the egg, and are dependent upon water passage into and out of this space. "At higher salinities, flow of water through the chamber declines, retarding development and increasing the incidence of malformations" (Karraker and Ruthig 2009). Spotted salamanders spend 5-6 weeks in the egg stage, whereas green frogs remain in the egg for only a week or less before hatching (Karraker 2007, Karraker and Ruthig 2009). The relatively brief egg developmental period of the green frog may make it less vulnerable to altered conditions during the egg stage (Karraker and Ruthig 2009).

In contrast to these road salt scenarios, the natural challenge for a freshwater animal is hyperosmoregulation, keeping enough ions *in* the body. Amphibians have cells scattered over their skin that function in sodium and chloride ion uptake (Harvey 1992, Marshall 2002). These chloride cells were first known from fish.

To maintain an internal osmolarity around one-third seawater, fish take in necessary ions in fresh water and shed excess ions in salt water (Katoh *et al.* 2001). Chloride cells (currently more often called mitochondria-rich cells) are found in greatest density on the gills, and are interspersed between flatter pavement cells (Marshall 2002). In fresh water, epithelial chloride cells maintain an internal negative charge by actively pumping out hydrogen ions with H^+ATPase pumps. This allows sodium ions to passively diffuse into the chloride cell through sodium channels. Once inside the chloride cell, Na^+ is actively pumped into the fish bloodstream. This takes place at the base of the chloride cell, where Na^+,K^+-ATPase pumps are located. In fresh water, pavement cells are also active. In both chloride cells and pavement cells HCO_3^- /Cl^- exchangers allow chloride ion into the cells. Chloride ion exits to fish blood from either cell type via anion channels (Marshall 2002).

In salt water, at the base of the chloride cells, Na^+,K^+,$2Cl^-$ co-transporters bring chloride ion from fish blood into the chloride cell. From there it exits through anion channels at the apical surface into sea water. Meanwhile sodium ions that were pumped into fish blood from the base of the chloride cell cause an electrochemical gradient of Na^+. Sodium ions escape into seawater by passing through intercellular junctions between chloride cells and accessory cells. In salt water, pavement cells are much less active. Calcium ion uptake also goes on in chloride cells, in both fresh and salt water (Marshall 2002).

High chloride ion concentrations are required to damage fresh water fish eggs or embryos. Rainbow trout (*Oncorhynchus mykiss*) eggs and embryos have a 7-day EC_{25} test (effect concentration at which 25% died) of 989 mg/L Cl^- (PMRA 2006). Fathead minnow (*Pimephales promelas*) larvae 1-, 4-, and 7-days old had a no-effect concentration (NOEC, normal survival and growth) of 4,000 mg/L NaCl (2,424 mg/L Cl) and a subchronic value

(SCV, derived from the geometric mean of the NOEC and lowest-observed-effect concentration LOEC) of 5,700 mg/L (3,455 mg/L $Cl^{-)}$, Pickering *et al.* 1996).

Adult fish also have an extremely high tolerance to chloride ion. In 96-hour LC_{50} tests, mosquito fish (*Gambusia affinis*) reached 50% mortality at 10,616 mg/L Cl^-, rainbow trout at 6743 mg/L Cl^-, fathead minnow at 4,000-6,570 mg/L Cl^- (different studies reported in PMRA 2006), bluegill (*Lepomis macrochirus*) at 5,840 mg/L Cl^-. Goldfish (*Carassius auratus*) fared worst of adult fish in 96-hour tests, with an LC_{50} of 4,453 mg/L Cl^- (PMRA 2006). Several fish species had no mortality after 24-hour exposure of adults to 10,000 mg/L NaCl (6066 mg/L Cl^-). These were rainbow trout, fathead minnow, bluegill, brown trout (*Salmo trutta*), channel catfish (*Ictalurus punctatus*), walleye (*Stizostedion vitreum*) and yellow perch (*Perca flavescens*), (PMRA 2006).

These LC_{50} values for adult fish are higher than LC_{50} values for amphibians, which possibly has ecological implications. The 96 hour LC_{50} value for wood frog tadpoles established by Sanzo and Hecnar (2006) was 2,636.5 mg/L NaCl (1,598 mg/L Cl^-), implying that fish are less susceptible to salt-induced mortality than amphibians. Thus road salt runoff could disrupt predator-prey equilibria, since fish often prey on amphibians (Sanzo and Hecnar 2006).

1.7: Road Salt and Benthic Invertebrates

Several studies have tested the responses of benthic macroinvertebrates, especially aquatic insect nymphs, to road salt both in the laboratory and field. Many of these taxa show tolerance of road salt. In a study of the response of aquatic insects in Michigan to differing concentrations of road salt, insects were found to tolerate high concentrations of NaCl, and to have NaCl LC_{50} values in excess of field concentrations measured along Michigan streams (Blasius and Merritt 2002). Stream sites in this study contained at most 9 or16 mg/L Cl^-, whereas laboratory acute exposure experiments used concentrations of 1000 to 10,000 mg/L NaCl (Blasius and Merritt 2002). Three of the seven test species, two perlid stoneflies (*Acroneuria abnormis*, *Agnetina capitata*) and a tipulid crane fly (*Tipula abdominalis*), were given 96-hour LC_{50} tests and did not exhibit any significant mortality at any of the treatment levels. Black fly (*Simulium vittatum* Zett) larvae, accidentally introduced as a contaminant, also showed no significant mortality at any treatment level (Blasius and Merritt 2002). Only an amphipod species (*Gammarus pseudolimnaeus*) and two caddisflies (*Pycnopsyche guttifer* and *P. lepida*, both family Limnephilidae), exhibited a dose response in these trials, with LC_{50} values of 7,700 and 3,526 mg/L NaCl respectively (Blasius and Merritt 2002).

Diversity of macroinvertebrate stream communities did not vary significantly in small Adirondack streams along with differences in chloride concentration, but did show a trend for more diversity with lower chloride (Demers 1992). Four Adirondack streams crossed by a state road were found to have significantly more chloride ion downstream than upstream, as much as 66 times more (Demers 1992). Hester-Dendy plates were used to survey the benthic invertebrate community at upstream and downstream sites, and were left in place for a six-week period between April and June, 1988. Taxa collected were identified to family. Comparison of Shannon-Weiner diversity indices were not significantly different: 0.87 upstream, 0.53 downstream, $P = 0.08$ (Demers 1992).

High pulses of chloride ion in laboratory and field trials had little effect on the drift of aquatic insect larvae (Crowther and Hynes 1977). Drift refers to a benthic invertebrate entering the water column and being carried downstream. In laboratory trials, Trichoptera of two genera (*Cheumatopsyche analis* and *Hydropsyche betteni,* both in family Hydropsychidae) never varied their drift rate of one organism per day, and continued normal growth and metamorphosis at levels of 1650 mg/L Cl^- (Crowther and Hynes 1977). In field trials, drift patterns appeared unaffected by salt concentration, and never altered community composition (Crowther and Hynes 1977). In that study the amphipod *Gammarus pseudolimnaeus* did not alter its drift rate during chloride pulses of 800 mg/L, but in a later study *G. pseudolimnaeus* did show a dose response in drift. At 1000 mg/L NaCl, 23% of individuals of this taxon drifted, and drift increased in *G. pseudolimnaeus* until 68% had drifted at 10,000 mg NaCl (Blasius and Merritt 2002). Salt treatment had no apparent effect on drift for any other taxa (Blasius and Merritt 2002).

Despite this evidence of macroinvertebrate resilience to road salt pollution, it has been shown that road salt can alter macroinvertebrate communities. One study used outdoor "mesocosms" of different salinities, into which mosquitoes and other flying insects were free to oviposit (Petranka and Doyle 2010). Mesocosms were simply artificial pools with water, oak leaves, macrozooplankton, and a food source. Road salt was added to create a range of salinities that would reflect salinity levels in wetlands near roads that receive de-icing salt.

Among the most abundant of the invertebrates recovered from mesocosms were mosquitoes (*Culex restuans*) and cladocerans. Unsalinated and low-salinity pools had relatively few mosquito larvae in them, but they did host abundant cladocerans. Cladocerans were rare or absent at concentrations above 1200 mg/L NaCl (664 mg/L Cl), while those mesocosms had abundant mosquitoes. Mesocosm salinity alone, in the absence of cladocerans, did not appear to affect the rates of *C. restuans* oviposition. The authors note that mosquito larvae and cladocerans may compete for food, and that ovipositing mosquitoes are known to favor pools without high densities of the competitors of mosquito larvae (Petranka and Doyle 2010).

1.8: Multimetric Studies

For decades, macroinvertebrate assemblages at disturbed aquatic sites have been seen as potential sources of information on type and degree of habitat degradation. In the US, the Clean Water Act of 1972 (the Federal Water Pollution Control Act Amendments) referred to the need to “restore and maintain” the “biological integrity” of North American streams and rivers. Local governments responded by attempting to remove water pollutants, often at great expense, and sometimes in a counter-productive manner (Karr *et al.* 1986, Karr 1991, Karr and Chu 1999). Continued loss of aquatic biodiversity in the face of considerable effort focused solely on removing water pollutants motivated resource managers to develop the concept of the biotic index, in which typical aquatic taxa of a relatively undisturbed (or “reference”) site could be compared to those of a nearby disturbed site, and quantitative values (“metrics”) could be assigned to presence or percentages of different taxonomic groups, based on understanding of their relative tolerance (Karr *et al.* 1986, Yoder 1991). Such “multimetric” indices had to be designed for particular regions and based on considerable natural history knowledge.

The Index of Biotic Integrity approach of Karr and others defined “biotic integrity” as the ability of ecosystems to “support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region” (Karr *et al*. 1986). Fish assemblages were the classic vehicle for determining biotic integrity (Miller *et al.* 1988), but both fish and benthic macroinvertebrates have been used as the basis for biotic indices. While focusing on fish had the advantage of ease of identification (Karr 1981), macroinvertebrates were sometimes shown to convey more information. In a comparison of the sensitivity of aquatic insects and fish for monitoring stream sediment alteration in an agricultural area of Missouri, Berkman *et al.* (1986) found that when aquatic insect assemblage results were displayed in Detrended Correspondence Analysis ordination (sites in species space), the results grouped in a way that could be related to scores given to the study sites in a Habitat Quality Index. The groupings could also be analyzed for species diversity, and in this they also reflected habitat quality understanding of the sites. In contrast, the fish results in this study did not form distinctive groups in DCA, and “many sites that were distinctly different in their invertebrate assemblage structure . . . were closely similar in their fish fauna” (Berkman *et al.* 1986).

1.9: The EPT Index

While diverse taxa of benthic macroinvertebrates may contribute to assessing the ecosystem health of any particular habitat, the ideal benthic measure of habitat health would be relatively fast and easy. The EPT taxa: ephemeroptera (mayflies), plecoptera (stoneflies) and trichoptera (caddisflies), are considered to be less tolerant of pollution and generally associated with clean water (Crawford and Lenat 1989). For decades EPT taxa have been found useful in bioassessment across different bioregions. “The EPT groups may contain some tolerant species, but the diversity of these groups has been repeatedly associated with water quality in North Carolina streams and rivers” (Lenat 1988). Counting EPT taxa is a relatively easy means of measuring ecosystem health, less cumbersome than multimetric indices but just as useful. "The EPT index was by far the easiest to use from both the standpoint of time required for sample processing and ease of application . . . and displayed a remarkable ability to track secondary production of invertebrates in the treatment stream" (Wallace *et al.* 1996).

The EPT Index was included in an aggregated index developed for six states along the eastern seaboard of the United States. Various metrics were evaluated and compared for ability to discriminate "reference sites from sites impaired by habitat disturbance and organic pollution" (Maxted *et al.* 2000). Number of EPT taxa scored in the top five out of 26 metrics (number of intolerant taxa, North Carolina Biotic Index, and so on) in "percent of stressed sites correctly assigned" and was therefore included in the final combined metric, the Coastal Plain Macroinvertebrate Index (Maxted *et al.* 2000).

Research on the effects of road salt runoff has shown that not every EPT organism is sensitive to this form of pollution. Williams *et al.* (1999) devised a biological index to monitor the degradation of groundwater by road salt contamination. Their Chloride Contamination Index is based on aquatic insects found in springs, the "natural outlets of groundwater" (Williams *et al.* 1999). The authors sampled 16 springs in the Greater Toronto Area, Canada, taking benthic and water samples. The relationship between the benthic invertebrates and the chloride ion concentrations was explored using Canonical Correspondence Analysis and cluster analysis. Six of the spring macroinvertebrate species received laboratory testing for chloride ion tolerance.

Plecopterans and trichopterans grouped with taxa less tolerant to chloride ion contamination. (Ephemeropterans were not found). However, in laboratory trials the trichopteran *Lepidostoma* sp. and the plecopteran *Nemoura trispinosa* survived 96 hours of 4500 mg/L Cl^- without apparent stress. *Nemoura* was also “found at high densities in contaminated springs” although it grouped with less-tolerant species. The least tolerant species found was not an EPT, but *Gammarus pseudolimnaeus*. This amphipod was intolerant in laboratory trials, and in the field it was “abundant in samples from low Cl sites” but “never occurred as more than one or two individuals in the benthic samples from high Cl sites” (Williams *et al.* 1999).

Short *et al.* (1991) took advantage of oilfield-wastewater pollution of streams in Kentucky to study macroinvertebrate salinity tolerance. The seven field sites of this study, situated along a small stream network, had varying salinities but similar dissolved oxygen. At their most polluted site, where chloride ion concentrations were 17386 +/- 5284 mg/L Cl^- and no fish were ever observed, there were no EPT taxa present at all. At a site with 3165 +/- 677 mg/L Cl^- two species of Trichoptera and a plecopteran were present. At a site with 1105 +/- 247 mg/L Cl^- one species each of Ephemeroptera and Trichoptera, and two species of Plecoptera were present. Two more ephemeropterans, two plecopterans, and three trichopterans appeared at 96.7 +/- 72.6 mg/L Cl^- , and three E, three T, and one P were present at 67.8 +/- 20 mg/L Cl^- (Short *et al.* 1991).

1.10: Osmoregulation in EPT Nymphs

1.10: *Ephemeroptera*

The resilience of benthic macroinvertebrates in conditions of chloride ion pollution depends on their osmoregulatory ability. Yet the osmoregulatory adaptations of most aquatic insects are optimized for hyperosmotic regulation, creating concentrated haemolymph relative to a hypotonic environment. This evolutionary trend is reflected in the distribution of freshwater aquatic insects. One of the early researchers of aquatic nymph chloride cells pointed out that although aquatic insects could be found "from nearly salt-free springs to salt lakes containing sodium chloride at saturation" (Komnick 1977) there is a big difference in relative numbers of aquatic insect species in these different environments. Aquatic insects "flourish in fresh water, whereas the number of species tolerating saline environments is relatively small. This ecological dependence indicates that osmorgulatory adaptation is the main limiting factor in the distribution of aquatic insects. Their osmoregulatory mechanisms apparently can handle low external concentrations of electrolytes better than high ones" (Komnick 1977).

This was demonstrated by research on Ephemeroptera, using mayfly nymphs of two species in family Baetidae. Wichard *et al.* (1973) found that the haemolymph of mayfly nymphs is hyperosmotic with respect to the aquatic environment. Whether the nymphs were adapted in the wild to fresh or brackish water, in laboratory tests they had significantly higher survival when held in water more dilute than their normal conditions, as opposed to saltier test conditions than normal. The test nymphs were shown to "better tolerate major dilutions than concentrations of the external salinity" suggesting that "this species possesses an effective mechanism for hyperregulation. The high mortality at approximately iso-osmotic situations indicates that there is little, if any, ability of hyporegulation" (Wichard *et al.* 1973). The authors point out that in the natural habitats of these species seasonal heavy rains typically create temporary hypo-osmotic conditions, necessitating the ability to withstand this environmental change.

Most Ephemeropteran nymphs are found at low salinities, although there are exceptions (Chadwick *et al*. 2002). Nymphs of the Ephemeropteran genus *Tricorythus* (Tricorythidae) are found in water at up to 3 ppt salinity, *Callibaetis floridanus* of the Baetidae is found at up to 10 ppt salinity, and *Hexagenia limbata* (Ephemeridae) regularly survives 8-hour periods of 25 ppt salinity in tidal portions of the Mobile River, Alabama (Chadwick *et al*. 2002).

In an experiment *Hexagenia limbata* nymphs that had been at 0 ppt salinity in the wild were acclimated in a laboratory over a 7-day period to salinities of 0, 5, 8, and 12 ppt, after which their haemolymph was extracted and tested. It was found that only the highest of these test salinities resulted in 100% fatality over the seven-day period, although nymphs did tolerate 12 ppt salinity for 8 hours, as they would in a tidal pulse (Chadwick *et al*. 2002). At the 0 and 5 ppt test salinities, nymphs osmoregulated their haemolymph to be hyperosmotic to the water. In the wild, of course, all freshwater nymphs have hyperosmotic haemolymph relative to their surrounding water, and the haemolymph of test nymphs at 5 ppt was not significantly different from that of the control. At the 8 ppt salinity test water, nymphs' haemolymph became "essentially isosmotic" and significantly different from the control, but they did all survive the test period. At the highest salinity 12 ppt the nymphs "lost the ability to osmoregulate and began to osmoconform" (Chadwick *et al*. 2002).

Those aquatic invertebrates that do survive in very wide salinity ranges, like larval euryhaline species of mosquito (found at up to 20 ppt salinity), may do so by producing amino acids and proteins in their haemolymph, thereby increasing their haemolymph osmotic pressure (Chadwick *et al*. 2002). Apparently, freshwater aquatic nymphs with relatively narrow salinity tolerances lack the ability to do this. While the osmolality of the haemolymph of these mayfly nymphs “increased with increasing salinity”, the osmotic pressure of their haemolymph, a measure of relative concentration, decreased with increasing salinity (Chadwick *et al*. 2002).

The main osmoregulatory adaptation for aquatic nymphs of the Ephemeroptera (mayflies) and Plecoptera (stoneflies) is the chloride cell, or mitochondria-rich cell. Chloride cells may be single cells or clusters of cells (Komnick 1977). When cells of this type were first observed in the 1970s, they were named after fish chloride cells, to which they are functionally similar (Wichard and Komnick 1971). Unlike the chloride cells of saltwater fish however, aquatic nymph chloride cells do not excrete excess chloride. They function in ion uptake only, allowing the absorption of both sodium and chloride (Komnick and Stockem 1973). Experiments using radioactive chloride showed that no chloride ion is excreted from ephemerid chloride cells (Komnick 1977, Wichard *et al.* 1973).

The cuticle above a typical chloride cell such as those in Ephemeroptera is filled with channels, forming a ”porous plate” (Wichard and Komnick 1971, Komnick 1977) facing the external environment. Below the porous plate, the apical epithelium of the chloride cell is folded, increasing its surface area (Wichard and Komnick 1971). Chloride cells showed ultrastructural changes when nymphs were held in water of different salinities (Wichard *et al.* 1973). After three hours of abnormally low salinity the chloride cell apical epithelium of ephemerid nymphs (Baetidae) showed increased infolding, resulting in more surface area for absorption, whereas these folds almost disappeared after three hours of abnormally high salinity (Wichard *et al.* 1973). Similarly, after a molt mayfly nymphs will have more or fewer chloride cells depending on the test salinity at which they have been held (Wichard *et al.* 1973).

1.11: *Plecoptera*

Chloride cells are also seen in stonefly nymphs. They may be single or formed from a group of cells, and may be any of four different shapes. Although chloride cells in Ephemeroptera and Plecoptera are superficially different they all have a similar design, with an apical porous arrangement of the cuticle, a folded membrane (“plasma-membrane plications”), and abundant mitochondria, all features that are “characteristic of cells with active transport functions” (Komnick 1977). Chloride was localized within plecopteran chloride cells by histochemical precipitation as silver chloride, confirmed by selected area electron diffraction, as was done with ephemeropteran chloride cells (Komnick 1977).

Chloride cells are the normal mode of entry of salt ions into stonefly larvae, and aquatic nymphs in general, but under conditions of osmotic stress plecopteran larvae may also drink, thereby taking in ambient electrolytes. In research using the plecopteran *Paragnetina media* Walker (Perlidae), nymphs’ normal haemolymph was hypertonic to their freshwater creek habitat, which had 0.04% NaCl, or 13 mOsm/L (Kapoor 1979). Test nymphs showed 100% survival when held at salinities from zero (distilled water) up to 0.95% NaCl (382 mOsm/L). At 1.1% NaCl there was 15% mortality after 72 hours, 80% mortality after 72 hours in 1.2% NaCl (Kapoor 1979). At this final salinity the nymphs’ haemolymph was “slightly hyperosmotic to the medium.” At the highest salinity the nymphs’ haemolymph approached isosmolality with the test medium, “thus indicating a breakdown in osmoregulatory mechanisms” (Kapoor 1979). There was a significant gain in body weight at 1.1 and 1.2% NaCl, attributed by the researcher to “drinking and retention of water in the tissues due to the increased level of salt in the body fluids” (Kapoor 1979).

This study is contrasted by Kapoor with other research on a different plecopteran species in which nymphs were kept in distilled water for 28 days without mortality, despite significant decrease in their haemolymph osmolality (Kapoor 1979). As with studies on Ephemeroptera cited above, nymphs are better adapted to survive large decreases in ambient salinity than large increases, probably because sudden dilutions happen regularly in nature.

1.12: *Trichoptera*

The site of salt ion absorption in caddisfly larvae is either chloride epithelia or anal papillae, depending on Trichopteran family (Komnick 1977). The trichopteran families Limnephilidae and Goeridae have oval patches of chloride epithelia on their ventral abdominal surface (sometimes the dorsal surface as well), whereas the Glossosomatidae and Philopotamidae have anal papillae (Komnick 1977). When specimens of Limnephilidae or Goeridae are dipped in a dilute solution of silver nitrate, a silver chloride precipitate covers the oval abdominal patches of chloride epithelia. The cuticle of chloride epithelia is about half as thick as that of the rest of the abdomen. Cells that make up the chloride epithelia are columnar with abundant mitochondria and apical and basolateral membranes highly folded into "numerous plications" (Komnick 1977).

Experiments using radioactive sodium chloride solution have shown that chloride epithelia absorb both sodium and chloride ions (Komnick 1977). It has also been shown that when *Limnephilis stigma* is kept in external media of different salinities, the patches of chloride epithelium on its abdomen enlarge or shrink significantly, in inverse relation to the salinity level (Komnick 1977). Anal papillae, seen in some genera of Trichoptera, also have mitochondria-rich cells with plasma-membrane plications (Komnick 1977).

Larvae of the freshwater caddisfly species *Limnephilus stigma* Curtis and *Anabolia nervosa* Leach (both Limnephilidae) were tested in water of various salinities, from 60 up to 220 mM NaCl/L. Haemolymph chloride concentration in both species was well regulated, staying hypotonic to all external media, and rising only just before death of the larvae (Sutcliffe 1961b). Haemolymph sodium concentration was less well controlled, increasing and becoming hypertonic to the external medium in both species. Mortality of both species was high, but was “slightly improved” by lowering the water temperature (Sutcliffe 1961b), a result that is strengthened in light of later research showing a link between water temperature and salinity tolerance (below).

There are actually Trichoptera species the larvae of which are adapted to an estuarine or even a marine environment. The relevance of these Trichoptera to freshwater Trichoptera exposed to road salt runoff is that if we could understand the osmoregulatory strategy of the marine or brackish-water species we might have an idea to what environmental extremes the freshwater species might acclimate. Unfortunately, only tidbits of such osmoregulatory information are available.

A few species of the Trichopteran family Limnephilidae spend their larval stages in brackish water. One of these is *Limnephilus ademus* from Eastern Canada, found in salinities of 11-25 ppt, or 31-71% of normal seawater (Flint and Giberson 2005). Limnephilidae is a family where chloride epithelia are sometimes seen, however *Limnephilus ademus* has no chloride epithelia (Flint and Giberson 2005). This is not surprising, as chloride epithelia function in ion uptake in freshwater.

Limnephilus ademus larvae can be seen in very early spring in salt marsh pools on Prince Edward Island and are already pupating at the end of May. They emerge mid to late June. This is rapid development compared to freshwater Limnephilids, which typically have an adult summer diapause and don't oviposit until after mid-summer. The early schedule for *Limnephilus ademus* means that these larvae develop when salt marsh pools are fairly cool "rarely exceeding 30 ^{o}C" or 86 ^{o}F (Flint and Giberson 2005). This may be a strategy for surviving in high salinities, as a study on Death Valley caddisflies found that "elevated temperature can reduce tolerance to salinity" (Flint and Giberson 2005).

Limnephilis assimilis Banks is found in Death Valley California in waters of widely differing salinity, from fresh to 18 ppt NaCl (Colburn 1983). The larvae are only found in winter, however, never in the warmer months, and never in thermal springs (Colburn 1983). In the laboratory they were acclimated to a range of salinities at two different temperatures, 8 and 20 ^{o}C. At both temperatures, larvae hyperregulate at salinities from 1 to 14 ppt, that is, their haemolymph has higher osmotic concentration than the external medium at these salinity levels. At higher salinities, from 15 to 22 ppt, larvae osmoconformed, their osmotic concentration increasing along with that of the external medium but remaining slightly hypo-osmotic to it (Colburn 1983).

The osmotic concentration of the larval haemolymph was not entirely a function of sodium and chloride ions. At all salinities the concentration of these ions was "strongly hypotonic to the medium" (Colburn 1983). Sodium and chloride ions accounted for only half of the increase in osmotic concentration with increasing salinity. The rest of the osmotic concentration was presumably a function of increases in organic molecules in the haemolymph (Colburn 1983).

Temperature affected haemolymph osmolarity and chloride levels. At 20 ^{o}C in salinities from 1-14 ppt, haemolymph osmolarity was significantly lower than at 8 ^{o}C (Colburn 1983). At all salinity levels haemolymph chloride levels were significantly higher at 20 ^{o}C than at 8 ^{o}C. To control haemolymph chloride at high salinity, the larvae must be able to shed excess chloride ions, possibly by active transport using cellular ionic pumps, “a metabolically costly activity” (Colburn 1983). Rising temperatures mean water that contains less dissolved oxygen, which may necessitate a lower rate of ionic pumping (Colburn 1983).

This Death Valley study has relevance to Trichoptera challenged by road salt runoff in that a seasonal salt pulse occurs at spring melt, when water is cold and oxygen levels high. In August there may be another salt spike due to evaporation. At this point in the season, water will be warmer, and trichoptera may possibly be more stressed by salinity.

Limnephilus affinis Curtis, of European and Icelandic salt marshes, is the most salt-tolerant of the brackish-water Limnephilidae. It is found in salt marshes at salinities from 10 to 30 ppt (30-85% of seawater), but it is also found in freshwater lakes and streams (Flint and Giberson 2005). Haemolymph sodium and chloride varies with ambient salinity in captive *L. affinis*, remaining hypotonic to the external medium up to 85% the salinity of normal seawater (Sutcliffe 1961a). Above that level, the haemolymph sodium and chloride levels rise rapidly, and larvae only survive a few days. The larvae produce urine (“rectal fluid”) which is hypertonic to their haemolymph by “at least treble” the chloride concentration (Sutcliffe

1961a). At high salinities, the urine of the larvae is also hypertonic to the external medium (Sutcliffe 1961a). In this way the larvae are able to shed excess salt ions. To test the permeability of their body wall to sodium and chloride ions, larvae were habituated to tap water and then placed into solutions with higher chloride ion concentrations, or radiolabeled sodium (^{24}Na), with their mouths sealed to prevent drinking. The haemolymph of the test larvae gained salt ions much more slowly than controls, indicating that their body wall is “relatively impermeable to both sodium and chloride” (Sutcliffe 1961a). (The reciprocal experiment, to see if the larvae shed salt ions through their body wall into their test medium, was not performed). Experiments with larvae prevented from drinking also showed that their body walls are permeable to water influx (as opposed to ion influx) to about the same degree that freshwater Trichoptera larvae are permeable to water (Sutcliffe 1962).

The most interesting observation regarding *Limnephilus affinis* larvae came about by comparing the conductivity of larval haemolymph at higher salt concentrations with the ionic concentration of that haemolymph. Salt ions alone did not account for the rise in haemolymph conductivity, suggesting that the larvae increase the “non-electrolyte fraction” of their haemolymph, probably by liberating amino acids into their haemolymph thereby increasing its osmotic pressure in response to osmotic stress (Sutcliffe 1961a). A similar suggestion was made regarding *Limnephilis assimilis* in Death Valley--that it made up part of its osmotic concentration by secreting organic molecules into its haemolymph (Colburn 1983). This is similar to the strategy employed by euryhaline mosquitoes, who survive rises in ambient salt concentration, followed by rises in haemolymph concentration, by synthesizing amino acids and sugars in their cells, thus avoiding diffusion of water from cells into haemolymph (Chadwick *et al.* 2002). If it is true that brackish-water Limnephilid caddisfy larvae can use amino acids (or proteins) as a salt-stress coping device, one wonders if freshwater caddisfly larvae have any similar ability, given the apparent lack of selection pressure for this trait up until the age of road salt.

Trichoptera larvae of the Chathamiidae, Australia and New Zealand, inhabit tide pools at 35 ppt NaCl, or full-strength salinity (Flint and Giberson 2005). Only the two genera, five species of this family are truly marine trichopterans (Flint and Giberson 2005). They are without chloride epithelia or anal papillae (based on examination of drawings and description in Riek 1976). One of the Chathamiidae Trichoptera, *Philanisus plebeius* Walker, oviposits into the coelom of a starfish arm. The eggs develop inside the starfish coelom for about 18 days, during which time they are protected from tidal forces and predation. After hatching, the first-instar larvae leave the starfish (probably by eating their way out of the host tissue) and continue their life cycle in the tide pool (Anderson and Lawson-Kerr 1977).

Larvae of *Philanisus plebeius* are normally found at full strength sea water, and can adapt to external media up to 150% sea water, with haemolymph levels of sodium and chloride strongly regulated, and rising only slightly (Leader 1972). At salinities higher than 150% sea water, the level of haemolymph sodium rises rapidly (chloride unreported, but presumably behaves similarly) and the larvae die (Leader 1972). The really interesting osmotic behavior of *Philanisus* concerns haemolymph chloride ion concentration at low salinities. At full sea water, 606 mM NaCl/L, haemolymph chloride of *Philanisus* larvae is 144 +/- 16 m-equiv/L (Leader 1972). Haemolymph chloride ion falls as the salinity of the external medium is reduced, until at 60 mM NaCl/L, haemolymph chloride was the same as chloride ion concentration in the external medium. Therefore the larvae are “incapable of concentrating chloride ions . . . completely unlike any freshwater insect” (Leader 1972).

In the same study, larvae of *Philanisus plebeius* were found to drink sea water, however they are unable to form urine hyperosmotic to sea water (or hyperosmotic to any test fluid to which they are adapted), so they must have another means of shedding ions and keeping themselves hydrated. Using radiolabeled sodium (^{22}Na), and larvae ligatured to prevent urination, Leader (1972) was able to show that there is a constant outward flow of sodium ions through the body wall of *Philanisus* against the concentration gradient, therefore representing active transport, not diffusion. Apparently both sodium and chloride are actively transported out of the larvae, as chloride ion does not accumulate inside the larval body more than sodium does (Leader 1972).

Two salient points of osmoregulation might shed light on the possibility of trichopteran adaptation to road salt: one concerns excretion of excess salt ions, the other organic molecule production to alter osmotic concentration.

Chloride epithelia cannot excrete excess salt ions; it is only capable of ion uptake, as proved by radiolabeled sodium chloride solution and also by the observation that chloride epithelia vary in size inversely to ambient salt concentration (Komnick 1977). Can freshwater trichoptera larvae transport salt ions out through their body wall into the external medium? Leader (1972) found active transport of sodium (and presumably chloride) ions out through the body wall of the marine *Philanisus*, and Colburn (1983) believed that the brackish-water *Limnephilus assimilis* does this as well. While direct experiments to investigate whether freshwater trichoptera larvae have any similar ability are apparently lacking, many experiments show freshwater trichoptera larvae die at too high a salt concentration, making it unlikely that they can excrete salt ions.

Can freshwater trichoptera larvae produce organic molecules, such as amino acids or proteins, to reduce salt-induced stress? A spike in the osmotic concentration of external medium requires higher haemolymph and cellular osmotic concentration to prevent dehydration and cell shrinkage (Chadwick *et al.* 2002). Selection pressure for such an ability, if it exists in any freshwater caddisfly species, might come from the tendency of streams to shrink in late summer, and to form pools that would be more concentrated with any ambient ions.

1.13: Summary, Ecological Effects of Road Salt

It has been established that road salt runoff has accumulated in surface and groundwater in snowbelt areas as a result of winter de-icing activities. Excess salt can damage animal health, including that of aquatic invertebrates. Excess salt ions can have deleterious effects on plant health, by changing soil composition and by the direct effects of salt deposition on leaves.

1.14: Patterns of Road Salt Runoff in Adirondack Headwater Streams

Significant amounts of road de-icing salt enter the environment every year. The United States as a whole used 18.7 million tons of road salt in 2010, about 22 tons per lane mile in New York State (Kelting and Laxson 2010, USGS 2011). Once road salt goes into solution as runoff the positively charged sodium ion tends to bind to soil particles, attracted by negative charges on clay and organic particles (Godwin *et al.* 2003, Jones *et al.* 1992, Kelting and Laxson 2010, PMRA 2006). After years of road salting, sodium can build up in soil and groundwater and appear in well water (Novotny *et al.* 2007). Chloride ions, with their negative charge, do not adsorb to substrate, nor do they enter into biochemical reactions with other particles (Jones *et al.* 1992). Instead, chloride ions move with the water, persisting and accumulating in the aquatic environment. For this reason road salt runoff into streams and lakes is often measured as chloride ion content.

The Adirondacks of New York State present an opportunity to compare the results of very different road salting regimes. The Adirondack Park is a historically and ecologically important 9000-square mile (5.9 million acre) state park composed of mixed wilderness and residential areas, a patchwork of private and public land where different practices can show different results side by side.

County roads in the Adirondacks are maintained by county highway departments, which follow the traditional local practice of allowing a snowpack of a few inches to form on top of the road asphalt. After plowing, a mixture of salt and sand is added to this snowpack. The mixture is 92% sand, 8% salt (added mostly to keep the sand pile from freezing solid. Craig Donaldson, Harrietstown Highway Supervisor, personal communication). In at least one Adirondack town, county roads receive sand only, no salt having been added to the salt pile. In this case, local residents had expressed concern that sodium might contaminate local wells (Town and Hamlet of Newcomb Superintendent of Highways Mark Yandon, personal communication). In contrast, state roads are maintained by the New York State Highway Department, are plowed down to bare pavement after each snowfall, and receive only salt, no sand.

Chloride ion has been measured in Adirondack forest streams 100 m below points at which the streams were crossed by a road, far in excess of background levels, and months after winter road salt application or spring melt (Demers and Sage 1990). However while that study did compare stream chloride ion concentrations upstream versus downstream of a road crossing, there have not been studies comparing this effect between streams crossed by roads that receive different winter treatments, nor have monthly chloride fluctuations over a full year been adequately explored.

Across the northern tier of the United States, road salt is believed to be accumulating in groundwater. Road salt pollution has been called “acute and increasing” (Williams *et al.* 1999) and is known to persist in both surface and groundwater (Demers and Sage 1990, Williams *et al.* 1999). It has been said that “salinization associated with increasing suburban and urbanization deserves attention as one of the most significant threats to the integrity of freshwater ecosystems in the northeastern United States (Kaushal *et al.* 2005). It therefore will be increasingly important to have information on the degree of road salt runoff into waterbodies such as streams, and to what extent that can be affected by local municipal choices. In this current study, road salt runoff was measured by chloride ion concentration in 18 study streams that are crossed by roads in the Adirondacks, New York State. The study streams are crossed by different categories of road receiving three different winter treatments.

1.15: EPT Taxa versus Road Salt Contamination in Adirondack Streams

Benthic macroinvertebrates are a natural choice for assessing the effects of road salt pollution. Aquatic insect larvae have a long history of use in monitoring ecosystem health (Rosenberg and Resh 1993). Their ubiquitous presence in the aquatic environment, their relatively long life cycles in which they are typically affected by local conditions for months, and their many species with wide ranges of tolerances are among the advantages of their use in biomonitoring (Bode *et al.* 2002, Rosenberg and Resh 1993). When study streams are small rocky headwaters, benthic macroinvertebrates such as aquatic insect larvae offer an important advantage over the use of fish as biomonitors: fish are not always present in these habitats, whereas benthic macroinvertebrates are.

The EPT taxa of aquatic insect larvae: Ephemeroptera, Plecoptera, and Trichoptera, are often chosen as target organisms for biomonitoring because they are “sensitive to most types of pollution” and their numbers are expected to “decrease with a decrease in water quality” (Norris and Georges 1993). Use of EPT taxa richness (number of Ephemeroptera + Plecoptera + Trichoptera taxa) has a long history in aquatic biomonitoring, and has become an accepted measure of freshwater aquatic ecosystem health (Lenat and Penrose 1996). EPT taxa richness, also known as the EPT index, is considered “a sensitive indicator of stream perturbations” and as such is often used by agencies that conduct environmental monitoring (Wallace *et al.* 1996).

In this study, the effects of road salt runoff on ecosystem health were examined by comparing EPT collections from 18 study streams in the Adirondacks, New York State, with chloride ion concentrations of water collected from the same 36 study sites.

1.16: Recruitment of Trees in Areas of Road Salt Runoff

Roads deliver road salt runoff downgradient all along their length, to soil as well as to water. Sodium inputs to soil decrease soil fertility, as the sodium ion displaces other cations from bonding sites on negatively-charged organic and clay particles. Plant macro- and micronutrients calcium, copper, magnesium, manganese, molybdenum, potassium and zinc plus ammonium ions (NH_4^+) leach out of soil, reducing its fertility and changing soil structure as “cation bridging” by calcium no longer saves clay particles from being leached into surface waters (Green *et al.* 2008, Kelting and Laxson 2010). Soil changes may affect forest tree assemblage. If there are changes in forest composition as a result of road salt runoff, those changes ought to be visible in recruitment. Young trees might give the most visible sign of the effect, if any, of salt on a forest.

To determine whether recruitment of trees is affected by road salt runoff, forest composition was studied by point-centered quarter analysis along transects parallel to roads that cross study streams. Transects were sited upstream and downstream from the road, centered on study streams or extending from stream to stream. To see how young trees differed from older trees within a transect, an additional run of point-centered quarter analysis was performed on the lowest quartile of trees (by circumference) in each transect.

2: Materials and Methods

2.1: Methods, Chloride Ion Concentration of Stream Water

Eighteen first or second-order streams (Strahler 1957) that are crossed by roads were chosen for study within the Adirondack Park, New York, USA. Two study sites were established per stream, 30 meters upstream and downstream from the road. Twelve streams were chosen that are crossed by county roads. Of the twelve study streams crossed by a county road, eight are crossed by a road receiving the traditional mixture of 92% sand, 8% salt above a snowpack of a few inches. Four streams are crossed by a road that does not receive any salt treatment in winter, only sand on top of the snowpack, as no salt is added to the sand pile. Six streams were chosen that are crossed by state roads. These roads are plowed to bare pavement in winter and salted. They do not receive sand. Altogether there were 36 study sites.

In 2007 and 2008 the study included only one state road crossed by two streams and one county road crossed by two streams. Water samples were taken monthly at upstream and downstream sites on these streams throughout 2007 and 2008. At this time it was noticed that the upstream section of one of the streams crossed by a county road ("Cougar Creek" crossed by County Road 45, Panther Mountain Road) had anomalously high chloride ion content. It was felt that no general statement about the relative saltiness of streams crossed by state versus county roads could be made on the basis of two county road-crossed streams, one behaving as expected and one not. Therefore it was felt that many more streams should be added to the study, *mostly streams crossed by county roads*, and that these could each be surveyed a few times rather than monthly. It will be seen that more sampling effort was expended on low-salt streams rather than high-salt streams, which will seem odd in light of research questions regarding the ecological effects of high road salt runoff. It was the question about Cougar Creek that brought about this pattern of sampling effort.

Fourteen streams were added to the study in 2009. These consisted of four additional streams crossed by a state road, and ten additional streams crossed by county roads. In 2009 one stream crossed by a county road ("Glacier Creek" on Route 45, named for numerous glacial erratics) was dropped from further water sampling because its chloride ion values had been very stable for two years. That left seventeen streams. Water samples were taken from thirty-four study sites on these streams in April, June, and August of 2009.

Whether on public or private land, all stream sites are forested and approximately 100 m from any buildings. The locations and Adirondack zoning of the eighteen study streams are here described, followed by a table of the study streams. Of the twelve streams crossed by a county road, eight receive the traditional 92% sand/8% salt mixture. Two streams are located in Harrietstown, Franklin County, and are crossed by County Route 45 (Panther Mountain Road) between Routes 3 and 30 ("Glacier Creek" and "Cougar Creek"). Both upstream sites for these streams are on state land designated Wild Forest, natural landscape crossed by roads (Jenkins and Keal 2004). The streams are then crossed by Panther Mountain Road, and enter private land designated Hamlet below the road. The Hamlet zone does not regulate building density (Jenkins and Keal 2004). One downstream site on this road is in minimally disturbed second-growth forest over 100 m from the nearest building ("Glacier Creek"). This stream was sampled only in 2007 and 2008. The other downstream site on this road ("Cougar Creek") lies beside a parking area that serves a powerlines clearing and a driveway, leading to a house. All of these structures are further downstream. The site is approximately 3 m from the edge of the parking area, slightly upgrade from the parking area. This stream was sampled in all three years.

The other six streams crossed by a county road receiving a sand/salt mixture are located in Piercefield, Franklin County. One is crossed by County Route 62 just below Mount Arab ("Mount Arab 1") and five are crossed by Mount Arab Road ("Mount Arab 2-6"). All sites on these six streams are on private land zoned Resource Management (APA 2003). The Resource Management zone permits 15 buildings per square mile (Jenkins and Keal 2004); however a house is visible from only from one of these stream sites.

The four streams that received only sand as a winter treatment are located in Newcomb, Essex County, and are crossed by Goodnow Flow Road. All stream sites along these streams are on land zoned Resource Management that formerly belonged to the timber company Finch, Pruyn and Company. As with all sites, these are fully forested.

The remaining six study streams are crossed by state roads. Route 28 in Hamilton County, which crosses four study streams south of the Lake Durant parking lot, cuts between Wild Forest to the north and Wilderness (roadless forest) to the south. These four study streams are designated by mile marker numbers ("1295, 1313, 1324, 1333"). Two study streams are crossed by Route 3 in Franklin County between Tupper Lake and Saranac Lake (Dutton Brook and McKenna Brook). Dutton Brook and McKenna Brook are the only study streams that have official names that may be seen on maps. The actual "McKenna Brook" sampled is a small offshoot of the main stream, called for convenience "McKenna". All study sites on these streams are on land zoned Wild Forest. Both of the Route 3 study streams flow down from springs on Ampersand Mountain. The downstream site of one of them, Dutton

Brook, lies east of the Ampersand Mountain trail parking lot. The two Route 3 streams were sampled in all three years.

Table 2.1 summarizes locations of these streams. Figures 2.1 – 2.6 present maps of the Adirondacks and the streams. Tables 2.2 and 2.3 present GPS locations, taken from the road, where study streams are crossed by roads. GPS locations were obtained with a Garmin “etrex Legend” hand held GPS device.

Table 2.1: Streams crossed by state and county roads

Streams crossed by **state** roads

Winter Treatment: 100 % salt

- Route 28 in Hamilton County (four streams)
    - Route 28 Streams 1295, 1313, 1324, 1333, crossed by State Route 28

Franklin County in Harrietstown (two streams)

- Dutton Brook and McKenna Brook, crossed by State Route 3

Streams crossed by **county** roads

Winter Treatment: 92% sand, 8% salt

- Franklin County in Harrietstown (two streams) crossed by County Route 45 (Panther Mountain Road)
    - Glacier Creek and Cougar Creek
- St. Lawrence County in Piercefield (six streams)
    - Mount Arab Stream 1, crossed by County Route 62.
    - Mount Arab Streams 2 – 6, crossed by Mount Arab Road.

Winter Treatment: 100 % sand

- Essex County, in Newcomb (Four streams)
    - Goodnow Streams 1 – 4, crossed by Goodnow Flow Road.

Figure 2.1: The Adirondack Park in New York State

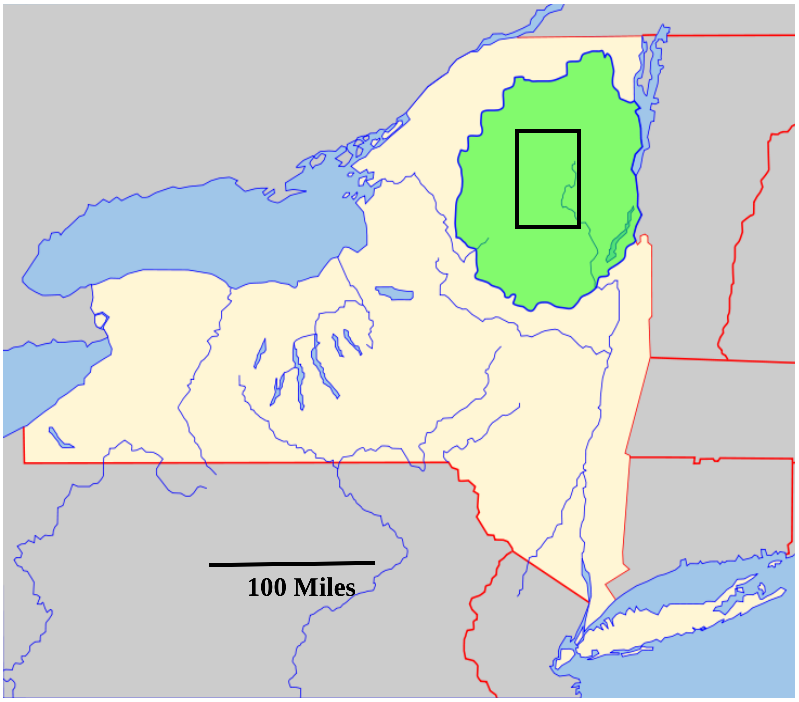


Figure 2.2: Locations of groups of study streams

1: Area of County Route 45

2: Area of Mount Arab

3: State Route 3

4: State Route 28

5: Area of Goodnow Flow Road

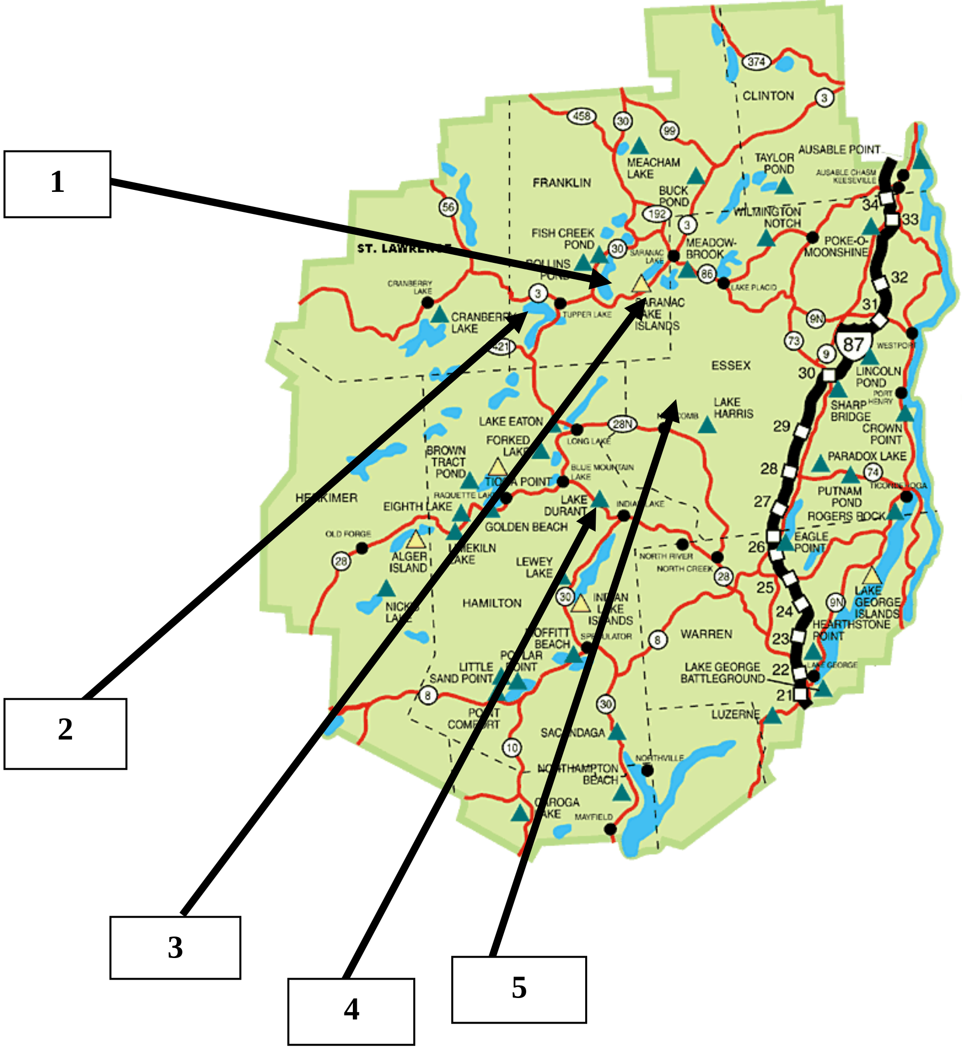


Figure 2.3: Locations of streams crossed by state and county roads.

G: “Glacier Creek”, crossed by County Route 45 (Panther Mountain Road)

C: “Cougar Creek”, crossed by County Route 45

D: Dutton Brook, crossed by State Route 3

McK: McKenna Brook, crossed by State Route 3

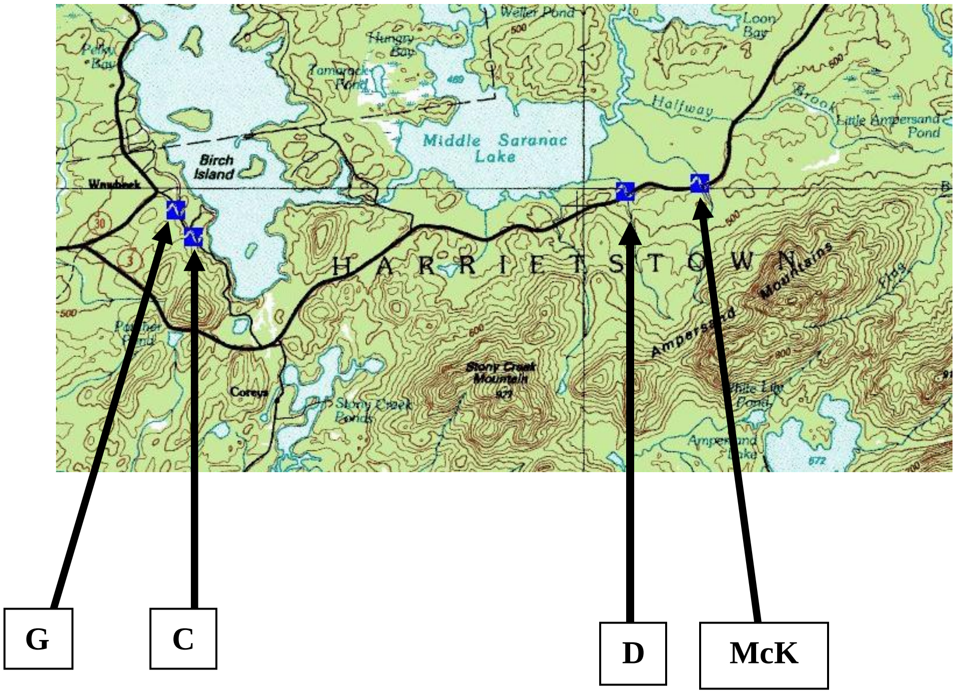


Figure 2.4: Locations of streams crossed by county roads.

MtA-1: Mt Arab 1 crossed by County Route 62

MtA-2: Mt Arab 2 crossed by County Route Mt Arab Road

MtA-3: Mt Arab 3 crossed by Mt Arab Road

MtA-4: Mt Arab 4 crossed by Mt Arab Road

MtA-5: Mt Arab 5 crossed by Mt Arab Road

MtA-6: Mt Arab 6 crossed by Mt Arab Road

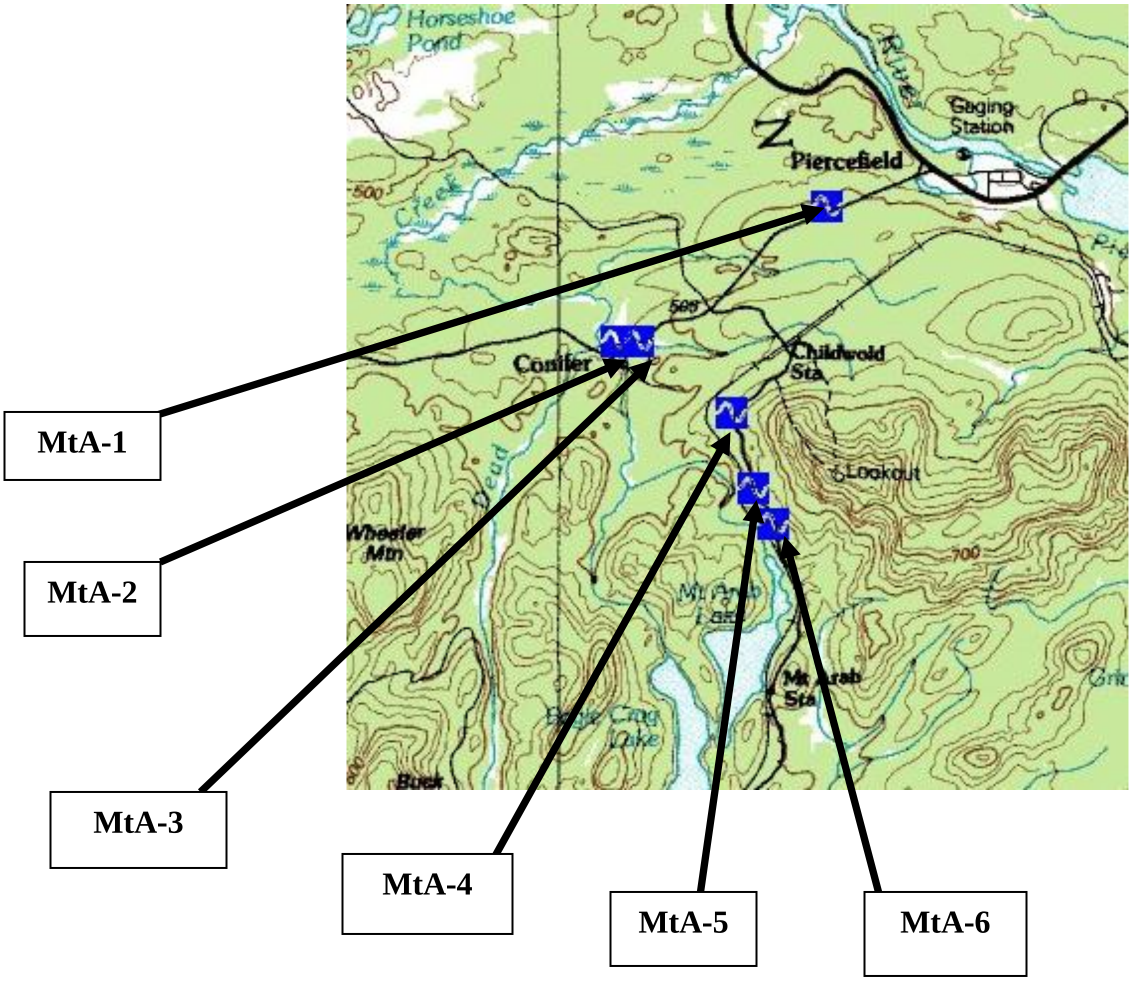


Figure 2.5: Locations of streams crossed by county roads.

G-1: Goodnow 1, crossed by Goodnow Flow Road

G-2: Goodnow 2, crossed by Goodnow Flow Road

G-3: Goodnow 3, crossed by Goodnow Flow Road

G-4: Goodnow 4, crossed by Goodnow Flow Road

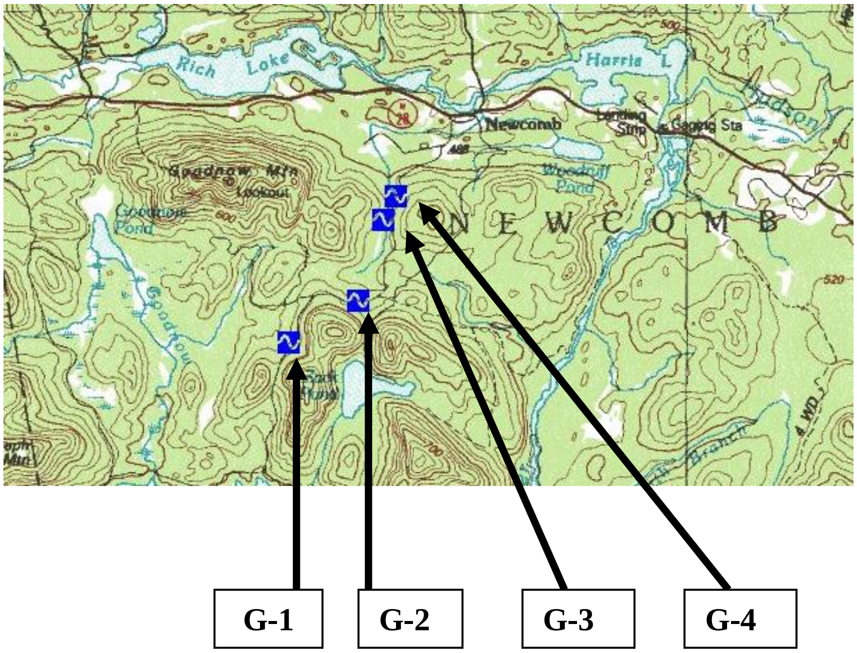


Figure 2.6: Locations of streams crossed by a state road.

1295: Stream crossed by State Route 28 at mile marker 1295

1313: Stream crossed by State Route 28 at mile marker 1313

1324: Stream crossed by State Route 28 at mile marker 1324

1333: Stream crossed by State Route 28 at mile marker 1333

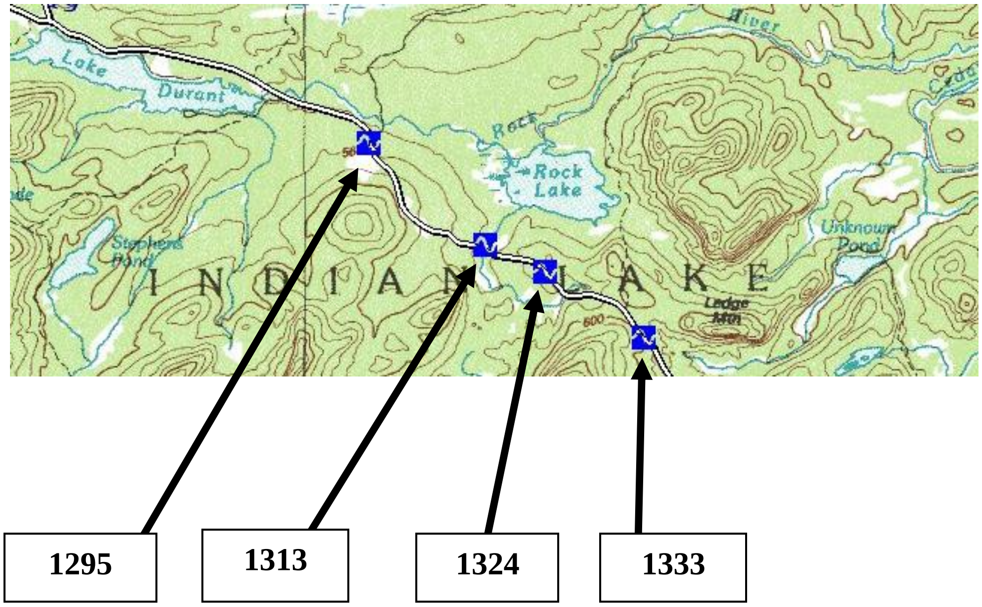


Table 2.2: GPS locations of intersections of study streams crossed by state roads

	Latitude	Longitude
Streams crossed by State Route 3		
Dutton Brook	N 44^{o} 15.111'	W 074^{o} 14.299'
McKenna Brook	N 44^{o} 15.182'	W 074^{o} 13.845'
Streams crossed by State Route 28		
Stream 1295	N 43^{o} 50.170'	W 074^{o} 22.047'
Stream 1313	N 43^{o} 49.244'	W 074^{o} 20.828'
Stream 1324	N 43^{o} 48.921'	W 074^{o} 19.775'
Stream 1333	N 43^{o} 48.353'	W 074^{o} 18.995'

Table 2.3: GPS locations of intersections of study streams crossed by county roads

	Latitude	Longitude
Streams crossed by County Route 45		
"Glacier" Creek	N 44^o 14.573'	W 074^o 19.820'
"Cougar" Creek	N 44^o 14.212'	W 074^o 19.622'
Streams crossed by county roads Route 62 and Mt Arab Road		
Mt Arab 1	N 44^o 13.452'	W 074^o 35.945'
Mt Arab 2	N 44^o 13.052'	W 074^o 35.744'
Mt Arab 3	N 44^o 13.021'	W 074^o 35.717'
Mt Arab 4	N 44^o 12.368'	W 074^o 35.991'
Mt Arab 5	N 44^o 12.116'	W 074^o 35.875'
Mt Arab 6	N 44^o 11.917'	W 074^o 35.781'
Streams crossed by county road Goodnow Flow Road		
Goodnow 1	N 43^o 57.515'	W 074^o 10.753'
Goodnow 2	N 43^o 57.266'	W 074^o 10.841'
Goodnow 3	N 43^o 56.643'	W 074^o 11.075'
Goodnow 4	N 43^o 56.320'	W 074^o 11.900'

Road salt runoff was measured by analyzing water samples for chloride ion concentration by the silver nitrate method, using a Hach digital titrator, model 16900 (Yoder 1919, Hach Company 2006). This titrator and method has been used in the literature relevant to road salt (Williams *et al.* 1999). Water was analyzed at the Laboratory for Marine and Estuarine Research, Lehman College of the City University of New York. Water samples were taken in deionized water-rinsed 500 ml wide mouth polyethylene bottles (Wildlife Supply Company), one bottle per sample. At the laboratory, each sample was divided into five subsamples and each subsample was titrated. The mean of these five subsample results per sample is reported.

Every effort was made to analyze water samples within a few days, however occasionally in 2007 or 2008 and throughout 2009 it took two weeks to analyze all water samples. The HACH Digital Titrator User Manual (Hach Company 2006) advises that water samples should be analyzed within one week of collection, without specifying what the risks of a longer testing period might be (Hach 2006). I performed a test to determine whether results would vary from a sample of stream water analyzed two days after collection and then repeatedly for approximately seven weeks until the sample was used up. A large sample was collected on 17 August 2008 from the downstream site on Dutton Brook, and then approximately 500 ml portions of this large sample were tested at the lab exactly as any other sample would be tested, with five repeated titrations. The large sample provided enough water for six tests over a seven-week period. Results are shown in Table 2.4. One-way ANOVA showed no significant difference in results (P = 0.98), and linear regression of the chloride ion concentrations from Table 2.4 against time produced a slope not significantly different from zero (P = 0.41). Time (days 2 to 49) explained only 2.5% of the total variation.

Table 2.4: Chloride Ion Concentration (mg/L) from Repeated Testing of One Sample for Over a Period of Seven Weeks

	19-Aug 2008	20-Aug 2008	27-Aug 2008	3-Sep 2008	10-Sep 2008	7-Oct 2008
Days After Collection	2 days	3 days	10 days	17 days	24 days	7 weeks
Chloride Ion Concentration from Repeated Titrations	4.30	5.20	4.50	4.30	4.70	4.50
	5.50	4.50	5.30	5.40	5.00	5.20
	4.90	4.90	5.10	4.90	4.70	4.60
	5.60	5.30	5.10	5.40	5.40	5.20
	4.90		5.10	4.70	4.80	4.80
Mean	5.04	4.98	5.02	4.94	4.92	4.86
Standard Deviation	+/- 0.53	+/- 0.36	+/- 0.30	+/- 0.47	+/- 0.29	+/- 0.33

Physical parameters of stream sites were taken at all sampling events. These consisted of water temperature, pH, dissolved oxygen, and flow. PH was measured by use of a Hach HQ40D dual-input digital meter and Hach standard pH gel probe. Dissolved oxygen was measured as luminescent dissolved oxygen with a Hach LDO probe. Probes were calibrated each sampling day. Water temperature was the mean of temperature readings from each probe.

Flow was measured as surface flow, and was simply the mean of five trials of the floatation speed of a ball in seconds taken with a stopwatch over a pre-measured distance. While sub-surface laminar flow is commonly reported, in small streams it varies greatly with minute changes of equipment position, whereas surface flow is more consistent at a particular site and time.

Data on stream chloride ion content were analyzed by single ANOVA using Microsoft Excel 2007.

2.2: Methods, Collection of EPT Taxa

Stream communities were characterized by macroinvertebrate sampling at eight stream sites in May, June, July, August, and September of 2007 and 2008, and at 34 stream sites in April, June, and August of 2009. Benthic invertebrates were collected by use of a Surber sampler, a net with mesh size 500 um and an attached frame enclosing one square foot, or about 30 cm^2. The Surber design with attached cod bucket (Wildlife Supply Company) was used. Substrate within the attached frame was agitated by hand, and disturbed macroinvertebrates were swept into the net by the water current. One Surber net worth of substrate was taken at each study site per sampling day, transferred into a labeled jar at the site, and preserved in 75% ethanol within a few hours. Invertebrates were later separated from sand and pebbles by floatation with saturated calcium chloride, and picked out of leaf and twig debris.

The EPT index is the number of taxa of Ephemeroptera, Plecoptera or Trichoptera in a 100-organism subsample (Bode *et al.* 2002). In this study, however, one Surber net was collected per sample, and this did not necessarily yield 100 organisms. The EPT number reported here refers to the total number of EPT, and numbers of E, P, or T genera per sample, that is, per one Surber sample. Ephemeroptera, Plecoptera, and Trichoptera, were identified to genus using appropriate keys in Merritt and Cummins (1978) and Peckarsky *et al.* 1990. Additional keys for Plecoptera were provided by Stewart and Stark 1988, and for Trichoptera by Wiggins 1996. Helpful images of Ephemeroptera were found in Schweibert 2007.

EPT catch data were converted to catch-per-unit effort (number of EPT individuals collected / number of samples). CPUE data were aggregated in different ways, such as by chloride level.

Chloride values were divided into range groupings. Most water samples (144 of 155 samples) fell into the 2 – 35 mg/L range, and four were in the 75-200 mg/L range. These seemed natural ranges at which to group EPT taxa to calculate catch per unit effort at different chloride levels. The higher chloride values were seen only in 2009, when the study had been expanded to seventeen streams. Separate CPUE results are presented for June and August 2009, the two months sampled that year. All chloride values are shown graphically in Figure 2.7.

CPUE values were analyzed by two-tailed paired T-test after transformation by

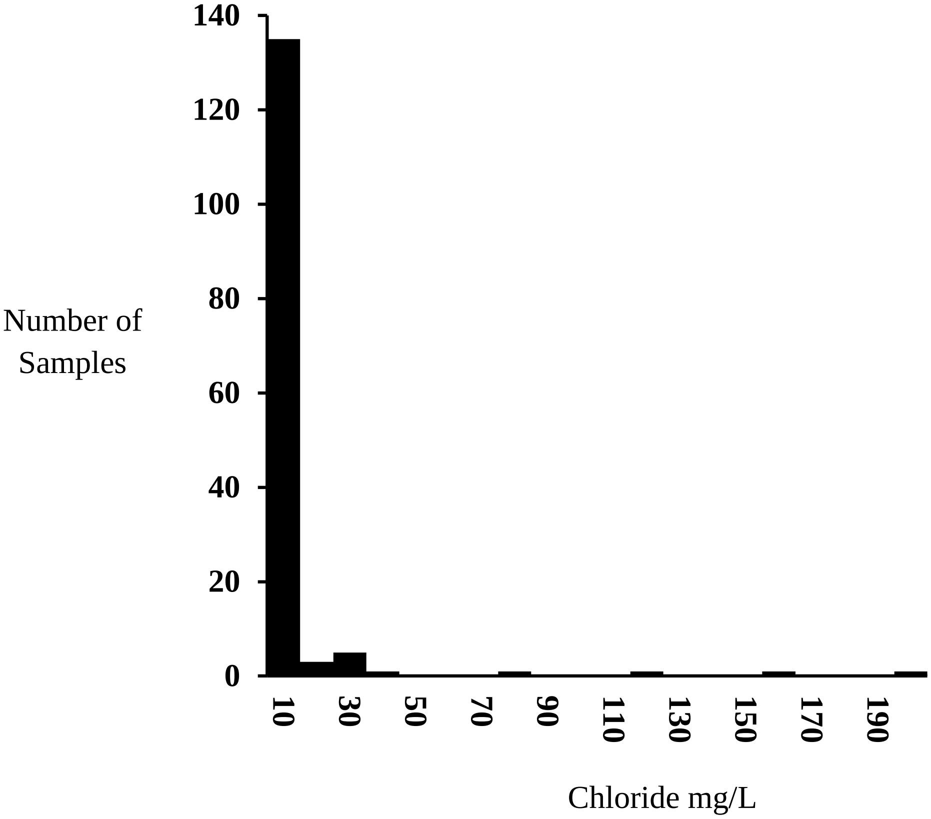
$(x + 0.5)^{½}$ (Powers *et al.* 2006). Although transformed values were tested, untransformed values are presented for comparison in Tables 4.1 – 4.5.

Additional collections were made at a small man-made wetland that receives high road-salt runoff, in an attempt to determine an upper limit of chloride concentration for EPT genera. The wetland ("Ampersand Slough") begins at the outflow of a plastic drainage pipe that lies buried beneath Route 3, and terminates at the western edge of the same parking lot where it becomes an intermittent stream traveling down to Middle Saranac Lake. This stream only reaches the lake during high flow; at other times the wetland has no real drainage. The slough is about 20 by 4m, with its long axis parallel to Route 3, no more than 1-2 m away and considerably downslope from the roadway. Seven samples were taken from the wetland Ampersand Slough, all in the 200-400 mg/L chloride range.

Data were organized using Microsoft Excel 2007 and analyzed using PAST: Paleontological Statistics Software Package for Education and Data Analysis version 2.17 (Hammer, Ø. *et al.* 2001).

Figure 2.7: Chloride Concentrations (mg/L) of Water Samples

May 2007 – September 2009



2.3: Methods, Analysis of Tree Recruitment in Areas of Road Salt Runoff

Forest on either side of state roads that cross study streams was selected for analysis. Mean chloride ion content of water at stream sites in April, June, and August of 2009 was used to differentiate the salt exposure of stretches of forest land. Point-centered quarter analysis was used to create ten transects on either side of two state roads. Four of the study streams are crossed by State Route 28, and a total of eight transects were created on Route 28, each parallel to the road and centered on one of the study streams. On each side, transects were 30 m in from the road. Centering a transect on a study stream proceeded as follows: at the stream, 30 m in from the road, an object (a trowel with neon streamers for visibility) was thrown in a direction parallel to the road. The location where it fell became a data point, which according to point-centered quarter technique was the center of four quadrants. The distance to the nearest tree in each quadrant plus its circumference were measured, and that tree was identified to species. For convenience, circumference at 130 cm was measured (Mitchell 2007, Brokaw and Thompson 2000) rather than dbh. The object was thrown parallel to the road until 15 points had been recorded (15 x 4 trees measured and identified). Then the same stream was returned to, and the process was repeated in the opposite direction for another 15 points, until a 30-point transect had been described centered on that study stream.

A slightly different process was undertaken on Route 3, because the two study streams that are crossed by that road lie close enough to each other that it was possible to start a transect some distance beyond one of these streams (McKenna) and proceed parallel to the road, cross McKenna, keep going and eventually cross the other study stream (Dutton) and end the transect some distance beyond Dutton. Transects averaging 48 points were created on either side on Route 3, encompassing McKenna and Dutton. Each transect began 30 m (measured parallel to the road) beyond McKenna, and ended approximately 30 m beyond Dutton. As at Route 28, each transect on Route 3 was 30 m in from the road.

The point-centered quarter method (PCQM) does not require a measured transect, however the length of this transect can be estimated given the fact that the two streams are 0.7 miles apart according to roadside mile markers. Each McKenna-Dutton transect, on the upstream or downstream side, was therefore approximately 1186 meters long. On Route 28, Stream 1295 (stream names derive from mile markers) is 1.9 miles north of Stream 1313, which is 1.1 miles north of Stream 1324, which is 0.9 miles north of Stream 1333. Transects along Route 28 were about 260 to 300 meters long.

As noted, chloride ion contents of stream sites in April, June, and August were averaged to provide a number indicating road salt runoff. For each of the two McKenna-Dutton transects this was the mean of six numbers, for each of the Route 28 streams, it was the mean of three numbers.

Data was analyzed following Cottam and Curtis (1956) and Mitchell (2007). The point-centered quarter method was adapted by Cottam and Curtis (1956) for ecological use from an old land-surveyors technique. Each sampling point along a transect is considered to be an indeterminate area divided into four quarters. The distance from the center point to the nearest tree in each quarter (quadrant) is measured, along with the species and circumference (or diameter) of that tree. The position of sampling points may come from use of a random numbers table (Mitchell 2007) or sampling points may be found by randomly tossing an object or tool.

The distances measured from sampling point to nearest tree in each quadrant are summed and divided by the number of quarters sampled to give mean radius. The central idea of the point-centered quarter method is that mean radius $\check{r}$ (in m) can be used to derive an estimate of density, the number of trees per meter squared. If λ = absolute density in trees/m^2, then $1 / \lambda$ is the mean area occupied by a single tree, and Absolute density $= \lambda = 1 / \check{r}^2$. Cottam and Curtis (1956) showed that this works in practice, and Masaaki Morisita at the University of Kyushu demonstrated the relationship mathematically (Mitchell 2007).

The following calculations were made for each transect: 1) Absolute tree density overall; 2) Absolute and relative tree density per tree species; 3) Absolute and relative dominance per tree species; 4) Absolute and relative frequency per tree species; and 5) Importance value per tree species.

Absolute tree density overall is a measure of how many trees can be expected in any given area, in this case one hectare, or 10,000 m^2. The mean of distances measured from the center point to the nearest tree in each quarter is used to calculate absolute tree density overall.

Mean density = Sum of the distances/ Number of quarters.

Absolute tree density = desired area / mean density^2

Absolute tree density per tree species can be found by the number of quarters that contain that species divided by the total number of quarters at that stream. Mitchell (2007) calls this value “frequency per quarter”. Frequency per quarter is multiplied by the number of trees per hectare (the absolute density overall) to get the absolute density of a species of tree at that stream. Relative density per tree species is frequency per quarter x 100 (Mitchell 2007).

Dominance is based on basal area, which in this case was measured as circumference. Area was calculated for each tree in the transect, and mean area was calculated per tree species.

If a tree had multiple trunks at 130 cm from the ground, as often happens with speckled alder *Alnus incana,* the basal area for each trunk is “computed separately and the results summed” (Mitchell 2007). To get absolute dominance of a tree species, mean basal area (in cm^2) is multiplied by one of the density values, the absolute dominance per taxon (trees per hectare). A conversion factor is needed to express absolute dominance in m^2/ha: $1m^2/10000\ cm^2$ (Mitchell 2007). Absolute dominance for all species is then summed for a total dominance in m^2 /ha. Relative dominance for any particular species is found by dividing the absolute dominance for that species by the total dominance and multiplying the result by 100, for a percentage.

Absolute frequency is “the percentage of sample points at which a species occurs” (Mitchell 2007). To calculate absolute frequency, the number of sample points with that species is divided by the total number of sample points, and the result is multiplied by 100. Relative frequency is absolute frequency of a species divided by the sum of absolute frequencies of all species, multiplied by 100. Importance value is obtained by adding Relative Density, Relative Dominance, and Relative Frequency.

Two separate analyses were run on the data from each transect. After the first analysis of a transect’s data, the first quartile circumference (the quartile of smallest trees by circumference) was separated out as a new database, and all PCQM calculations were performed again on this quartile. This lowest quartile represents recruitment. In order to capture the data on these young trees, the cutoff for measuring a tree trunk was 1 cm diameter.

Software used for data visualization and analysis was Microsoft Excel 2007, PAST: Paleontological Statistics Software Package for Education and Data Analysis version 2.17

(Hammer, Ø. *et al.* 2001), and ACD Systems Incorporated Canvas 9 software, version 9.0.1 for Windows.

3.1: Hypotheses With Regard to Chloride Ion Concentration in Streams:

H_1: Chloride ion concentration in streams crossed by state roads in the Adirondacks is greater than chloride ion concentration in streams crossed by county roads in the Adirondacks.

H_0: Chloride ion concentration in streams crossed by state roads in the Adirondacks is not greater than chloride ion concentration in streams crossed by county roads in the Adirondacks.

H_1: Chloride ion concentration in streams crossed by state roads in the Adirondacks is greater downstream from the road than it is upstream from the road.

H_0: Chloride ion concentration in streams crossed by state roads in the Adirondacks is not greater downstream from the road than it is upstream from the road.

H_1: Chloride ion concentration in streams crossed by county roads in the Adirondacks is greater downstream from the road than it is upstream from the road.

H_0: Chloride ion concentration in streams crossed by county roads in the Adirondacks is not greater downstream from the road than it is upstream from the road.

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H_1: Chloride ion concentration in streams crossed by state roads in the Adirondacks is greater downstream from the road than it is downstream from the road in streams crossed by county roads in the Adirondacks.

H_0: Chloride ion concentration in streams crossed by state roads in the Adirondacks is not greater downstream from the road than it is downstream from the road in streams crossed by county roads in the Adirondacks.

H_1: Chloride ion concentration in streams crossed by county roads in the Adirondacks that receive the traditional salt/sand winter mixture is greater downstream from the road than chloride ion concentration in streams crossed by county roads in the Adirondacks that receive sand only, no salt.

H_0: Chloride ion concentration downstream from the road in streams crossed by county roads in the Adirondacks that receive the traditional salt/sand winter mixture is not greater than chloride ion concentration in streams crossed by county roads in the Adirondacks that receive sand only, no salt.

3.2: Results, Chloride Ion Concentration in Streams

Table 3:1: Chloride ion concentrations (mg/L) at stream sites upstream and downstream from **county** roads, 2007. Sites on two streams crossed by County Route 45

2007	Glacier Upstream	Glacier Downstream	Cougar Upstream	Cougar Downstream
Jan	2.23	1.56	2.00	3.70
Feb	2.16	5.00	2.16	Frozen
Mar	2.50	2.46	2.60	3.40
Apr	3.24	3.56	3.14	5.02
May	3.54	2.98	2.46	4.22
Jun	3.26	3.08	3.64	5.90
Jul	3.00	5.50	3.26	10.20
Aug	3.12	3.04	3.06	9.80
Sept	2.70	2.96	2.42	7.32
Oct	2.88	3.40	2.94	21.00
Nov	2.56	2.22	2.44	3.30
Dec	2.52	2.84	2.88	3.64

Table 3:2: Chloride ion concentrations (mg/l) at stream sites upstream and downstream from **county** roads, 2008. Sites on two streams crossed by County Route 45

	Glacier	Glacier	Cougar	Cougar
2008	Upstream	Downstream	Upstream	Downstream
Jan	2.56	2.52	2.20	2.28
Feb	2.76	3.18	2.60	7.54
Mar	2.78	2.90	2.64	5.18
Apr	2.40	2.10	2.88	3.32
May	3.08	2.94	3.06	8.63
Jun	2.82	2.38	2.90	6.32
Jul	2.88	2.78	3.08	6.30
Aug	2.66	2.76	2.78	3.16
Sept	2.76	2.78	2.68	4.14
Oct	3.04	2.84	2.78	4.24
Nov	3.12	2.92	3.10	2.84
Dec	2.72	3.26	2.72	3.08

Table 3:3: Chloride ion concentrations (mg/L) at stream sites upstream and downstream from **state** roads, 2008. Sites on two streams crossed by State Route 3

2008	Dutton Upstream	Dutton Downstream	McKenna Upstream	McKenna Downstream
Jan	2.40	2.44	2.20	6.64
Feb	2.54	5.28	2.58	6.92
Mar	2.72	4.96	2.74	8.44
Apr	2.94	3.12	2.94	2.88
May	3.00	4.00	2.80	4.88
Jun	2.78	4.30	2.98	7.84
Jul	2.96	5.36	2.84	5.70
Aug	2.86	5.04	2.40	6.10
Sept	2.64	6.28	2.34	4.60
Oct	2.98	5.84	2.84	4.86
Nov	2.76	3.24	3.14	5.32
Dec	2.98	2.80	2.96	4.06

Figure 3.1: Chloride ion concentrations in stream sites upstream and downstream from **county** roads, 2008. Sites on two streams crossed by County Route 45: Route 45 “Glacier” Up, Route 45 “Glacier” Down, Route 45 “Cougar” Up, Route 45 “Cougar” Down

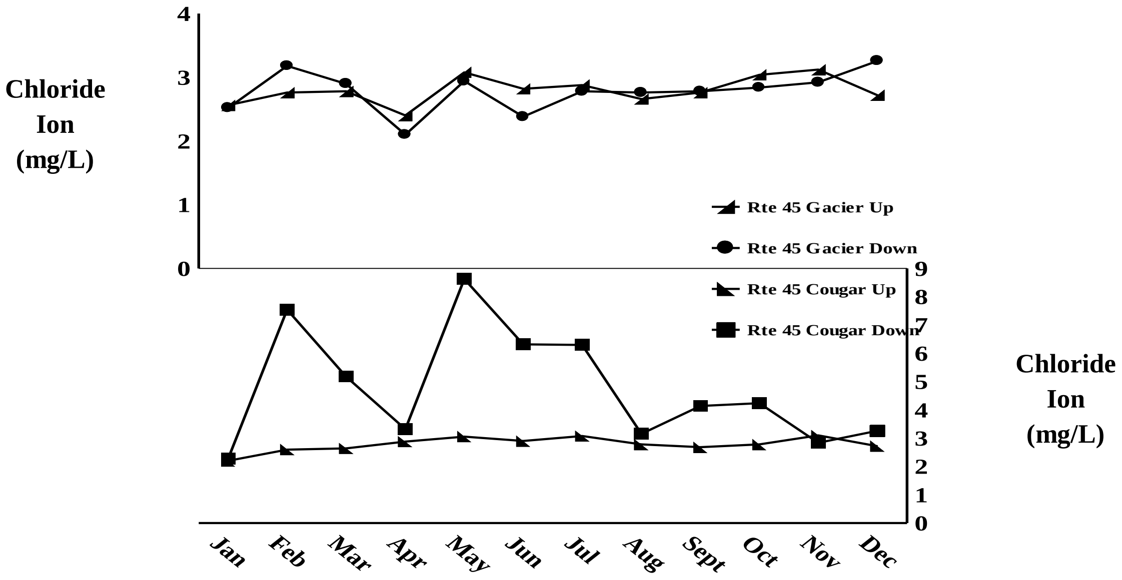


Figure 3.2: Chloride ion concentrations at stream sites upstream and downstream from **state** roads, 2008. Sites on two streams crossed by State Route 3: Route 3 McKenna Up, Route 3 McKenna Down, Route 3 Dutton Up, Route 3 Dutton Down

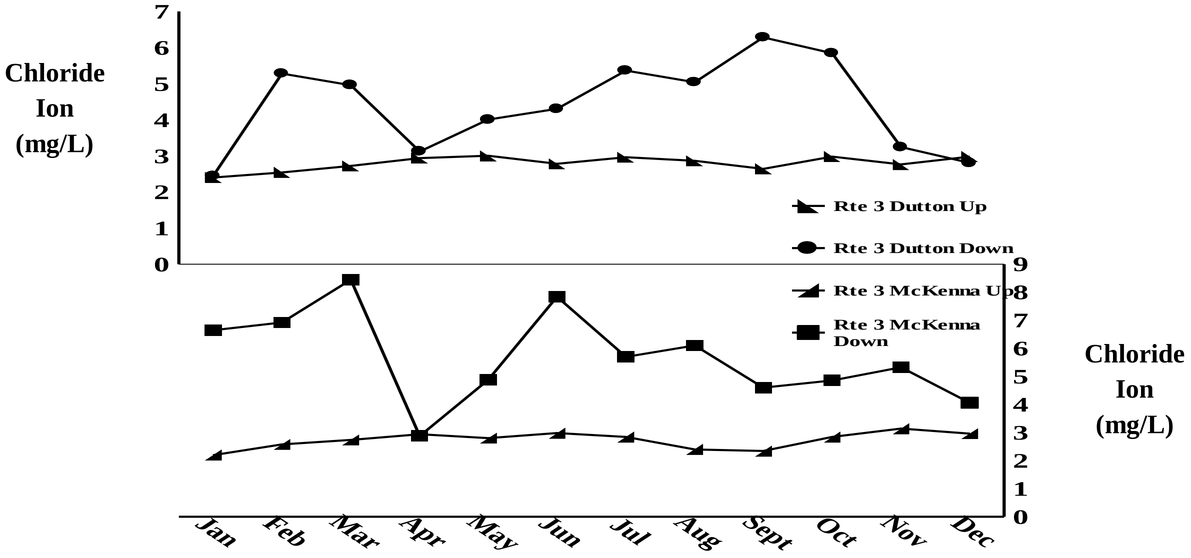


Figure 3.3: **April 2009** chloride ion concentrations (mg/L) at stream sites upstream and downstream from **State** Route 3 and **State** Route 28

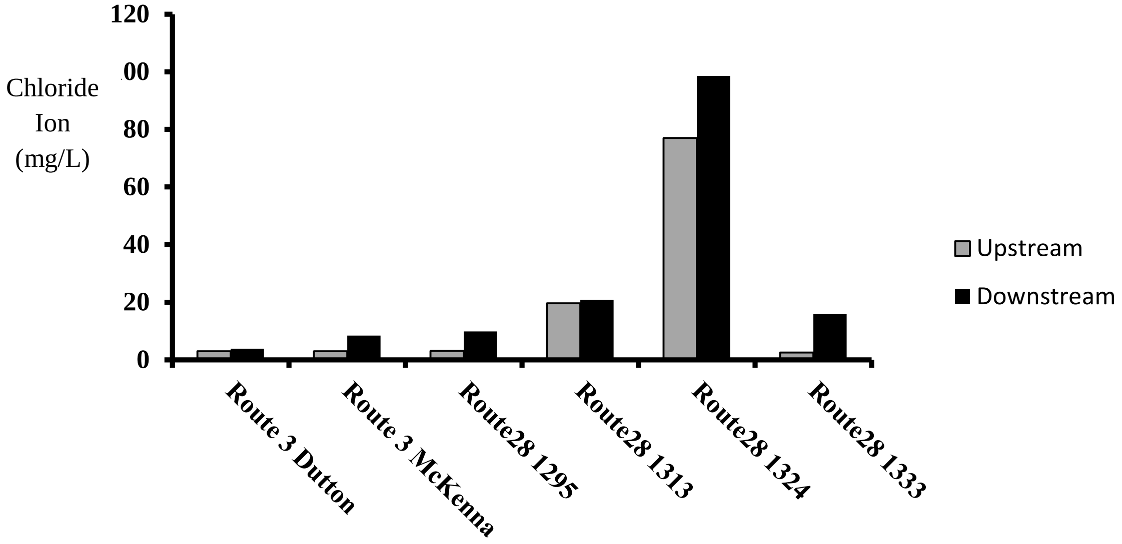


Table 3:3: **April 2009** chloride ion concentrations (mg/L) at stream sites upstream and downstream from **State** Route 3 and **State** Route 28

	Upstream	Downstream
Route 3 Dutton	2.96	3.82
Route 3 McKenna	3.00	8.36
Route28 1295	3.12	9.90
Route28 1313	19.62	20.84
Route28 1324	77.00	98.50
Route28 1333	2.54	15.82

Figure 3.4: **April 2009** chloride ion concentrations at sites on eleven streams upstream and downstream from **county** roads

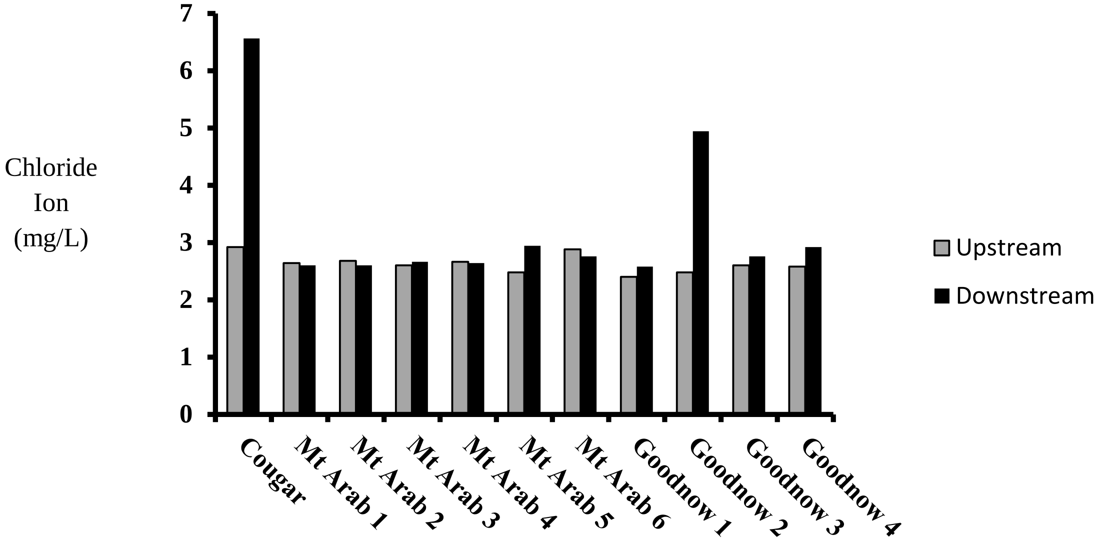


Table 3.4: **April 2009** chloride ion concentrations (mg/L) at sites on eleven streams upstream and downstream from **county** roads

	Upstream	Downstream
Cougar	2.92	6.56
Mt Arab 1	2.64	2.60
Mt Arab 2	2.68	2.60
Mt Arab 3	2.60	2.66
Mt Arab 4	2.66	2.64
Mt Arab 5	2.48	2.94
Mt Arab 6	2.88	2.76
Goodnow 1	2.40	2.58
Goodnow 2	2.48	4.94
Goodnow 3	2.60	2.76
Goodnow 4	2.58	2.92

Figure 3.5: **June 2009** chloride ion concentrations (mg/L) at stream sites upstream and downstream from **State** Route 3 and **State** Route 28

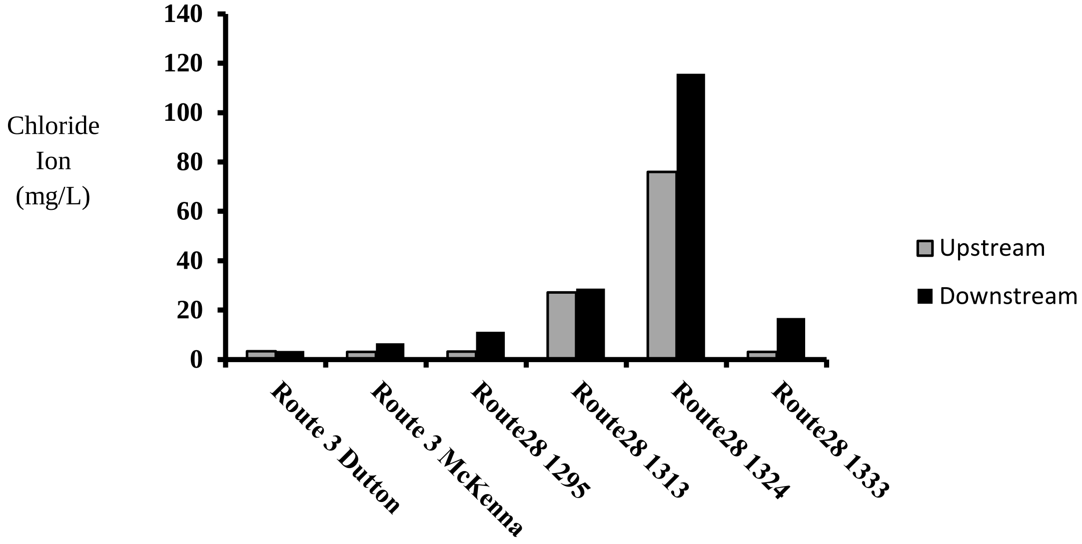


Table 3.5**: June 2009** chloride ion concentrations (mg/L) at stream sites upstream and downstream from **State** Route 3 and **State** Route 28

	Upstream	Downstream
Route 3 Dutton	3.30	3.50
Route 3 McKenna	3.02	6.54
Route28 1295	3.22	11.26
Route28 1313	27.18	28.70
Route28 1324	76.00	115.80
Route28 1333	3.08	16.82

Figure 3.6: **June 2009** chloride ion concentrations (mg/L) at sites on eleven streams upstream and downstream from **county** roads

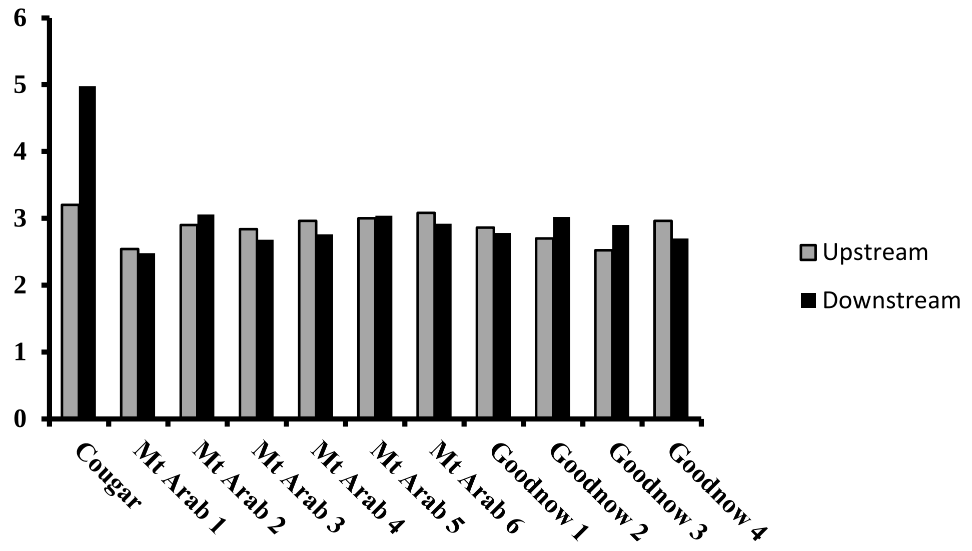


Table 3.6: **June 2009** chloride ion concentrations (mg/L) at sites on eleven streams upstream and downstream from **county** roads

	Upstream	Downstream
Cougar	3.20	4.98
Mt Arab 1	2.54	2.48
Mt Arab 2	2.90	3.06
Mt Arab 3	2.84	2.68
Mt Arab 4	2.96	2.76
Mt Arab 5	3.00	3.04
Mt Arab 6	3.08	2.92
Goodnow 1	2.86	2.78
Goodnow 2	2.70	3.02
Goodnow 3	2.52	2.90
Goodnow 4	2.96	2.70

Figure 3.7: **August 2009** chloride ion concentrations (mg/L) at stream sites upstream and downstream from **State** Route 3 and **State** Route 28

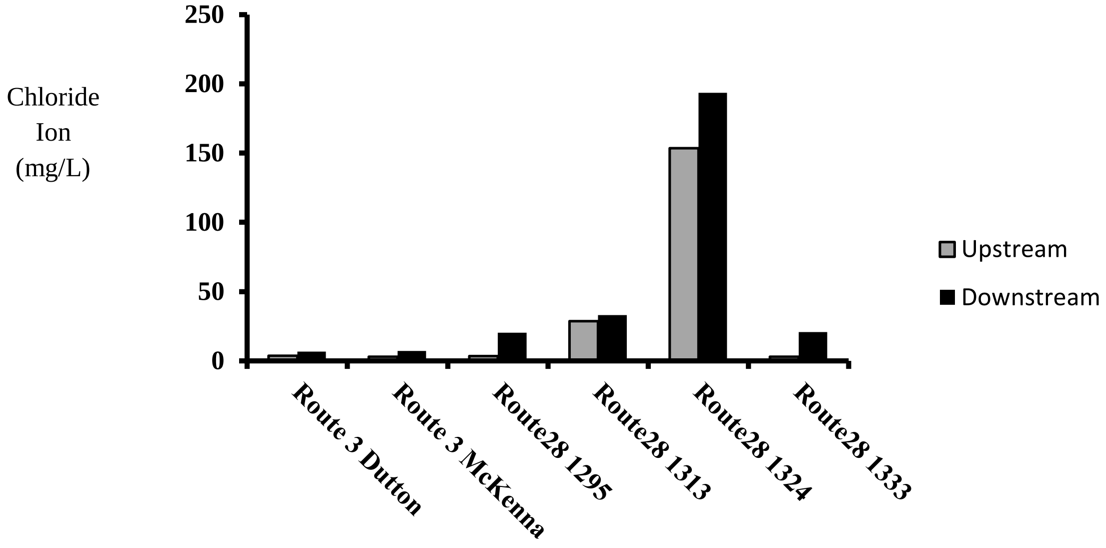


Table 3.7: **August 2009** chloride ion concentrations (mg/L) at stream sites upstream and downstream from **State** Route 3 and **State** Route 28

	Upstream	Downstream
Route 3 Dutton	3.60	6.74
Route 3 McKenna	3.02	7.08
Route28 1295	3.32	20.40
Route28 1313	28.52	33.04
Route28 1324	153.40	193.40
Route28 1333	3.06	20.76

Figure 3.8: **August 2009** chloride ion concentrations (mg/L) associated with sites on eleven streams crossed by **county** roads

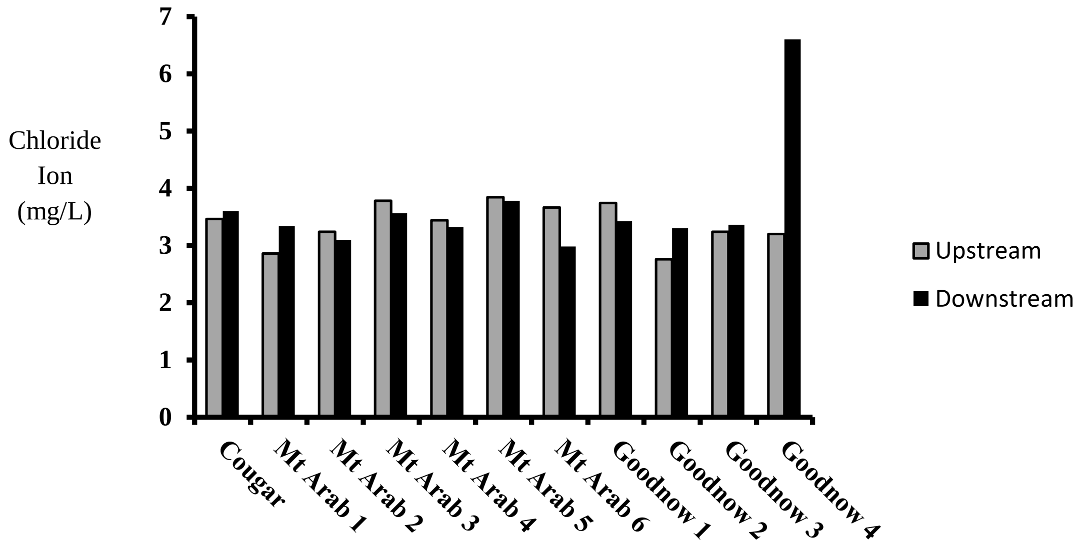


Table 3.8: **August 2009** chloride ion concentrations (mg/L) associated with sites on eleven streams crossed by **county** roads

	Upstream	Downstream
Cougar	3.46	3.60
Mt Arab 1	2.86	3.34
Mt Arab 2	3.24	3.10
Mt Arab 3	3.78	3.56
Mt Arab 4	3.44	3.32
Mt Arab 5	3.84	3.78
Mt Arab 6	3.66	2.98
Goodnow 1	3.74	3.42
Goodnow 2	2.76	3.30
Goodnow 3	3.24	3.36
Goodnow 4	3.20	6.60

3.2: Results Continued, Chloride Ion Concentration in Streams

Monthly chloride ion concentrations from 2007 are shown from streams crossed by a county road only, as streams crossed by a state road in 2007 had to be changed during the year. Glacier Creek was sampled in 2007 and 2008 only, then dropped in 2009 because of consistency of results. Cougar Creek was sampled in 2007, 2008, and kept in the study in 2009.

H_1: *Chloride ion concentration in streams crossed by state roads in the Adirondacks is greater than chloride ion concentration in streams crossed by county roads in the Adirondacks.*

H_0: *Chloride ion concentration in streams crossed by state roads in the Adirondacks is not greater than chloride ion concentration in streams crossed by county roads in the Adirondacks.*

Upstream and Downstream chloride ion concentrations were averaged for each pair of samples taken in streams crossed by county or state roads in 2008 or 2009, and a mean of the means taken. (2007 data was not used because of one missing value). The 24 pairs of samples taken in 2008 from the two streams crossed by county roads had a mean chloride concentration of 3.28 mg/L +/- 0.19 standard error. The 24 pairs of samples taken in 2008 from the two streams crossed by state roads had a mean chloride concentration of 3.90 +/- 0.16 standard error. Means from streams crossed by state versus county roads in 2008 were **significantly different**. Single factor ANOVA: F(1, 46) = 62.65. P = $3.94E^{\mathbf{-10}}$.

The 33 pairs of samples taken in 2009 from eleven streams crossed by county roads had a mean chloride concentration of 3.14 mg/L +/- 0.10 standard error. The 18 pairs of samples taken in 2009 from the six streams crossed by state roads had a mean chloride concentration of 28.90 +/- 10.66 standard error. Means from streams crossed by state or county roads in 2009 were **significantly different**. Single factor ANOVA: F (1, 49) = 10.89. P = 0.002.

H_1: Chloride ion concentration in streams crossed by state roads in the Adirondacks is greater downstream from the road than it is upstream from the road.

H_0: Chloride ion concentration in streams crossed by state roads in the Adirondacks is not greater downstream from the road than it is upstream from the road.

In 2008, the **mean chloride concentration** at upstream sites of the two streams crossed by **state roads** was 2.76 +/- 0.24 (standard deviations unless otherwise noted). The mean chloride concentration at downstream sites at the same streams was 5.04 +/- 1.56. Upstream versus downstream concentrations were **significantly different.** . Single factor ANOVA: F (1, 46) = 50.04, P = 7.06 E$^{\mathbf{-09}}$.

In 2009 the mean chloride concentration at upstream sites of the six streams crossed by state roads was 23.28 +/- 40.25. The mean chloride concentration at downstream sites at the same streams was 34.52 +/- 50.46. There was **no significant difference** between the upstream and downstream values. Single factor ANOVA: F (1,34) = 0.55, P = 0.47.

H_1: Chloride ion concentration in streams crossed by county roads in the Adirondacks is greater downstream from the road than it is upstream from the road.

H_0: Chloride ion concentration in streams crossed by county roads in the Adirondacks is not greater downstream from the road than it is upstream from the road.

Mean chloride ion concentration for the site on Glacier Creek upstream from the **county road** in 2007 and 2008 was 2.80 mg/L +/- 0.33, while the site downstream from the road had a mean of 3.00 mg/L +/- 0.82. There is **no significant difference** between upstream and downstream Glacier Creek for combined 2007-2008 values.
Single factor ANOVA: F (3, 44) = 1.39, P = 0.26.

Mean chloride ion concentration for the upstream site of Cougar Creek in 2007 and 2008 was 2.77 mg/L +/- 0.38, while the downstream site had mean of 5.85 mg/L +/- 4.00. The high standard deviation of downstream Cougar Creek is accounted for by chloride spikes, the highest being 21.00 mg/L in October 2007. There is a **significant difference** between upstream and downstream Cougar Creek for combined 2007-2008 values.
Single factor ANOVA: F (3, 44) = 5.77, P = 0.002. When Glacier and Cougar Creeks are combined for 2007 and 2008, the **mean chloride concentration** at upstream sites of the two streams was 2.79 +/- 0.35. The mean chloride concentration at downstream sites at the same streams was 4.39 +/- 3.17. Upstream versus downstream concentrations were **significantly different.** Single factor ANOVA: F (1, 93) = 12.19, P = 0.001.

In 2009, there were eleven streams crossed by **county roads**. The highest chloride ion value in 2009 in these streams crossed by county roads was at Cougar Creek downstream from the road in April: 6.56 mg/L. In April, June, and August 2009, the mean chloride ion concentration for the upstream sites of all streams crossed by county roads was 2.96 +/- 0.41. Downstream sections on those same streams had a mean chloride ion concentration of 3.32 mg/L +/- 1.02. Upstream sections on these eleven streams were **not significantly different** from downstream sections. Single factor ANOVA: F (1, 64) = 3.59, P = 0.06.

H_1: Chloride ion concentration in streams crossed by state roads in the Adirondacks is greater downstream from the road than it is downstream from the road in streams crossed by county roads in the Adirondacks.

H_0: Chloride ion concentration in streams crossed by state roads in the Adirondacks is not greater downstream from the road than it is downstream from the road in streams crossed by county roads in the Adirondacks.

In 2008, **downstream sites** on the two streams crossed by a **county road** had a mean chloride concentration of 3.77 +/- 1.75. Downstream sites on the two streams crossed by a **state road** in that year had a mean chloride concentration of 5.04 +/- 1.56.

There was a **significant difference** between downstream values for streams crossed by state or county roads in 2008. Single factor ANOVA: F(1,46) = 7.09, P = 0.01.

In 2009, **downstream sites** on the eleven streams crossed by a **county road** had a mean chloride concentration of 3.32 +/- 1.02. Downstream sites on the six streams crossed by a **state road** in that year had a mean chloride concentration of 34.52 +/- 50.45. Downstream values for streams crossed by state or county roads in 2009 were **significantly different**.

Single factor ANOVA: F(1,49) = 12.83, P = 0.001.

H_1: Chloride ion concentration in streams crossed by county roads in the Adirondacks that receive the traditional salt/sand winter mixture is greater than chloride ion concentration in streams crossed by county roads in the Adirondacks that receive sand only, no salt.

H_0: Chloride ion concentration in streams crossed by county roads in the Adirondacks that receive the traditional salt/sand winter mixture is not greater than chloride ion concentration in streams crossed by county roads in the Adirondacks that receive sand only, no salt.

Mt Arab Road receives traditional county roads winter treatment, whereas Goodnow Road receives sand only, no salt. The six **downstream** sites of Mt Arab streams were compared with the four Goodnow Road **downstream** sites. The downstream Mt. Arab sites had a mean chloride ion concentration of 2.96 mg/L, s.d. +/- 0.36. The four downstream Goodnow sites had a mean chloride ion concentration of 3.44 mg/L, s.d. +/- 1.17. The two sets of downstream sites were **not significantly different**. Single factor ANOVA: F (1, 28) = 2.71, P = 0.11.

3.3: Discussion of Chloride Results

Road salt will continue to be of interest in coming decades, as salt ion inputs to groundwater are increasingly seen in surface waters. Groundwater initially acts as a sink for both sodium and chloride ions, but it then releases these ions as their concentration in groundwater increases (Howard and Haynes 1993). This creates a lag effect, in which chloride ions deposited years earlier will appear in increasing amounts in springs and in streams by baseflow recharge (Howard and Haynes 1993, Kelly *et al*. 2008). It is important therefore to see whether differences in road de-icing strategy, such as are seen in the Adirondacks, make a measurable difference in road salt runoff.

The alternate hypothesis: *chloride ion concentration in streams crossed by state roads in the Adirondacks is greater than chloride ion concentration in streams crossed by county roads in the Adirondacks* was supported. As expected, the local practice of driving on snowpacked roads, with sand and a little salt, delivers less salt to local streams than the bare roads policy of salting state roads. The results in this case were clear cut because this hypothesis allowed upstream and downstream chloride values to be combined. Other hypotheses were affected by anomalous chloride ion spikes usually at downstream, but sometimes at upstream, sites.

The null hypothesis: *chloride ion concentration in streams crossed by state roads in the Adirondacks is not greater downstream from the road than it is upstream from the road* must be accepted, because although 2008 results showed larger chloride downstream and significant difference between upstream and downstream, 2009 results were not significant. The very large standard deviations and lack of significant difference in 2009 results are due to high chloride levels at upstream sites on two streams crossed by State Route 28. These are likely due to baseflow recharge of chloride-contaminated groundwater.

Groundwater should not be presumed to flow smoothly and predictably like an underground stream. In reality, groundwater flow is directed by relative hydrological energies in different areas that create a "hydraulic gradient" (Wei 2013). The kinetic energy of groundwater, its flow velocity, is usually low. Kinetic energy plus two other energy components form what is called the "hydraulic head" at any given location. Hydraulic head depends on the height of water at that point (its potential energy) and the pressure of that water (its elastic energy) together with the generally negligible kinetic energy (Wei 2013). Differences in hydraulic head from point to point form the hydraulic gradient, which may be visualized as a changeable surface of potential flow directions. Groundwater flows slowly down the hydraulic gradient taking a path affected by local changes in that gradient. The direction in which groundwater is moving can only be known by installing piezometers, essentially small study wells, or actual wells (Rosenberry *et al.* 1997, Wei 2013).

On Route 28, the streams 1313 and 1333 both have high upstream as well as downstream chloride concentration. The streams are not adjacent, and stream 1324 between them does not show this pattern. It is likely that the local hydraulic gradient directs salt-bearing groundwater to the upstream portions of streams 1313 and 1324. Groundwater is known to carry salt contamination from road de-icing (Rosenberry *et al.* 1997). Snow plows push salt off the road on both sides all along the road length. The snow melts in the spring, becomes part of the local groundwater, and moves as it is directed by the local hydraulic gradient. It is probable that on most roads, the higher-gradient side directs groundwater underneath the road to the lower gradient side, but that in some locations, more compacted soil beneath the road or another aspect of local hydraulic gradient keeps the water on the upgradient side long enough to join a stream on the upstream side of the road.

Anomalous chloride ion spikes that are seen on the downstream side of Cougar Creek, crossed by County Route 45, Panther Mountain Road, make it necessary to accept the null hypothesis: *chloride ion concentration in streams crossed by county roads in the Adirondacks is not greater downstream from the road than it is upstream from the road*. Most upstream and downstream sites on streams crossed by county roads have a chloride ion concentration lower than 4 mg/L. However, in 2007 the downstream site at Cougar Creek exceeded 5 mg/L chloride in April, June, July, August, September and October (the highest Cougar value, 21 mg/L). In 2007 Glacier Creek hit at or just above 5 mg/L in February and July, with no subsequent high values. Cougar Creek exceeded 5 mg/L in 2008 in February, March, May, June, and July, and in 2009 in April.

A powerlines clearing bisects Cougar Creek below the downstream site, and a driveway and parking lot are adjacent to the downstream section. The end of a drainage pipe that goes under the road may be seen protruding from the slope below the road and above the downstream Cougar Creek site. It is possible that heavy rain events carry water from the area of the houses above the road down to the Cougar downstream site. If so, there may possibly be chloride input related to a septic tank and leach field in one of the houses above the road.

The alternate hypothesis: *chloride ion concentration in streams crossed by state roads in the Adirondacks is greater downstream from the road than it is downstream from the road in streams crossed by county roads in the Adirondacks* is supported by higher chloride values downstream from state roads and significant difference between state and county downstream sites. This comparison is free of the ambiguity introduced by anomalous chloride spikes, and demonstrates that the traditional winter road treatment as practiced on county roads in the Adirondacks is less polluting.

Another clear cut result comes from comparison of two groups of streams crossed by county roads: Mt Arab Road, that receives the usual mixture of sand with a little salt, and Goodnow Road, that receives sand only. The null hypothesis must be accepted, that: *chloride ion concentration in streams crossed by county roads in the Adirondacks that receive the traditional salt/sand winter mixture is not greater downstream from the road than chloride ion concentration downstream from the road in streams crossed by county roads in the Adirondacks that receive sand only, no salt*. In fact, although Goodnow Flow Road receives no salt in winter, mean downstream chloride values for streams crossed by Goodnow Flow Road are higher than those of streams crossed by Mt Arab Road. The greater mean for Goodnow sites reflects chloride ion spikes seen in April and August 2009 in two different streams crossed by Goodnow Flow Road. It is not always possible to discern the cause of a salt spike, but the chloride spike in Goodnow 4 in August 2009 is easy to understand. In August 2009 the Goodnow 4 stream had almost dried up, concentrating any ions present, which could come from groundwater chloride levels.

Road salt inputs into streams in the Adirondacks flow downstream into lakes, especially the chloride portion with its greater mobility. Roads can also follow lake shores and deposit runoff directly to the lake. Road salt in lakes is diluted within a far greater volume of water than in a stream, however effects such as chemical stratification leading to reduced vertical mixing have been observed in urban lakes in Minnesota (Novotny *et al.* 2007). Paved roads in general were associated with increased chloride concentrations in Adirondack lakes. Ninety percent of lakes in watersheds with no paved roads were found to have chloride concentrations on average below 2.5 mg/L, with a range of 0.1 to 5.3 mg/L (Kelting *et al*. 2012). Where watersheds contained paved roads, 80% of lakes had on average more than 2.5 mg/L Cl^-, with a range of 0.1 to 58.4 mg/L (Kelting *et al*. 2012).

The very different road salt runoff contributions from state and county roads found in this study are confirmed by Kelting *et al*. (2012), who showed the extent to which variation in chloride concentrations in Adirondack lakes is explained by proximity to roads of different types. "When paved road density was analyzed by road type in a multilinear regression model, the variation in both sodium and chloride explained by paved road density increased substantially, with road density by type explaining 85% of the variation in sodium and 87% of the variation in chloride" (Kelting *et al*. 2012). The presence within watersheds of local roads such as county roads did not significantly explain variation in lake sodium or chloride levels, whereas state roads in watersheds "explained almost all of the variation for both ions" (Kelting *et al*. 2012).

When considering the effect of road salting on streams or lakes, it's important to see these surface water features as connected to and affecting groundwater. A long-term study of the ultimate fate of chloride ion input from road salting in the Highland Creek Basin of the Metropolitan Toronto and Region Watershed showed that no more than 45% of the chloride deposited into the watershed by winter road de-icing was removed by overland flow into streams. That 45% was then transported with the stream water out of the basin, and the rest was stored in groundwater (Howard and Haynes 1993). During the years 1989-90, 3427 tons of chloride (31%) left the basin in streamwater before the end of April. Another 1609 tons (14%) exited during summer rains before the end of October (Howard and Haynes 1993). In these calculations, 55% of the chloride input per year was being stored in groundwater, where it would eventually (in about 20 years) raise the water table chloride concentration to 426 +/-

50 mg/L chloride, almost twice the maximum acceptable drinking water chloride concentration (Howard and Haynes 1993). A study like this encourages us to think of surface waters as part of a connected system, the major part of which is not seen. Conceptualizing the future of surface waters like streams and lakes requires not just this spatial understanding, but temporal understanding as well, as surface water contamination alters groundwater for the foreseeable future.

4.1: Hypotheses with Regard to EPT Assemblage Relative to Road Salt Runoff:

H_1: EPT assemblage in streams receiving high levels of road salt runoff is different from EPT assemblage in streams not receiving high road salt runoff.

H_0: EPT assemblage in streams receiving high levels of road salt runoff is not different from EPT assemblage in streams not receiving high road salt runoff.

H_1: EPT abundance in streams crossed by county roads in the Adirondacks is greater downstream from the road than EPT abundance downstream from the road in streams crossed by state roads in the Adirondacks.

H_0: EPT abundance in streams crossed by county roads in the Adirondacks is not greater downstream from the road than EPT abundance downstream from the road in streams crossed by state roads in the Adirondacks.

H_1: EPT abundance in streams crossed by county roads receiving low levels of road salt is different from EPT abundance in streams crossed by county roads receiving no road salt.

H_0: EPT abundance in streams crossed by county roads receiving low levels of road salt is not different from EPT abundance in streams crossed by county roads receiving no road salt.

4.2: Results, Collection of EPT Taxa Exposed to Different Levels of Road Salt Runoff

This study yielded 1259 EPT specimens: Ephemeroptera (292 individuals in 14 genera), Plecoptera (495 in 9 genera), and Trichoptera (469 in 28 genera). Almost all genera collected are also represented in a survey of EPT species in Adirondack lakes and streams (Myers *et al.* 2011). Only one nymph was collected that is not represented in that survey, however that nymph (Trichoptera, genus *Psychoglypha*) is within its reported range. Myers *et al.* 2011 were able to obtain species identifications by collecting adults, hand-rearing nymphs, or resorting to DNA barcoding. In this study, using only keys for identification, genus is the lowest taxonomic level practible. Myers *et al.* (2011) report 47 genera of Ephemeroptera can be found in the Adirondacks, 39 genera of Plecoptera, and 70 genera of Trichoptera.

Five Ephemeroptera genera were collected in May, ten in June, five in July, ten in August, and eight in September. Only two genera of Ephemeroptera were collected in all five months. One Plecoptera genus was found in all five months. Three Plecoptera genera were collected in May, seven genera in June, four genera in July, five genera in August, and three genera in September. One Trichoptera genus was found in all five months, seven genera in May, fifteen genera in June, three genera in July, eighteen genera in August, and seventeen genera in September. Chloride ion concentration, dissolved oxygen, pH, water temperature, and surface flow are shown for all samples in Appendix A. Ephemeroptera, Plecoptera, and Trichoptera collected in each sample are shown in Appendix B.

Additional collections were made at a small man-made wetland that receives high road-salt runoff, to determine chloride tolerances for EPT genera.

Table 4.1: June 2007 - 2009 Catch per Unit Effort of Ephemeroptera, Plecoptera, and Trichoptera at Two Chloride Ion Levels

	2-35 mg/L (6×10^{-5} M – 9.9×10^{-4} M) 48 Samples	75-200 mg/L (2.12×10^{-3} M – 5.64×10^{-3} M) 2 Samples
EPT	10.60	3.50
E	2.10	0.00
P	4.27	3.00
T	4.13	0.50

Table 4.2: August 2007 - 2009 Catch per Unit Effort of Ephemeroptera, Plecoptera, and Trichoptera at Two Chloride Ion Levels

	2-35 mg/L 6.00×10^{-5} M - 9.90×10^{-4} 48 Samples	75-200 mg/L 2.12×10^{-3} - 5.64×10^{-3} M 2 Samples
EPT	6.93	12.50
E	2.58	1.50
P	1.04	9.50
T	3.31	1.50

Table 4.3: Catch per Unit Effort of Ephemeroptera, Plecoptera, and Trichoptera May through September 2007-2009 Downstream from the Road at Streams Crossed by State and County Roads

	Downstream from County Roads 42 Samples	Downstream from State Roads 32 samples
EPT	4.07	7.22
E	0.81	2.75
P	0.86	2.72
T	2.40	1.75

Table 4.4: June 2009 Catch per Unit Effort of Ephemeroptera, Plecoptera, and Trichoptera at Streams Crossed by Mt Arab Road and Goodnow Flow Road

	June Mt Arab 2.48 - 3.08 mg/L (7 x 10^{-5} M – 9 x 10^{-5} M) 12 Samples	June Goodnow 2.52 - 3.02 mg/L (7 x 10^{-5} M – 9 x 10^{-5} M) 8 Samples
EPT	15.33	9.00
E	3.33	0.75
P	5.16	2.13
T	6.83	6.13

Table 4.5: August 2009 Catch per Unit Effort of Ephemeroptera, Plecoptera, and Trichoptera at Streams Crossed by Mt Arab Road and Goodnow Flow Road

	August Mt Arab 2.86 - 3.84 mg/L (7 x 10^{-5} M – 9 x 10^{-5} M) 12 Samples	August Goodnow 2.76 - 6.60 mg/L (7 x 10^{-5} M – 9 x 10^{-5} M) 8 Samples
EPT	12.83	1.13
E	3.58	0.25
P	1.67	0.38
T	7.58	0.50

Table 4.1 shows that in June 2007 - 2009, the CPUE of total EPT collected at samples with low chloride concentration (2-35 mg/L) was 10.60, whereas at high chloride concentration (75-200 mg/L) during that month, the CPUE was 3.50. Lowered CPUE of total EPT is caused by the loss of Ephemeroptera at high chloride concentration. In August 2007 – 2009 (Table 4.2) the low chloride sites had a CPUE of 6.93, whereas the higher chloride concentration had a CPUE for total EPT of 12.50. Two factors account for these higher CPUE values at high chloride concentration in August. In August 2009, three individual Ephemeroptera were collected from one genus, *Habrophlebiodes*, the only Ephemeroptera collected at 75 – 200 mg/L Cl^-. *Habrophlebiodes* is considered a tolerant genus, at least as regards organic pollution such as PAHs (Bode *et al.* 2002). In addition, there was a high CPUE for Plecoptera in August. Eighteen individual plecopterans of the genus *Leuctra* were found in one of the two high chloride samples in August.

Comparison of EPT collections downstream from state versus county roads (Table 4.3) showed higher CPUE for EPT, E, and P collected from sites crossed by state roads, and only higher T at sites crossed by county roads. Comparison of EPT collections upstream and downstream at sites along Mt Arab Road (receiving some winter salt) and Goodnow Road (receiving no winter salt) showed higher CPUE for EPT, E, P, and T at sites on streams crossed by Mt Arab Road, as seen in Tables 4.4 and 4.5.

CPUE results are presented untransformed. Table 4.6 shows two-tailed paired T tests that were performed on all CPUE results, after data was transformed $(x + 0.5)^{½}$ after the method in Powers (2006). No significant differences were found (for transformed or untransformed data).

Table 4.6: Two-tailed T tests of CPUE comparisons on transformed data

Comparison of CPUE low versus high chloride sites:

June $P = 0.09708$

August $P = 0.3677$

Comparison of CPUE Downstream state versus county:

$P = 0.6418$

Comparison of CPUE between Mt Arab and Goodnow sites:

June $P = 0.06365$

August $P = 0.07638$

Additional collections at a road-salt impacted wetland indicate genera which can habituate to high chloride concentration. In contrast to the study streams, all of which are crossed perpendicularly by a road, Ampersand Slough lies parallel to Route 3. The small wetland is downgradient from Route 3 and has little drainage. Table 4.7 shows chloride ion concentrations at Ampersand Slough in 2008 and 2009. Table 4.8 shows EPT genera collected at high chloride concentrations. Chloride samples below 200 mg/L were taken at Route 28 Stream 1324, upstream and downstream sites. Chloride samples above 200 mg/L were taken at Ampersand Slough.

Table 4:7: Ampersand Slough Chloride Ion Concentration mg/L

January – December 2008 and April, June, August 2009

Ampersand Slough	2008	Ampersand Slough	2009
Jan	1014.00		
Feb	862.50	April	941.50
Mar	1636.50	June	292.00
Apr	733.00	August	214.50
May	424.00		
Jun	492.50		
Jul	398.00		
Aug	281.00		
Sept	220.00		
Oct	209.00		
Nov	268.00		
Dec	948.00		

Table 4.8: EPT taxa found at high chloride, with highest chloride level at which collected

	Chloride level (mg/L)	
Ephemeroptera	153.4	*Habrophlebiodes*
Plecoptera	220	*Diploperla*
	281	*Soyedina*
	292	*Amphinemura*
	292	*Utaperla*
	398	*Leuctra*
Trichoptera	76	*Hydropsyche*
	153.4	*Hydatophylax*
	193.4	*Oligostomis*
	220	*Wormaldia*
	281	*Diplectrona*
	281	*Hydroptila*
	281	*Neureclipsis*
	281	*Parapsyche*
	281	*Triaenodes*
	292	*Molanna*
	398	*Lepidostoma*

4.3: Discussion of EPT Results

Catch per unit effort is a standard fisheries technique that enables meaningful comparisons of collections based on different numbers of samples. The comparison of collections at low versus high chloride concentration shows that benthic invertebrate data are subject to the extreme variability and patchiness of the benthic environment. Results showed higher CPUE at low chloride in one month, higher CPUE at high chloride in another month, and were not statistically significant. No greater abundance of EPT individuals was seen at lower chloride concentration. However, the EPT assemblage between high and low chloride sites was clearly different. No Ephemeroptera were seen above a certain chloride level, 154 mg/L.

Three individuals of the Ephemeropteran genus *Habrophlebiodes* were collected at 153.4 mg/L Cl^- at a stream site August 2009, but no Ephemeroptera at higher chloride concentrations. No Ephemeroptera were collected at the next two lowest chloride concentrations, 115.8 mg/L and 76 mg/L Cl^-. The next lowest chloride concentration at which Ephemeroptera were collected was 33.04 mg/L, at which four genera were collected. We must accept the alternate hypothesis that *EPT assemblage in streams receiving high levels of road salt is different from EPT assemblage in streams not receiving high road salt runoff.*

EPT abundance was not seen to be greater at a site downstream from a county road as opposed to a site downstream from a state road. Similarly, EPT abundance was not seen to be greater at a site receiving no winter salting than at a site receiving minimal winter salt. These results likely reflect the overall richness of the sites. The streams crossed by county roads may have differed in their degree of anthropogenic disturbance and trophic resources in ways not visible to the human observer. The streams on Mount Arab are on state land. The streams crossed by Goodnow Flow Road were in a conservation easement owned by a timber company at the time of these collections. The land around the Goodnow streams may have a more recent history of logging than Mount Arab, and it is possible that there was less allochthonous debris in the Goodnow streams. We must accept two null hypotheses*: EPT abundance in streams crossed by county roads in the Adirondacks is not greater downstream from the road than EPT abundance downstream from the road in streams crossed by state roads in the Adirondacks, and EPT abundance in streams crossed by county roads receiving low levels of road salt is not different from EPT abundance in streams crossed by county roads receiving no road salt.*

This study, focusing on road salt runoff in the Adirondacks and its effects on aquatic life, did not face a confounding issue in acid rain. The western Adirondacks have been severely affected by acid rain, namely precipitation containing sulfuric acid from Midwestern power plants and nitrogen oxides (NO, NO_2 or N_2O) from power plants and vehicle exhaust. The geology of the western Adirondacks provides low acid neutralizing capacity, and lakes below pH 5 without fish have been found in the western Adirondacks (Jenkins and Keal 2004, Jenkins *et al*. 2005). This study used streams in the central Adirondacks, where many lakes have the same pH as when surveyed in the 1930s. For example Stony Creek Ponds, 3 km from one of the study sites of this study and close to others, had pH values from 6.2-7.2 in July of 1933 (measured at different points) and was at pH 6.82 in July of 1984, when the Adirondack acid rain problem was more severe than it is today (ALSC 1987, Jenkins *et al*. 2005, SNYCD 1934).

One high-chloride wetland was sampled to test salt tolerances of EPT genera. Table 4.8 adds to the information developed by Williams *et al*. (1999) by showing which EPT taxa were collected at the highest chloride levels observed in this study. Table 4.7 was added for clarity.

In their survey of headwater spring fauna for chloride tolerance, Williams *et al.* (1999) found five Trichoptera genera and two Plecoptera genera to be associated with lower tolerance to chloride. Springs offer a window onto the composition of groundwater. Road salt contamination of groundwater (as measured by chloride ion content) is more stable over time than such contamination of surface water (Williams *et al.* 1999). Chloride ion contents of 16 streams in the greater Toronto area ranged from a mean of 1092 mg/L at a spring adjacent to a highway down to a mean of 107 mg/L at a more rural and less disturbed area. It was found that certain taxa are more or less likely to be found in springs with higher chloride ion content. Trichopterans *Molanna* and *Pseudostenophylax* were found to be more tolerant of water with higher chloride ion content, whereas trichopterans *Lepidostoma* and *Parapsyche* were less tolerant of this pollutant. Plecopterans *Nemoura* and *Soyedina* were also less tolerant of high chloride ion content. No plecopterans were identified as being more tolerant, and no ephemeropterans were collected (Williams *et al*. 1999).

Williams *et al*. (1999) identifies the trichopterans *Molanna* and *Pseudostenophylax* as being tolerant of high chloride concentration. *Molanna* was collected at Ampersand Slough at 292 mg/L chloride ion concentration as well as in several samples at low-chloride study sites, which accords with the view of Williams *et al*. (1999). *Pseudostenophylax* was also collected in this study, but only at 2.7 – 2.9 mg/L. The trichopteran *Nemoura*, identified by Williams *et al*. (1999) as being less tolerant of high chloride, was found in this study only at low chloride levels, never more than 3.42 mg/L.

The trichopteran *Lepidostoma*, identified by Williams *et al*. (1999) as being less tolerant of high chloride, was found in this study at 220 mg/L chloride in September 2008 at Ampersand Slough, at 281 mg/L chloride in August 2009 at Ampersand Slough, and at 398 mg/L at Ampersand Slough in July 2008, as well as numerous times in streams with low chloride values. The trichopteran *Parapsyche,* called by Williams *et al*. (1999) less tolerant of high chloride concentration, was found in this study at 214.5 mg/L chloride in August 2009 and at 220 mg/L chloride in September 2008. Similarly, the trichopteran *Soyedina*, also identified by Williams *et al*. (1999) as being less tolerant of high chloride, was found in this study at 153.4 mg/L chloride in August 2009 at Route 28 1324 Upstream, at 220 mg/L in September 2009 at Ampersand Slough, and at 281 mg/L in August 2009 at Ampersand Slough, as well as in June 2009 at Goodnow streams with low chloride values.

That this study found different information for these genera from the information developed by Williams *et al*. (1999) may mean, on the one hand, that we simply collected different species with different tolerances, or on the other hand it may reflect the high variability and element of chance inherent in studies of EPT nymphs in the field. Absence of a taxon may not mean that it could not live at that site (that is, under the conditions of that site), it may just mean that it was not there on the day the site was sampled. Presence of a taxon carries information, absence of a taxon may be less informative.

The strongest pattern observed in the EPT data in this study is the absence of Ephemeroptera at high chloride levels. Near urban areas, road salt runoff may produce far higher chloride ion concentrations than this. In the Greater Toronto Area, Highland Creek had a yearly mean chloride concentration of 316 mg/L, while in the same area the Rouge River had a mean 162 mg/L Cl^- (Williams *et al.* 1999). These chloride levels may effectively exclude Ephemeroptera, which may impact other taxa for which Ephemeroptera are a food source.

Ephemeroptera are an important food resource for some bird species, and emerging mayflies attract birds to streams (Gray 1993). In the American tallgrass prairie, densities of insectivorous birds in the vicinity of streams varied in accordance with emergence of aquatic insects such as mayflies (Gray 1993). Emerging Ephemeroptera made up approximately 25% of total emergence biomass at gallery forest sites and provided food for several bird species (Gray 1993). Ephemeroptera nymphs were found to be an important part of the diet of young smallmouth bass (*Micropterus dolomieu*) in an oligotrophic Adirondack Lake, especially fish below 150 mm in length. At larger sizes smallmouth bass diet shifted from small prey such as mayfly nymphs to crayfish and fish (Weidel *et al.* 2000). The effects of road salt runoff should be considered in light of local animal populations, the needs of which may change during the year. Are local migratory birds feeding on emergent insects? Are local streams nursery areas for young fish, and is fishing a locally important activity?

Consideration of EPT fauna as important bird and fish food sources may inappropriately discount the needs of winter motorists, whose safety is more important than the food abundance of local wildlife. However, plowing and salting to bare pavement does not necessarily protect motorists. Adirondack residents are accustomed to driving slowly on snowpacked county roads and they regard these roads as safe, due to the sand that supplies friction. Today in the Adirondacks locals attempt to avoid freshly salted state roads during snowfalls, detouring onto county roads when possible, and report that the slickness of newly-melted slush on state roads has caused fatal accidents (Craig Donaldson, Harrietstown Highway Supervisor, personal communication).

Many studies have found a link between the degree of impervious surface in a watershed and EPT abundance (Wang and Kanehl 2003). "The effects of urbanization on stream macroinvertebrates are manifested at surprisingly low levels of imperviousness. The initial apparent impact is about 7 percent effective imperviousness, and beyond that macroinvertebrate conditions are inevitably poor" (Wang and Kanehl 2003). Roads are a major contributor to impervious surface. While impervious surface within watersheds is associated with higher water temperatures, which degrades the quality of habitat for aquatic macroinvertebrates (Wang and Kanehl 2003), winter road salting would also be associated with urbanization, and watershed impervious surface. Loss of Ephemeroptera nymphs in areas of high road salt runoff may lower total EPT abundance to the point of degrading habitat quality, especially for those fauna that would otherwise use Ephemeroptera as a seasonally abundant food source.

5.1: Hypothesis With Regard to Recruitment of Trees in Areas of Road Salt Runoff

H_1: Tree recruitment in forest receiving high levels of road salt runoff is different from tree recruitment in forest not receiving high levels of road salt runoff.

H_0: Tree recruitment in forest receiving high levels of road salt runoff is not different from tree recruitment in forest not receiving high levels of road salt runoff.

5.2: Results, Recruitment of Trees in Areas of Road Salt Runoff

Ten transects were used to collect data by the point-centered quarter method. Figures 5.1 and 5.2 show the placement of transects on either side of Routes 3 and 28. Transects were centered on study streams, the average chloride ion content of which is presumed to describe road salt levels to which the forest soils are exposed. Mean chloride ion content for each transect is shown in Table 5.2. A total of 1344 trees were measured and identified, comprising 15 species in 11 genera. Table 5.1 lists trees recorded.

Tables 5.3 – 5.22 show the results of Point-Centered Quarter Method analysis of each transect, first the whole database, then new calculations for the lowest quartile by circumference, representing recruiting tree species. Table 5.23 lists the tree species with the first- and second-highest importance value per transect (whole database and lowest quartile) arranged by increasing chloride ion concentration of the local stream. Table 5.24 shows transects organized by chloride with importance values for four common Adirondack trees found in the transects: balsam, beech, red spruce, and hemlock. Table 5.25 shows the Shannon-Weiner diversity and evenness of each of the lowest quartiles, as well as elevation per transect. Figures 5.3, 5.4, and 5.5 show graphs of the importance values for balsam, the Shannon-Weiner diversity, and the evenness for the lowest quartile of each transect respectively, along with the chloride values for that transect.

Figure 5.1: Transects above and below Route 3

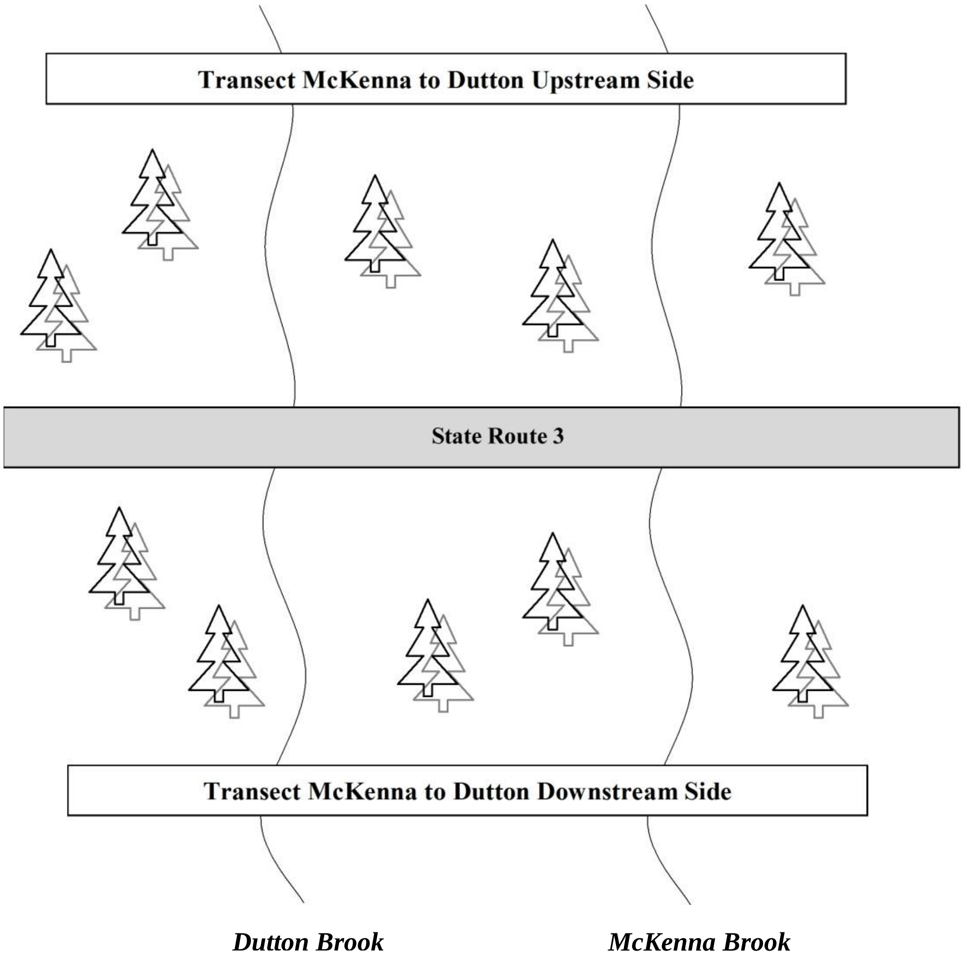


Figure 5.2: Transects above and below Route 28

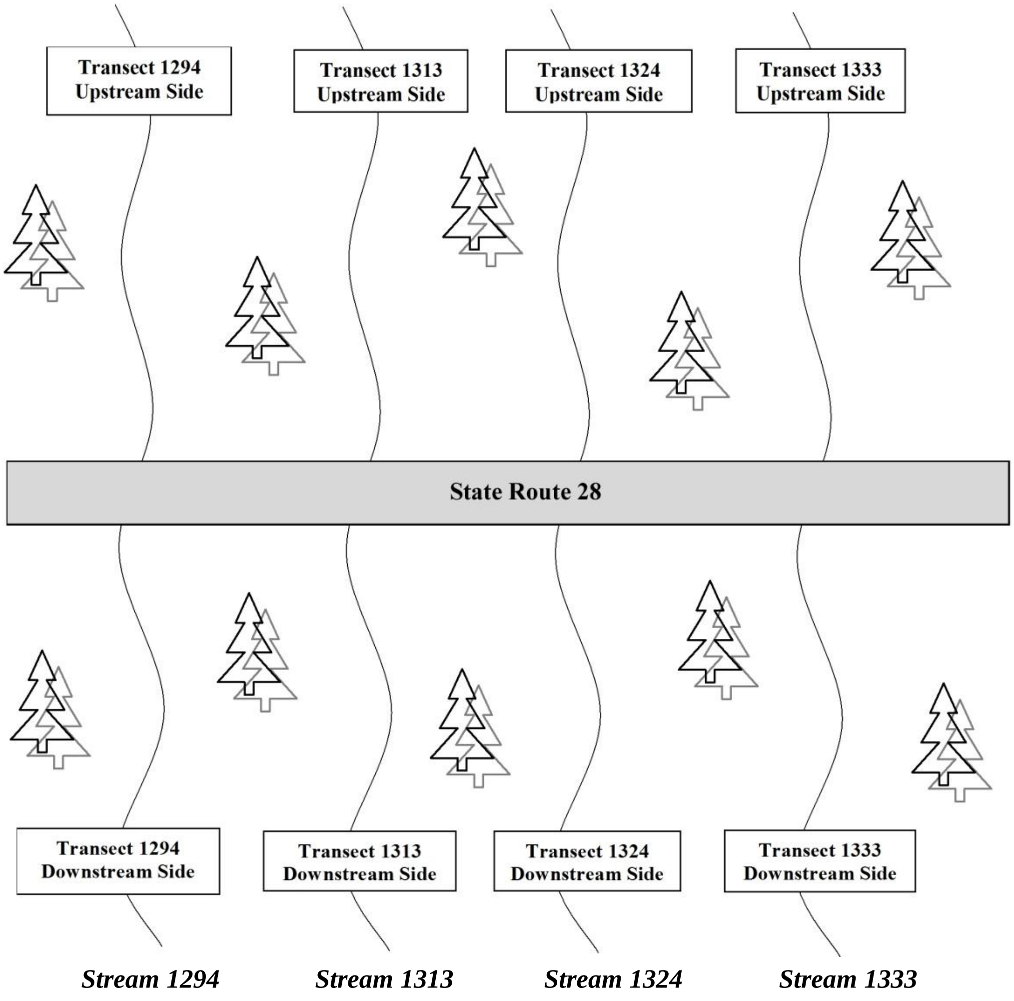


Table 5.1: Trees Recorded in Point-Centered Quarter Analysis

Abies balsamea L. Mill.	Balsam fir
Acer rubrum L.	Red maple
Acer pensylvanicum L.	Striped maple
Acer saccharum Marshall	Sugar maple
Alnus incana(L.) Moench ssp. *rugosa* (Du Roi) R.T. Clausen	Speckled alder
Betula alleghaniensis Britton	Yellow birch
Chamaecyparis thyoides (L.) Britton, Sterns & Poggenb.	Atlantic white cedar
Fagus grandifolia Ehrh.	American beech
Fraxinus americana L.	White ash
Fraxinus nigra Marshall	Black ash
Larix laricina (Du Roi) K. Koch	Larch
Picea mariana (Mill.) Britton, Sterns & Poggenb.	Black spruce
Picea rubens Sarg.	Red spruce
Populus tremuloides Michx.	Quaking aspen
Tsuga canadensis (L.) Carrière	Eastern hemlock

Table 5.2: Road salt burden of forest transects as indicated by mean April, June, August 2009 chloride ion content of local streams

Stream-Centered Transect	Mean Chloride Concentration +/- Standard Deviation	Stream-Centered Transect	Mean Chloride Concentration +/- Standard Deviation
McKenna-to-Dutton	Upstream from Route 3 3.15 +/- 0.25	McKenna-to-Dutton	Downstream from Route 3 6.01 +/- 1.93
1295	3.22 +/- 0.10	1295	13.85 +/- 5.71
1313	25.11 +/- 4.80	1313	27.53 +/- 6.18
1324	102.13 +/- 44.40	1324	135.9 +/- 50.54
1333	2.89 +/- 0.31	1333	17.8 +/- 2.61

Table 5.3: McKenna to Dutton **upstream from** Route 3, whole data set

Mean Chloride Ion Content 3.15 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Tsuga canadensis	55	25.94	74.26	27.82	128.02
Fagus grandifolia	77	36.32	3.76	27.82	67.90
Acer saccharum	20	9.43	8.65	9.77	27.85
Abies balsamea	19	8.96	1.59	9.02	19.57
Picea rubens	17	8.02	2.10	9.02	19.14
Acer pensylvanicum	13	6.13	0.52	8.27	14.93
Chamaecyparis thyoides	4	1.89	3.64	3.01	8.54
Betula alleghaniensis	4	1.89	3.02	3.01	7.91
Fraxinus americana	1	0.47	1.94	0.75	3.16
Acer rubrum	2	0.94	0.52	1.50	2.97

Table 5.4: McKenna to Dutton **upstream from** Route 3, lowest quartile circumference

Mean Chloride Ion Content 3.15 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Fagus grandifolia	33	63.46	74.41	50.00	187.87
Picea rubens	10	19.23	10.18	25.00	54.41
Abies balsamea	5	9.62	4.03	10.00	23.64
Acer saccharum	3	5.77	7.78	10.00	23.55
Tsuga canadensis	1	1.92	3.60	5.00	10.53

Table 5.5: McKenna to Dutton **downstream from** Route 3, whole data set

Mean Chloride Ion Content 6.01 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	118	68.60	32.84	48.78	150.23
Chamaecyparis thyoides	7	4.07	18.92	7.32	30.31
Fraxinus americana	11	6.40	12.35	10.98	29.72
Tsuga canadensis	5	2.91	19.45	4.88	27.23
Acer rubrum	11	6.40	4.05	10.98	21.42
Betula alleghaniensis	6	3.49	8.66	7.32	19.46
Picea mariana	9	5.23	0.64	3.66	9.53
Picea rubens	3	1.74	2.79	3.66	8.19
Acer pensylvanicum	1	0.58	0.30	1.22	2.10
Larix laricina	1	0.58	0.01	1.22	1.81

Table 5.6: McKenna to Dutton **downstream from** Route 3, lowest quartile Mean Chloride Ion Content 6.01 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	34	77.27	80.67	62.50	220.44
Picea mariana	7	15.91	13.85	18.75	48.51
Picea rubens	1	2.27	4.61	6.25	13.13
Larix laricina	1	2.27	0.44	6.25	8.96
Acer rubrum	1	2.27	0.44	6.25	8.96

Table 5.7: Transect 1295 **upstream from** Route 28, whole data set

Mean Chloride Ion Content 3.22 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	25	20.83	32.02	23.94	76.80
Picea rubens	36	30.00	16.70	29.58	76.27
Fagus grandifolia	33	27.50	4.43	19.72	51.65
Betula alleghaniensis	11	9.17	16.21	12.68	38.05
Tsuga canadensis	2	1.67	19.99	2.82	24.47
Acer rubrum	6	5.00	10.07	5.63	20.70
Picea mariana	7	5.83	0.58	5.63	12.05

Table 5.8: Transcect 1295 **upstream from** Route 28, lowest quartile

Mean Chloride Ion Content 3.22 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Fagus grandifolia	17	53.13	47.70	33.33	134.15
Picea rubens	8	25.00	30.91	33.33	89.24
Picea mariana	4	12.50	14.27	13.33	40.10
Abies balsamea	2	6.25	6.05	13.33	25.64
Acer rubrum	1	3.13	1.07	6.67	10.86

Table 5.9: Transect 1295 **downstream from** Route 28, whole data set

Mean Chloride Ion Content 13.85 mg/L

	Number of Trees	Relative Density	Relative Dominance	Relative Frequency	Importance Value
Abies balsamea	33	27.50	20.56	96.75	144.81
Fagus grandifolia	42	35.00	9.27	1.17	45.44
Betula alleghaniensis	6	5.00	23.58	0.31	28.88
Picea rubens	20	16.67	10.34	0.87	27.87
Acer rubrum	5	4.17	13.99	0.25	18.41
Tsuga canadensis	4	3.33	13.91	0.20	17.45
Prunus serotina	1	0.83	7.14	0.05	8.03
Acer pensylvanicum	5	4.17	0.31	0.20	4.68
Picea mariana	3	2.50	0.04	0.15	2.69
Acer saccharum	1	0.83	0.86	0.05	1.74

Table 5.10: Transect 1295 **downstream from** Route 28, lowest quartile

Mean Chloride Ion Content 13.85 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Fagus grandifolia	15	46.88	42.09	35.29	124.26
Abies balsamea	8	25.00	24.37	17.65	67.02
Picea rubens	4	12.50	24.44	17.65	54.58
Picea mariana	3	9.38	6.70	17.65	33.72
Acer pensylvanicum	2	6.25	2.41	11.76	20.42

Table 5.11: Transect 1313 **upstream from** Route 28, whole data set

Mean Chloride Ion Content 25.11 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	92	76.67	52.83	57.70	187.19
Acer rubrum	7	5.83	28.48	13.46	47.77
Fraxinus americana	3	2.50	7.10	5.77	15.37
Betula alleghaniensis	2	1.67	8.28	3.85	13.79
Alnus incana	8	6.67	0.34	5.77	12.78
Picea rubens	3	2.50	1.89	5.77	10.16
Picea mariana	2	1.67	0.30	1.92	3.89
Acer pensylvanicum	1	0.83	0.32	1.92	3.08
Fagus grandifolia	1	0.83	0.29	1.92	3.05
Populus tremuloides	1	0.83	0.17	1.92	2.93

Table 5.12: Transect 1313 **upstream from** Route 28, lowest quartile

Mean Chloride Ion Content 25.11 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	24	75.00	89.83	70.00	234.83
Alnus incana	7	21.88	9.98	20.00	51.86
Fraxinus americana	1	3.13	0.19	10.00	13.31

Table 5.13: Transect 1313 **downstream from** Route 28, whole data set

Mean Chloride Ion Content 27.53 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	94	78.33	43.47	62.50	184.31
Acer rubrum	6	5.00	31.14	10.42	46.56
Fagus grandifolia	6	5.00	19.78	10.42	35.19
Alnus incana	9	7.50	0.83	10.42	18.75
Fraxinus americana	1	0.83	3.46	2.08	6.38
Picea mariana	3	2.50	1.16	2.08	5.74
Picea rubens	1	0.83	0.15	2.08	3.07

Table 5.14: Transect 1313 **downstream from** Route 28, lowest quartile

Mean Chloride Ion Content 27.53 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	22	68.75	75.95	57.14	201.84
Alnus incana	6	18.75	18.79	21.43	58.97
Fagus grandifolia	3	9.38	2.38	14.29	26.04
Picea mariana	1	3.13	2.89	7.14	13.16

Table 5.15: Transect 1324 **upstream from** Route 28, whole data set

Mean Chloride Ion Content 102.13 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	94	78.33	49.09	57.70	185.12
Picea rubens	11	9.17	25.55	19.23	53.95
Acer rubrum	3	2.50	9.62	5.77	17.89
Tsuga canadensis	2	1.67	9.84	3.85	15.35
Betula alleghaniensis	3	2.50	1.90	5.77	10.17
Picea mariana	3	2.50	0.63	1.92	5.05
Fagus grandifolia	2	1.67	1.12	1.92	4.71
Populus tremuloides	1	0.83	1.61	1.92	4.36
Acer pensylvanicum	1	0.83	0.64	1.92	3.40

Table 5.16: Transect 1324 **upstream from** Route 28, lowest quartile

Mean Chloride Ion Content 102.13 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	27	84.38	88.38	66.67	239.42
Picea rubens	2	6.25	2.94	16.67	25.86
Picea mariana	2	6.25	2.82	8.33	17.41
Betula alleghaniensis	1	3.13	5.86	8.33	17.32

Table 5.17: Transect 1324 **downstream from** Route 28, whole data set

Mean Chloride Ion Content 135.90 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	108	90.00	67.80	73.17	230.97
Tsuga canadensis	3	2.50	15.41	4.88	22.79
Acer pensylvanicum	4	3.33	1.07	9.76	14.16
Populus tremuloides	1	0.83	10.09	2.44	13.36
Acer rubrum	2	1.67	4.17	4.88	10.72
Picea rubens	1	0.83	1.38	2.44	4.65
Fraxinus nigra	1	0.83	0.08	2.44	3.35

Table 5.18: Transect 1324 **downstream from** Route 28, lowest quartile

Mean Chloride Ion Content 135.90 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Abies balsamea	30	93.75	91.07	80.00	264.82
Tsuga canadensis	1	3.13	5.89	10.00	19.02
Fraxinus nigra	1	3.13	3.04	10.00	16.17

Table 5.19: Transect 1333 **upstream from** Route 28, whole data set

Mean Chloride Ion Content 2.89 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Fagus grandifolia	89	74.17	41.89	55.56	171.62
Acer saccharum	14	11.67	22.39	20.37	54.42
Tsuga canadensis	5	4.17	21.13	5.56	30.85
Abies balsamea	4	3.33	3.45	3.70	10.49
Acer rubrum	1	0.83	6.53	1.85	9.21
Picea rubens	3	2.50	0.40	5.56	8.46
Acer pensylvanicum	3	2.50	0.27	5.56	8.33
Betula alleghaniensis	1	0.83	3.94	1.85	6.63

Table 5.20: Transect 1333 **upstream from** Route 28, lowest quartile

Mean Chloride Ion Content 2.89 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Fagus grandifolia	28	87.50	88.13	72.73	248.35
Abies balsamea	2	6.25	7.34	9.09	22.68
Acer saccharum	1	3.13	3.42	9.09	15.63
Acer pensylvanicum	1	3.13	1.12	9.09	13.33

Table 5.21: Transect 1333 **downstream from** Route 28, whole data set

Mean Chloride Ion Content 17.80 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Fagus grandifolia	60	0.50	26.92	40.62	68.04
Abies balsamea	28	0.23	32.33	21.87	54.44
Betula alleghaniensis	5	0.04	23.13	7.81	30.98
Acer rubrum	4	0.03	15.01	4.69	19.73
Acer pensylvanicum	13	0.11	0.73	12.50	13.34
Acer saccharum	6	0.05	0.94	7.81	8.80
Picea rubens	2	0.02	0.29	3.12	3.43
Fraxinus americana	2	0.02	0.64	1.56	2.22

Table 5.22: Transect 1333 **downstream from** Route 28, lowest quartile

Mean Chloride Ion Content 17.80 mg/L

	Number of Trees	Relative density	Relative dominance	Relative frequency	Importance Value
Fagus grandifolia	19	59.38	53.85	50.00	163.22
Acer pensylvanicum	9	28.13	33.06	28.57	89.75
Abies balsamea	3	9.38	12.57	14.29	36.23
Acer saccharum	1	3.13	0.53	7.14	10.79

Table 5.23: Tree Species with Highest Importance Value per Transect, by Lowest to Highest Chloride Concentration of Local Streams

Transect	Chloride (mg/L)	Whole Database Highest IV	Whole Database 2nd-highest IV	Lowest Quartile Recruitment Highest IV	Lowest Quartile Recruitment 2nd-highest IV
1333 Up	2.89	*Fagus grandifolia* 171.62	*Acer saccharum* 54.42	*Fagus grandifolia* 248.35	*Abies balsamea* 22.68
McKenna-Dutton Up	3.15	T*suga canadensis* 128.02	*Fagus grandifolia* 67.9	*Fagus grandifolia* 187.87	*Picea rubens* 54.41
1295 Up	3.22	*Abies balsamea* 76.8	*Picea rubens* 76.27	*Fagus grandifolia* 134.15	*Picea rubens* 89.24
McKenna-Dutton Down	6.01	*Abies balsamea* 150.23	*Chamaecyparis thyoides* 30.31	*Abies balsamea* 220.44	*Picea mariana* 48.51
1295 Down	13.85	*Abies balsamea* 144.81	*Fagus grandifolia* 45.44	*Fagus grandifolia* 124.26	*Abies balsamea* 67.02

Table 5.23 **Continued**: Tree Species with Highest Importance Value per Transect, by Lowest to Highest Chloride Concentration of Local Streams

	Chloride (mg/L)	Whole Database Highest IV	Whole Database 2nd-highest IV	Lowest Quartile Recruitment Highest IV	Lowest Quartile Recruitment 2nd-highest IV
Transect 1333 Down	17.8	*Fagus grandifolia* 68.04	*Abies balsamea* 54.44	*Fagus grandifolia* 163.22	*Acer pensylvanicum* 89.75
1313 Up	25.11	*Abies balsamea* 187.19	*Acer rubens* 47.77	*Abies balsamea* 234.83	*Alnus incana* 51.86
1313 Down	27.53	*Abies balsamea* 184.31	*Acer rubens* 46.56	*Abies balsamea* 201.84	*Alnus incana* 58.97
1324 Up	102.13	*Abies balsamea* 185.12	*Picea rubens* 53.95	*Abies balsamea* 239.42	*Picea rubens* 25.86
1324 Down	135.9	*Abies balsamea* 230.97	*Tsuga canadensis* 22.79	*Abies balsamea* 264.82	*Tsuga canadensis* 19.02

Table 5.24: Importance Values of *Abies balsamea*, balsam, *Fagus grandifolia*, beech, *Picea rubens*, red spruce, and *Tsuga canadensis*, Hemlock, in Young Trees, with Mean Chloride Concentration of Local Streams

Lowest Quartiles of Transects	Chloride mg/L	IV Balsam	IV Beech	IV Red spruce	IV Hemlock
1333 Up	2.89	22.68	248.35	0.00	0.00
McKenna-Dutton Up	3.15	23.64	187.87	54.41	10.53
1295 Up	3.22	25.64	134.15	89.24	0.00
McKenna-Dutton Down	6.01	220.44	0.00	13.13	0.00
1295 Down	13.85	67.02	124.26	54.58	0.00
1333 Down	17.8	36.23	163.22	0.00	0.00
1313 Up	25.11	234.83	0.00	0.00	0.00
1313 Down	27.53	201.84	26.04	0.00	0.00
1324 Up	102.13	239.42	0.00	25.86	0.00
1324 Down	135.9	264.82	0.00	0.00	19.01

Table 5.25: Shannon-Weiner Diversity and Evennes of Lowest Quartiles in Ten Transects with Transect Elevations and Mean Chloride Concentration of Local Streams

Lowest Quartiles of Transects	Chloride mg/L	Lowest Quartile Shannon-Weiner Diversity	Lowest Quartile Evenness	Elevation Meters
1333 Up	2.89	0.64	0.48	595.27
McKenna-Dutton Up	3.15	1.66	0.53	477.62
1295 Up	3.22	1.32	0.75	543.15
McKenna-Dutton Down	6.01	0.87	0.48	476.10
1295 Down	13.85	1.44	0.84	540.41
1333 Down	17.80	1.07	0.73	590.40
1313 Up	25.11	0.63	0.63	580.34
1313 Down	27.53	0.94	0.64	575.46
1324 Up	102.13	0.72	0.51	566.32
1324 Down	135.90	0.44	0.52	563.88

Figure 5.3: Importance Values of *Abies balsamea* Among Young Trees in Ten Transects Exposed to Road Salt Runoff and Chloride Concentration (mg/L) of Local Streams

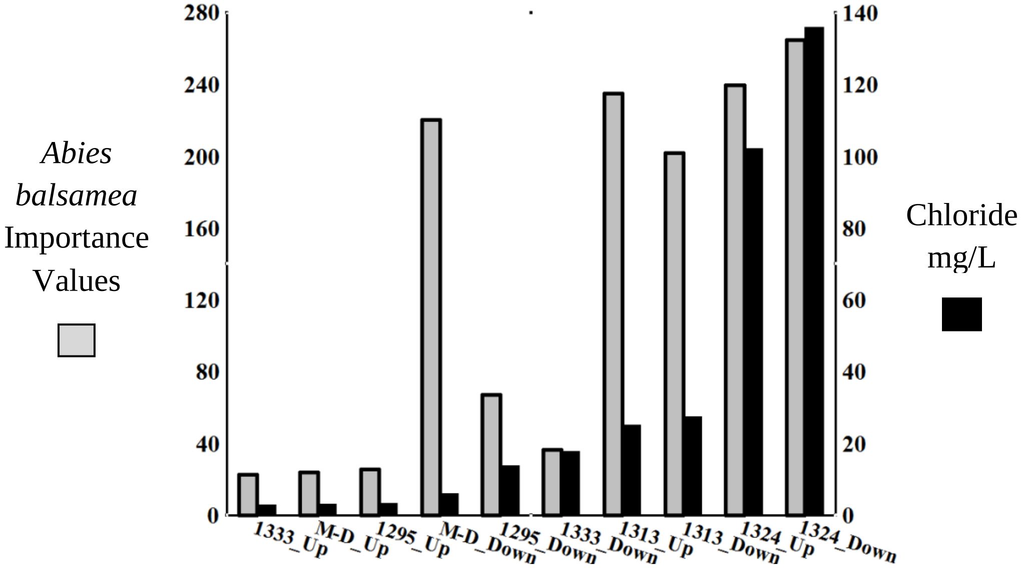


Figure 5.4: Shannon-Weiner Diversity Index Among Young Trees in Ten Transects Exposed to Road Salt Runoff and Chloride Concentration (mg/L) of Local Streams

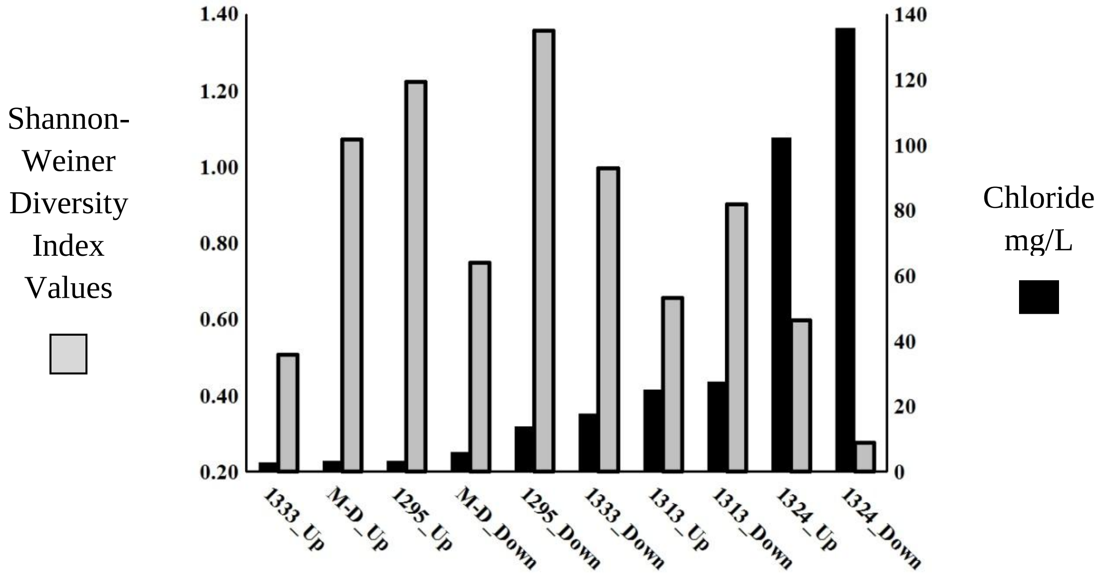
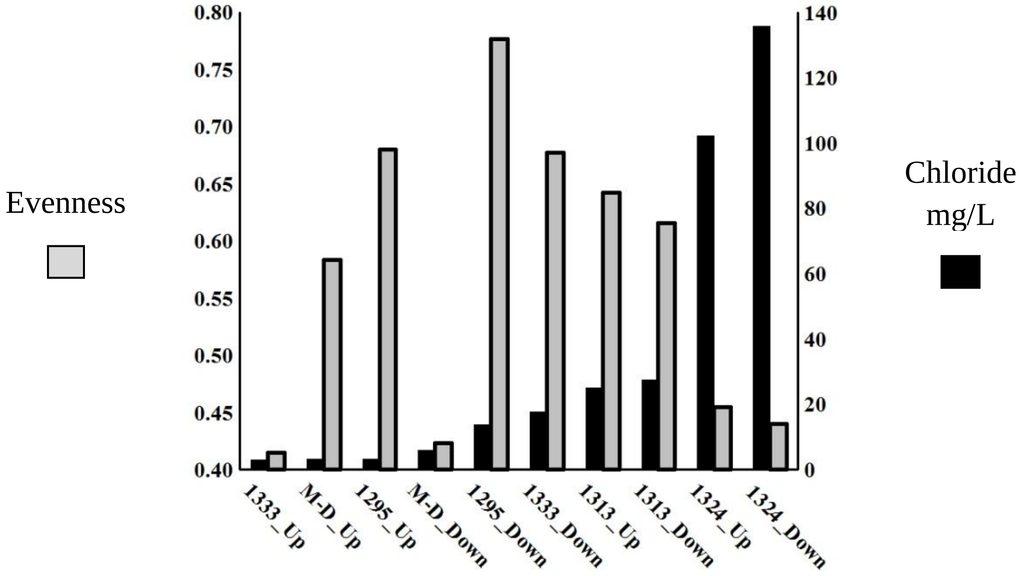


Figure 5.5: Evenness Among Young Trees in Ten Transects Exposed to Road Salt Runoff and Chloride Concentration (mg/L) of Local Streams



5.3: Discussion: Recruitment of Trees in Areas of Road Salt Runoff

Table 5.23 shows which tree species had the first- and second-highest importance value in each transect, with transects in order of increasing chloride. The first three transects listed, 1333 Up (upstream side of Route 28 at stream 1333), McKenna-Dutton Up (upstream side of Route 3), and 1295 Up, were centered on streams with low chloride ion concentrations. Beech, *Fagus grandifolia*, is well represented in these low-salt transects, both in whole databases and lowest quartiles. As seen in Table 5.24, beech continues to be represented in the recruiting trees of most transects, until the highest mean chloride concentrations are reached.

Table 5.25 shows chloride concentrations, Shannon-Weiner Index values, evenness, and elevations for the ten transects. The Shannon-Weiner Index, H, bases diversity on numbers of individuals and taxa. A high H would indicate many taxa in a community, "each with a few individuals" (Hammer 2012). Evenness is e^H/S, "a measure of species equitability" (Buzas and Gibson 1969) where S is the number of species observed and H comes from the Shannon-Weiner Index. Elevation was similar for all transects and does not vary in concert with Shannon-Weiner diversity. Elevation would not be a confounding variable in the transects.

Figure 5.5 shows evenness in the lowest quartiles of each transect. A low evenness value means that most of the young trees belong to one species. Transect 1333 Up was exposed to the least road salt runoff, and also shows extremely low evenness of the recruiting tree species. Out of 120 trees in the whole database, more than 50% (89 trees) are beech, and out of 32 trees in the lowest quartile, 28 are beech. Here we see beech forming a thicket, a very common process in the Adirondacks (Jenkins 1997). In the Adirondacks as a whole the most important hardwoods are beech and sugar maple. Factors which promote beech recruitment and thicket-formation are the "extreme" shade hardiness of beech (Hane 2005), the unattractiveness of beech leaves to browsing deer (Ketchledge 1996), and root suckering. Older beech infected with beech bark disease, caused by a scale insect in association with a fungus, typically send out large numbers of root suckers before dying (Jenkins 1997). Patches of dense young beech, as seen at this transect, are common in the Adirondacks.

The fourth transect listed in Table 5.23 is McKenna-Dutton Down. There are no beech at this transect, either in the whole database or in the lowest quartile. Balsam fir, *Abies balsamea*, is the tree species with the highest importance value in this transect, in both the whole database and the recruiting trees. The forest conditions observed on this downstream side transect of Route 3 were unlike those of any of the other nine transects of PCQM data. The ground was notably moist throughout and was littered with fallen trees, some of relatively recent vintage, many older and covered with carpets of moss. It seems likely that swampy soil provided somewhat unstable anchorage for roots, leading to more fallen trees than observed elsewhere. The distinct nature of this transect is supported by its inclusion of a tree species having the highest wetland-indicator status. Atlantic white cedar *Chamaecyparis thyoides* is classed as an “obligate wetland” tree (Tiner 2005) Obligate wetland species “almost always occur in wetlands” and “are the best plant indicators of a wetland” (Tiner 2005). The upstream McKenna to Dutton transect also contains this species, but at lower importance values (8.54 upstream McKenna to Dutton whole data set, 30.31 downstream McKenna to Dutton whole data set).

That McKenna-Dutton Down (but not McKenna-Dutton Up) is different from the other nine transects in this study can be seen in Figure 5.5, showing evenness. As with the transect 1333 Up, McKenna-Dutton Down is exposed to relatively little road salt runoff, but shows low evenness. The species with the highest importance value at McKenna-Dutton Down, in the whole data set or in the lowest quartile, is balsam, *Abies balsamea*. The wetland-indicator status of balsam is “facultative”, meaning a species that is no more likely to be seen in a wetland than in an upland, but that can be a dominant species in a wetland (Tiner 2005). Balsam fir “dominates some forested wetlands” (Tiner 2005).

Referring again to Table 5.23, the next transect in ascending order of road salt exposure is 1295 Down. Here, balsam has the highest importance value in the whole database, and the second-highest in the lowest quartile. Beech is second-highest in the whole database, and the major recruiting species. This transect has high diversity and evenness in its lowest quartile. As seen in Figures 5.4, transect 1295 Down has the highest diversity of any succeeding transect, although diversities do not decrease smoothly as chloride concentration rises, and 1313 Down has higher diversity than the transect immediately before it, 1313 Up. Figure 5.5 shows that after transect 1295 evenness declines with each rise in chloride concentration.

Transect 1333 Down has moderately higher mean chloride ion concentration than 1295 Down. Beech has the highest importance value in at this transect in both the whole database and the lowest quartile. Among the recruiting species, striped maple, *Acer pennsylvanicum*, has the second-highest importance value. Striped maple is a common Adirondack understory tree (Jenkins 1997). Diversity and evenness of 1333 Down are both lower than in the preceeding transect in Figures 5.4 and 5.5.

The last four transects listed in Table 5.23 are exposed to considerable road salt runoff. In each of these transects balsam has the highest importance value in both the whole databases and lowest quartiles. Figure 5.3 shows that in the lowest quartiles, the importance values of balsam increase as road salt runoff increases. Balsam becomes almost the only species being recruited in these high-road salt transects. The two 1313 transects are very similar in road salt exposure, both with mean chloride concentration of the local stream around 25 mg/L. Upstream 1313 has 8 trees in two species besides balsam, while 1313 Down has 10 trees in three species besides balsam. The next most road salt-exposed transect, 1324 Up, 102.13 mg/L chloride, has 5 trees in three species besides balsam in its lowest quartile. Finally, 1324 Down, 135.90 mg/L chloride, has two trees in two species being recruited besides balsam.

Table 5.24 shows importance values of four common Adirondack tree species. Red spruce, *Picea rubens*, and Hemlock, *Tsuga canadensis*, show some recruitment in the face of high road salt runoff. Beech is not seen in the lowest quartiles of the two highest-salt transects, although beech is present in the whole database of 1324 Up.

Figure 5.4 shows that Shannon-Weiner diversity of lowest quartiles declining smoothly in the last three transects as chloride concentration increases. Figure 5.5 shows evenness declining in the last six transects, and becoming especially low in the last two. Hillebrand *et al.* (2008) note that evenness often responds rapidly to anthropogenic disturbance, including biogeochemical change. Reduced evenness, fewer species for a given area, can depauperate fragmented and isolated habitats and possibly lead to local extinctions (Hillebrand *et al.* 2008). While the forest transects in the Adirondacks are not located in fragmented habitats, road salting occurs in urban areas where habitats are typically fragmented, and therefore road salting might be expected to result in fewer tree species and local loss of some tree species.

In these high-salt transects balsam shows tolerance to road salt and is able to out-compete other tree species. There are other cases in which balsam acts as a superior competitor. Balsam is noted in the Adirondacks for quickly colonizing sites after blow-downs and for growing closer to the timberline than other species (Ketchledge 1996). Balsam is also known for filling in gaps after the deaths of large trees, and for increasing in areas where red spruce has declined (Bedison, *et al.* 2007). The highest road-salt impacted transects in this study are filled with balsam, and their recruiting trees are almost all balsam. The null hypothesis, that tree recruitment in forest receiving high levels of road salt runoff is not different from tree recruitment in forest not receiving high road salt runoff, must be rejected.

The dominance of balsam at sites of high road salt runoff may be due to local depletion of soil calcium. In conditions of road salt runoff, excess sodium ions displace other cations on negatively-charged clay and organic particles in soil. Road salt runoff depletes soil of calcium, magnesium, and other positively-charged plant nutrients, which become unbound and wash out of road-salt impacted soil (Kelting and Laxson 2010). The situation may be similar to that caused by acid rain.

Acid rain is caused by the release into the atmosphere of sulfur and nitrogen oxides during the burning of fossil fuels. These compounds come back to earth as sulfuric and nitric acid (Rosenberg and Butcher 2010). Acid deposition displaces soil calcium and other soil cations that serve as plant nutrients (Driscoll *et al.* 2003). A decrease in soil exchangeable calcium has been shown at northeastern forests such as the Hubbard Brook Experimental Forest in New Hampshire (Boyce 2007). Red spruce and sugar maple have declined in the northeast, and this may be due to calcium deficiency, as calcium has a role in photosynthesis (Boyce 2007). In a study comparing chlorophyll fluorescence in foliage of red spruce and balsam between a site treated by calcium addition to the soil and a reference site, red spruce was considered the target experimental species and balsam was considered to be a control, because balsam has not shown the regional decline that has been observed in red spruce (Boyce 2007). Surprisingly, both red spruce and balsam showed increased fluorescence of foliar chlorophyll, suggesting that both species are affected by decreased soil calcium, although the effect on balsam is not severe enough to cause a decline in population (Boyce 2007). Red spruce suffers increased winter injury under calcium deprivation, and apparently this has been the cause of its decline (Boyce 2007).

Road salt may exert an effect on the forest in this study by a similar mechanism. Red spruce declines under conditions of calcium stress, which can be caused by road salt as well as by acidic deposition. Balsam does not show decline under calcium stress (Boyce 2007). Therefore, the dominance of balsam in recruiting trees at the transects studied may be due to declines in red spruce and possibly other tree species, due to calcium stress. Red spruce and balsam have been tested for response to added calcium, but there may be similar effects in other forest trees that have not been tested.

In addition to calcium, excess sodium out-competes soil macronutrients magnesium and potassium, and micronutrients copper, zinc, manganese and molybdenum (Kelting and Laxson 2010). It is therefore also possible that balsam gains its competitive edge under road salt stress because other trees that might have recruited in the same area have been more negatively affected by loss of a plant nutrient other than calcium.

6: Summary

In this study it was found that road salt from winter de-icing impacts Adirondack ecology. This adds to the growing awareness of road salt contamination in the United States and elsewhere. Road salt was measured as chloride concentration in stream or wetland water. More chloride ion is deposited to streams that are crossed by roads that are plowed bare and salted in response to snow (the policy of New York State) than those that receive only sand with a little added salt (92% sand, 8% salt) on top of packed snow (the traditional county policy). However, if a county chooses not to add salt to their sandpile, that does not necessarily mean their local streams will actually have less chloride ion concentration than county roads treated with the traditional sand/salt mixture.

Aquatic nymphs of the Ephemeroptera, Plecoptera, and Trichoptera are exposed to water pollution. No Ephemeroptera were seen at chloride ion concentrations above 155 mg/L. Benthic invertebrates such as the EPT taxa provide food for wildlife such as fish and birds. They are a food source as nymphs and upon emerging, and should be conserved as important components of local ecosystems.

It was also seen that road salt runoff onto forest soil is associated with increasing importance value of balsam, *Abies balsamea*, decreasing Shannon-Weiner diversity and decreasing evenness. Road salt runoff is therefore seen to affect both aquatic and terrestrial ecosystems. Benthic invertebrate assemblage and forest tree assemblage both change under conditions of road salt runoff.

7: Appendix A: Abiotic Factors at Study Sites in May 2007, 2008

Month, Year	Study Site on Stream	Chloride mg/L	DO mg/L	pH	Water T °C	Flow m/sec
May-07	Glacier Creek Upstream	3.54	11.08	6.50	7.20	ND
May-07	Glacier Creek Downstream	2.98	10.96	6.80	7.20	ND
May-07	Cougar Creek Upstream	2.46	9.21	6.57	12.40	ND
May-07	Cougar Creek Downstream	4.22	9.43	6.70	12.75	ND
May-07	Dutton Brook Upstream	2.88	8.47	6.65	15.40	ND
May-07	Dutton Brook Downstream	3.40	9.07	6.73	14.45	ND
May-07	McKenna Brook Upstream	2.92	9.66	7.33	12.25	ND
May-07	McKenna Brook Downstream	7.64	9.48	7.26	12.55	ND
May-08	Glacier Creek Upstream	3.08	10.85	6.78	8.30	0.16
May-08	Glacier Creek Downstream	2.94	10.86	7.08	9.80	0.25
May-08	Cougar Creek Upstream	3.06	10.37	6.41	8.95	0.17
May-08	Cougar Creek Downstream	8.63	10.22	6.69	9.20	0.23
May-08	Dutton Brook Upstream	3.00	10.84	6.62	8.05	0.21
May-08	Dutton Brook Downstream	4.00	10.92	6.66	8.15	0.25
May-08	McKenna Brook Upstream	2.80	11.22	6.93	7.00	0.26
May-08	McKenna Brook Downstream	4.88	11.49	7.15	6.70	0.20

Abiotic Factors at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Chloride mg/L	DO mg/L	pH	Water T °C	Flow m/sec
Jun-07	Glacier Creek Upstream	3.26	8.78	6.74	14.70	ND
Jun-07	Glacier Creek Downstream	3.08	8.84	7.12	15.10	ND
Jun-07	Cougar Creek Upstream	3.64	8.44	6.57	14.05	ND
Jun-07	Cougar Creek Downstream	5.90	7.85	6.65	15.05	ND
Jun-07	Dutton Brook Upstream	3.30	9.17	6.88	13.20	ND
Jun-07	Dutton Brook Downstream	3.60	9.39	6.94	13.00	ND
Jun-07	McKenna Brook Upstream	3.40	9.99	7.25	10.35	ND
Jun-07	McKenna Brook Downstream	4.78	9.89	7.26	10.00	ND
Jun-08	Glacier Creek Upstream	2.82	8.43	6.39	15.10	0.45
Jun-08	Glacier Creek Downstream	2.38	9.24	7.08	15.65	0.11
Jun-08	Cougar Creek Upstream	2.90	5.76	6.65	15.60	0.06
Jun-08	Cougar Creek Downstream	6.32	8.24	6.38	16.65	0.11
Jun-08	Dutton Brook Upstream	2.78	6.16	6.45	16.10	0.05
Jun-08	Dutton Brook Downstream	4.30	8.76	6.47	16.40	0.23
Jun-08	McKenna Brook Upstream	2.98	9.91	7.16	11.55	0.25
Jun-08	McKenna Brook Downstream	7.84	9.84	6.49	14.25	0.09
Jun-09	Cougar Creek Upstream	3.20	10.02	6.09	10.30	0.14
Jun-09	Cougar Creek Downstream	4.98	9.88	6.22	10.90	0.40
Jun-09	Dutton Brook Upstream	3.30	9.64	6.40	11.85	0.28
Jun-09	Dutton Brook Downstream	3.50	9.58	6.31	12.05	0.44
Jun-09	McKenna Brook Upstream	3.02	9.88	6.72	10.15	0.30
Jun-09	McKenna Brook Downstream	6.54	9.98	6.61	10.00	0.32
Jun-09	Mt Arab 1 Upstream	2.54	9.90	6.60	11.15	0.36
Jun-09	Mt Arab 1 Downstream	2.48	9.99	6.67	11.50	0.34
Jun-09	Mt Arab 2 Upstream	2.90	7.83	6.43	14.55	0.16

Abiotic Factors at Study Sites in June 2009

Month, Year	Study Site on Stream	Chloride mg/L	DO mg/L	pH	Water T °C	Flow m/sec
Jun-09	Mt Arab 2 Downstream	3.06	8.28	6.28	14.70	0.18
Jun-09	Mt Arab 3 Upstream	2.84	9.43	6.55	12.30	0.42
Jun-09	Mt Arab 3 Downstream	2.68	9.52	6.62	12.55	0.10
Jun-09	Mt Arab 4 Upstream	2.96	9.33	5.88	13.05	0.14
Jun-09	Mt Arab 4 Downstream	2.76	9.48	6.13	13.05	0.17
Jun-09	Mt Arab 5 Upstream	3.00	9.11	5.22	13.00	0.26
Jun-09	Mt Arab 5 Downstream	3.04	9.75	6.00	12.70	0.20
Jun-09	Mt Arab 6 Upstream	3.08	9.49	6.47	11.80	0.39
Jun-09	Mt Arab 6 Downstream	2.92	9.46	6.22	11.70	0.27
Jun-09	Stream 1333 Upstream	3.08	9.71	6.30	11.90	0.08
Jun-09	Stream 1333 Downstream	16.82	9.77	6.76	12.05	0.38
Jun-09	Stream 1324 Upstream	76.00	9.29	6.65	11.30	0.32
Jun-09	Stream 1324 Downstream	115.80	8.54	6.62	11.55	0.17
Jun-09	Stream 1313 Upstream	27.18	8.36	6.44	14.50	0.25
Jun-09	Stream 1313 Downstream	28.70	8.74	6.44	14.70	0.48
Jun-09	Stream 1295 Upstream	3.22	9.18	6.47	11.90	0.37
Jun-09	Stream 1295 Downstream	11.26	9.80	6.73	11.85	0.25
Jun-09	Goodnow 1 Upstream	2.86	9.56	5.79	11.05	0.12
Jun-09	Goodnow 1 Downstream	2.78	7.77	5.66	11.30	0.09
Jun-09	Goodnow 2 Upstream	2.70	9.52	6.00	10.65	0.18
Jun-09	Goodnow 2 Downstream	3.02	6.61	5.83	12.15	0.06
Jun-09	Goodnow 3 Upstream	2.52	9.40	6.00	11.55	0.23
Jun-09	Goodnow 3 Downstream	2.90	9.80	6.85	11.45	0.16
Jun-09	Goodnow 4 Upstream	2.96	9.51	6.35	11.10	0.05
Jun-09	Goodnow 4 Downstream	2.70	9.46	6.35	11.75	0.13

Abiotic Factors at Study Sites in July 2007, 2008

Month, Year	Study Site on Stream	Chloride mg/L	DO mg/L	pH	Water T °C	Flow m/sec
Jul-07	Glacier Creek Upstream	3.00	ND	ND	ND	ND
Jul-07	Glacier Creek Downstream	5.50	ND	ND	ND	ND
Jul-07	Cougar Creek Upstream	3.26	ND	ND	ND	ND
Jul-07	Cougar Creek Downstream	10.20	ND	ND	ND	ND
Jul-07	Dutton Brook Upstream	3.02	ND	ND	ND	ND
Jul-07	Dutton Brook Downstream	3.22	ND	ND	ND	ND
Jul-07	McKenna Brook Upstream	3.90	ND	ND	ND	ND
Jul-07	McKenna Brook Downstream	6.10	ND	ND	ND	ND
Jul-08	Glacier Creek Upstream	2.88	8.66	6.10	15.85	0.17
Jul-08	Glacier Creek Downstream	2.78	9.37	7.17	15.25	0.11
Jul-08	Cougar Creek Upstream	3.08	8.21	6.53	16.40	0.00
Jul-08	Cougar Creek Downstream	6.30	8.05	6.30	17.25	0.13
Jul-08	Dutton Brook Upstream	2.96	8.16	6.75	16.55	0.04
Jul-08	Dutton Brook Downstream	5.36	8.66	6.51	16.85	0.29
Jul-08	McKenna Brook Upstream	2.84	9.56	6.85	14.00	0.28
Jul-08	McKenna Brook Downstream	5.70	9.50	7.06	14.10	0.25

Abiotic Factors at Study Sites in August 2007, 2008, 2009

		Chloride mg/L	DO mg/L	pH	Water T °C	Flow m/sec
Aug-07	Glacier Creek Upstream	3.12	8.63	ND	ND	0.06
Aug-07	Glacier Creek Downstream	3.04	8.70	ND	ND	0.11
Aug-07	Cougar Creek Upstream	3.06	6.51	ND	ND	0.08
Aug-07	Cougar Creek Downstream	9.80	5.80	ND	ND	0.12
Aug-07	Dutton Brook Upstream	3.04	8.20	ND	ND	0.10
Aug-07	Dutton Brook Downstream	3.76	8.36	ND	ND	0.13
Aug-07	McKenna Brook Upstream	3.38	9.38	ND	ND	0.14
Aug-07	McKenna Brook Downstream	3.78	9.38	ND	ND	0.18
Aug-08	Glacier Creek Upstream	2.66	9.46	6.85	13.80	0.07
Aug-08	Glacier Creek Downstream	2.76	9.74	7.27	14.15	0.14
Aug-08	Cougar Creek Upstream	2.78	9.11	6.49	14.25	0.11
Aug-08	Cougar Creek Downstream	3.16	9.12	6.70	14.85	0.04
Aug-08	Dutton Brook Upstream	2.86	9.15	6.99	14.60	0.27
Aug-08	Dutton Brook Downstream	5.04	9.22	6.80	14.75	0.28
Aug-08	McKenna Brook Upstream	2.40	9.92	7.18	11.85	0.25
Aug-08	McKenna Brook Downstream	6.10	9.89	7.39	11.90	0.17
Aug-09	Cougar Creek Upstream	3.46	8.91	6.38	14.70	0.09
Aug-09	Cougar Creek Downstream	3.60	8.75	6.54	15.20	0.15
Aug-09	Dutton Brook Upstream	3.02	8.90	6.68	15.10	0.32
Aug-09	Dutton Brook Downstream	7.08	8.86	6.64	15.35	0.12
Aug-09	McKenna Brook Upstream	3.60	9.81	6.85	12.40	0.19
Aug-09	McKenna Brook Downstream	6.74	9.63	6.80	12.50	0.19
Aug-09	Mt Arab 1 Upstream	2.86	8.95	6.61	13.50	0.12
Aug-09	Mt Arab 1 Downstream	3.34	9.77	6.72	13.10	0.15
Aug-09	Mt Arab 2 Upstream	3.24	7.47	6.55	15.70	0.12

Abiotic Factors at Study Sites in August 2009

		Chloride mg/L	DO mg/L	pH	Water T °C	Flow m/sec
Aug-09	Mt Arab 2 Downstream	3.10	7.53	6.50	16.05	0.11
Aug-09	Mt Arab 3 Upstream	3.78	9.24	6.56	13.90	0.11
Aug-09	Mt Arab 3 Downstream	3.56	8.91	7.04	15.65	0.28
Aug-09	Mt Arab 4 Upstream	3.44	8.53	5.62	14.55	0.26
Aug-09	Mt Arab 4 Downstream	3.32	9.28	6.08	14.45	0.14
Aug-09	Mt Arab 5 Upstream	3.84	9.03	4.98	14.50	0.21
Aug-09	Mt Arab 5 Downstream	3.78	9.49	6.15	14.50	0.22
Aug-09	Mt Arab 6 Upstream	3.66	9.49	6.21	12.75	0.20
Aug-09	Mt Arab 6 Downstream	2.98	9.27	5.94	13.25	0.17
Aug-09	Stream 1333 Upstream	3.06	9.75	6.69	13.65	0.10
Aug-09	Stream 1333 Downstream	20.76	9.52	7.04	13.80	0.29
Aug-09	Stream 1324 Upstream	153.40	9.09	6.99	13.25	0.30
Aug-09	Stream 1324 Downstream	193.40	9.11	6.46	12.95	0.06
Aug-09	Stream 1313 Upstream	28.52	6.58	6.57	16.25	0.26
Aug-09	Stream 1313 Downstream	33.04	8.37	6.60	16.45	0.29
Aug-09	Stream 1295 Upstream	3.32	8.63	6.63	14.70	0.15
Aug-09	Stream 1295 Downstream	20.40	9.21	7.08	14.65	0.28
Aug-09	Goodnow 1 Upstream	3.74	9.53	5.94	13.25	0.11
Aug-09	Goodnow 1 Downstream	3.42	9.16	6.10	14.05	0.15
Aug-09	Goodnow 2 Upstream	2.76	8.44	5.86	12.05	0.00
Aug-09	Goodnow 2 Downstream	3.30	4.40	6.28	14.05	0.00
Aug-09	Goodnow 3 Upstream	3.24	9.65	6.40	12.60	0.09
Aug-09	Goodnow 3 Downstream	3.36	9.83	6.52	13.10	0.39
Aug-09	Goodnow 4 Upstream	3.20	9.66	6.44	12.60	0.09
Aug-09	Goodnow 4 Downstream	6.60	8.63	6.44	12.35	0.08

Abiotic Factors at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Chloride mg/L	DO mg/L	pH	Water T °C	Flow m/sec
Sep-07	Glacier Creek Upstream	2.70	9.23	6.36	12.40	0.12
Sep-07	Glacier Creek Downstream	2.96	9.08	6.40	13.45	0.11
Sep-07	Cougar Creek Upstream	2.42	8.34	6.19	13.40	0.13
Sep-07	Cougar Creek Downstream	7.32	3.36	6.02	13.15	0.12
Sep-07	Dutton Brook Upstream	2.56	8.67	7.23	14.60	0.05
Sep-07	Dutton Brook Downstream	2.64	9.64	6.66	13.70	0.14
Sep-07	McKenna Brook Upstream	2.88	9.89	7.09	10.85	0.15
Sep-07	McKenna Brook Downstream	2.64	9.61	7.12	11.30	0.23
Sep-08	Glacier Creek Upstream	2.76	9.87	7.01	10.10	0.07
Sep-08	Glacier Creek Downstream	2.78	9.82	7.38	11.25	0.16
Sep-08	Cougar Creek Upstream	2.68	9.17	6.72	11.70	0.07
Sep-08	Cougar Creek Downstream	4.14	9.28	6.91	11.10	0.06
Sep-08	Dutton Brook Upstream	2.64	10.23	6.93	9.85	0.14
Sep-08	Dutton Brook Downstream	6.28	10.49	6.86	8.80	0.25
Sep-08	McKenna Brook Upstream	2.34	10.98	7.24	7.55	0.14
Sep-08	McKenna Brook Downstream	4.60	10.91	7.24	7.50	0.18

8: Appendix B: Ephemeroptera Collected at Study Sites in May 2007, 2008

Month, Year	Study Site on Stream	Acerpenna	Ameletus	Baetis
May-07	Glacier Creek Upstream	0	0	0
May-07	Glacier Creek Downstream	0	0	0
May-07	Cougar Creek Upstream	0	0	0
May-07	Cougar Creek Downstream	0	0	0
May-07	Dutton Brook Upstream	0	0	0
May-07	Dutton Brook Downstream	4	0	0
May-07	McKenna Brook Upstream	0	0	0
May-07	McKenna Brook Downstream	0	0	0
May-08	Glacier Creek Upstream	0	0	0
May-08	Glacier Creek Downstream	0	0	0
May-08	Cougar Creek Upstream	0	1	0
May-08	Cougar Creek Downstream	0	0	0
May-08	Dutton Brook Upstream	0	0	0
May-08	Dutton Brook Downstream	0	0	0
May-08	McKenna Brook Upstream	0	0	0
May-08	McKenna Brook Downstream	1	0	1

Continued: Ephemeroptera Collected at Study Sites in May 2007, 2008

	Month, Year	Study Site on Stream	Ephemerella	Eurylophella
7-May	May-07	Glacier Creek Upstream	0	0
7-May	May-07	Glacier Creek Downstream	0	0
7-May	May-07	Cougar Creek Upstream	0	3
7-May	May-07	Cougar Creek Downstream	0	0
7-May	May-07	Dutton Brook Upstream	0	0
7-May	May-07	Dutton Brook Downstream	0	0
7-May	May-07	McKenna Brook Upstream	0	0
7-May	May-07	McKenna Brook Downstream	0	0
8-May	May-08	Glacier Creek Upstream	0	0
8-May	May-08	Glacier Creek Downstream	0	0
8-May	May-08	Cougar Creek Upstream	0	2
8-May	May-08	Cougar Creek Downstream	0	0
8-May	May-08	Dutton Brook Upstream	0	0
8-May	May-08	Dutton Brook Downstream	0	0
8-May	May-08	McKenna Brook Upstream	0	0
8-May	May-08	McKenna Brook Downstream	1	0

Plecoptera Collected at Study Sites in May 2007, 2008

	Month, Year	Study Site on Stream	Amphinemura	Leuctra	Utaperla
7-May	May-07	Glacier Creek Upstream	0	0	0
7-May	May-07	Glacier Creek Downstream	0	0	0
7-May	May-07	Cougar Creek Upstream	0	2	0
7-May	May-07	Cougar Creek Downstream	0	1	0
7-May	May-07	Dutton Brook Upstream	0	0	0
7-May	May-07	Dutton Brook Downstream	0	0	0
7-May	May-07	McKenna Brook Upstream	1	0	0
7-May	May-07	McKenna Brook Downstream	0	1	0
8-May	May-08	Glacier Creek Upstream	0	0	0
8-May	May-08	Glacier Creek Downstream	0	0	0
8-May	May-08	Cougar Creek Upstream	0	0	0
8-May	May-08	Cougar Creek Downstream	0	0	2
8-May	May-08	Dutton Brook Upstream	0	1	0
8-May	May-08	Dutton Brook Downstream	0	0	0
8-May	May-08	McKenna Brook Upstream	1	0	0
8-May	May-08	McKenna Brook Downstream	1	0	0

Tricoptera Collected at Study Sites in May 2007, 2008

Month, Year	Study Site on Stream	Agarodes	Lepidostoma	Neophylax	Neureclipsis
May-07	Glacier Creek Upstream	0	0	0	0
May-07	Glacier Creek Downstream	0	0	0	0
May-07	Cougar Creek Upstream	0	0	0	0
May-07	Cougar Creek Downstream	0	0	0	0
May-07	Dutton Brook Upstream	0	0	1	0
May-07	Dutton Brook Downstream	1	2	1	0
May-07	McKenna Brook Upstream	0	0	0	0
May-07	McKenna Brook Downstream	0	0	0	0
May-08	Glacier Creek Upstream	0	4	0	0
May-08	Glacier Creek Downstream	0	0	0	0
May-08	Cougar Creek Upstream	0	0	0	0
May-08	Cougar Creek Downstream	0	0	0	0
May-08	Dutton Brook Upstream	0	0	0	0
May-08	Dutton Brook Downstream	0	0	0	0
May-08	McKenna Brook Upstream	0	0	0	1
May-08	McKenna Brook Downstream	0	0	0	0

Continued: Tricoptera Collected at Study Sites in May 2007, 2008

Month, Year	Study Site on Stream	Parapsyche	Psilotreta	Pycnopsyche
May-07	Glacier Creek Upstream	0	0	0
May-07	Glacier Creek Downstream	0	0	0
May-07	Cougar Creek Upstream	0	0	0
May-07	Cougar Creek Downstream	0	0	0
May-07	Dutton Brook Upstream	0	0	1
May-07	Dutton Brook Downstream	0	1	0
May-07	McKenna Brook Upstream	0	0	0
May-07	McKenna Brook Downstream	0	0	0
May-08	Glacier Creek Upstream	0	0	0
May-08	Glacier Creek Downstream	0	0	0
May-08	Cougar Creek Upstream	0	0	0
May-08	Cougar Creek Downstream	0	0	0
May-08	Dutton Brook Upstream	0	0	0
May-08	Dutton Brook Downstream	0	0	0
May-08	McKenna Brook Upstream	0	0	0
May-08	McKenna Brook Downstream	1	0	0

Ephemeroptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Ameletus	Arthroplea	Baetis	Cinygmula
Jun-07	Glacier Upstream	0	0	0	0
Jun-07	Glacier Downstream	0	0	0	0
Jun-07	Cougar Upstream	0	0	0	0
Jun-07	Cougar Downstream	0	0	0	0
Jun-07	Dutton Upstream	0	0	0	0
Jun-07	Dutton Downstream	0	0	0	0
Jun-07	McKenna Upstream	0	0	0	0
Jun-07	McKenna Downstream	0	0	0	0
Jun-08	Glacier Upstream	0	0	0	0
Jun-08	Glacier Downstream	0	0	0	0
Jun-08	Cougar Upstream	0	0	0	0
Jun-08	Cougar Downstream	0	0	0	0
Jun-08	Dutton Upstream	0	0	3	0
Jun-08	Dutton Downstream	0	1	0	0
Jun-08	McKenna Upstream	0	0	1	0
Jun-08	McKenna Downstream	0	0	0	0
Jun-09	Cougar Upstream	0	0	0	0
Jun-09	Cougar Downstream	1	0	0	0
Jun-09	Dutton Upstream	0	0	0	0
Jun-09	Dutton Downstream	0	0	1	0
Jun-09	McKenna Upstream	0	0	1	0
Jun-09	McKenna Downstream	0	0	0	1

Continued: Ephemeroptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Dannella	Epeorus	Ephemerella
Jun-07	Glacier Upstream	0	0	0
Jun-07	Glacier Downstream	0	0	0
Jun-07	Cougar Upstream	0	0	0
Jun-07	Cougar Downstream	0	0	0
Jun-07	Dutton Upstream	0	0	0
Jun-07	Dutton Downstream	0	0	0
Jun-07	McKenna Upstream	0	0	0
Jun-07	McKenna Downstream	0	0	0
Jun-08	Glacier Upstream	0	0	0
Jun-08	Glacier Downstream	0	0	0
Jun-08	Cougar Upstream	0	0	0
Jun-08	Cougar Downstream	0	0	0
Jun-08	Dutton Upstream	0	0	0
Jun-08	Dutton Downstream	0	0	3
Jun-08	McKenna Upstream	0	0	0
Jun-08	McKenna Downstream	0	0	0
Jun-09	Cougar Upstream	0	0	0
Jun-09	Cougar Downstream	0	0	0
Jun-09	Dutton Upstream	0	0	0
Jun-09	Dutton Downstream	0	0	1
Jun-09	McKenna Upstream	0	0	3
Jun-09	McKenna Downstream	1	1	1

Continued: Ephemeroptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Eurylophella	Habrophlebiodes	Serratella
Jun-07	Glacier Upstream	0	0	0
Jun-07	Glacier Downstream	1	0	0
Jun-07	Cougar Upstream	10	0	0
Jun-07	Cougar Downstream	0	0	0
Jun-07	Dutton Upstream	0	0	0
Jun-07	Dutton Downstream	0	0	0
Jun-07	McKenna Upstream	0	0	0
Jun-07	McKenna Downstream	0	0	0
Jun-08	Glacier Upstream	0	0	0
Jun-08	Glacier Downstream	0	0	0
Jun-08	Cougar Upstream	3	0	0
Jun-08	Cougar Downstream	1	0	0
Jun-08	Dutton Upstream	0	1	0
Jun-08	Dutton Downstream	1	0	0
Jun-08	McKenna Upstream	1	0	0
Jun-08	McKenna Downstream	0	0	0
Jun-09	Cougar Upstream	2	0	0
Jun-09	Cougar Downstream	1	0	0
Jun-09	Dutton Upstream	0	0	0
Jun-09	Dutton Downstream	0	0	0
Jun-09	McKenna Upstream	0	0	0
Jun-09	McKenna Downstream	0	0	1
Jun-09	Mt Arab 1 Upstream	3	1	0
Jun-09	Mt Arab 1 Downstream	12	0	1
Jun-09	Mt Arab 2 Upstream	0	0	0

Continued: Ephemeroptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Ameletus	Baetis	Ephemerella
Jun-09	Mt Arab 1 Upstream	0	0	13
Jun-09	Mt Arab 1 Downstream	0	0	0
Jun-09	Mt Arab 2 Upstream	0	0	0
Jun-09	Mt Arab 2 Downstream	0	0	0
Jun-09	Mt Arab 3 Upstream	0	0	0
Jun-09	Mt Arab 3 Downstream	0	0	0
Jun-09	Mt Arab 4 Upstream	0	0	0
Jun-09	Mt Arab 4 Downstream	0	0	0
Jun-09	Mt Arab 5 Upstream	0	0	0
Jun-09	Mt Arab 5 Downstream	0	0	0
Jun-09	Mt Arab 6 Upstream	0	0	0
Jun-09	Mt Arab 6 Downstream	0	0	0
Jun-09	Stream 1333 Upstream	0	0	0
Jun-09	Stream 1333 Downstream	0	0	0
Jun-09	Stream 1324 Upstream	0	0	0
Jun-09	Stream 1324 Downstream	0	0	0
Jun-09	Stream 1313 Upstream	0	0	0
Jun-09	Stream 1313 Downstream	0	0	1
Jun-09	Stream 1295 Upstream	0	0	0
Jun-09	Stream 1295 Downstream	0	0	0
Jun-09	Goodnow 1 Upstream	1	0	0
Jun-09	Goodnow 1 Downstream	0	0	0
Jun-09	Goodnow 2 Upstream	0	0	0
Jun-09	Goodnow 2 Downstream	0	0	0
Jun-09	Goodnow 3 Upstream	0	0	0
Jun-09	Goodnow 3 Downstream	0	0	0
Jun-09	Goodnow 4 Upstream	0	0	0
Jun-09	Goodnow 4 Downstream	2	0	0

Continued: Ephemeroptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Eurylophella	Habrophlebiodes
Jun-09	Mt Arab 1 Upstream	3	1
Jun-09	Mt Arab 1 Downstream	12	0
Jun-09	Mt Arab 2 Upstream	0	0
Jun-09	Mt Arab 2 Downstream	0	0
Jun-09	Mt Arab 3 Upstream	0	0
Jun-09	Mt Arab 3 Downstream	0	0
Jun-09	Mt Arab 4 Upstream	1	0
Jun-09	Mt Arab 4 Downstream	0	0
Jun-09	Mt Arab 5 Upstream	0	0
Jun-09	Mt Arab 5 Downstream	0	0
Jun-09	Mt Arab 6 Upstream	8	0
Jun-09	Mt Arab 6 Downstream	1	0
Jun-09	Stream 1333 Upstream	5	0
Jun-09	Stream 1333 Downstream	0	0
Jun-09	Stream 1324 Upstream	0	0
Jun-09	Stream 1324 Downstream	0	0
Jun-09	Stream 1313 Upstream	1	1
Jun-09	Stream 1313 Downstream	0	11
Jun-09	Stream 1295 Upstream	0	0
Jun-09	Stream 1295 Downstream	0	0
Jun-09	Goodnow 1 Upstream	0	0
Jun-09	Goodnow 1 Downstream	0	0
Jun-09	Goodnow 2 Upstream	0	0
Jun-09	Goodnow 2 Downstream	0	0
Jun-09	Goodnow 3 Upstream	1	0
Jun-09	Goodnow 3 Downstream	0	0
Jun-09	Goodnow 4 Upstream	1	0
Jun-09	Goodnow 4 Downstream	1	0

Plecoptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Amphinemura	Leuctra	Prostoia	Utaperla
Jun-07	Glacier Upstream	0	2	0	0
Jun-07	Glacier Downstream	0	0	0	0
Jun-07	Cougar Upstream	0	4	0	0
Jun-07	Cougar Downstream	0	0	0	0
Jun-07	Dutton Upstream	0	1	0	0
Jun-07	Dutton Downstream	0	0	0	0
Jun-07	McKenna Upstream	0	0	0	0
Jun-07	McKenna Downstream	0	0	0	0
Jun-08	Glacier Upstream	0	1	0	0
Jun-08	Glacier Downstream	0	0	0	0
Jun-08	Cougar Upstream	0	1	0	1
Jun-08	Cougar Downstream	0	0	0	0
Jun-08	Dutton Upstream	0	0	1	0
Jun-08	Dutton Downstream	0	1	0	0
Jun-08	McKenna Upstream	0	0	0	0
Jun-08	McKenna Downstream	0	0	0	0
Jun-09	Cougar Upstream	0	11	0	2
Jun-09	Cougar Downstream	0	0	0	0
Jun-09	Dutton Upstream	0	0	0	0
Jun-09	Dutton Downstream	0	0	0	0
Jun-09	McKenna Upstream	15	22	0	0
Jun-09	McKenna Downstream	20	24	0	2

Continued: Plecoptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Amphinemura	Leuctra	Nemoura
Jun-09	Mt Arab 1 Upstream	8	14	0
Jun-09	Mt Arab 1 Downstream	2	4	0
Jun-09	Mt Arab 2 Upstream	1	6	0
Jun-09	Mt Arab 2 Downstream	0	0	0
Jun-09	Mt Arab 3 Upstream	2	6	0
Jun-09	Mt Arab 3 Downstream	0	3	0
Jun-09	Mt Arab 4 Upstream	0	2	0
Jun-09	Mt Arab 4 Downstream	1	3	0
Jun-09	Mt Arab 5 Upstream	1	0	0
Jun-09	Mt Arab 5 Downstream	0	0	0
Jun-09	Mt Arab 6 Upstream	0	3	0
Jun-09	Mt Arab 6 Downstream	0	0	0
Jun-09	Stream 1333 Upstream	0	0	0
Jun-09	Stream 1333 Downstream	0	0	0
Jun-09	Stream 1324 Upstream	2	1	0
Jun-09	Stream 1324 Downstream	0	3	0
Jun-09	Stream 1313 Upstream	1	3	0
Jun-09	Stream 1313 Downstream	4	8	0
Jun-09	Stream 1295 Upstream	1	0	0
Jun-09	Stream 1295 Downstream	1	0	0
Jun-09	Goodnow 1 Upstream	0	2	0
Jun-09	Goodnow 1 Downstream	0	0	0
Jun-09	Goodnow 2 Upstream	0	0	1
Jun-09	Goodnow 2 Downstream	0	0	0
Jun-09	Goodnow 3 Upstream	0	0	0
Jun-09	Goodnow 3 Downstream	0	0	0
Jun-09	Goodnow 4 Upstream	0	0	0
Jun-09	Goodnow 4 Downstream	0	6	0

Continued: Plecoptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Paranemoura	Soyedina	Utaperla
Jun-09	Mt Arab 1 Upstream	2	0	3
Jun-09	Mt Arab 1 Downstream	0	0	0
Jun-09	Mt Arab 2 Upstream	0	0	0
Jun-09	Mt Arab 2 Downstream	0	0	0
Jun-09	Mt Arab 3 Upstream	0	0	0
Jun-09	Mt Arab 3 Downstream	0	0	0
Jun-09	Mt Arab 4 Upstream	0	0	0
Jun-09	Mt Arab 4 Downstream	0	0	0
Jun-09	Mt Arab 5 Upstream	1	0	0
Jun-09	Mt Arab 5 Downstream	0	0	0
Jun-09	Mt Arab 6 Upstream	0	0	0
Jun-09	Mt Arab 6 Downstream	0	0	0
Jun-09	Stream 1333 Upstream	0	0	0
Jun-09	Stream 1333 Downstream	0	0	0
Jun-09	Stream 1324 Upstream	0	0	0
Jun-09	Stream 1324 Downstream	0	0	0
Jun-09	Stream 1313 Upstream	0	0	0
Jun-09	Stream 1313 Downstream	0	0	0
Jun-09	Stream 1295 Upstream	0	0	0
Jun-09	Stream 1295 Downstream	0	0	0
Jun-09	Goodnow 1 Upstream	0	0	1
Jun-09	Goodnow 1 Downstream	0	0	0
Jun-09	Goodnow 2 Upstream	0	3	0
Jun-09	Goodnow 2 Downstream	0	1	0
Jun-09	Goodnow 3 Upstream	0	0	0
Jun-09	Goodnow 3 Downstream	0	0	0
Jun-09	Goodnow 4 Upstream	0	0	0
Jun-09	Goodnow 4 Downstream	0	0	3

Tricoptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Diplectrona	Hydroptila	Lepidostoma	Lype
Jun-07	Glacier Upstream	0	0	4	0
Jun-07	Glacier Downstream	0	0	1	0
Jun-07	Cougar Upstream	0	0	6	0
Jun-07	Cougar Downstream	0	0	0	0
Jun-07	Dutton Upstream	0	0	0	0
Jun-07	Dutton Downstream	1	0	0	0
Jun-07	McKenna Upstream	0	0	0	0
Jun-07	McKenna Downstream	0	0	0	0
Jun-08	Glacier Upstream	0	0	6	0
Jun-08	Glacier Downstream	0	0	0	0
Jun-08	Cougar Upstream	0	0	5	0
Jun-08	Cougar Downstream	0	0	0	0
Jun-08	Dutton Upstream	0	0	1	0
Jun-08	Dutton Downstream	0	1	1	1
Jun-08	McKenna Upstream	0	0	0	0
Jun-08	McKenna Downstream	0	0	0	0
Jun-09	Cougar Upstream	0	0	7	0
Jun-09	Cougar Downstream	0	0	3	0
Jun-09	Dutton Upstream	0	0	0	0
Jun-09	Dutton Downstream	0	0	0	0
Jun-09	McKenna Upstream	0	0	0	0
Jun-09	McKenna Downstream	0	0	2	0
Jun-09	Mt Arab 1 Upstream	0	1	3	0
Jun-09	Mt Arab 1 Downstream	0	9	0	0

Continued: Tricoptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Molanna	Nyctiophylax	Parapsyche	Phylocentropus
Jun-07	Glacier Upstream	0	0	0	0
Jun-07	Glacier Downstream	0	0	0	0
Jun-07	Cougar Upstream	1	0	0	0
Jun-07	Cougar Downstream	0	0	0	0
Jun-07	Dutton Upstream	0	0	0	0
Jun-07	Dutton Downstream	0	0	0	0
Jun-07	McKenna Upstream	0	0	0	0
Jun-07	McKenna Downstream	0	0	0	0
Jun-08	Glacier Upstream	0	0	0	0
Jun-08	Glacier Downstream	0	0	0	0
Jun-08	Cougar Upstream	1	0	0	0
Jun-08	Cougar Downstream	0	0	0	0
Jun-08	Dutton Upstream	0	0	0	0
Jun-08	Dutton Downstream	0	0	0	0
Jun-08	McKenna Upstream	0	0	0	0
Jun-08	McKenna Downstream	0	0	0	0
Jun-09	Cougar Upstream	0	0	0	0
Jun-09	Cougar Downstream	0	0	0	0
Jun-09	Dutton Upstream	0	0	0	0
Jun-09	Dutton Downstream	0	0	0	0
Jun-09	McKenna Upstream	0	1	0	5
Jun-09	McKenna Downstream	0	0	1	0
Jun-09	Mt Arab 1 Upstream	0	2	0	0
Jun-09	Mt Arab 1 Downstream	0	0	0	0

Continued: Tricoptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Hydatophylax	Hydropsyche	Lepidostoma	Lype
Jun-09	Mt Arab 2 Upstream	0	0	1	1
Jun-09	Mt Arab 2 Downstream	0	0	0	0
Jun-09	Mt Arab 3 Upstream	5	0	5	0
Jun-09	Mt Arab 3 Downstream	10	0	1	0
Jun-09	Mt Arab 4 Upstream	0	0	9	0
Jun-09	Mt Arab 4 Downstream	0	0	15	0
Jun-09	Mt Arab 5 Upstream	0	0	1	0
Jun-09	Mt Arab 5 Downstream	1	0	3	0
Jun-09	Mt Arab 6 Upstream	1	0	5	0
Jun-09	Mt Arab 6 Downstream	0	0	0	0
Jun-09	Stream 1333 Upstream	0	0	4	0
Jun-09	Stream 1333 Downstream	0	0	1	0
Jun-09	Stream 1324 Upstream	0	1	0	0
Jun-09	Stream 1324 Downstream	0	0	0	0
Jun-09	Stream 1313 Upstream	0	0	0	0
Jun-09	Stream 1313 Downstream	0	1	0	0
Jun-09	Stream 1295 Upstream	0	0	1	0
Jun-09	Stream 1295 Downstream	0	0	0	0
Jun-09	Goodnow 1 Upstream	0	0	1	0
Jun-09	Goodnow 1 Downstream	0	0	0	0
Jun-09	Goodnow 2 Upstream	2	0	6	0
Jun-09	Goodnow 2 Downstream	0	0	0	0
Jun-09	Goodnow 3 Upstream	0	0	3	0
Jun-09	Goodnow 3 Downstream	0	0	1	0
Jun-09	Goodnow 4 Upstream	0	0	18	0
Jun-09	Goodnow 4 Downstream	0	0	11	0

Continued: Tricoptera Collected at Study Sites in June 2007, 2008, 2009

Month, Year	Study Site on Stream	Molanna	Nyctiophylax	Phylocentropus	Pseudostenophylax
Jun-09	Mt Arab 2 Upstream	0	0	0	0
Jun-09	Mt Arab 2 Downstream	0	0	0	0
Jun-09	Mt Arab 3 Upstream	0	0	0	0
Jun-09	Mt Arab 3 Downstream	0	0	0	0
Jun-09	Mt Arab 4 Upstream	1	0	0	0
Jun-09	Mt Arab 4 Downstream	0	0	0	0
Jun-09	Mt Arab 5 Upstream	0	0	0	0
Jun-09	Mt Arab 5 Downstream	0	0	0	0
Jun-09	Mt Arab 6 Upstream	0	0	0	0
Jun-09	Mt Arab 6 Downstream	0	0	1	0
Jun-09	Stream 1333 Upstream	0	0	0	0
Jun-09	Stream 1333 Downstream	0	0	0	0
Jun-09	Stream 1324 Upstream	0	0	0	0
Jun-09	Stream 1324 Downstream	0	0	0	0
Jun-09	Stream 1313 Upstream	1	0	0	0
Jun-09	Stream 1313 Downstream	0	0	0	0
Jun-09	Stream 1295 Upstream	0	0	0	0
Jun-09	Stream 1295 Downstream	0	0	0	0
Jun-09	Goodnow 1 Upstream	0	0	0	0
Jun-09	Goodnow 1 Downstream	0	0	0	0
Jun-09	Goodnow 2 Upstream	0	1	0	3
Jun-09	Goodnow 2 Downstream	0	0	0	0
Jun-09	Goodnow 3 Upstream	0	0	0	0
Jun-09	Goodnow 3 Downstream	0	0	0	1
Jun-09	Goodnow 4 Upstream	0	0	0	0
Jun-09	Goodnow 4 Downstream	0	1	0	0

Ephemeroptera Collected at Study Sites in July 2007, 2008

Month, Year	Study Site on Stream	Acerpenna	Baetis	Eurylophella
Jul-07	Glacier Upstream	0	0	0
Jul-07	Glacier Downstream	0	0	0
Jul-07	Cougar Upstream	0	0	1
Jul-07	Cougar Downstream	0	0	0
Jul-07	Dutton Upstream	0	0	0
Jul-07	Dutton Downstream	1	0	0
Jul-07	McKenna Upstream	0	0	0
Jul-07	McKenna Downstream	0	0	0
Jul-08	Glacier Upstream	0	0	0
Jul-08	Glacier Downstream	0	0	0
Jul-08	Cougar Upstream	0	0	1
Jul-08	Cougar Downstream	0	0	2
Jul-08	Dutton Upstream	0	0	0
Jul-08	Dutton Downstream	0	2	0
Jul-08	McKenna Upstream	1	0	0
Jul-08	McKenna Downstream	0	0	1

Continued: Ephemeroptera Collected at Study Sites in July 2007, 2008

Month, Year	Study Site on Stream	Habrophlebiodes	Litobrancha
Jul-07	Glacier Upstream	0	0
Jul-07	Glacier Downstream	0	0
Jul-07	Cougar Upstream	0	0
Jul-07	Cougar Downstream	0	0
Jul-07	Dutton Upstream	0	0
Jul-07	Dutton Downstream	0	0
Jul-07	McKenna Upstream	0	0
Jul-07	McKenna Downstream	0	0
Jul-08	Glacier Upstream	0	0
Jul-08	Glacier Downstream	0	0
Jul-08	Cougar Upstream	0	0
Jul-08	Cougar Downstream	0	0
Jul-08	Dutton Upstream	0	1
Jul-08	Dutton Downstream	0	0
Jul-08	McKenna Upstream	1	0
Jul-08	McKenna Downstream	0	0

Plecoptera Collected at Study Sites in July 2007, 2008

Month, Year	Study Site on Stream	Amphinemura	Leuctra	Nemoura	Utaperla
Jul-07	Glacier Creek Upstream	0	0	0	0
Jul-07	Glacier Creek Downstream	0	0	0	3
Jul-07	Cougar Creek Upstream	0	0	0	0
Jul-07	Cougar Creek Downstream	0	0	0	0
Jul-07	Dutton Brook Upstream	0	1	0	0
Jul-07	Dutton Brook Downstream	0	0	0	0
Jul-07	McKenna Brook Upstream	0	1	0	0
Jul-07	McKenna Brook Downstream	0	0	0	0
Jul-08	Glacier Creek Upstream	0	0	0	0
Jul-08	Glacier Creek Downstream	0	0	0	0
Jul-08	Cougar Creek Upstream	0	0	0	0
Jul-08	Cougar Creek Downstream	0	0	0	0
Jul-08	Dutton Brook Upstream	0	0	0	0
Jul-08	Dutton Brook Downstream	0	0	0	0
Jul-08	McKenna Brook Upstream	2	8	1	1
Jul-08	McKenna Brook Downstream	0	0	0	0

Tricoptera Collected at Study Sites in July 2007, 2008

Month, Year	Study Site on Stream	Lepidostoma	Molanna	Oligostomis
Jul-07	Glacier Creek Upstream	0	0	0
Jul-07	Glacier Creek Downstream	0	0	0
Jul-07	Cougar Creek Upstream	0	0	0
Jul-07	Cougar Creek Downstream	0	0	0
Jul-07	Dutton Brook Upstream	0	0	0
Jul-07	Dutton Brook Downstream	0	0	0
Jul-07	McKenna Brook Upstream	0	0	0
Jul-07	McKenna Brook Downstream	0	0	0
Jul-08	Glacier Creek Upstream	0	0	0
Jul-08	Glacier Creek Downstream	0	0	0
Jul-08	Cougar Creek Upstream	2	1	0
Jul-08	Cougar Creek Downstream	1	0	0
Jul-08	Dutton Brook Upstream	0	0	0
Jul-08	Dutton Brook Downstream	0	0	0
Jul-08	McKenna Brook Upstream	0	0	1
Jul-08	McKenna Brook Downstream	0	0	0

Ephemeroptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Baetis	Dannella	Epeorus	Ephemerella
Aug-07	Glacier Creek Upstream	0	0	0	0
Aug-07	Glacier Creek Downstream	0	0	0	0
Aug-07	Cougar Creek Upstream	0	0	0	0
Aug-07	Cougar Creek Downstream	0	0	0	0
Aug-07	Dutton Brook Upstream	0	0	0	0
Aug-07	Dutton Brook Downstream	0	0	0	0
Aug-07	McKenna Brook Upstream	0	0	0	0
Aug-07	McKenna Brook Downstream	0	0	0	0
Aug-08	Glacier Creek Upstream	0	0	0	0
Aug-08	Glacier Creek Downstream	0	0	0	0
Aug-08	Cougar Creek Upstream	0	0	0	0
Aug-08	Cougar Creek Downstream	0	0	0	0
Aug-08	Dutton Brook Upstream	0	0	0	0
Aug-08	Dutton Brook Downstream	0	0	0	0
Aug-08	McKenna Brook Upstream	2	0	0	0
Aug-08	McKenna Brook Downstream	0	0	0	0
Aug-09	Cougar Creek Upstream	0	0	0	0
Aug-09	Cougar Creek Downstream	0	0	0	0
Aug-09	Dutton Brook Upstream	0	0	0	0
Aug-09	Dutton Brook Downstream	0	0	0	0
Aug-09	McKenna Brook Upstream	0	0	0	0
Aug-09	McKenna Brook Downstream	0	1	2	7
Aug-09	Mt Arab 1 Upstream	0	0	0	0
Aug-09	Mt Arab 1 Downstream	0	0	0	0

Continued: Ephemeroptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Eurylophella	Habrophlebiodes	Litobrancha
Aug-07	Glacier Creek Upstream	0	0	0
Aug-07	Glacier Creek Downstream	1	0	0
Aug-07	Cougar Creek Upstream	0	0	0
Aug-07	Cougar Creek Downstream	0	0	0
Aug-07	Dutton Brook Upstream	0	1	0
Aug-07	Dutton Brook Downstream	0	0	2
Aug-07	McKenna Brook Upstream	1	1	0
Aug-07	McKenna Brook Downstream	0	0	0
Aug-08	Glacier Creek Upstream	0	0	0
Aug-08	Glacier Creek Downstream	0	0	0
Aug-08	Cougar Creek Upstream	3	0	0
Aug-08	Cougar Creek Downstream	1	0	0
Aug-08	Dutton Brook Upstream	0	0	0
Aug-08	Dutton Brook Downstream	2	1	0
Aug-08	McKenna Brook Upstream	0	0	0
Aug-08	McKenna Brook Downstream	0	0	0
Aug-09	Cougar Creek Upstream	1	0	0
Aug-09	Cougar Creek Downstream	0	0	0
Aug-09	Dutton Brook Upstream	1	3	0
Aug-09	Dutton Brook Downstream	1	5	0
Aug-09	McKenna Brook Upstream	0	0	0
Aug-09	McKenna Brook Downstream	1	0	0
Aug-09	Mt Arab 1 Upstream	15	1	0
Aug-09	Mt Arab 1 Downstream	4	0	0

Continued: Ephemeroptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Siphlonurus	Stenonema
Aug-07	Glacier Creek Upstream	0	0
Aug-07	Glacier Creek Downstream	0	0
Aug-07	Cougar Creek Upstream	0	0
Aug-07	Cougar Creek Downstream	0	0
Aug-07	Dutton Brook Upstream	0	0
Aug-07	Dutton Brook Downstream	0	0
Aug-07	McKenna Brook Upstream	$\boxed{1}$	0
Aug-07	McKenna Brook Downstream	0	0
Aug-08	Glacier Creek Upstream	0	0
Aug-08	Glacier Creek Downstream	0	0
Aug-08	Cougar Creek Upstream	0	0
Aug-08	Cougar Creek Downstream	0	0
Aug-08	Dutton Brook Upstream	0	0
Aug-08	Dutton Brook Downstream	0	0
Aug-08	McKenna Brook Upstream	0	$\boxed{1}$
Aug-08	McKenna Brook Downstream	0	0
Aug-09	Cougar Creek Upstream	0	0
Aug-09	Cougar Creek Downstream	0	0
Aug-09	Dutton Brook Upstream	0	0
Aug-09	Dutton Brook Downstream	0	0
Aug-09	McKenna Brook Upstream	0	0
Aug-09	McKenna Brook Downstream	0	$\boxed{2}$
Aug-09	Mt Arab 1 Upstream	0	0
Aug-09	Mt Arab 1 Downstream	0	0

Continued: Ephemeroptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Acerpenna	Baetis
Aug-09	Mt Arab 2 Upstream	0	0
Aug-09	Mt Arab 2 Downstream	0	0
Aug-09	Mt Arab 3 Upstream	0	0
Aug-09	Mt Arab 3 Downstream	0	0
Aug-09	Mt Arab 4 Upstream	0	0
Aug-09	Mt Arab 4 Downstream	0	0
Aug-09	Mt Arab 5 Upstream	0	0
Aug-09	Mt Arab 5 Downstream	0	0
Aug-09	Mt Arab 6 Upstream	0	0
Aug-09	Mt Arab 6 Downstream	0	0
Aug-09	Stream 1333 Upstream	0	0
Aug-09	Stream 1333 Downstream	0	0
Aug-09	Stream 1324 Upstream	0	0
Aug-09	Stream 1324 Downstream	0	0
Aug-09	Stream 1313 Upstream	0	2
Aug-09	Stream 1313 Downstream	3	2
Aug-09	Stream 1295 Upstream	0	0
Aug-09	Stream 1295 Downstream	1	0
Aug-09	Goodnow 1 Upstream	0	0
Aug-09	Goodnow 1 Downstream	0	0
Aug-09	Goodnow 2 Upstream	0	0
Aug-09	Goodnow 2 Downstream	0	0
Aug-09	Goodnow 3 Upstream	0	0
Aug-09	Goodnow 3 Downstream	0	0
Aug-09	Goodnow 4 Upstream	0	0
Aug-09	Goodnow 4 Downstream	0	0

Continued: Ephemeroptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Eurylophella	Habrophlebiodes	Stenonema
Aug-09	Mt Arab 2 Upstream	0	9	0
Aug-09	Mt Arab 2 Downstream	0	1	0
Aug-09	Mt Arab 3 Upstream	0	0	2
Aug-09	Mt Arab 3 Downstream	0	0	0
Aug-09	Mt Arab 4 Upstream	0	0	0
Aug-09	Mt Arab 4 Downstream	0	0	0
Aug-09	Mt Arab 5 Upstream	0	0	0
Aug-09	Mt Arab 5 Downstream	0	0	0
Aug-09	Mt Arab 6 Upstream	4	7	0
Aug-09	Mt Arab 6 Downstream	0	0	0
Aug-09	Stream 1333 Upstream	7	2	0
Aug-09	Stream 1333 Downstream	2	0	0
Aug-09	Stream 1324 Upstream	0	3	0
Aug-09	Stream 1324 Downstream	0	0	0
Aug-09	Stream 1313 Upstream	0	5	0
Aug-09	Stream 1313 Downstream	9	5	0
Aug-09	Stream 1295 Upstream	0	0	0
Aug-09	Stream 1295 Downstream	0	0	0
Aug-09	Goodnow 1 Upstream	0	0	0
Aug-09	Goodnow 1 Downstream	0	0	0
Aug-09	Goodnow 2 Upstream	0	0	0
Aug-09	Goodnow 2 Downstream	0	1	0
Aug-09	Goodnow 3 Upstream	0	0	0
Aug-09	Goodnow 3 Downstream	1	0	0
Aug-09	Goodnow 4 Upstream	0	0	0
Aug-09	Goodnow 4 Downstream	0	0	0

Plecoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Amphinemura	Leuctra	Utaperla
Aug-07	Glacier Creek Upstream	0	0	0
Aug-07	Glacier Creek Downstream	0	0	0
Aug-07	Cougar Creek Upstream	0	0	0
Aug-07	Cougar Creek Downstream	0	0	0
Aug-07	Dutton Brook Upstream	0	0	0
Aug-07	Dutton Brook Downstream	0	1	0
Aug-07	McKenna Brook Upstream	0	2	0
Aug-07	McKenna Brook Downstream	0	1	2
Aug-08	Glacier Creek Upstream	0	0	0
Aug-08	Glacier Creek Downstream	0	0	0
Aug-08	Cougar Creek Upstream	0	0	0
Aug-08	Cougar Creek Downstream	0	0	0
Aug-08	Dutton Brook Upstream	0	0	0
Aug-08	Dutton Brook Downstream	0	1	0
Aug-08	McKenna Brook Upstream	0	11	0
Aug-08	McKenna Brook Downstream	0	0	0
Aug-09	Cougar Creek Upstream	0	0	0
Aug-09	Cougar Creek Downstream	0	0	1
Aug-09	Dutton Brook Upstream	0	0	0
Aug-09	Dutton Brook Downstream	0	1	0
Aug-09	McKenna Brook Upstream	0	0	0
Aug-09	McKenna Brook Downstream	2	0	0
Aug-09	Mt Arab 1 Upstream	0	2	0
Aug-09	Mt Arab 1 Downstream	0	0	0

Continued: Plecoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Leuctra	Nemoura	Soyedina	Utaperla
Aug-09	Mt Arab 2 Upstream	9	0	0	0
Aug-09	Mt Arab 2 Downstream	0	0	0	0
Aug-09	Mt Arab 3 Upstream	3	0	0	1
Aug-09	Mt Arab 3 Downstream	0	0	0	0
Aug-09	Mt Arab 4 Upstream	1	0	0	0
Aug-09	Mt Arab 4 Downstream	1	0	0	0
Aug-09	Mt Arab 5 Upstream	0	0	0	0
Aug-09	Mt Arab 5 Downstream	0	0	0	0
Aug-09	Mt Arab 6 Upstream	3	0	0	0
Aug-09	Mt Arab 6 Downstream	0	0	0	0
Aug-09	Stream 1333 Upstream	1	0	0	0
Aug-09	Stream 1333 Downstream	0	0	0	0
Aug-09	Stream 1324 Upstream	18	0	1	0
Aug-09	Stream 1324 Downstream	0	0	0	0
Aug-09	Stream 1313 Upstream	0	0	0	0
Aug-09	Stream 1313 Downstream	0	0	0	0
Aug-09	Stream 1295 Upstream	3	0	0	1
Aug-09	Stream 1295 Downstream	0	0	0	0
Aug-09	Goodnow 1 Upstream	0	0	0	0
Aug-09	Goodnow 1 Downstream	1	1	0	0
Aug-09	Goodnow 2 Upstream	0	0	0	0
Aug-09	Goodnow 2 Downstream	0	0	0	0
Aug-09	Goodnow 3 Upstream	0	0	0	0
Aug-09	Goodnow 3 Downstream	0	0	0	0
Aug-09	Goodnow 4 Upstream	0	0	0	0
Aug-09	Goodnow 4 Downstream	1	0	0	0

Tricoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Cheumatopsyche	Diplectrona	Hydatophylax
Aug-07	Glacier Creek Upstream	0	0	0
Aug-07	Glacier Creek Downstream	0	0	0
Aug-07	Cougar Creek Upstream	0	0	0
Aug-07	Cougar Creek Downstream	0	0	0
Aug-07	Dutton Brook Upstream	0	0	0
Aug-07	Dutton Brook Downstream	0	0	1
Aug-07	McKenna Brook Upstream	0	0	0
Aug-07	McKenna Brook Downstream	0	0	0
Aug-08	Glacier Creek Upstream	0	0	0
Aug-08	Glacier Creek Downstream	0	0	0
Aug-08	Cougar Creek Upstream	0	0	0
Aug-08	Cougar Creek Downstream	0	0	0
Aug-08	Dutton Brook Upstream	0	0	0
Aug-08	Dutton Brook Downstream	3	16	0
Aug-08	McKenna Brook Upstream	0	0	0
Aug-08	McKenna Brook Downstream	0	0	0
Aug-09	Cougar Creek Upstream	0	0	0
Aug-09	Cougar Creek Downstream	0	0	0
Aug-09	Dutton Brook Upstream	0	0	0
Aug-09	Dutton Brook Downstream	0	0	0
Aug-09	McKenna Brook Upstream	0	0	0
Aug-09	McKenna Brook Downstream	0	0	0
Aug-09	Mt Arab 1 Upstream	0	0	0
Aug-09	Mt Arab 1 Downstream	0	0	0

Continued: Tricoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Nectopsyche	Lepidostoma	Molanna
Aug-07	Glacier Creek Upstream	0	0	0
Aug-07	Glacier Creek Downstream	0	0	0
Aug-07	Cougar Creek Upstream	0	1	0
Aug-07	Cougar Creek Downstream	0	0	0
Aug-07	Dutton Brook Upstream	0	0	0
Aug-07	Dutton Brook Downstream	0	0	0
Aug-07	McKenna Brook Upstream	0	0	0
Aug-07	McKenna Brook Downstream	0	0	0
Aug-08	Glacier Creek Upstream	0	0	0
Aug-08	Glacier Creek Downstream	0	0	0
Aug-08	Cougar Creek Upstream	0	0	0
Aug-08	Cougar Creek Downstream	0	0	0
Aug-08	Dutton Brook Upstream	0	0	0
Aug-08	Dutton Brook Downstream	0	0	0
Aug-08	McKenna Brook Upstream	0	1	0
Aug-08	McKenna Brook Downstream	0	1	0
Aug-09	Cougar Creek Upstream	0	0	2
Aug-09	Cougar Creek Downstream	0	0	0
Aug-09	Dutton Brook Upstream	0	1	0
Aug-09	Dutton Brook Downstream	0	0	0
Aug-09	McKenna Brook Upstream	0	1	0
Aug-09	McKenna Brook Downstream	0	0	0
Aug-09	Mt Arab 1 Upstream	1	0	0
Aug-09	Mt Arab 1 Downstream	0	0	0

Continued: Tricoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Neophylax	Oligostomis	Parapsyche
Aug-07	Glacier Creek Upstream	0	0	0
Aug-07	Glacier Creek Downstream	0	0	0
Aug-07	Cougar Creek Upstream	0	1	0
Aug-07	Cougar Creek Downstream	0	1	0
Aug-07	Dutton Brook Upstream	0	0	0
Aug-07	Dutton Brook Downstream	0	0	0
Aug-07	McKenna Brook Upstream	0	0	0
Aug-07	McKenna Brook Downstream	0	0	0
Aug-08	Glacier Creek Upstream	0	0	0
Aug-08	Glacier Creek Downstream	1	0	0
Aug-08	Cougar Creek Upstream	0	0	0
Aug-08	Cougar Creek Downstream	0	0	0
Aug-08	Dutton Brook Upstream	0	0	0
Aug-08	Dutton Brook Downstream	0	1	0
Aug-08	McKenna Brook Upstream	0	0	0
Aug-08	McKenna Brook Downstream	0	0	0
Aug-09	Cougar Creek Upstream	0	3	0
Aug-09	Cougar Creek Downstream	0	0	0
Aug-09	Dutton Brook Upstream	0	0	0
Aug-09	Dutton Brook Downstream	0	0	0
Aug-09	McKenna Brook Upstream	0	0	0
Aug-09	McKenna Brook Downstream	0	0	0
Aug-09	Mt Arab 1 Upstream	0	0	0
Aug-09	Mt Arab 1 Downstream	0	0	6

Continued: Tricoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Phylocentropus	Psilotreta	Theliopsyche
Aug-07	Glacier Creek Upstream	0	0	0
Aug-07	Glacier Creek Downstream	0	0	0
Aug-07	Cougar Creek Upstream	0	0	0
Aug-07	Cougar Creek Downstream	0	0	0
Aug-07	Dutton Brook Upstream	0	0	0
Aug-07	Dutton Brook Downstream	1	0	0
Aug-07	McKenna Brook Upstream	0	0	0
Aug-07	McKenna Brook Downstream	0	0	0
Aug-08	Glacier Creek Upstream	0	0	0
Aug-08	Glacier Creek Downstream	0	0	0
Aug-08	Cougar Creek Upstream	0	0	0
Aug-08	Cougar Creek Downstream	0	0	0
Aug-08	Dutton Brook Upstream	0	0	0
Aug-08	Dutton Brook Downstream	0	0	0
Aug-08	McKenna Brook Upstream	0	0	0
Aug-08	McKenna Brook Downstream	0	0	0
Aug-09	Cougar Creek Upstream	0	0	0
Aug-09	Cougar Creek Downstream	0	0	0
Aug-09	Dutton Brook Upstream	0	2	2
Aug-09	Dutton Brook Downstream	0	0	0
Aug-09	McKenna Brook Upstream	0	0	0
Aug-09	McKenna Brook Downstream	0	0	0
Aug-09	Mt Arab 1 Upstream	0	1	0
Aug-09	Mt Arab 1 Downstream	0	0	0

Continued: Tricoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Cheumatopsyche	Diplectrona	Frenesia	Hydatophylax
Aug-09	Mt Arab 2 Upstream	3	34	0	0
Aug-09	Mt Arab 2 Downstream	0	3	0	0
Aug-09	Mt Arab 3 Upstream	0	1	0	0
Aug-09	Mt Arab 3 Downstream	0	0	0	0
Aug-09	Mt Arab 4 Upstream	0	0	0	0
Aug-09	Mt Arab 4 Downstream	0	0	0	0
Aug-09	Mt Arab 5 Upstream	0	0	0	0
Aug-09	Mt Arab 5 Downstream	0	0	0	0
Aug-09	Mt Arab 6 Upstream	0	0	0	0
Aug-09	Mt Arab 6 Downstream	0	0	0	0
Aug-09	Stream 1333 Upstream	0	0	0	0
Aug-09	Stream 1333 Downstream	0	0	0	0
Aug-09	Stream 1324 Upstream	0	0	0	1
Aug-09	Stream 1324 Downstream	0	0	0	0
Aug-09	Stream 1313 Upstream	0	0	1	4
Aug-09	Stream 1313 Downstream	0	0	0	0
Aug-09	Stream 1295 Upstream	0	0	0	0
Aug-09	Stream 1295 Downstream	0	0	0	0
Aug-09	Goodnow 1 Upstream	0	0	0	0
Aug-09	Goodnow 1 Downstream	0	0	0	0
Aug-09	Goodnow 2 Upstream	0	0	0	0
Aug-09	Goodnow 2 Downstream	0	0	0	0
Aug-09	Goodnow 3 Upstream	0	0	0	0
Aug-09	Goodnow 3 Downstream	0	0	0	0
Aug-09	Goodnow 4 Upstream	0	0	0	0
Aug-09	Goodnow 4 Downstream	0	0	0	0

Continued: Tricoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Hydroptila	Hydropsyche	Lepidostoma	Micrasema
Aug-09	Mt Arab 2 Upstream	0	11	0	0
Aug-09	Mt Arab 2 Downstream	0	1	0	0
Aug-09	Mt Arab 3 Upstream	0	0	0	0
Aug-09	Mt Arab 3 Downstream	0	0	0	0
Aug-09	Mt Arab 4 Upstream	0	0	0	0
Aug-09	Mt Arab 4 Downstream	0	0	0	0
Aug-09	Mt Arab 5 Upstream	0	0	0	0
Aug-09	Mt Arab 5 Downstream	0	0	0	0
Aug-09	Mt Arab 6 Upstream	0	0	0	0
Aug-09	Mt Arab 6 Downstream	0	0	0	0
Aug-09	Stream 1333 Upstream	0	0	0	0
Aug-09	Stream 1333 Downstream	0	0	0	0
Aug-09	Stream 1324 Upstream	0	0	0	0
Aug-09	Stream 1324 Downstream	0	0	0	0
Aug-09	Stream 1313 Upstream	0	0	0	0
Aug-09	Stream 1313 Downstream	4	0	0	2
Aug-09	Stream 1295 Upstream	0	0	0	0
Aug-09	Stream 1295 Downstream	0	0	0	0
Aug-09	Goodnow 1 Upstream	0	0	0	0
Aug-09	Goodnow 1 Downstream	0	0	0	0
Aug-09	Goodnow 2 Upstream	0	0	0	0
Aug-09	Goodnow 2 Downstream	0	0	0	0
Aug-09	Goodnow 3 Upstream	0	0	0	0
Aug-09	Goodnow 3 Downstream	0	0	0	0
Aug-09	Goodnow 4 Upstream	0	0	0	0
Aug-09	Goodnow 4 Downstream	0	0	1	0

Continued: Tricoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Molanna	Nectopsyche	Neureclipsis	Oligostomis
Aug-09	Mt Arab 2 Upstream	0	0	2	0
Aug-09	Mt Arab 2 Downstream	0	0	0	0
Aug-09	Mt Arab 3 Upstream	0	0	1	0
Aug-09	Mt Arab 3 Downstream	0	0	0	0
Aug-09	Mt Arab 4 Upstream	0	0	0	0
Aug-09	Mt Arab 4 Downstream	0	0	1	0
Aug-09	Mt Arab 5 Upstream	0	0	0	0
Aug-09	Mt Arab 5 Downstream	0	0	0	0
Aug-09	Mt Arab 6 Upstream	0	6	0	0
Aug-09	Mt Arab 6 Downstream	0	0	0	0
Aug-09	Stream 1333 Upstream	0	9	0	0
Aug-09	Stream 1333 Downstream	0	0	0	0
Aug-09	Stream 1324 Upstream	0	0	0	0
Aug-09	Stream 1324 Downstream	0	0	0	2
Aug-09	Stream 1313 Upstream	1	0	0	0
Aug-09	Stream 1313 Downstream	0	0	0	0
Aug-09	Stream 1295 Upstream	0	0	0	0
Aug-09	Stream 1295 Downstream	0	0	0	0
Aug-09	Goodnow 1 Upstream	0	0	0	1
Aug-09	Goodnow 1 Downstream	0	0	0	1
Aug-09	Goodnow 2 Upstream	0	0	0	0
Aug-09	Goodnow 2 Downstream	0	0	0	0
Aug-09	Goodnow 3 Upstream	0	0	0	0
Aug-09	Goodnow 3 Downstream	0	0	0	0
Aug-09	Goodnow 4 Upstream	0	0	0	0
Aug-09	Goodnow 4 Downstream	0	1	0	0

Continued: Tricoptera Collected at Study Sites in August 2007, 2008, 2009

Month, Year	Study Site on Stream	Parapsyche	Phylocentropus	Psilotreta	Triaenodes
Aug-09	Mt Arab 2 Upstream	2	0	0	0
Aug-09	Mt Arab 2 Downstream	0	1	0	16
Aug-09	Mt Arab 3 Upstream	0	0	0	0
Aug-09	Mt Arab 3 Downstream	0	0	0	0
Aug-09	Mt Arab 4 Upstream	0	0	0	0
Aug-09	Mt Arab 4 Downstream	0	0	0	0
Aug-09	Mt Arab 5 Upstream	0	0	0	0
Aug-09	Mt Arab 5 Downstream	0	0	0	0
Aug-09	Mt Arab 6 Upstream	0	0	1	0
Aug-09	Mt Arab 6 Downstream	0	0	0	0
Aug-09	Stream 1333 Upstream	0	0	3	0
Aug-09	Stream 1333 Downstream	0	0	0	0
Aug-09	Stream 1324 Upstream	0	0	0	0
Aug-09	Stream 1324 Downstream	0	0	0	0
Aug-09	Stream 1313 Upstream	0	0	0	0
Aug-09	Stream 1313 Downstream	0	0	1	0
Aug-09	Stream 1295 Upstream	0	0	0	0
Aug-09	Stream 1295 Downstream	0	0	0	0
Aug-09	Goodnow 1 Upstream	0	0	0	0
Aug-09	Goodnow 1 Downstream	0	0	0	0
Aug-09	Goodnow 2 Upstream	0	0	0	0
Aug-09	Goodnow 2 Downstream	0	0	0	0
Aug-09	Goodnow 3 Upstream	0	0	0	0
Aug-09	Goodnow 3 Downstream	0	0	0	0
Aug-09	Goodnow 4 Upstream	0	0	0	0
Aug-09	Goodnow 4 Downstream	0	0	0	0

Ephemeroptera Collected at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Acerpenna	Baetis	Epeorus	Ephemerella
Sep-07	Glacier Creek Upstream	0	0	0	0
Sep-07	Glacier Creek Downstream	0	0	0	0
Sep-07	Cougar Creek Upstream	0	0	0	0
Sep-07	Cougar Creek Downstream	0	0	0	0
Sep-07	Dutton Brook Upstream	1	0	0	0
Sep-07	Dutton Brook Downstream	0	0	0	0
Sep-07	McKenna Brook Upstream	0	4	1	5
Sep-07	McKenna Brook Downstream	2	0	0	0
Sep-08	Glacier Creek Upstream	0	0	0	0
Sep-08	Glacier Creek Downstream	0	0	0	0
Sep-08	Cougar Creek Upstream	0	0	0	0
Sep-08	Cougar Creek Downstream	0	0	0	0
Sep-08	Dutton Brook Upstream	0	0	0	0
Sep-08	Dutton Brook Downstream	0	0	0	0
Sep-08	McKenna Brook Upstream	5	3	0	0
Sep-08	McKenna Brook Downstream	0	0	0	0

Continued: Ephemeroptera Collected at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Eurylophella	Habrophlebiodes	Litobrancha	Stenonema
Sep-07	Glacier Creek Upstream	0	0	0	0
Sep-07	Glacier Creek Downstream	1	0	0	0
Sep-07	Cougar Creek Upstream	0	0	0	0
Sep-07	Cougar Creek Downstream	0	0	0	0
Sep-07	Dutton Brook Upstream	0	2	2	0
Sep-07	Dutton Brook Downstream	0	0	1	0
Sep-07	McKenna Brook Upstream	0	1	0	0
Sep-07	McKenna Brook Downstream	0	1	0	1
Sep-08	Glacier Creek Upstream	0	0	0	0
Sep-08	Glacier Creek Downstream	1	0	0	0
Sep-08	Cougar Creek Upstream	2	0	0	0
Sep-08	Cougar Creek Downstream	0	0	0	0
Sep-08	Dutton Brook Upstream	0	0	0	0
Sep-08	Dutton Brook Downstream	2	0	0	0
Sep-08	McKenna Brook Upstream	0	2	0	0
Sep-08	McKenna Brook Downstream	0	0	0	0

Plecoptera Collected at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Isoperla	Leuctra	Soyedina	Utaperla
Sep-07	Glacier Creek Upstream	0	0	0	0
Sep-07	Glacier Creek Downstream	0	0	0	0
Sep-07	Cougar Creek Upstream	0	0	0	1
Sep-07	Cougar Creek Downstream	0	0	0	0
Sep-07	Dutton Brook Upstream	0	0	0	0
Sep-07	Dutton Brook Downstream	0	0	0	0
Sep-07	McKenna Brook Upstream	1	17	0	2
Sep-07	McKenna Brook Downstream	0	5	0	0
Sep-08	Glacier Creek Upstream	0	1	0	0
Sep-08	Glacier Creek Downstream	0	1	0	0
Sep-08	Cougar Creek Upstream	0	0	0	0
Sep-08	Cougar Creek Downstream	0	0	0	1
Sep-08	Dutton Brook Upstream	0	0	0	0
Sep-08	Dutton Brook Downstream	0	1	0	0
Sep-08	McKenna Brook Upstream	0	9	0	3
Sep-08	McKenna Brook Downstream	0	8	0	0

Tricoptera Collected at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Diplectrona	Hydatophylax	Hydroptila
Sep-07	Glacier Creek Upstream	0	0	0
Sep-07	Glacier Creek Downstream	0	0	0
Sep-07	Cougar Creek Upstream	0	0	0
Sep-07	Cougar Creek Downstream	0	0	0
Sep-07	Dutton Brook Upstream	0	0	0
Sep-07	Dutton Brook Downstream	0	0	1
Sep-07	McKenna Brook Upstream	0	0	0
Sep-07	McKenna Brook Downstream	0	0	0
Sep-08	Glacier Creek Upstream	0	0	0
Sep-08	Glacier Creek Downstream	0	0	0
Sep-08	Cougar Creek Upstream	0	0	0
Sep-08	Cougar Creek Downstream	0	0	0
Sep-08	Dutton Brook Upstream	0	0	0
Sep-08	Dutton Brook Downstream	1	0	1
Sep-08	McKenna Brook Upstream	0	1	0
Sep-08	McKenna Brook Downstream	0	0	0

Continued: Tricoptera Collected at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Lepidostoma	Lype	Molanna
Sep-07	Glacier Creek Upstream	0	0	0
Sep-07	Glacier Creek Downstream	0	0	0
Sep-07	Cougar Creek Upstream	0	0	0
Sep-07	Cougar Creek Downstream	0	0	0
Sep-07	Dutton Brook Upstream	0	0	0
Sep-07	Dutton Brook Downstream	0	$\boxed{1}$	0
Sep-07	McKenna Brook Upstream	0	0	0
Sep-07	McKenna Brook Downstream	0	0	$\boxed{2}$
Sep-08	Glacier Creek Upstream	0	0	0
Sep-08	Glacier Creek Downstream	0	0	0
Sep-08	Cougar Creek Upstream	0	0	0
Sep-08	Cougar Creek Downstream	0	0	0
Sep-08	Dutton Brook Upstream	0	0	0
Sep-08	Dutton Brook Downstream	0	0	0
Sep-08	McKenna Brook Upstream	$\boxed{1}$	0	0
Sep-08	McKenna Brook Downstream	0	0	0

Continued: Tricoptera Collected at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Mystacides	Nectopsyche	Neophylax
Sep-07	Glacier Creek Upstream	0	0	0
Sep-07	Glacier Creek Downstream	0	1	0
Sep-07	Cougar Creek Upstream	0	0	0
Sep-07	Cougar Creek Downstream	0	0	0
Sep-07	Dutton Brook Upstream	0	0	0
Sep-07	Dutton Brook Downstream	0	0	0
Sep-07	McKenna Brook Upstream	0	0	0
Sep-07	McKenna Brook Downstream	0	0	0
Sep-08	Glacier Creek Upstream	0	0	0
Sep-08	Glacier Creek Downstream	0	0	0
Sep-08	Cougar Creek Upstream	2	0	0
Sep-08	Cougar Creek Downstream	0	0	0
Sep-08	Dutton Brook Upstream	0	0	1
Sep-08	Dutton Brook Downstream	0	0	0
Sep-08	McKenna Brook Upstream	0	0	0
Sep-08	McKenna Brook Downstream	0	0	0

Continued: Tricoptera Collected at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Neureclipsis	Oligostomis	Parapsyche
Sep-07	Glacier Creek Upstream	0	0	0
Sep-07	Glacier Creek Downstream	0	0	0
Sep-07	Cougar Creek Upstream	0	0	0
Sep-07	Cougar Creek Downstream	0	0	0
Sep-07	Dutton Brook Upstream	0	0	0
Sep-07	Dutton Brook Downstream	0	0	0
Sep-07	McKenna Brook Upstream	0	0	6
Sep-07	McKenna Brook Downstream	0	0	0
Sep-08	Glacier Creek Upstream	0	0	0
Sep-08	Glacier Creek Downstream	0	0	0
Sep-08	Cougar Creek Upstream	0	1	0
Sep-08	Cougar Creek Downstream	0	0	0
Sep-08	Dutton Brook Upstream	0	0	0
Sep-08	Dutton Brook Downstream	1	0	0
Sep-08	McKenna Brook Upstream	1	0	0
Sep-08	McKenna Brook Downstream	0	0	0

Continued: Tricoptera Collected at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Phylocentropus	Polycentropus	Psilotreta
Sep-07	Glacier Creek Upstream	0	0	0
Sep-07	Glacier Creek Downstream	0	0	0
Sep-07	Cougar Creek Upstream	0	0	0
Sep-07	Cougar Creek Downstream	0	0	0
Sep-07	Dutton Brook Upstream	0	0	0
Sep-07	Dutton Brook Downstream	0	0	1
Sep-07	McKenna Brook Upstream	0	0	0
Sep-07	McKenna Brook Downstream	0	0	0
Sep-08	Glacier Creek Upstream	0	0	0
Sep-08	Glacier Creek Downstream	0	0	0
Sep-08	Cougar Creek Upstream	0	1	0
Sep-08	Cougar Creek Downstream	0	0	0
Sep-08	Dutton Brook Upstream	0	0	0
Sep-08	Dutton Brook Downstream	0	0	0
Sep-08	McKenna Brook Upstream	1	0	0
Sep-08	McKenna Brook Downstream	0	0	0

Continued: Tricoptera Collected at Study Sites in September 2007, 2008

Month, Year	Study Site on Stream	Pycnopsyche	Rhyacophila
Sep-07	Glacier Creek Upstream	0	0
Sep-07	Glacier Creek Downstream	0	0
Sep-07	Cougar Creek Upstream	0	0
Sep-07	Cougar Creek Downstream	0	0
Sep-07	Dutton Brook Upstream	0	0
Sep-07	Dutton Brook Downstream	0	0
Sep-07	McKenna Brook Upstream	1	1
Sep-07	McKenna Brook Downstream	0	1
Sep-08	Glacier Creek Upstream	0	1
Sep-08	Glacier Creek Downstream	0	0
Sep-08	Cougar Creek Upstream	0	0
Sep-08	Cougar Creek Downstream	0	0
Sep-08	Dutton Brook Upstream	0	0
Sep-08	Dutton Brook Downstream	0	0
Sep-08	McKenna Brook Upstream	0	0
Sep-08	McKenna Brook Downstream	0	0

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