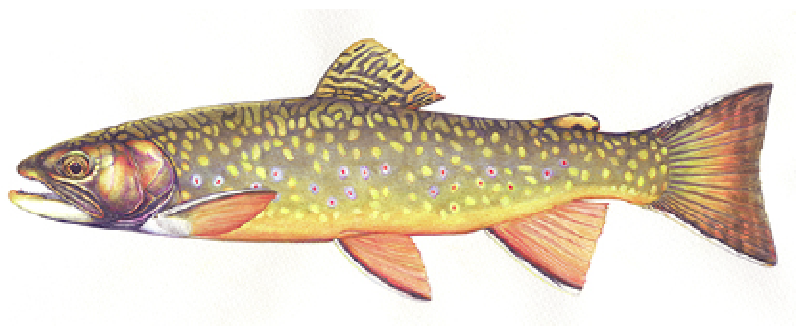
CONTROLLED FLOW, TEMPERATURE AND BROOK TROUT (*Salvelinus fontinalis* Mitchell) FRY EMERGENCE ON THE AGUASABON RIVER, TERRACE BAY, ONTARIO, 2011-2016

By
Allison Hanna Hauser

Source: Ontario Power Generation 2016



Source: Parks Canada 2015

Faculty of Natural Resources Management
Lakehead University
Thunder Bay Ontario

April 2017

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An undergraduate thesis submitted in partial fulfillment of the requirements for the degree of Honours Bachelor of Environmental Management

Faculty of Natural Resources Management
Lakehead University

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Major Advisor - Dr. Brian McLaren

Second Reader – Ray Tyhuis

A CAUTION TO THE READER

This HBEM thesis has been through a semi-formal process of review and comment by one faculty member. It has also been through the same process with a biologist of the Ministry of Natural Resources and Forestry (MNRF). It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific natural resources management.

The reader should be aware that opinions and conclusions expressed in this document are those of the student and do not necessarily reflect the opinions of the thesis supervisor, the faculty, Lakehead University, or the MNRF.

ABSTRACT

This thesis reviews factors that affect brook trout (*Salvelinus fontinalis* Mitchell) fry emergence and their relevance to population fitness. A series of drift nets were deployed from 2010 to 2016, April through May, on the Aguasabon River, near Terrace Bay, Ontario, to capture brook trout fry drifting downstream. Fry were live captured, counted and released alive each year. The drift nets recorded flow, and nearby data loggers recorded temperature of the redd. Graphical review of these data was used to determine any significant relationships between brook trout drift, net flow and temperature. Flow does not affect temperature, but brook trout fry respond numerically to an optimal temperature, and high flows encourage drifting. These relationships are described relative to management of an impounded brook trout spawning stream.

Key words: Aguasabon River, brook trout, data analysis, drift netting, fry emergence, hydroelectric dam, river flow, temperature

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INTRODUCTION

We have been altering nature for many years, and building dams to create a renewable energy source is an example of our using nature for our own gain. Installing a dam influences the fish community in a river. Factors such as temperature flux and river flow affect many fish species, but when they are an effect of hydroelectric dams and may have net negative effects, specific knowledge is required for mitigation. For example, fry emergence and drifting in brook trout (*Salvelinus fontinalis* Mitchell) may be affected by changes in river flow and associated changes in stream temperature (Bilotta et al. 2016). Hydroelectric dams also create flow ramping, which alters sediment flow and temperatures, in turn changing the habitat and biological responses of brook trout (Armanini et al. 2014). Brook trout, which need to move to and from tributaries and the main waterbody, may also be vulnerable to habitat fragmentation that occurs with dam installation (Kanno et al. 2014). With climate change, we are trying to find ways to harness more renewable energy, so there will be more demand for hydroelectric dams, and their effects on river fish species should be studied.

The Aguasabon River, seventy kilometres in length including Long Lake to Lake Superior, is near Terrace Bay, Ontario, where a generation station operated by Ontario Power Generation (OPG) is located. The central question driving the research in this thesis is what is the significance of temperature flux and river flow on brook trout fry emergence in the Aguasabon River? My hypothesis is that temperature is affected by river flow, and ultimately brook trout fry emergence is affected by river flow because temperature change causes fry emergence to happen earlier or later in the season. River flow causes a sample bias, as do periods of non-sampling, when drift netting is the source of emergence data. The objectives of this thesis are to: (1) explore how temperature is affected by flow through the nets in the Aguasabon River, (2) determine if brook trout emergence in these two sites is related to changes in temperature, flow, or some combination, (3) describe effects of the control structure on the Aguasabon River on temperature and brook trout recruitment, and (4) test for the situation of sample bias in the drift net methodology. I predict that river flow and temperature will affect each other, which in turn will have an effect on emergence. There are two sample lenses that will be used to test this prediction: a day-to-day lens for the same year, and a year-to-year lens for the period 2011 to 2016.

LITERATURE REVIEW

Hydroelectric Dam Effects on River Systems

Hydroelectric energy is falling water energy converted into electricity (the flow of electrons) with a dam across a river to hold water or by use of natural drops in the river, such as waterfalls and rapids. It has been a renewable energy source in Ontario for many years (OPG 2016a). Above a control structure or dam, water is collected in a forebay or holding bay before it flows through a pipe (penstock), creating pressure and causing a generator turbine to spin. The process continues inside the generator with large electromagnets attached to a rotor located in copper coils; this is where the magnets are spun and a flow of electrons is created.

The construction of dams and reservoirs on alluvial rivers disrupts the normal patterns of flow and sediment transfer, thereby altering geomorphic processes and forcing modifications of downstream channels (Smith et al. 2016). Changes can include widening of the river channel, deposition of bed materials, and changes to bedload, sediments and normal outflow patterns. In general, dams create flow ramping, which is defined as rising and receding rates of change in river flow. Ramping is a consequence of peaking hydroelectric operations, and understanding its ecological impacts is crucial to the development of sustainable river management guidelines (Armanini et al. 2014). The effects on fish communities may be the more obvious indicator of flow ramping, but fish may be hard to sample at times. Thus, Armanini et al. (2014) used a Before-After/Control-Impact (BACI) experimental design to test if benthic invertebrate communities are affected by flow ramping. The benthic community responded to changes in ramping, and the Canadian Ecological Flow Index (CEFI) was able to discriminate the alteration signal and to diagnose the impact.

Large-scale hydroelectric power and run-of-river schemes are both forms of hydroelectric generation that can alter the river environment. Large-scale operations may cause reduced access to spawning grounds and nursery areas, leading to a decrease in migratory fish populations and fragmentation of non-migratory fish populations (Bilotta et al. 2016). Large-scale schemes can also significantly modify the downstream flow regime and may alter water temperature and quality. The change in the annual flow pattern, combined with changes to sediment transport caused by water storage and controlled-release, can significantly affect natural aquatic and terrestrial habitats in the river and along the shoreline and floodplain. Bilotta et al. (2016) used a BACI design to compare the effects of run-of-river damming schemes on spawning, water temperature and quality, sediment transport, and ultimately, natural aquatic and terrestrial habitats. The study showed that a statistically significant effect of construction and operation on the number of species but not on fish abundance.

Behaviour of Brook Trout

Brook trout inhabit clear, cold waters in eastern North America, spawning during autumn, when females will make depressions on the stream bottom and deposit their eggs in these nests called 'redds' (Kanno et al. 2014). Fry will emerge from the redds a few months later, in late March to early May, and start moving from river systems to deeper, slow moving waters called pools. Stream habitat is temporally variable due to seasonality (e.g., in river flow). Tributaries are considered important spawning areas for brook trout based on spawning activities and distribution of young-of-the-year fish. Thus, brook trout are vulnerable to habitat fragmentation.

Many of the current threats to brook trout involve changes to both stream connectivity and the quality of instream habitat, leading to the importance of studies that examine movement and habitat use by brook trout (Mollenhauer et al. 2013). Management includes conservation efforts directed to areas with suitable habitat, assisting populations by providing targets for stream restoration efforts, and predicting the consequences of potential habitat changes related to management actions.

Hydroelectric dams should have fish ladders, so that the fish can move from reach to reach, and populations do not become isolated. Many brook trout populations are fragmented in headwaters and as a result are genetically isolated (Mollenhauer et al. 2013). With habitat fragmentation, the risks of decreased genetic diversity and increased genetic drift become very real. Habitat fragmentation can be caused by natural barriers such as waterfalls, or be anthropogenic, such as with incorrect placement of culverts for forestry roads (Torterotot et al. 2014). While barriers occur in nature, added barriers in an anthropogenic landscape accelerate habitat fragmentation and can lead to endangerment or extinction.

Distributions of several salmonid species, including brook trout, are expected to become highly restricted within small, isolated cold-water streams as a result of long-term changes in water temperature and flow due to climate change (Petty et al. 2014). Food availability may also play a significant factor in brook trout growth and survival. There is the concept of the Temperature-Productivity squeeze, explaining that where prey abundance is low, brook trout will not take up otherwise available habitat. Brook trout distributions are controlled simultaneously by mechanisms that affect recruitment and survival within headwater streams (e.g., water quality and competition for food) and mechanisms that affect dispersal among tributaries and larger main stem habitats (e.g., isolation due to barriers). Intraspecific and interspecific competition, i.e. population density, has an effect on brook trout growth, which is influenced by a complex interaction of intraspecific competition, water temperature, and food availability.

Spawning phenology is a key life history trait in fish that has substantial implications for the survival of eggs and early life stages (Warren et al. 2012). Competitive exclusion determines why some fish spawn in the fall and others, such as rainbow trout (*Oncorhynchus mykiss*), spawn in the spring. Delayed spawning is likely to translate directly to delayed fry emergence for lentic brook trout (Warren et al. 2012). Lake-spawning brook trout build redds almost exclusively on discharging groundwater that is constant in temperature within and across years. Changes in temperature probably have an impact on salmonid spawning season. With warmer summer temperatures and reduced thermal refugia, there is later spawning and fry emergence the following spring.

Spawning success, egg survival and post-hatching survival have been linked to water temperature and stream flow (Kanno et al. 2016). The abundance of juveniles, or young-of-the-year fish, those in their first summer of life, when they can be caught by electrofishing equipment, are what is often monitored. Environmental conditions during all aspects of reproduction in fall-spawning salmonids will have an effect on the juvenile population. Winter precipitation is the strongest seasonal weather factor-determining class size of young-of-the-year, followed by stream discharge during egg development and hatching (Kanno et al. 2016). Precipitation can be used as a surrogate for river flow (i.e., determining natural effects on river flow).

Management of Brook Trout

The Ontario Ministry of Natural Resources and Forestry (MNRF) has a set of guidelines for managing brook trout. Like many fish species, brook trout are managed with a variety of open and closed seasons for anglers. The angling season closes at the latest on September 30, because brook trout are spawning and are more vulnerable during fall (MNRF 2007). The brook trout angling season ideally aligns with the lake trout season to avoid redirecting angling effort. Other recommendations have to deal with catch and possession limits, size limits, sanctuaries, special regulations, and introduced aquatic species. Catch and possession limits are ideally the same, size limits are recommended for regular, slow growing populations, and trophy angling and use of sanctuaries for rehabilitating populations are also recommended for brook trout (MNRF 2007). Restrictions on gear, bait, and/or harvest are some special regulations that should be considered, since brook trout are vulnerable to habitat disturbance and hooking mortality. There is also a caution against using live bait to reduce invasive aquatic species into brook trout waters.

One of the greatest challenges of modern conservation biology and resource management is predicting how populations within complex systems will respond to anthropogenic perturbation (Adams et al. 2016). One can better understand this complex interaction by using a stochastic model, in conjunction with sampling population abundance. Freshwater recreational fisheries provide model systems for evaluating stochastic life-history models, as they often consist of a large number of independent populations, show a broad range of phenotypic and genetic diversity, and exist at spatial scales that make manipulations feasible. Changes in management that were explored in the model matrix developed by Adams et al. (2016) showed brook trout populations respond differently depending on context. The primary use of this stochastic life-history approach is to provide a quantitative evaluation of the effectiveness of management strategies across a large proportion of the observed variance in a species' life history that one cannot get using population-specific data more useful at a local scale. The model is designed to incorporate the differences among populations and is useful on a regional scale.

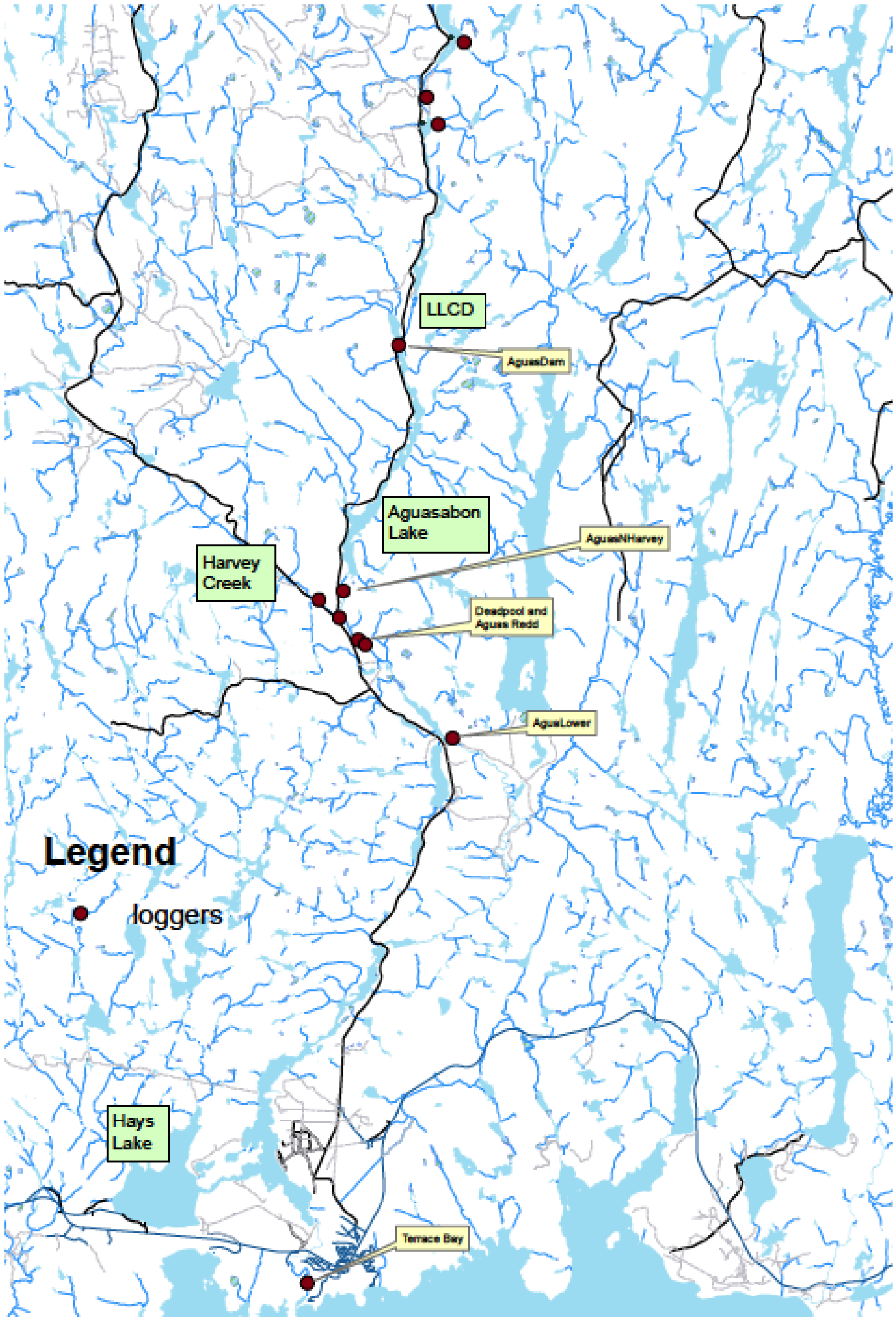
Building a dam to control flows into a generator has many effects on the environment, both positive and negative, and will change the shape and course of a river for many years. The system on the Aguasabon is a diversion system meaning that water that should flow into the Albany River is diverted into Long Lake and through the Long Lake Control Dam (LLCD) to the Aguasabon River and eventually Lake Superior. The system below the LLCD does not experience flow ramping, as there is insufficient capacity in the control structure. The control structure is manually changed and fish are locked in between LLCD and Hays Lake Dam, located near Terrace Bay (Figure 1).

The OPG owns the LLCD, located approximately nine kilometres north of the study site (Figure 1). The Hays Lake Reservoir, which is man-made, is approximately twenty-two kilometres south. The Aguasabon River system is regulated by the MNRF with a Water Management Plan (WMP) that guides the OPG's operations in managing water levels and flows to balance environmental, social and economic objectives, as well as various community interests (OPG 2016b). Flow monitored at Hays Lake Dam is representative of the flow coming out of Aguasabon River into the Hays Lake reservoir. The Brook trout population in question is locked between the LLCD and the Hays Lake Dam; they spend their entire life cycle there.

In 2010, the MNRF's WMP had a minimum outflow requirement of 2 m^3/s (Figure 2). The Nipigon District office of the MNRF started a drift netting study of brook trout in the Aguasabon River in 2010. That year, the redd was exposed and brook trout fry died, as there was no outflow from the LLCD. In 2013, the WMP was amended to include a minimum outflow of 12 m^3/s, which was achieved by 2013. The flow coming out of the LLCD is only a fraction of the flow measured at the Hays Lake Dam (Figure 3). The remainder of the flow measured is from the natural or original watershed of Hays Lake.

MATERIALS AND METHODS

Field Study



Source: Tyhuis 2016

Figure 1. Map of the Aguasabon River system

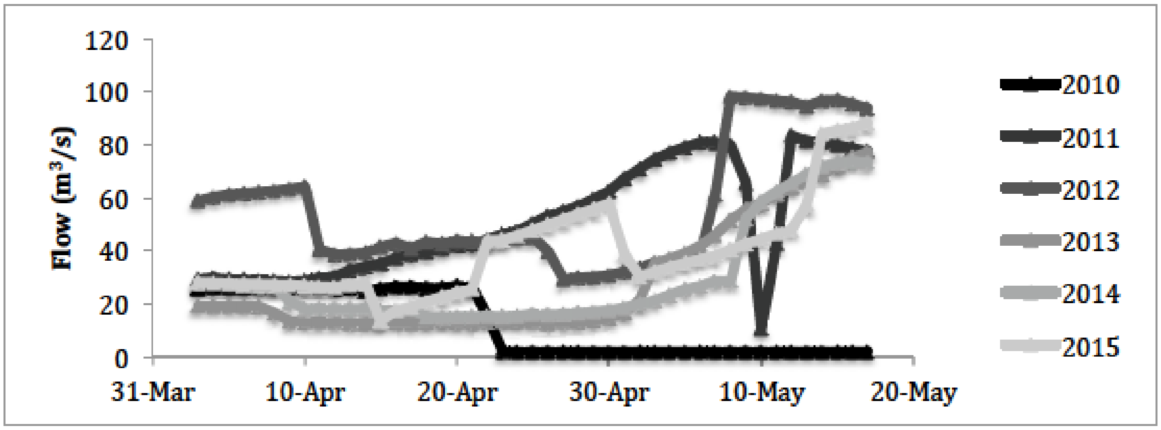


Figure 2. Outflow (m^3/s) during April and May 2010-2015 at the Long Lake Control Dam. 2010 in included as it represents the time where the water management plan did not have a minimum outflow requirement.

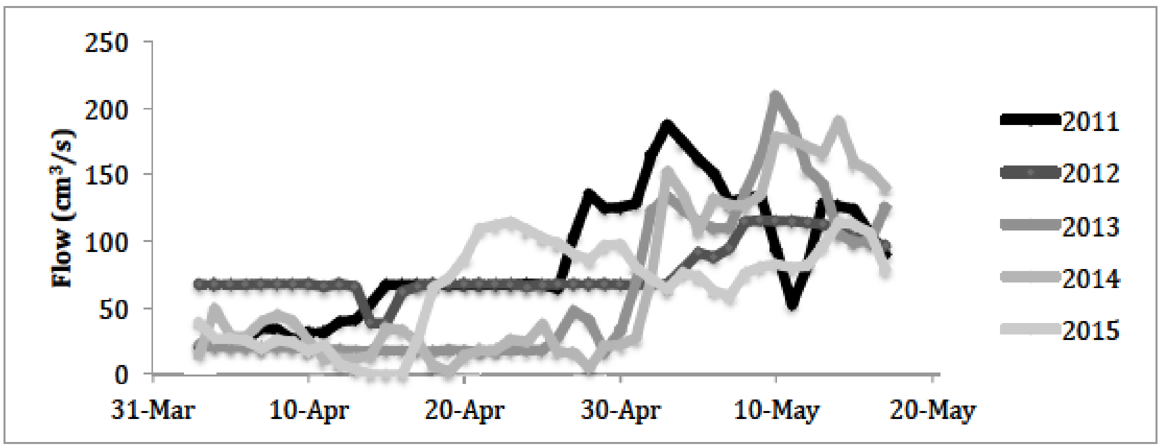


Figure 3. Outflow (cm^3/s) during April and May 2011-2015 at the Hays Lake Dam

There were three drift net set locations established in the Aguasabon River, below the spawning area (Figure 4). Only two nets are sampled at a time. The MNRF's strategy is to sample as close to shore as possible, but the net must be fully under water so that flow through the nets can be measured. If flow is low the two outer locations were used. If flow increases during the study the outer net is moved to the inner position. The middle position is always sampled but the inner and outer change through the study generally.

These sites are approximately twenty-three and twenty-five kilometres away from Terrace Bay, according to kilometre markers on the forestry road (Figure 1). These nets are used to trap emerged and drifting brook trout fry. Before 2014, sampling would start the first week of April but has moved to the second week since the majority of fry do not drift until that second week. Sampling runs three to four weeks, and ends when fry catches begin to decline indicating that a peak has occurred in fry drift. Fry are still drifting at this time.

Source: Hauser 2016

Figure 4. Drift nets on Aguasabon River near Terrace Bay, Ontario

Net sets occurred on Mondays, and on remaining weekdays the nets were emptied into sampling containers and fry were counted and then released alive into the river. Fridays the nets were taken out of the river for the weekend, and the cycle repeated the following Monday. Temperature loggers (Hobo pro temp loggers) were set below the substrate of the redd and on the substrate across the river from the redds (known as the deadpool) near where the nets were set by the MNRF. Flow meters that count flow in revolutions were connected to the drift nets and calibrated by the MNRF to record ambient flow through the nets.

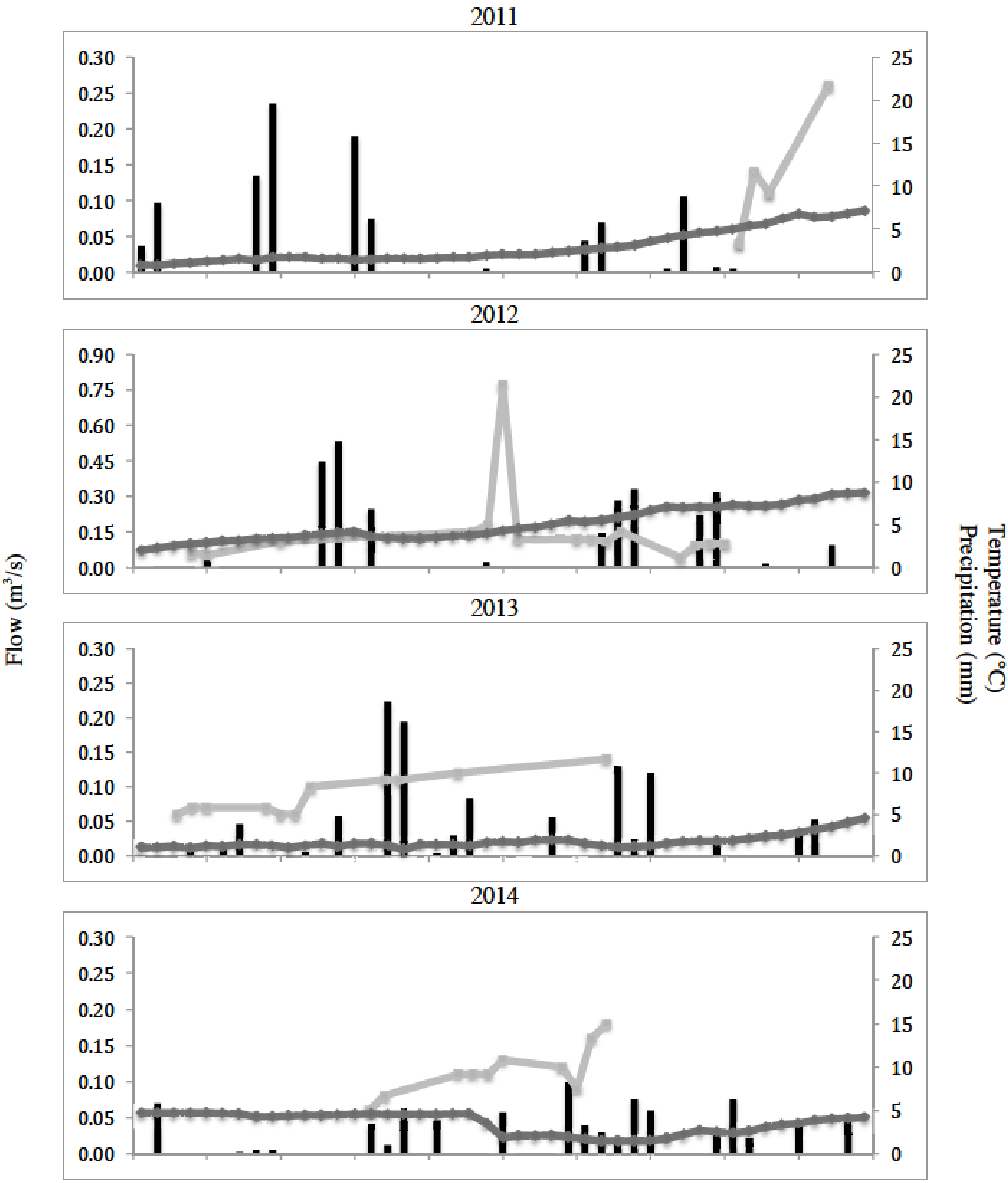
<u>Graphical Analysis</u>

I built graphs based on two of my four objectives: to explore whether temperature is affected by net flow in the Aguasabon River, and to determine whether brook trout recruitment in these two sites is affected by temperature (obtained by MNRF), net flow (flow meters on nets maintained by MNRF), or some combination. The flows calculated at the drift nets represent a fraction of the outflows of the LLCD and the Hays Lake Dam, so correspondence between net flows and the outflows was also visually explored. The first series of graphs compare temperature, flow, and precipitation data obtained from Environment Canada at the Geraldton A Station, which is eighty-five kilometres away from the study site. The second series reflects the hypothesis of association of trout recruitment with temperature, showing these two-time series together. The final series of graphs illustrates flow and its association with trout recruitment, related to the third and fourth objectives, for which OPG has collected outflow data from the Long Lake Control Dam (LLCD) from 2011 to 2015 (Appendix II). Hays Lake Dam outflow data is also collected by OPG and is more representative of the study site flow (Appendix III).

RESULTS

Throughout the study years, river temperature measured near the redds stayed low (below 2°C) for the entire month of April, with the exception of 2012 and 2014 (Figure 5). With the exception of 2014, temperature increased quickly from 2.5°C in late April or the beginning of May. Flows through the nets were not affected by precipitation; heavy rains did not result in higher flows. Flows through the net increased throughout the study period and fluctuate for the majority of the study period. In 2012, there was a high flow through the nets at 0.77 m^3/s on April 25. In 2013, flow through the nets was stable at 0.11 to 0.14 from April 12 to May 2. In 2015, there was a steep incline in net flow from April 23 and April 24 from 0.11 m^3/s to 0.24 m^3/s that was not seen in other years.

The increased flow measured through the nets in 2015 was not recorded at the LLCD and Hays Lake Dam outflow monitors, where flows remained 45.0 m^3/s and 105.5 m^3/s. In 2016, flow generally decreases over the study period, and this would be shown if I fixed a trend line to the flow data. The LLCD outflow during April 24-26, 2012 increased to 45.7 m^3/s. For the Hays Lake Dam, the outflow was constantly high at 67.1 m^3/s, with little variance before April 24. The outflows for LLCD and Hays Lake Dam were on average 13.2 m^3/s and 17.9 m^3/s, with both dams having an increase in outflow on May 1 and 2, 2013. With these examples and others in the graphical analysis, it is unclear how changes to dam outflow affected peaks in river flow.


2011
2012
2013
2014
Flow (m3/s)
Temperature (°C)
Precipitation (mm)

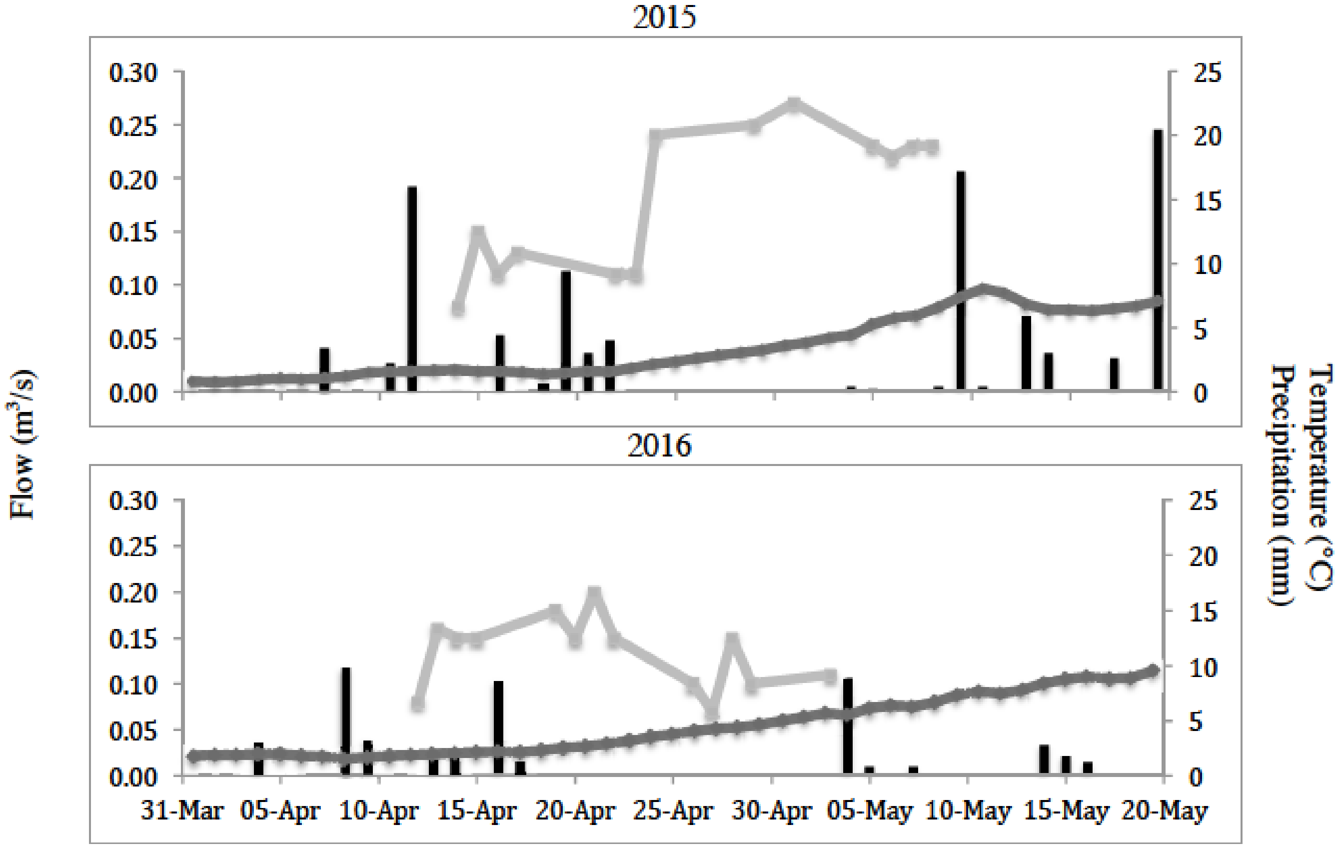
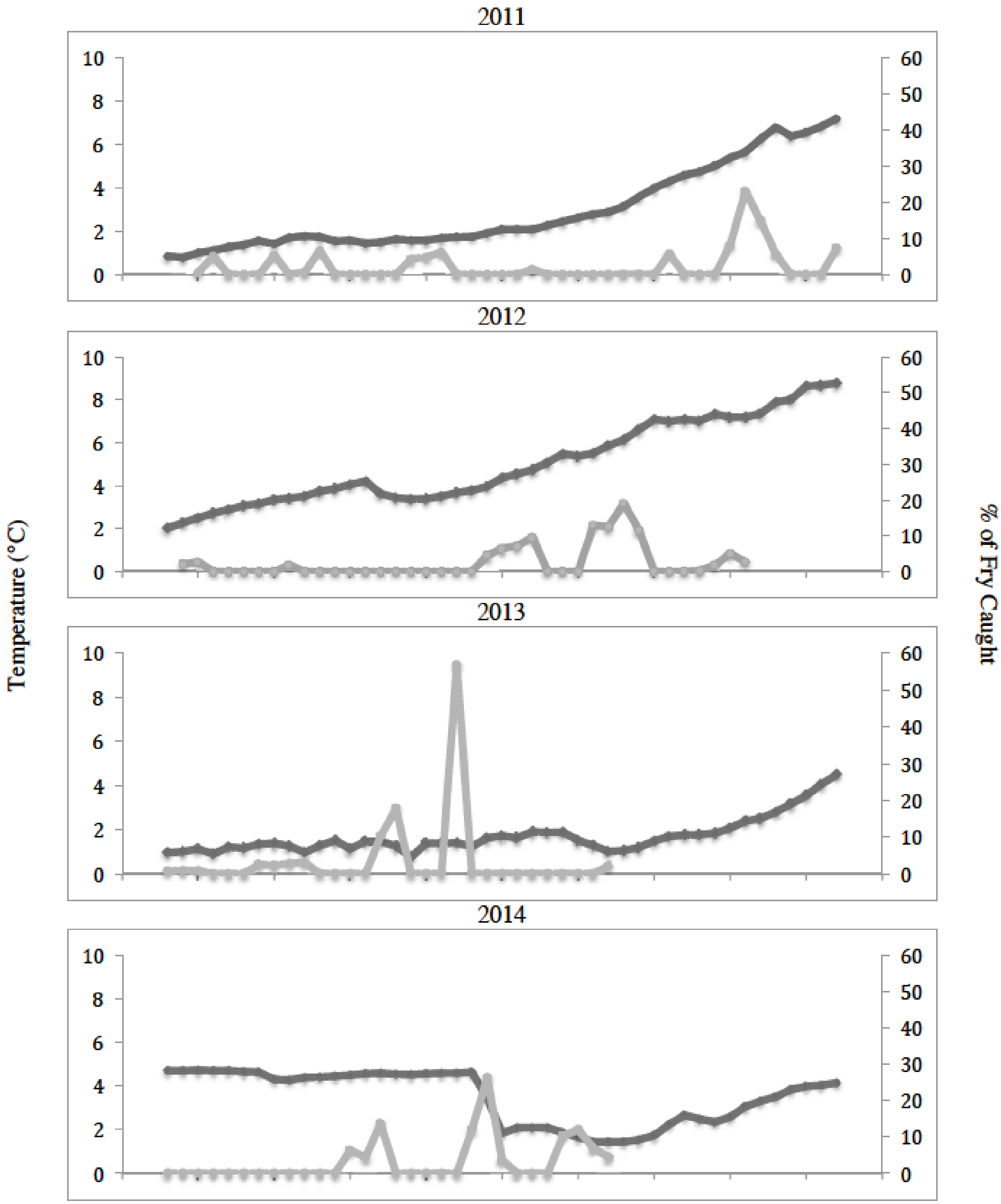


Figure 5. Flow (left axis, light grey lines, m^3/s), water temperature at the redd (right axis, dark grey lines, °C), and precipitation (right axis, black bars, mm) during April and May 2011-2016 at the Aguasabon River, Terrace Bay.

In all years, fry started to drift around the first week of April, and continued until well into May. The field program netted during the peak period, which lasts around three weeks. With the exception of 2013, the largest percentage of the total catch that occurred in a single day was 20-30%, and in 2013, 60% of the fry caught were caught on one day (Figure 6). In 2011 and 2012, fry drifted later into May. During 2013 and 2014, 60% of the fry were caught by late April. In most years, fry started drifting when the water temperature reached 2°C. When temperatures dropped in 2014 and 2015, fry appeared to stop drifting.


2011
2012
2013
2014
Temperature (°C)
% of Fry Caught
0
2
4
6
8
10
0
10
20
30
40
50
60

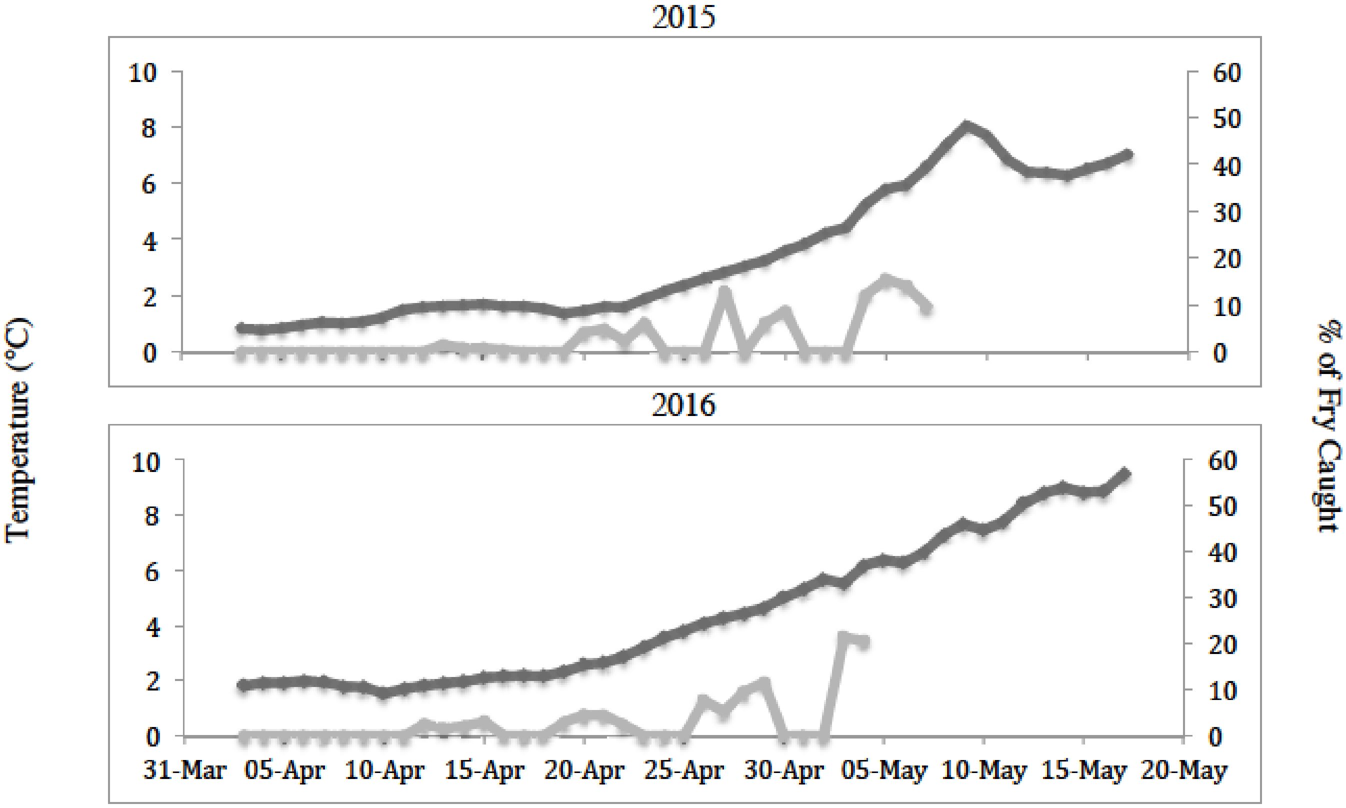
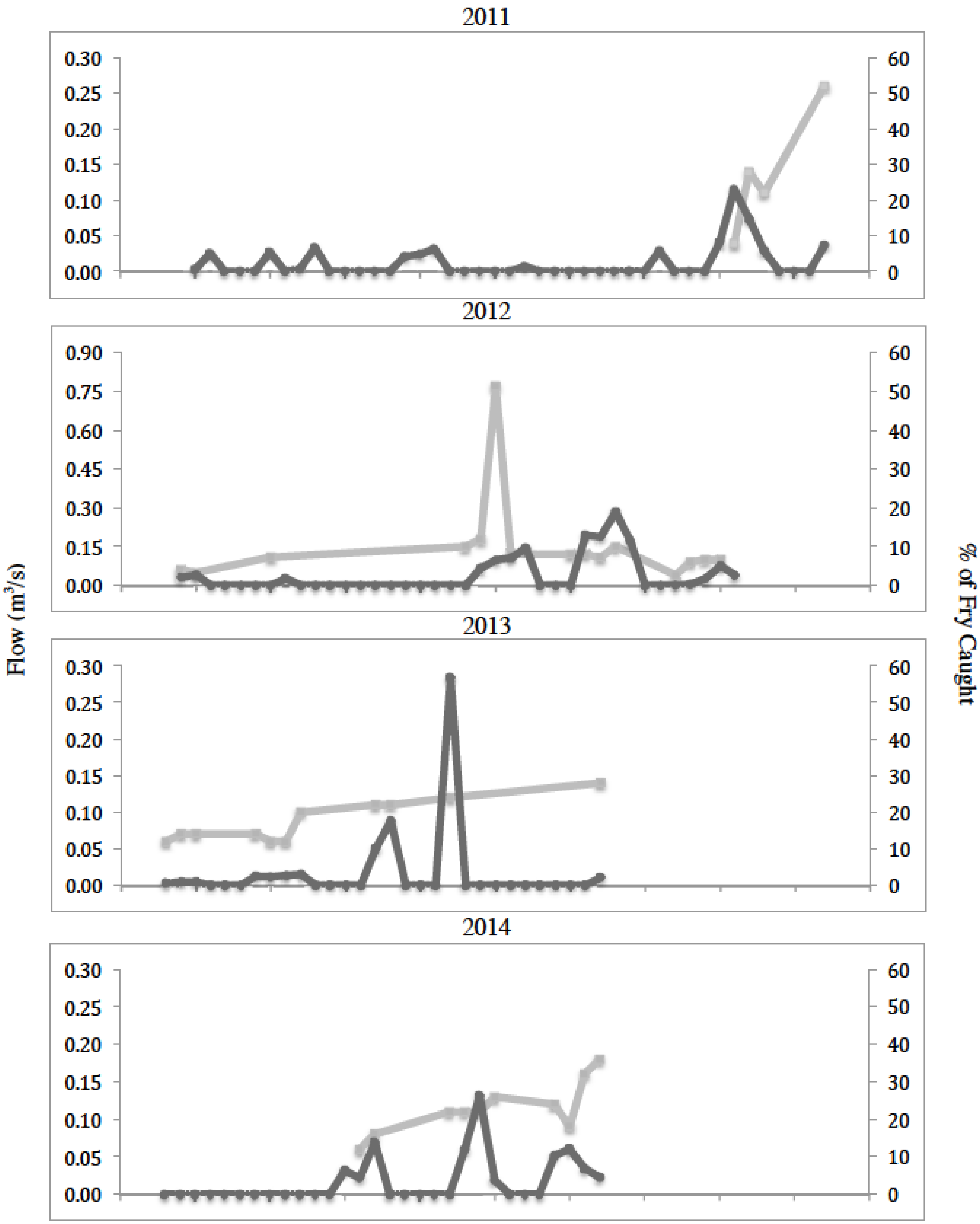


Figure 6. Temperature at the redd (left axis, dark grey) and fry caught (right axis, light grey) during April and May 2011-2016 at the Aguasabon River, Terrace Bay.

With fluctuating flows, peaks in percentage of fry caught appeared when flow was lower (Figure 7). There were not sufficient flow data collected in 2011, since the MNRF was using five-digit flow meters that were problematic. In 2012 high flow and a peak in fry captures co-occurred, but the percentage of the catch was higher after that high flow. In 2013, 60% of fry were caught on April 22 during the stable flow period from April 12 to May 2 In 2015, most of the catch peaks occurred after the increase in flow through the nets on April 24. In 2016, flow generally decreases over the study period, and the largest fry peak is at the end of the study period.


2011
2012
2013
2014
Flow (m3/s)
% of Fry Caught
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.45
0.60
0.75
0.90
0
10
20
30
40
50
60

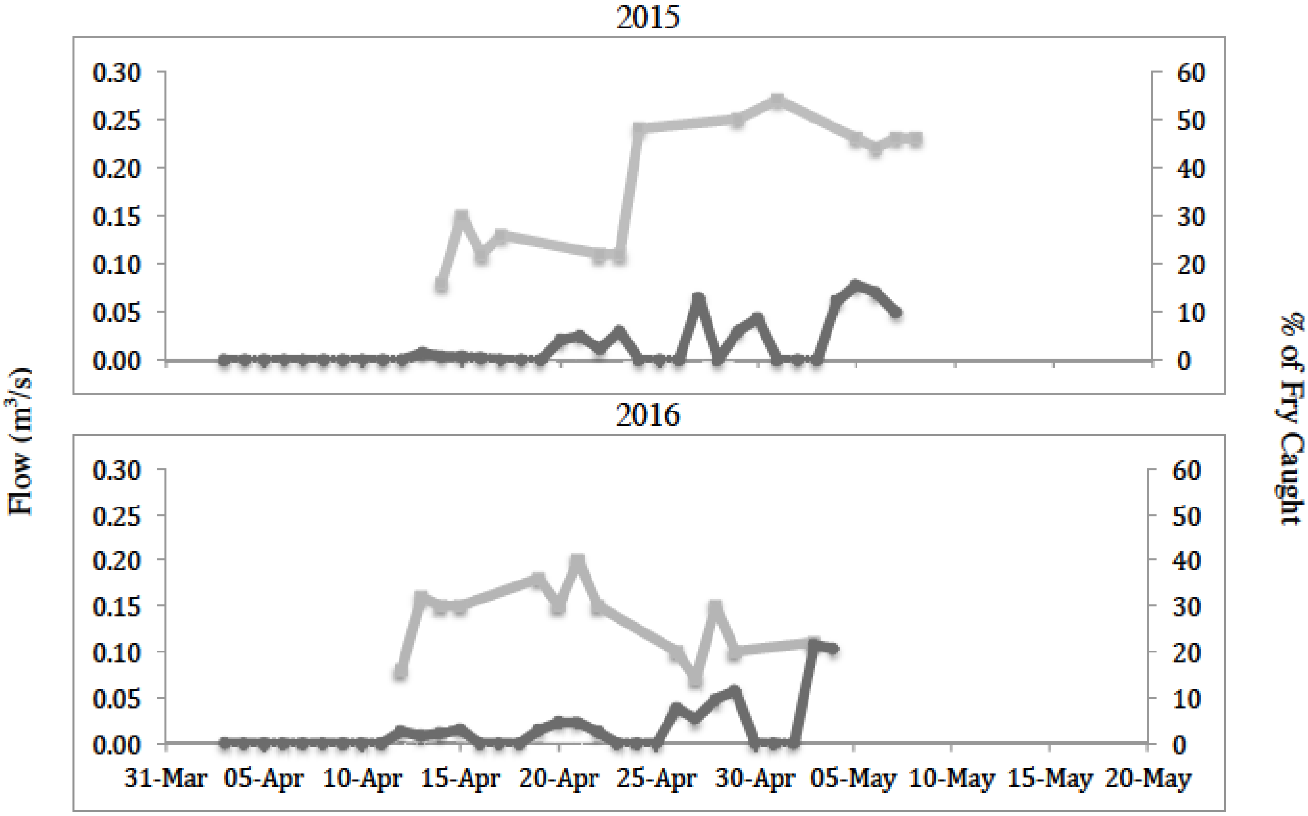


Figure 7. Flow (left axis, light grey lines, m^3/s) and fry caught (right axis, dark grey lines, percentages) during April and May 2011-2016 at the Aguasabon River, Terrace Bay.

DISCUSSION

Spring river temperature recorded on the Aguasabon River appeared not to be affected by flow through the nets measured at the drift net sets. Flow also appeared not to be affected by precipitation, suggesting it is more affected by dam outflow, but the relationship was not obvious or consistent across the six years of monitoring. Brook trout recruitment in the Aguasabon River appeared to have been affected by temperature, such that above a certain threshold, fry drifting increased. It also appeared that with temperature drops, fry drifting paused until temperature increased again.

The sample-bias related prediction that high flow will decrease the number of fry caught did hold; high flow resulted in less fry caught in the drift nets. Flow that is measured through the nets represents a fraction of the total river flow at the study site. Sample bias happens as high river flow correlates with high flow through the nets, causing debris to get trapped in the net and may prevent fry from entering the net. Debris in nets can also suffocate fry that are already caught and cause them to die. In most years, the LLCD will have an increase in outflow, and then the flow through nets will reflect this by increasing as well. The Hays Lake Dam will have an increase in outflow as well. This increase happens on the same day, or one to two days after flow through nets increase. In 2012, this relationship did not hold.

Variable climate in Northwestern Ontario led to outliers in the results of this study. With warmer temperatures in 2011 and 2012, fry drifting was able to continue well into May. The netting program stopped after the peak is documented, when fry did not necessarily stop drifting. In 2012, LLCD outflow decreased before the flow through the nets increased to 0.77 m^3/s on April 25. Flows can get so high that the LLCD gets shut down because there is too much water in Terrace Bay (flooding). This may also not show up in Hays Lake data if the lake is actually low and filling. The 2014 season is a good example of variable temperature, when it was warm at the beginning of the study period and the temperature decreased at the end of April. The majority of the fry had already drifted before this temperature change, since it was warm enough early on. During the 2013 season, there were colder temperatures at the start of the study period persisting into the end of the study period. Sixty percent of the fry have drifted early compared to other years occurred with these colder temperatures.

Genetic diversity allows an adaptation for brook trout fry to emerge at different times from season to season. Not all of the population emerges on the same day, because some eggs hatch early and are better adapted to those conditions associated with warmer spring (Kanno et al. 2016). Other eggs hatch later, adapted to delayed warming in spring. The control structure on the Aguasabon river system likely has not impaired genetic diversity in the brook trout population that occurs below the dam. There was no connectivity between LLCD and Aguasabon River before the diversion structure was built to allow controlled flow into Aguasabon.

Dams cause changes to occur on a river system. In this study, stream flow appears to be most influenced by outflow of the Long Lake Control Dam. In the Armanini et al. (2014) study, benthic communities responded to flow ramping; benthic invertebrates being an important food source for brook trout. Another change to river systems caused by dams is sediment deposition. In this study, the majority of brook trout fry were caught during high flow days. Spawning is not directly affected by outflow, but high flows can affect the fall spawn success. High outflows in the spring affect sediment deposition, which may affect where redds are built the following fall. The fish are spawning against a man-made bank, the stream corridor is on both sides of this bank, but one side has no flow. The Aguasabon River is a highly manipulated system.

Environmental conditions during the fall spawning period have the potential to affect the next spring's juvenile brook trout population. This idea is explored in the Kanno et al. (2016) study. For example, flow conditions in the fall that reduce brook trout spawning success will result in a lower recruiting population in the spring. Egg survival over the winter months can be reduced if flows are too high or if temperatures are too warm during early winter in January and February. High temperatures early in the incubation period could potentially cause hatching and drifting to occur too early, and result in young-of-the-year fish death if spring temperatures suddenly drop. In 2014 has a drop in temperature at the end of April, causing a potential mortality in the twenty-six percent of fry that were caught drifting right before the temperature crash. Mortality in the nets is usually caused by an increase in drifting debris that suffocate the fry. This mortality rate is small compared to the number of fry successfully hatching and drifting.

Warmer temperatures in the fall affected the timing of spawning, sometimes delaying it, and caused delays in larval drifting as well. Fry started to drift once water temperature reached approximately 2°C, and temperature increases earlier in the spring did not appear to have caused drift to occur earlier. Instead, the opposite happened, likely due to delayed spawning. As the Temperature-Productivity squeeze affects brook trout, they take up habitat where prey abundance is high (Petty et al. 2014). High flows in the fall pushed brook trout to spawn further up on the bank, a lower flow at any time before they hatched would cause them to be exposed and die. The MNRF observed this die-off in 2010 and the WMP was changed accordingly to address this; there is now a minimum flow at LLCD of 12 m^3/s to maintain water over the redds at the study site (Tyhuis 2011).

Literature suggests that fall environmental conditions affect spawning and therefore the spring drifting population, and a project that samples these fall conditions (i.e. temperature, flow, precipitation, count) could answer questions for the Aguasabon River about how fall temperature affects fry emergence and survival in the spring (Warren et al. 2012). Telemetry studies have been done and they determined that all brook trout on the Aguasabon River spawn at the same location. Coincident spawning occurs because the groundwater upwelling in the area influences brook trout behaviour (Warren et al. 2012). Groundwater upwelling and high stream flow (greater than 30 m^3/s) have been known to lower temperatures for a day or two, while ambient stream temperature may stay cold for longer.

Another recommendation for the field program on the Aguasabon River is to have more consistent river flow monitoring by installing permanent/semi-permanent flow meters. There are flow meters of this nature installed on the system, but they are not easy to maintain. OPG has maintained flow meters at the study site since 2014 and the MNRF hopes to compare them to Hays Lake flows.

Some limits of study, focusing on the conservation of brook trout, include minimal attention to habitat fragmentation. Literature suggests that brook trout are vulnerable to habitat fragmentation and genetic drift (Mollenhauer et al. 2013). Here, I infer high genetic diversity with adaptation to different hatch times in the study period. It cannot be stated, however, that habitat fragmentation is not a problem in the Aguasabon River study area, as it was not considered independently. There is known angling activity on the Aguasabon River, and creel surveys have been done in 2014, but due to access, surveys were not sufficiently complete to get an estimate of harvest. There are many opportunities for follow-up studies; one is to investigate other salmonid species, such as the lake trout that occur above the dam. Another could be to look at how cold river temperatures and less fry in nets are related.

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APPENDICES

Appendix I

Summary of Temperature, Flow, Precipitation, and Fry Caught Numbers and Percentage from 2011 to 2016 on the Aguasabon River, Terrace Bay

2011 data

Date	Temp	Flow	Precipitation	Fry Caught	%
03-Apr	0.847125		3		
04-Apr	0.789125		8		
05-Apr	1.013		0	3	0.5
06-Apr	1.110833		0	28	5.0
07-Apr	1.265417		0	0	0.0
08-Apr	1.372833		0		0.0
09-Apr	1.562458		0		0.0
10-Apr	1.412917		11.2	30	5.4
11-Apr	1.704083		19.6		0.0
12-Apr	1.785458		0	4	0.7
13-Apr	1.739042		0	37	6.7
14-Apr	1.527875		0		0.0
15-Apr	1.592375		0		0.0
16-Apr	1.4515		15.8		0.0
17-Apr	1.481917		6.2		0.0
18-Apr	1.631708		0		0.0
19-Apr	1.586792		0	24	4.3
20-Apr	1.58125		0	27	4.9
21-Apr	1.681292		0	35	6.3
22-Apr	1.737875		0		0.0
23-Apr	1.747208		0		0.0
24-Apr	1.92575		0.4		0.0
25-Apr	2.066292		0		0.0
26-Apr	2.081125		0		0.0
27-Apr	2.077458		0	8	1.4
28-Apr	2.267417		0		0.0
29-Apr	2.457125		0		0.0
30-Apr	2.625375		3.6		0.0
01-May	2.772417		5.8		0.0
02-May	2.867708		0		0.0
03-May	3.134958		0		0.0
04-May	3.5705		0	1	0.2
05-May	3.976667		0.4		0.0
06-May	4.286667		8.8	32	5.8
07-May	4.58175		0		0.0
08-May	4.744917		0.6		0.0

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09-May	5.013542		0.4		0.0
10-May	5.377542		0	45	8.1
11-May	5.637875	11088.2	0	128	23.1
12-May	6.244542	27693.1	0	82	14.8
13-May	6.780417	20442.6	0	31	5.6
14-May	6.375625		0		0.0
15-May	6.526917		0		0.0
16-May	6.824125		0		0.0
17-May	7.181583	55211.8	0	40	7.2

2012 data

Date	Temp	Flow	Precipitation	Fry Caught	%
03-Apr	2.029083		0		
04-Apr	2.263208	17661.88	0	14	2.1
05-Apr	2.503208	18115.05	0	18	2.7
06-Apr	2.713125		0		0.0
07-Apr	2.879458		1		0.0
08-Apr	3.074208		0		0.0
09-Apr	3.156292		0		0.0
10-Apr	3.354292		0		0.0
11-Apr	3.411792	18856.4	0	12	1.8
12-Apr	3.498167		0		0.0
13-Apr	3.72925		0		0.0
14-Apr	3.8725		12.4		0.0
15-Apr	4.054333		14.8		0.0
16-Apr	4.207875		0		0.0
17-Apr	3.609042		6.8		0.0
18-Apr	3.44225		0		0.0
19-Apr	3.362375		0		0.0
20-Apr	3.387458		0		0.0
21-Apr	3.497208		0		0.0
22-Apr	3.654917		0		0.0
23-Apr	3.766583		0		0.0
24-Apr	3.951542	29313.3	0.6	30	4.4
25-Apr	4.355042	35575.41	0	44	6.5
26-Apr	4.546958	122103.76	0	48	7.1
27-Apr	4.750125	11349.78	0	65	9.6
28-Apr	5.083917		0		0.0
29-Apr	5.476625		0		0.0
30-Apr	5.365833		0		0.0
01-May	5.518375	13071.13	4	87	12.9
02-May	5.861125	15529.19	7.8	85	12.6
03-May	6.133042	17410.02	9.2	128	19.0
04-May	6.619625	15304.68	0	78	11.6
05-May	7.072042		0		0.0
06-May	6.998458		0		0.0
07-May	7.083208		6		0.0
08-May	7.019458	275.59	8.8	2	0.3
09-May	7.326292	7282.39	0	12	1.8
10-May	7.196958	34716.55	0	34	5.0
11-May	7.194083	37778.06	0.4	18	2.7
12-May	7.353417		0		0.0
13-May	7.896958		0		0.0
14-May	7.993917		0		0.0
15-May	8.621333		2.6		0.0

16-May	8.67375	0	0.0
17-May	8.769	0	0.0

2013 Data

Date	Temp	Flow	Precipitation	Fry Caught	%
03-Apr	0.949833	159058.6	0	8	0.7
04-Apr	1.02	176421.1	0	11	1.0
05-Apr	1.127375	176308	0	10	0.9
06-Apr	0.917208		1.4		0.0
07-Apr	1.221958		0		0.0
08-Apr	1.17		1		0.0
09-Apr	1.353375	173367.6	3.8	29	2.5
10-Apr	1.377792	161911.9	0	27	2.4
11-Apr	1.246458	156019.2	0	32	2.8
12-Apr	0.979958	152772.2	0	35	3.1
13-Apr	1.274875		0.4		0.0
14-Apr	1.520625		0		0.0
15-Apr	1.12		4.8		0.0
16-Apr	1.48		0		0.0
17-Apr	1.47	158877.1	0	116	10.1
18-Apr	1.255292	156227.6	18.6	202	17.6
19-Apr	0.7445		16.2		0.0
20-Apr	1.379875		0		0.0
21-Apr	1.391417		0.2		0.0
22-Apr	1.401375	262305.3	2.4	652	56.9
23-Apr	1.224		7		0.0
24-Apr	1.622458		0		0.0
25-Apr	1.709458		0		0.0
26-Apr	1.6255		0		0.0
27-Apr	1.921208		0		0.0
28-Apr	1.875333		4.6		0.0
29-Apr	1.887875		0		0.0
30-Apr	1.513667		0		0.0
01-May	1.279125		0		0.0
02-May	1.0155	172622	10.8	24	2.1
03-May	1.07025		2		0.0
04-May	1.190542		10		0.0
05-May	1.492958		0		0.0
06-May	1.702792		0		0.0
07-May	1.7695		0		0.0
08-May	1.775667		2.2		0.0
09-May	1.8465		0		0.0
10-May	2.06975		0		0.0
11-May	2.385208		0		0.0
12-May	2.507792		0		0.0
13-May	2.818583		2.4		0.0
14-May	3.156		4.4		0.0
15-May	3.549875		0		0.0

16-May	4.061625	0	0.0
17-May	4.4925	0	0.0

2014 data

Date	Temp	Flow	Precipitation	Fry Caught	%
03-Apr	4.714		0		0.0
04-Apr	4.714		5.8		0.0
05-Apr	4.716167		0		0.0
06-Apr	4.714		0		0.0
07-Apr	4.708583		0		0.0
08-Apr	4.669583		0		0.0
09-Apr	4.631667		0.2		0.0
10-Apr	4.298		0.4		0.0
11-Apr	4.283917		0.4		0.0
12-Apr	4.39225		0		0.0
13-Apr	4.420417		0		0.0
14-Apr	4.468083		0		0.0
15-Apr	4.51575		0	55	6.3
16-Apr	4.566667	170721.8	0	38	4.4
17-Apr	4.594833	160923.3	3.4	120	13.8
18-Apr	4.558		1		0.0
19-Apr	4.536333		5.2		0.0
20-Apr	4.572083		0		0.0
21-Apr	4.584		3.8		0.0
22-Apr	4.597	140016.7	0		0.0
23-Apr	4.627333	128226	0	103	11.8
24-Apr	3.448208	139487.1	0	230	26.4
25-Apr	1.853333	180506.1	4.8	32	3.7
26-Apr	2.085625		0		0.0
27-Apr	2.078292		0		0.0
28-Apr	2.097583		0		0.0
29-Apr	1.870917	160238.2	8.2	90	10.3
30-Apr	1.650458	39797.54	3.2	104	11.9
01-May	1.437708	219245.4	2.4	60	6.9
02-May	1.438708	251469.5	1	39	4.5
03-May	1.437667		6.2		0.0
04-May	1.524833		5		0.0
05-May	1.735125		0		0.0
06-May	2.239917		0		0.0
07-May	2.661667		0		0.0
08-May	2.496792		2.2		0.0
09-May	2.357167		6.2		0.0
10-May	2.575125		1.6		0.0
11-May	3.067917		0		0.0
12-May	3.31825		0		0.0
13-May	3.516		3.2		0.0
14-May	3.832		0		0.0
15-May	3.996458		0		0.0

16-May	4.034583	4.2	0.0
17-May	4.146708	0	0.0

2015 data

Date	Temp	Flow	Precipitation	Fry Caught	%
03-Apr	0.830333		0		0.0
04-Apr	0.7745		0		0.0
05-Apr	0.834625		0		0.0
06-Apr	0.948667		0		0.0
07-Apr	1.0535		0		0.0
08-Apr	1.008167		0		0.0
09-Apr	1.070042		3.4		0.0
10-Apr	1.218708		0		0.0
11-Apr	1.509208		0		0.0
12-Apr	1.589		2.2		0.0
13-Apr	1.633625		16	4	1.5
14-Apr	1.661208	201953.7	0	2	0.8
15-Apr	1.709542	205125.7	0	2	0.8
16-Apr	1.637333	138873.2	0	1	0.4
17-Apr	1.63	172303.4	4.4		0.0
18-Apr	1.540208		0		0.0
19-Apr	1.361958		0.6		0.0
20-Apr	1.452458		9.4	11	4.2
21-Apr	1.612		3	13	4.9
22-Apr	1.589542	294867.1	4	6	2.3
23-Apr	1.878583	290553.9	0	16	6.1
24-Apr	2.156708	302128.3	0		0.0
25-Apr	2.381		0		0.0
26-Apr	2.6205		0		0.0
27-Apr	2.851417		0	34	12.9
28-Apr	3.054167		0		0.0
29-Apr	3.245208	324139.6	0	16	6.1
30-Apr	3.600125	334304.4	0	23	8.7
01-May	3.847625	721172.9	0		0.0
02-May	4.224958		0		0.0
03-May	4.425042		0.4		0.0
04-May	5.263125		0.2	32	12.1
05-May	5.797958	283773.8	0	41	15.5
06-May	5.955292	282462.8	0	37	14.0
07-May	6.586917	282455.1	0.4	26	9.8
08-May	7.388875	285732.2	17.2		0.0
09-May	8.063417		0.4		0.0
10-May	7.711333		0		0.0
11-May	6.855333		5.8		0.0
12-May	6.392792		3		0.0
13-May	6.380583		0		0.0
14-May	6.296208		0		0.0
15-May	6.5175		2.6		0.0

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16-May	6.715875	0	0.0
17-May	7.034208	20.4	0.0

2016 data

Date	Temp	Flow	Precipitation	Fry Caught	%
03-Apr	1.821042		0		0.0
04-Apr	1.920792		0		0.0
05-Apr	1.935542		0		0.0
06-Apr	1.987958		3		0.0
07-Apr	1.95225		0		0.0
08-Apr	1.795208		0		0.0
09-Apr	1.760917		0		0.0
10-Apr	1.530625		9.8		0.0
11-Apr	1.714542		3.2		0.0
12-Apr	1.800625	205925.2	0	27	2.5
13-Apr	1.901417	207877.3	0	18	1.7
14-Apr	1.983875	191943.8	1.4	23	2.2
15-Apr	2.113625	188436.3	1.8	32	3.0
16-Apr	2.17075		0		0.0
17-Apr	2.181667		8.6		0.0
18-Apr	2.152583		1.2		0.0
19-Apr	2.32725	234968.2	0	31	2.9
20-Apr	2.580208	208910.1	0	49	4.6
21-Apr	2.657833	268755.9	0	48	4.5
22-Apr	2.876667	214870.5	0	26	2.4
23-Apr	3.21375		0		0.0
24-Apr	3.563167		0		0.0
25-Apr	3.796		0		0.0
26-Apr	4.078375	265080.5	0	82	7.7
27-Apr	4.2775	176910.9	0	57	5.4
28-Apr	4.441375	407386.7	0	102	9.6
29-Apr	4.643125	257245.7	0	123	11.5
30-Apr	5.020917		0		0.0
01-May	5.32125		0		0.0
02-May	5.677583		0		0.0
03-May	5.515333	293456.6	8.8	228	21.4
04-May	6.163667		0.8	219	20.6
05-May	6.391833		0		0.0
06-May	6.266958		0.8		0.0
07-May	6.651417		0		0.0
08-May	7.294458		0		0.0
09-May	7.682875		0		0.0
10-May	7.461917		0		0.0
11-May	7.781042		0		0.0
12-May	8.434667		2.8		0.0
13-May	8.791208		1.8		0.0
14-May	9.001375		1.2		0.0
15-May	8.830417		0		0.0

16-May	8.862458	0	0.0
17-May	9.490292	0	0.0

Appendix II

Ontario Power Generation Outflow Data of the Long Lake Control Dam

Date	2015	2014	2013	2012	2011	2010
03-Apr	28.3	27.7	19.3	58.8	29.2	26
04-Apr	28	28	19.3	60.3	29.8	26.4
05-Apr	27.7	27.5	19.3	61.3	29.2	26.4
06-Apr	27.5	27.2	19.3	61.7	29.2	26.6
07-Apr	27.5	26.9	19	62.1	28.6	26.6
08-Apr	27.2	26.9	16.6	62.8	28.6	26.8
09-Apr	27.2	21.1	13.5	63.5	28.4	26.4
10-Apr	26.9	18.1	13.2	64.2	28.6	26.4
11-Apr	26.6	18.4	13.2	40.5	29.8	26.4
12-Apr	26.3	18.1	13.2	38.5	30.4	26
13-Apr	27.2	18.1	13	38.8	32.8	26
14-Apr	27.5	18.4	12.9	39.4	34	25.4
15-Apr	13.6	17.9	13	41.4	35.2	25.8
16-Apr	17.6	17.6	13	43	37.4	26.6
17-Apr	18.9	18.1	13	41	38.6	26.6
18-Apr	21	15.2	13.2	43.3	39.6	26
19-Apr	22.7	14.9	13.8	42.7	41	26
20-Apr	24.3	15.2	13.3	44	42.2	26.8
21-Apr	25.7	15.2	13	43.7	42.8	26.4
22-Apr	43.9	15.4	13.2	43.3	44.4	15.5
23-Apr	44.2	15.2	13.5	44.7	46.2	2
24-Apr	45.8	15.4	13.2	45.7	47.4	2
25-Apr	47.8	16.1	13.2	45	50.4	2
26-Apr	49.8	15.9	13	39.7	53.2	2
27-Apr	51.9	16.1	13.2	29.3	55	2
28-Apr	53.9	16.6	13.3	29.9	57	2
29-Apr	55.7	17.1	13.8	30.2	59.6	2
30-Apr	57.8	17.6	14.8	30.8	62.4	2
01-May	38.9	18.7	16.7	32	67.2	2
02-May	30.5	20	21.5	33.2	70.8	2
03-May	32	21.3	35.2	35.7	74.6	2
04-May	33.8	23.5	37.1	36.7	77.2	2
05-May	35.4	25.5	39	38	79	2
06-May	37	26.9	41.9	39.2	81	2
07-May	38	28.7	46.1	61.2	81	2
08-May	40.5	28.8	51.5	98.3	79.8	2
09-May	42.8	52	55.7	97.8	65.7	2
10-May	44.5	58.5	58.1	97.4	10.6	2

11-May	46.5	62.4	61.3	96.6	42.7	2
12-May	47.9	65.7	63.9	96.2	83.4	2
13-May	57.4	69	66	94.6	81.4	2
14-May	84.1	71.9	68.6	96.6	81	2
15-May	85.7	73.4	72.3	97	79.8	2
16-May	86.2	73.8	75.3	95.4	78.6	2
17-May	88.2	73.4	77.2	93.8	77.6	2

Appendix III

Ontario Power Generation Outflow Data of the Hays Lake Dam

Date	2011	2012	2013	2014	2015
3-Apr	21.2	67.5	22.1	16.1	38.6
4-Apr	22.8	67.5	21.5	49	27
5-Apr	23.6	67.6	20.5	28.7	26.9
6-Apr	25.5	67.6	20.2	28.3	25.7
7-Apr	35	67.7	20.2	39.6	19.4
8-Apr	33.7	67.7	20.5	44.9	26
9-Apr	26.1	67.7	20.2	39.9	24.2
10-Apr	31.5	67.8	19.6	25.8	17.4
11-Apr	31.5	66.1	18.7	11.6	22.4
12-Apr	39.6	67.8	18.4	12.3	7.8
13-Apr	41	66.1	17.7	12.1	3.7
14-Apr	53.7	38.5	17.5	13.9	0
15-Apr	67.4	38.4	17.7	34.6	0
16-Apr	67.4	62.1	17.7	33.2	0
17-Apr	67.4	66.3	17.5	24.1	26.4
18-Apr	67.5	67.8	17.5	7	65
19-Apr	67.5	67.9	18.4	1.9	72.9
20-Apr	67.5	67.8	18	14	86.9
21-Apr	67.5	67.8	17.5	18.3	109.4
22-Apr	67.5	67.8	17.7	18.2	112.3
23-Apr	67.2	67.8	18.4	25.9	114.3
24-Apr	67.7	66	18.4	24.7	108.6
25-Apr	67.5	67.6	18.4	37.7	102.5
26-Apr	64.7	67.7	27.8	17.1	98.7
27-Apr	103.8	67.8	47.7	16.5	90.3
28-Apr	135.1	67.8	40.6	5	86.3
29-Apr	125.3	67.7	16.6	21.3	96.9
30-Apr	125.5	67.6	32.9	22	97.8
1-May	128.7	67.5	69.1	27.6	80.5
2-May	164.5	67.7	123.4	72.8	71.9
3-May	187.5	67.8	133.6	152.6	64
4-May	175.2	79	124	135.7	76
5-May	161.5	91.4	114.7	108.3	73.8
6-May	151	88.2	109.6	131.6	62.4
7-May	129.2	94.8	110.3	127.6	58.8
8-May	132.9	115.2	137.3	127.1	76.1
9-May	134.1	116	163.5	134.5	80.8
10-May	94.4	115.4	209.2	178.5	82.8
11-May	52.6	115.4	188.1	176.2	80.6
12-May	81.6	114.1	154.2	171.3	81.9
13-May	128.3	112.8	143.6	165.9	96.5
14-May	126.7	110.4	105.3	190.7	114.2

15-May	124.2	103.5	99.2	159.3	112.6
16-May	105.2	99	100	153.2	106.5
17-May	90.3	96.8	125.4	140.3	79