Boggy River Ecological Baseline Survey

22-23 September 2018

A Technical Report Prepared for:

A Rocha Manitoba and A Rocha Canada

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Abstract

The 40 km long Boggy River is located in Southeastern Manitoba and is part of the Whitemouth River watershed and the larger Winnipeg River basin. The purpose of this study was to conduct a baseline ecological survey for A Rocha Manitoba and A Rocha Canada, providing valuable information for ongoing management, and using standard, replicable methods that can be used in future surveys. The baseline survey was conducted in mid-September of 2018. The survey consisted of bank measurements, channel measurements, water chemistry, and sampling of benthic macroinvertebrates and small fishes. Our results categorize the river as a healthy, slow-moving river with a silt and clay channel and shoreline. The bank measurements showed minor erosion, and water chemistry and benthic macroinvertebrate measurements did not show evidence of pollution. A diversity of benthic macroinvertebrates and small fishes was observed, suggesting that the river contains habitat that can support the diversity of species expected in this region of southern Manitoba.

1. General Introduction

All living things on Earth require water. Rivers are very important to the health of ecosystems as they carry water and nutrients needed by all living things. Rivers also provide unique habitats which house a large diversity of organisms. Humans are continuing to change large aspects of our environment, including rivers, by diverting and damming them and through the addition of nutrients and other chemicals in the form of runoff; these changes can affect the habitats available to organisms and in turn the ecosystems that depend on rivers. Monitoring rivers can give key information on the health of the ecosystem and the diversity of plants and animals in the midst of such potential changes.

The 40 km long Boggy River is located in Southeastern Manitoba and is part of the Whitemouth River watershed and the larger Winnipeg River basin (Government of Manitoba 2018). It is a small river with a gradient of 0.38m/km that flows from Boggy Lake westward to a confluence with the Birch River and then the larger Whitemouth River (Clarke 1998). The topography of the area is typically flat land formed by the glacial Lake Agassiz with bedrock outcrops (Becker and Hamel 2017). The rivers that make up the Whitemouth River watershed flow through multiple different landscapes including wetlands, forests, and farms. This watershed is important for species diversity as it includes boreal coniferous forest, mixed forest, and peatland complexes (Becker and Hamel 2017). The Boggy River is surrounded by lush riparian forests, and towards East Braintree, mixed deciduous and coniferous forests (Becker and Hamel 2017).

East Braintree was established as a construction camp during the building of the Greater Winnipeg Water District Aqueduct to supply Winnipeg with fresh drinking water from the Lake of the Woods. In 1914 the Greater Winnipeg Water District Railway was built to haul in supplies needed for the aqueduct. Settlers who arrived to work on the aqueduct saw the rich looking riverbank soil along the Boggy and Birch Rivers and established there (Annell 2018). The Greater Winnipeg Water District Aqueduct at East Braintree runs parallel to the Boggy River and until 1996 a pipe was discharging chlorinated water into the Boggy River (Clarke 1998).

The Whitemouth River watershed is home to the gray wolf (C*anis lupus)*, the rare mottled duskywing (*Erynnis martialis*), and the rivers support one of Canada's only threatened carmine shiner populations (*Notropis percobromus*), as well as provincially significant northern brook lamprey (*Ichthyomyzon fossor),* and the horneyhead chub (*Nocomis biguttatu)* (Becker and Hamel 2017; Clarke 1998). The Whitemouth River watershed and surrounding areas are being conserved by Nature Conservancy Canada with special interest in: maintaining carmine shiner populations, protecting the eastern deciduous floodplain forest, and conserving the riparian areas that are often located on private land. Nature Conservation Canada has created a Natural Area Conservation plan that began in 2017 and continues till 2026 (Becker and Hamel 2017).

Though the Boggy River is located in an area of interest there have not been many ecological studies of it. Clark (1998) noted that Schneider-Vieira and MacDonell (1993) examined the Whitemouth River and its main tributaries for effects of construction of the TransCanada Pipeline. In 1991 McKenian et al. surveyed the Birch River in an area of a proposed pipeline crossing, and in 1979 Smart conducted a study of fish stomach contents to have further insight into the fish species, composition, and invertebrates. Lastly, in 1973 Yake evaluated whether the Whitemouth Lake and Monk creek were suitable to stock with trout (Clarke 1998).

The most recent study is that by Clarke (1998) and the members of the Birch River Renewal association (BRRA), made up of landowners and interested in maintaining and restoring the unique ecological community and its aesthetic value. This study was specifically conducted on the Birch and the Boggy Rivers, and the main purpose was to conduct a baseline ecological study that could be used for managing and maintaining the river. The field work was done from spring 1996 through fall 1997 (Clarke 1998). Clarke's study looked at the aquatic biology, terrestrial and aquatic geography, identified riparian and riverine sites with human impact, and analyzed flow rates, water chemistry, and collected and identified fishes and invertebrates (1998). There was also special interest in the significant northern brook lamprey, horneyhead chub, and the carmine shiner (Clarke 1998).

Our study, similar to Clarke's previous study, is an ecological survey based on a 100 metre length of the Boggy River located near East Braintree on the edge of the boreal forest. This river runs through land that belongs to the Walter Loewen family, who acquired the land with the intention of preserving it, and are now in the process of donating part of it to A Rocha Canada for continued, ongoing environmental stewardship and educational purposes (A Rocha 2018). The purpose of our study was to provide baseline ecological data using standardized and replicable methods that could be repeated annually to monitor the state of the river. Monitoring a river can give very important information on the heath of this ecosystem as well as how the large climate changes are affecting rivers. Our study may also be compared with those from previous studies in order to identify how the river is changing over time. Once completed a written report will be passed along to Christy Juteau, Conservation Science Director of A Rocha Canada, and Scott Gerbrandt, Manitoba Director of A Rocha Canada so that this information can be used now in conservation efforts and in the future if this survey was to be replicated. Further, data will also be presented to A Rocha Manitoba staff and others interested in the conservation work of A Rocha Manitoba. The macroinvertebrate samples were collected according to the Canadian Aquatic Biomonitoring Network (CABIN; CABIN 2011), which means that this data can be integrated into the national database at a later date to further provide information on Canada rivers. This study will provide A Rocha with valuable information on the health of the river ecosystem running through their property as well as protocol that can be used to replicate this study in order to see changes and respond accordingly.

2. Overall Methods

2.1 Reach Choice and Transect Setup

In order to gain the best information on the river the study needed to be conducted in a section of the river that included variation. This meant including a full bend in our sample that was accessible from our base, with a depth that did not exceed the height of our waders. Once we found a section of the river that fit our parameters we proceeded to conduct the kick net for benthic invertebrates. We did this first as to not disrupt the area prior to sampling when we were marking our transects. To mark transects we began at the top (upstream end) of our total sampling reach. Ten transects were marked 11.11 m apart, for a sampling reach of 100 m total length. For each transect we identified 6 observation points, by finding the wetted width of the river, dividing it into 6 sampling segments, and observing the centre point of each sampling segment. More information can be found in the CMU 2018/19 BIOL 3510 lab manual (Krause 2018). Sampling was done the evening of Septmebr 22 and the morning and afternoon of September 23, 2018.

3. Bank Measurements

3.1 Introduction

River banks hold invaluable information that describes a river's current state and health. In stream surveys, bank measurements go beyond the bankfull width and wetted width; important measurements include the bank angle, undercuts, sediment composition, canopy type, and streamside vegetation. The physical and hydraulic characterizations of a river system are often used to describe both benthic invertebrate and fish habitats (Newbury and Gaboury 1993), and are essential when assessing river systems because they provide a measure of stability which is used to protect against bank erosion.

The Ontario Stream Assessment Protocol (OSAP) classifies bank stability as one of four categories: eroding bank, vulnerable bank, protected bank, and deposition zone (OSAP 2017). These categories are based on bank angles, undercuts, and sediment type. The bank angle is the slope of the bank from its wetted width to bankfull width. Steeper angles are often formed due to erosion and characterize an unstable river system. These steep banks are formed by fluvial erosion – the direct removal of bank materials by water flow (Florsheim et al. 2008). Similarly, a bank's undercut holds some measure of erosion. Undercuts are often found on the outside bend of a meandering stream. Undercuts form when the lower bank, sometimes referred to as the toe, is subjected to fluvial erosion and the sediment beneath root systems is removed, at times exposing roots (Florsheim et al. 2008). In addition to bank angles and undercuts, the bank's sediment composition is used to explain stability. Materials such as sand or silt are more susceptible to erosion than clay and rock because they can more easily be displaced by stream discharge (OSAP 2017). Fluvial erosion is directly tied to stream flow and discharge; the greater the velocity of the stream, the more bank erosion will occur. The relationship of erosion with stream flow and discharge is why flooding and side channels—additional inputs of water—are important to take into consideration when assessing erosion and stability.

Streamside vegetation also plays a role in bank stability. Analysis of streamside vegetation helps with understanding bank stability and in describing stream habitats. The root systems of vegetation affect stability by providing a scaffold and acting as structural support. On the other hand, canopy cover is a visual estimation of the proportion of stream that is shaded by the tree canopy (CABIN 2012). The importance of this covering is twofold: first, the covering provides shade in summer which prevents the stream from overheating, and second, it is an input source of organic matter (CABIN 2012). These two factors impact fishes and benthic macroinvertebrate habitats.

In a stable ecosystem erosion will be present, but the rate of erosion will be at a much smaller magnitude than that of an unstable ecosystem. Erosion will also be limited to bends in a stable river and not to the straighter stretches. The purpose of collecting these measurements for a particular stretch of the Boggy River is to determine the stability of that stretch of river so that A Rocha can better protect the river system. A concern that might be present regarding the Boggy River is that severe erosion may lead to mass failure – slumping and collapsing of banks which can create dams and inhibit water flow (Department of Natural Resources and Water n.d.). These baseline measurements, and others taken over time, will aid in assessing this risk and in rehabilitation of the stream.

3.2 Methods

Assessment of the bank width, bank angle, undercuts, sediment composition, canopy type, and streamside vegetation followed OSAP (2017). Each measurement was performed at eight of the ten transects. The first two transects were excluded because entering and exiting the stream at these locations had altered the natural bank. The wetted width was the river's width at the time of sampling, while the bankfull width had to be estimated by observing changes in bank and vegetation composition. Since the measurements were collected in the fall, the river was very low and the wetted width was likely very it near its annual minimum.

The remainder of the measurements were made on both the right and left side of the transects. The bank angle was calculated using a bank profile tool (OSAP manual S4.M2:page 12) placed at the water's edge and held parallel to the ground. Heights were taken at 0, 0.25, 0.75, and 1.5 m from the water's edge to the bank; a visual of these bank heights can be found in figure 1 of the appendix. The undercut measurements were made holding a ruler parallel to the bank's overhang and measuring inward to the deepest part of the undercut; only the deepest undercut per transect was recorded. The substrate composition was determined at the base of the bank. Possible classifications of the substrate were: unconsolidated clay, consolidated clay, silt, sand, bedrock, concrete, organic detritus, or large boulders. When measuring the bank's dominant vegetation type, the distance from the wetted width to the bankfull width was the area observed. Vegetation was categorized as wetland, forest, scrubland, meadow, cropland, lawn, or no vegetation. Vegetation found above the bank was classified as canopy. These measurements were all taken on the same day.

3.3 Results and Discussion

Figure 1 demonstrates that the wetted width remains fairly consistently around approximately 10m. This would suggest that the flow of water remains fairly consistent. There are no points that demonstrate an increase in the volume of water flowing through any particular point, therefore, we can conclude that the flow of water is consistent throughout the river system. Any shifts in velocity would result in shifts in the morphology of the river, and because there is no clear change in the width of the river, it would reinforce the understanding that the river's water flow remains relatively consistent. This is consistent with water velocity, as measures in the middle of the river were consistently between 0.04m/s and 0.06m/s (Section 4.3).

The bankfull width was greater than the wetted width, as expected, but showed greater fluctuations than in the wetted width. There were notable peaks at transects 5 and 9. These widths would suggest that at some point in the river's history the flow of water has increased to these widths. This would inform us that the river has been significantly higher in the past. It also suggests that in this past, the flow of water was notably greater, therefore explaining the greater variations in bankfull width that are not observed in the wetted widths.

These measures of bankfull and wetted width are most helpful when they are used to better understand the other bank measurements. The larger differences between wetted and bankfull widths at transect 9 could have some influence on the overall measures of bank vegetation and sediment types, because the larger the area, the larger the observable space for these other important measures of the river. This could also have some effect on bank angle, as bankfull and wetted widths are key measures for determining the bank angle.

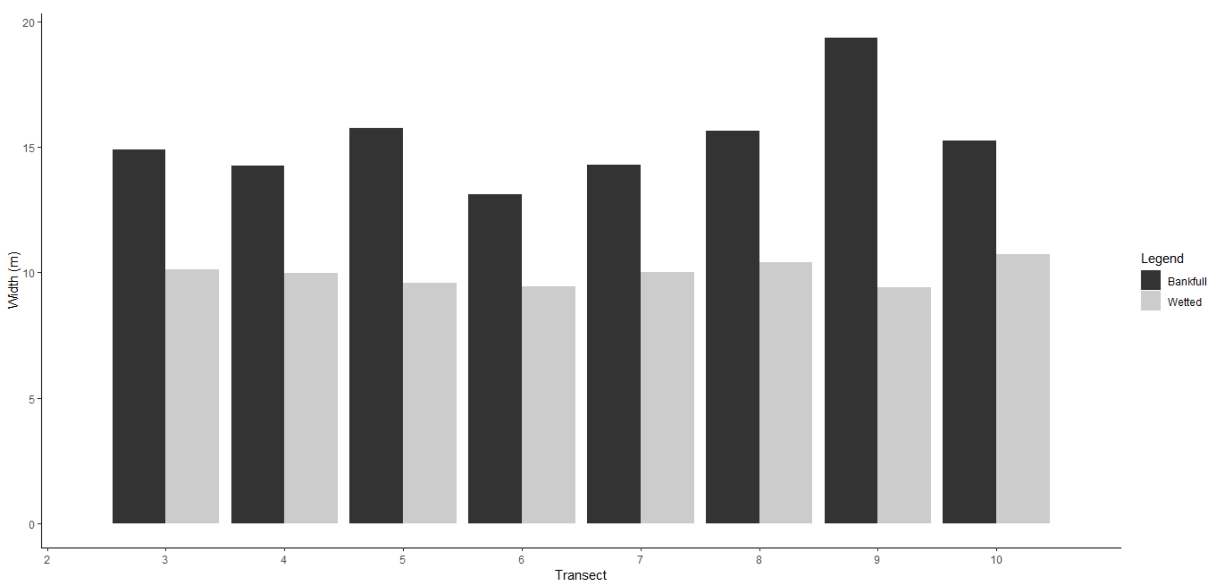

Figure 1. Bankfull and wetted widths of the river.

As mentioned previously, the bank angle holds some measure of bank erosion. Bank angle was calculated from bank heights found in Figure 2 of the appendix. The bank height measure at position 0 was used to calculate the bank angle, but the collection of bank heights show how the angle changes along the width of the bank. Figure 2 presents the changes in bank angle for the left and right bank. Trends observed are a relatively constant angle for the left bank throughout the sampling reach, while the right bank angle fluctuates. The greatest bank angle occurs at transects 7 and 8 of the right bank.

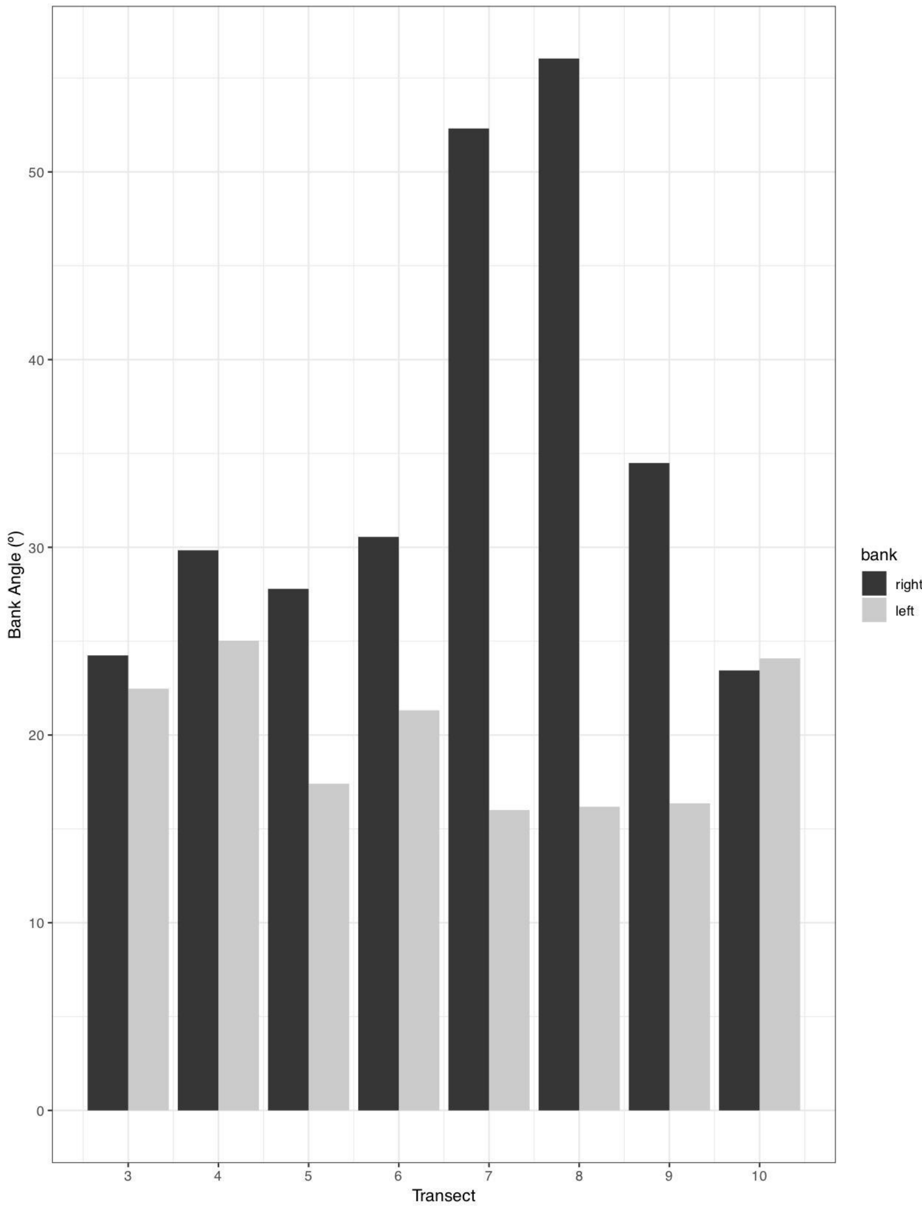

Figure 2. Bank angle for left and right sides of the river.

The right bank is shown to be more susceptible to erosion than the left bank from its continuously changing values. Part of this susceptibility is normal and can be explained by the bends in the meandering stream. The outlier values at transects 7 and 8 have a severe angle, making the bank increasingly vulnerable to more erosion and undercutting; the bank angle is almost entirely vertical—illustrated in figure 2 of the appendix. Looking at the data surrounding transects 7 and 8 more closely shows no obvious trend. This particular stretch of the river appears to be unique compared to the rest of the reach, likely because it is an outer bend of the river during times of higher flow. These large values may hold concern for the stability of the stream at this particular location.

Measurements of bank undercutting are found in Figure 3. The banks' undercut is shown to be more prominent on the right bank than the left. The most extreme undercutting occurs at transects 7 and 8 of the right bank, with measurements of 450 mm and 575 mm, respectively. This is consistent the measured bank angles at these transects, which were very steep. The only undercutting on the left bank transpires at transects 4 and 5; this corresponds to undercutting of a lower magnitude on the right bank. A noticeable trend in figure 3 is an increase in right bank undercutting, consistent with a decreased undercutting on the left bank. Surprisingly, the results show a large decline in undercutting between transects 8 and 9 from 575 mm to 112 mm.

The decrease in left bank undercutting and increase in right bank undercutting describes an inflection point in a meandering stream where the outside of the stream changes from the left bank to the right. While the undercutting is consistent with normal activity of a meandering stream, the undercutting does not occur at the same location on each bank. Left bank undercutting occurred close to the wetted width, while right bank undercutting was located nearer to the bankfull width. This suggests that the majority of fluvial erosion of the right bank occurs when the river discharge is greatest, and less erosion occurs when the stream is near its annual minimum. It is important to keep in mind that the sampling reach did not include a river bend where the left bank was the outermost bend of the river, so no conclusions can be made comparing the susceptibility of the left bank to the right. Explaining the substantial change in the right bank's undercutting is more complicated. It may be that the change in the river's direction was abrupt. These undercutting values are not concerning by themselves, but any larger change over the next few years would suggest that a protective intervention may be necessary.

The erosion observed with bank angles and undercuts could partially be explained by the presence vegetation and sediment type. The only variety of bank vegetation that was observed was unmowed grasses (Table 1). The measurements were taken in fall at a time when the water was low. Therefore, the bankside vegetation that was observed was under water earlier in the season. It makes sense that other types of vegetation, such as shrubs or trees, were not observed as these would be unable to grow in a location that is underwater for part of the year.

There was no bank vegetation seen on the right bank while almost all of the left bank had some grasses, excluding transect 6. The Boggy River curves to the left within our sampling reach, causing erosion on the right bank. This erosion can limit the ability of vegetation to take root and grow and could be the cause for the lack of vegetation on the right bank.

Bank vegetation is very important in bank stabilization. Without vegetation, river banks are at higher risk of erosion. While the movement of rivers is natural and to be expected, the curve that we observed in the Boggy River is moving towards the road. The lack of stabilization from bankside vegetation could be a compounding factor in the continual erosion of the river towards the road. It is important to note that sediment type observed on the bank was consistently silt.

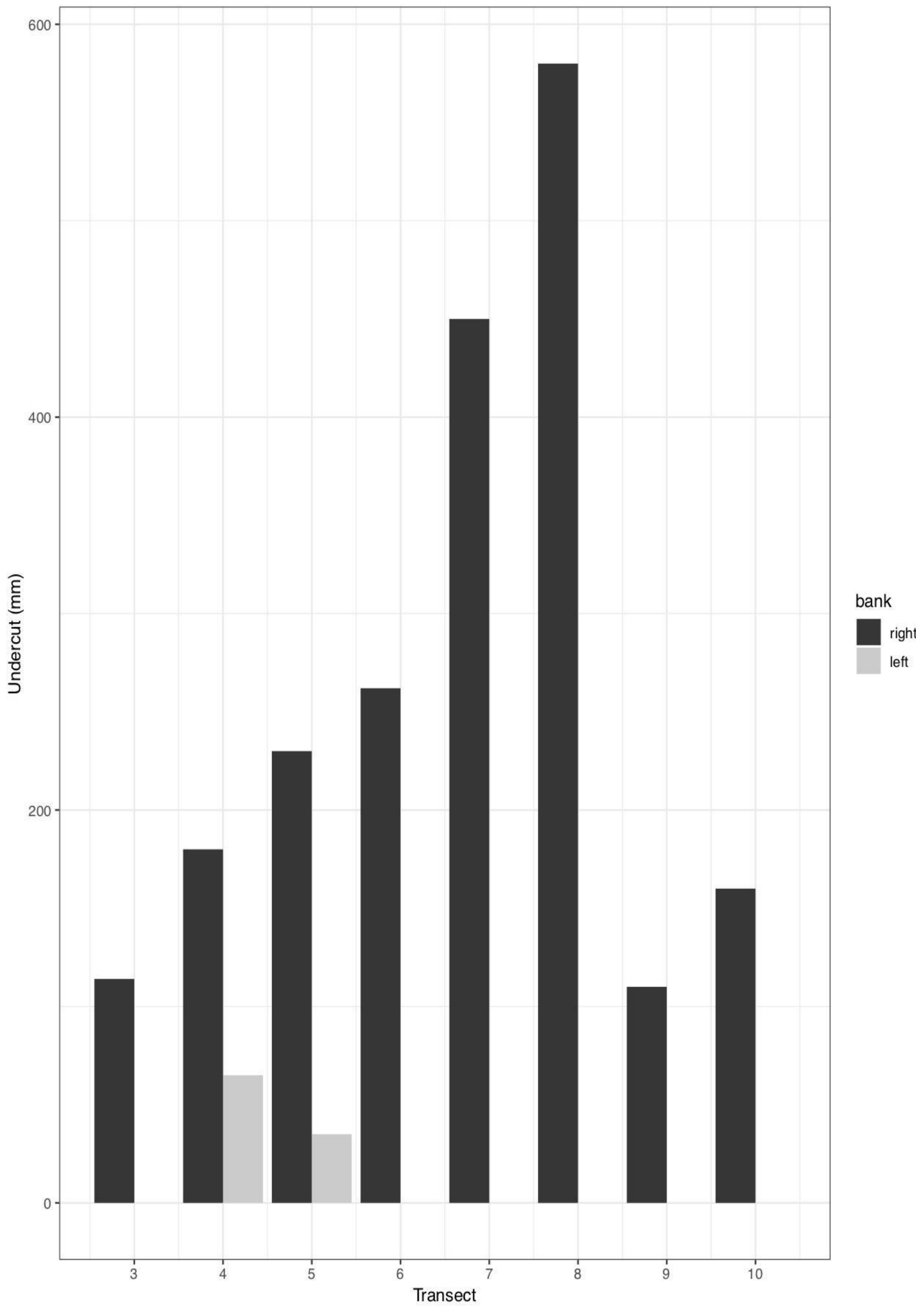

Figure 3. Bank undercutting for left and right sides of the river.

Table 1. Dominant vegetation observed along left and right banks of the Boggy River[1]

Transects		3	4	5	6	7	8	9	10
Dominant Vegetation	Left	M	M	M	none	M	M	M	M
	Right	none	none	M	none	none	none	none	none

[1] M represents grasslands that are not mowed

4. Channel Measurements

4.1. Introduction

Changes to the river system during times of flooding can change the morphology of the river, which needs to be understood relative to changes to the landscape and ecosystems around it. Channel depth constantly shifts as erosion occurs and sediment and debris build up. The morphology of an alluvial river channel is the consequence of sediment transport and sedimentation in the river (Church 2006). Understanding the types of substrate and particle size is important because it has impacts on the species that inhabit the river. Changes in sediment type may indicate a change in hydrology or that the gradient is disturbed in a river because of erosion (OSAP 2011). Build up of sediment and debris can lead to flow changes and can result in an alteration of the thalweg (the deepest, fastest moving point) in the river resulting in further change in the morphology of the river.

The channel measurement of velocity and depth changes throughout the year due to flooding (Newbury and Gaboury 1994), creating different flow patterns over time. Cultivating this understanding is imperative to the future state of the Boggy River as a preliminary study is needed to assess the impacts of climate change in the future. As the climate changes we can expect a change in precipitation that might lead to higher risks of flooding and a greater velocity at certain times in the year, which will further alter the river. The water depth is required to understand the space available for the ecosystem and organisms within it.

The species found within a river depend greatly on the channel and flow of a river. With increased flow rate, the density of macrophytes decreases. Macrophyte coverage provides a great habitat for benthic macroinvertebrates (CABIN 2011). A healthy ecosystem for macroinvertebrates in a river requires inputs and flow of water to maintain the course and prevent it from going stagnant. The velocity of the river must not be too strong as to wash their food source away. As the river changes over time we expect to see changes to the flow rate and the morphology of the river. Without understanding these components, it is hard to understand the reasons why we see the species, habitats and ecosystems that exist within the flowing body of water. By observing points along a transect, the river velocity changes could be observed as the river changed its course. The varying rates of flow and the macrophytes found within the cross sections are a good indicator of the species that could possibly be found in this river system.

Within the baseline study of the Boggy River the channel measurements and flow rate were collected to have a basic understanding of the way in which the river flows and to have a point of reference for future morphology of the river. These measurements can be helpful to determine the hydrologic characteristics and habitat conditions throughout the drainage basin (Newbury and Gaboury 1994).

4.2. Methods

Each transect had 6 observation points, as described above. The depth of the river was measured at each observation point using a meter stick. The water depth was used to set the flowmeter to 60% from the top of the water column to measure the average flow. Flow was measured in m/s. The flowmeter was placed directly on the observation point where possible, but when debris was found in the way, was placed as close to the observation point as possible while still out of the way of the debris to more accurately measure flow..

A pole with a cover ring (30 cm diameter) attached was used to observe channel characteristics at each observation point. Substrate type was determined by using the end of the pole to feel the bottom of the river. The particle size of the substrate was not determinable due to the river being too deep to reach a sample of it and because the substrate was mostly silt which is too fine to get a diameter measurement of. The macrophyte cover and woody debris that fell within the ring at each observation point were recorded.

4.3. Results and Discussion

The river was slightly deeper at the left side of the river (observation points 1 to 3; Figure 4A). There was no clear pattern in velocity relative to observation point, although it was higher in the middle of the river observation points 2 to 4, and the left side of the river tended to be slower (Figure 4B). Depth and flow were generally low with a maximum depth of 91cm and flow of 0.06m/s and a minimum of 17cm and 0m/s (Table 2).

Table 2. Mean ± standard error, minimum, and maximum channel depth (cm) and river velocity (m/s) at 40% depth, measured at 6 equidistant observations across the river for 8 transects along the sampling reach.

Observation Point	Channel depth (cm)		River velocity (m/s)	
	Mean ± SE	Min, max	Mean ± SE	Min, max
1	33.8 ± 3.67	17, 48.5	0.016 ± 0.008	0, 0.06
2	69.3 ± 5.53	40.5, 86	0.033 ± 0.006	0.01, 0.05
3	75.4 ± 5.86	54, 91	0.045 ± 0.005	0.02, 0.06
4	68.8 ±4.84	48, 81	0.036 ± 0.006	0.02, 0.06
5	55.3 ± 6.60	33, 75.5	0.011 ± 0.003	0, 0.02
6	30.6 ±3.19	22, 43.5	0.014 ± 0.004	0, 0.03

Water depth and flow change with season and it is expected that the depth and flow would be lower in fall than if we would take these measurements in spring. Depth was higher on the left side which relates to the morphology of the river. We measured at a site that captured a bend in the meandering stream, which meant that there was a change in the outside of the stream from left to right. This could explain why we saw that the depth was generally greater on the left side or observation points 2 and 3 (Figure 4B). The depth was generally low due to the dry season of fall.

Higher water velocity in the middle of the river is expected as there is the smallest amount of friction compared to the sides of the river that move along the banks. The variability could be explained by the shallow depth combined with the large amount of debris and woody matter found in the channel. Though in Figure 4B it appears that there is great change in velocity, the differences are actually quite small as the overall flow of the river was very slow, only ranging from 0 to 0.06 m/s. In some shallow observation points closest to the banks the water appeared to be still. There are not any previous measurements so it is not known whether these were very low compared to previous years. It appears that the river measurements were to be expected at this time of year and when measurements are taken again in future years these records can be used to determine if there is extremely low flow or water levels that could be detrimental to the health of the river and its inhabitants.

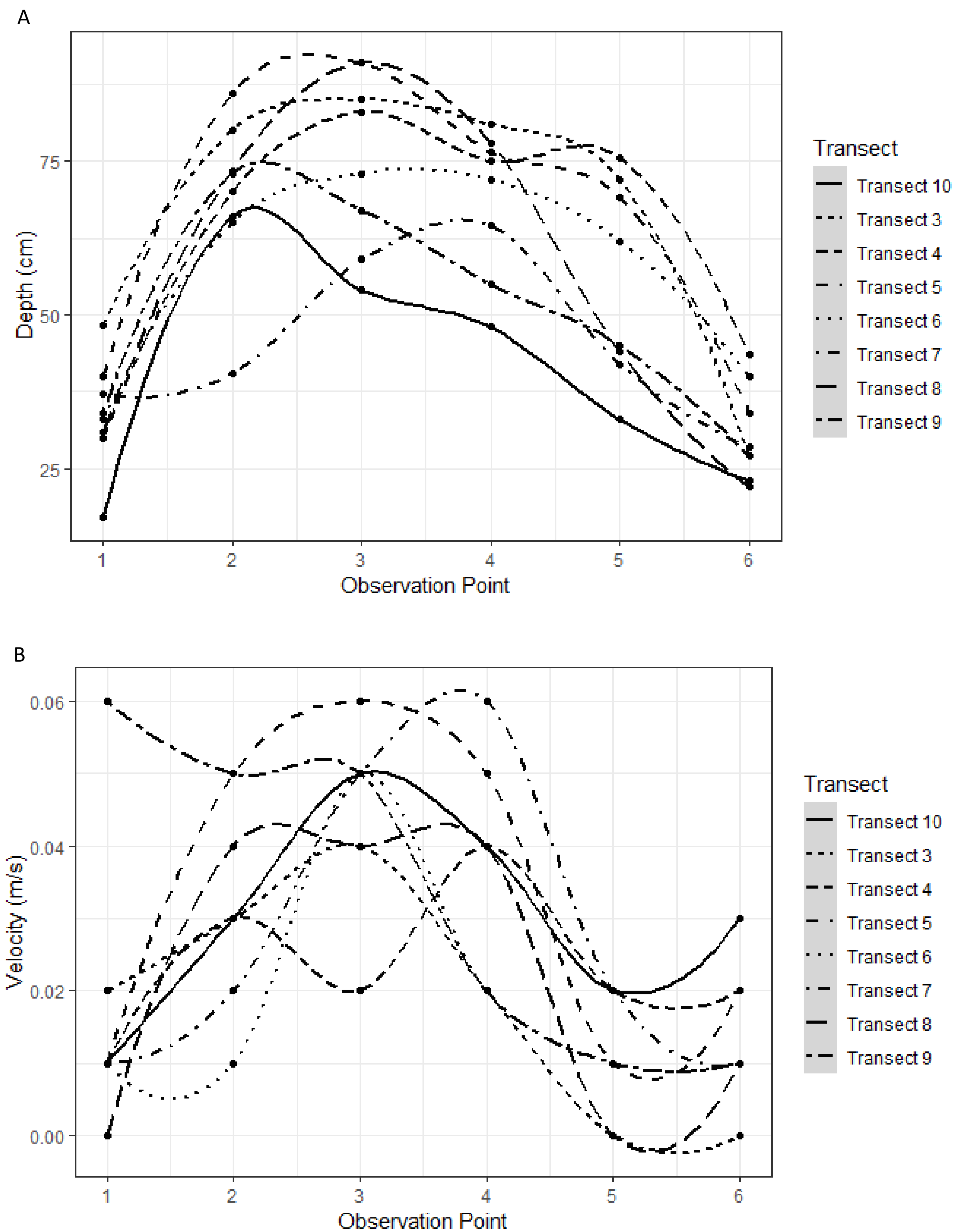

Figure 4. Channel measurements at 6 equidistant observations across the river for 8 transects along the sampling reach. Measurements are A) channel depth (cm) and B) river velocity (m/s) measured at 40% depth.

From Figure 5, we can see that the sediment composition of the Boggy River is consistently made up of silt. In all of the observed transects except for transect 10, we can see that the sediment type is dominated by silt. We might however be able to conclude that transect 10 is also dominated by silt, due to the categorization of soft silt. This of course was different enough to justify the alternate categorization, but not so much as to say that it was not silt. This is consistent with the very low velocity of the river, which is slow enough that silt could settle out of the water column, rather than being carried downstream.

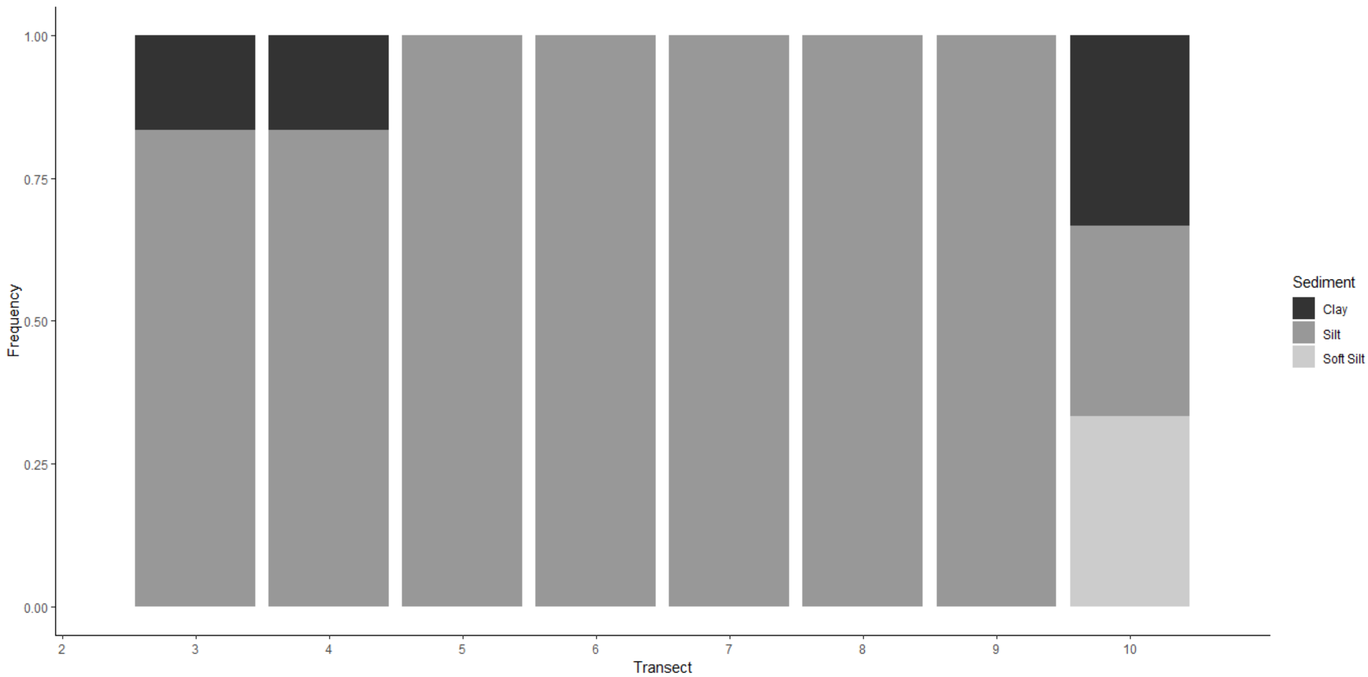

Figure 5. Sediment composition in the river channel by transect, with 3 being the bottom of the reach (most downstream) and 10 being the top (most upstream).

However, it is important not to dismiss the presence of clay that was observed in small frequencies at transects 3, 4, and 10. This could suggest higher water flow in these areas, as the clay has not been covered with deposited silt. Therefore these areas could be experiencing higher water flow.

The Boggy River has a low velocity and a fine substrate, making it a suitable ecosystem for instream vegetation growth (Morrow and Fischenich 2000). The results show that there are macrophytes present along the edges of the river while there is no vegetation at the center of the river. Figure 6 shows that there is more vegetation on the right side of the river than there is on the left side of the river. This could be due to the depth, as the left side of the river was found to be deeper than the right side. Shallower water allows more abundant sunlight and encourages more vegetation growth.

Instream vegetation is an important feature in fish habitat in river systems. Generally higher habitat complexity, due to features such as instream vegetation and woody debris, creates greater habitat for fishes and invertebrates to thrive in. In addition, macrophytes are an important food source for some fishes as well as for macroinvertebrate grazers. The common shiner, the fish that was most commonly observed in our baseline ecological study, thrives best in streams with 50% vegetation coverage (Trial et. al 1983). Macrophytes were observed at 42% of the measurement points observed, indicating that there is almost the ideal amount of instream vegetation for the common shiner specifically.

While the presence of vegetation indicates higher habitat complexity and therefore reflects positively on the general well-being of the Boggy River ecosystem, it is important to keep in mind that it is possible to have too much vegetation in a river. An overabundance of vegetation can lead to low levels of dissolved oxygen in the water as die-off from the vegetation decomposes, particularly in slow-moving rivers in which dead organic matter is not carried downstream but decomposes in place. The process of decomposition uses dissolved oxygen, leaving less oxygen for fish and invertebrates to use. While the current levels of vegetation seem relatively positive, in future management, vegetation and oxygen levels should continue to be monitored.

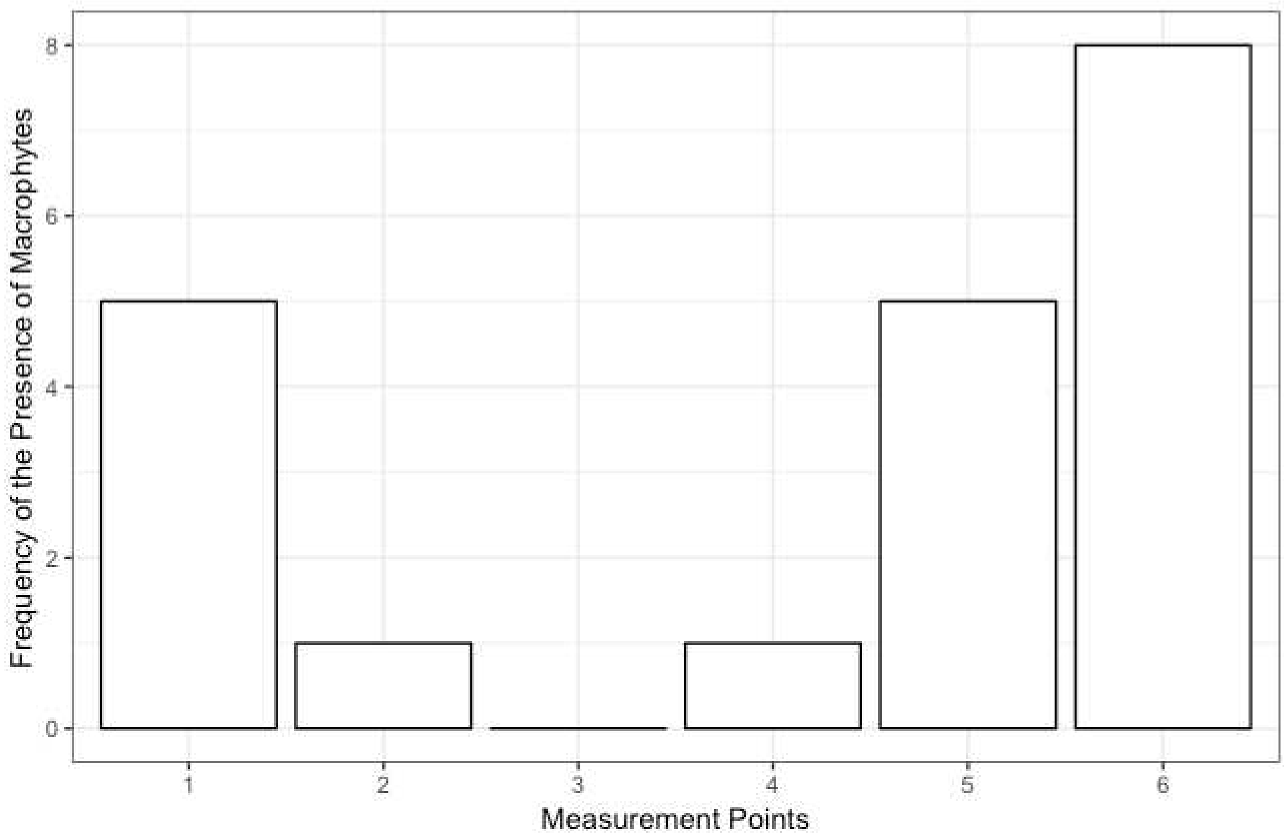

Figure 6. The frequency (count) of the presence of macrophytes at longitudinal measurement points taken at each transect, measurement points moving from left to right.

The results displayed in Figure 7 show that there is more woody debris present near the centre of the river, which is expected as the current of the river draws woody debris towards its quickest and deepest area. The third observation point in 5 out of 8 transects had woody debris, while most of the other observation points had only 2 of the 8 transects with woody debris, and the sixth observation point had only woody debris in only one transect.

Woody debris is another important aspect of fish and invertebrate habitat. Woody debris provides necessary cover, hiding places for prey to escape predators, places for fish eggs to adhere to, and a velocity break (Morrow and Fischenich 2000).Generally, the more complex the habitat, the better it is for fish populations and therefore the presence of woody debris in the Boggy River reflects positively on the well-being of the ecosystem. In addition, woody debris provides a substrate for algae to grow on. Algae is a food source for fishes and invertebrate grazers, making the presence of woody debris within river ecosystems important.

Management of ecosystems is often held in tension with human desires and needs. While woody debris is an important aspect of fish and invertebrate habitat, a surplus of woody debris can lead to flooding. Flooding can have many interesting ecological impacts on a river, distributing nutrients to riparian zones, having morphological impacts on the river, and perhaps creating pools nearby. However, flooding can be detrimental to human well-being. The main lodge that is used by A Rocha is right beside the Boggy River. As woody debris accumulates in the river over time, there could be an increased risk of flooding which could put the main lodge at risk. This tension of ecological and human needs should be kept in mind in future management of the Boggy River.

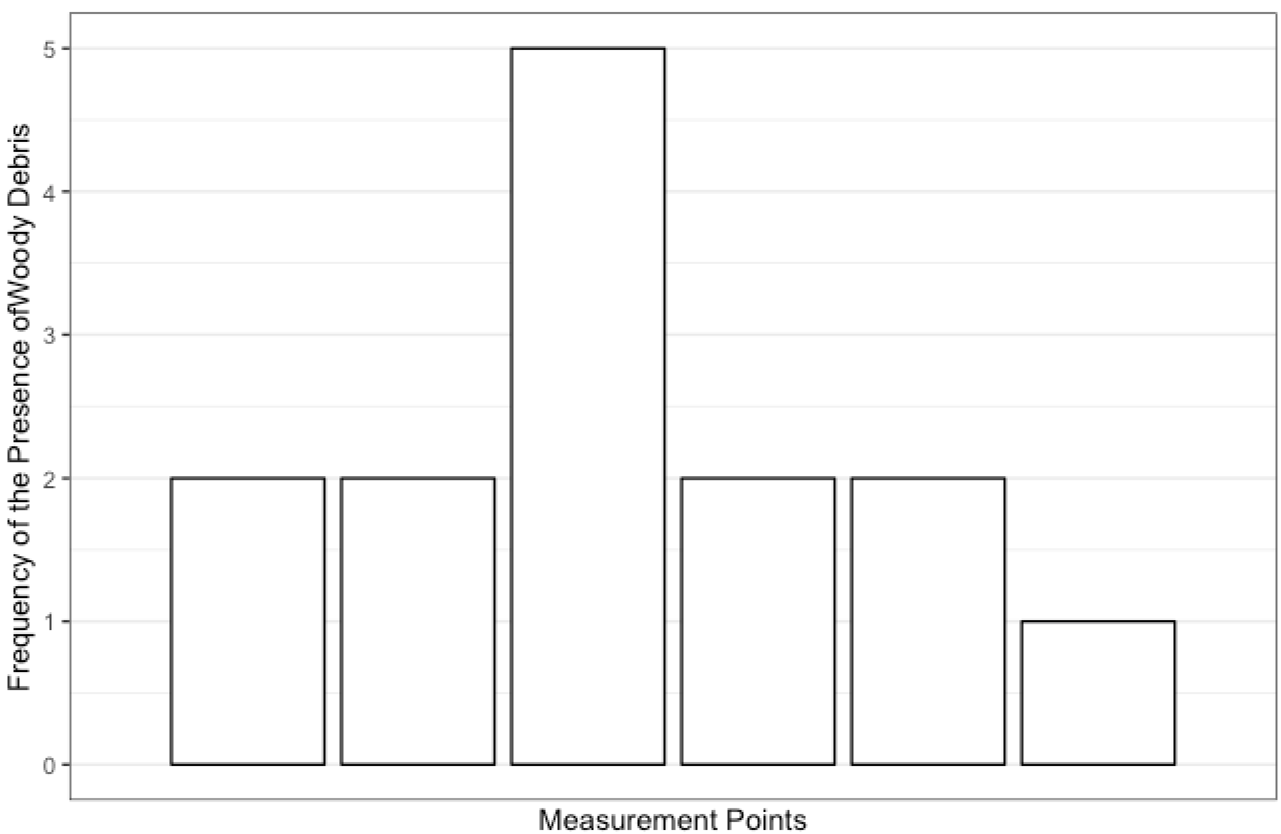

Figure 7. The frequency of the presence of woody debris at longitudinal measurement points taken at each transect, measurement points moving from left to right.

5. Water Chemistry

5.1 Introduction

Water chemistry data can be observed alongside biological data to evaluate the health of a river system. The chemical profile of a river affects the survival of benthic macroinvertebrates and fishes, and can also indicate pollution of the river. Therefore, chemistry measurements that can be helpful in health evaluation are: dissolved oxygen, presence of nitrates and phosphates, temperature, pH, specific conductivity, and total dissolved solids. Together, chemistry and biological data present an important story about the health of the Boggy River.

5.2 Methods

The water chemistry tests were performed using a handheld multi-meter for temperature, pH, total dissolved solids, and specific conductivity, a handheld dissolved oxygen meter for dissolved oxygen, and water testing kits for nitrates and phosphates. Water chemistry tests were performed once in the late afternoon, and once in the early morning the following day, with the exception of nitrates and phosphates, which were measured only once, in the afternoon. Measurements collected at different times allowed for the observation of daily levels of dissolved oxygen, as well as other daily fluctuations of water chemistry.

5.3 Results and Discussion

The water chemistry results in Table 3 show a relatively stable river with consistent numbers for both sampling times. The temperature change in the water can be explained by the weather, as it snowed shortly after the first test, leading to a drop in water temperature seen in the test the morning after. The dissolved oxygen level reduction of the later test seen in comparison to the first is due to the second test being done in the morning when there has been lower levels of photosynthesis occurring. The nitrates and phosphates were under the detectable level, as expected, as there is little human development or agriculture upstream of the sampling reach.

Table 3. Water chemistry measurements from the sample reach, measured at two times.

Date, time	**Air Temperature (°C)**	**Water Temperature (°C)**	**pH**	**Specific Conductance (µs/cm)**	**Dissolved Oxygen (mg/L)**	**Total Dissolved Solids (ppm)**
2018-09-22, 18:25	**2.9**	**9.3**	**7.8**	**394**	**7.8**	**276**
2018-09-23, 07:50	**4.3**	**7.0**	**7.6**	**381**	**7.0**	**266**

6. Benthic Macroinvertebrates

6.1 Introduction

Traditionally, water quality measurements have focused on physical and chemical characteristics of river ecosystems. Although these characteristics can give an important perspective, river systems are in a constant state of flux and therefore the conditions at any particular point in time cannot be assumed to represent the prevailing conditions of an ecosystem. In order to address this problem, and provide a more complete perspective on a river's condition, researchers have looked at biological characteristics of river systems (Environment Canada 2012). Biotic communities respond to both natural and human influenced changes of their habitat. Therefore, sampling biotic communities can provide a perspective on the ecological health of a particular ecosystem (Kenney et al. 2009).

Benthic macroinvertebrates were sampled as a biotic community for the baseline study of the Boggy River. Benthic macroinvertebrates are key players in the river ecosystems. They are decomposers, and therefore important in providing accessible nutrients for plant species. Benthic macroinvertebrates are also key participants in the food web as both prey and consumers (Kenney et al. 2009). In addition to their distinct importance to the health of their ecosystems, benthic macroinvertebrate communities are commonly sampled as indicators of the health of river ecosystems as they are relatively sedentary and therefore can provide information about a particular location (Kenney et al. 2009), and they are relatively long-lived, with lifespans of 1-3 years and therefore can provide data that demonstrates the health of a river for a sustained period of time (Environment Canada 2012). This contrasts with chemical and physical data, which is constantly in flux.

Human impact on the river through pollution or other disturbance would affect the overall diversity and abundance of benthic macroinvertebrates in the Boggy River (Moore and Palmer 2005). Pollution of the river would decrease the relative abundance of taxa that are sensitive to pollutants such as Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (Kenney et al. 2009). If these sensitive taxa are present in abundance, it would indicate a river system with relatively few disturbances or pollutants. If the Boggy River is undisturbed, we would expect to find these pollutant-sensitive taxa within our sample as well as high levels of species diversity.

The baseline ecological study that was conducted on the Boggy River can act as a reference point for the future condition of the river. In long-term monitoring, the change in the community of benthic macroinvertebrates needs to be monitored as an indicator of human-induced disturbances and of the general health of the river.

6.2 Methods

The benthic macroinvertebrate community of the Boggy River was sampled with a kicknet procedure, which was performed in a short section of the larger sampling reach that was representative of the total reach. The baseline study was conducted in early fall which is ideal for sampling benthic macroinvertebrates as most invertebrates are in their aquatic stage at this time of year, so the collected data provides an accurate picture of the organisms that are present in the Boggy River.

The kicknet procedure follows the Canadian Aquatic Biomonitoring Network (CABIN) protocol. By following this protocol, the data collected can be added to the CABIN national online database. In order to fulfill the requirements of CABIN, a number of other observations about the physical and chemical characteristics of the river were recorded. This included habitat type, canopy cover, macrophyte cover, streamside vegetation, and periphyton coverage.

The invertebrates that collected in the kicknet were sorted into families and their quantities were recorded. This data indicates the general diversity of benthic macroinvertebrates present as well as the relative abundance of pollutant-sensitive taxa.

6.3 Results and Discussion

The benthic macroinvertebrate sample found 433 individuals made up of 15 different families (Figure 8). The most common benthic invertebrates found were mayflies (Ephemeroptera), midge larvae (Chironomidae) and water mites (Acari). These three made up 74 percent of our findings. There were a few individuals that were captured in our kick net sample that were not benthic invertebrates; these were not included in the final results (Figure 8).

The abundance and diversity of our kick net sample suggests that the Boggy River is overall a healthy water system and has been for a while. The high number of mayflies is an indicator that the Boggy River is not polluted, because they are highly sensitive to pollution. This is also true of caddisflies and stoneflies. Caddisflies were found in the sample, though not at the same abundance as mayflies. There were no stoneflies found in the kicknet sample. Also, no dragonflies were found in our kicknet sample, although these are known to inhabit the area and were seen at other points during the data collection.

The benthic invertebrate sample taken at the Boggy River indicates that the river is healthy, with no major pollution. The river has likely been stable for a long enough period that pollution sensitive species have established and thrived, resulting in the high numbers of mayflies observed. This baseline survey of benthic invertebrates will provide context for any further studies of the Boggy River. In addition, the data collected using the CABIN protocol was recorded for the online database and can be found in the appendix.

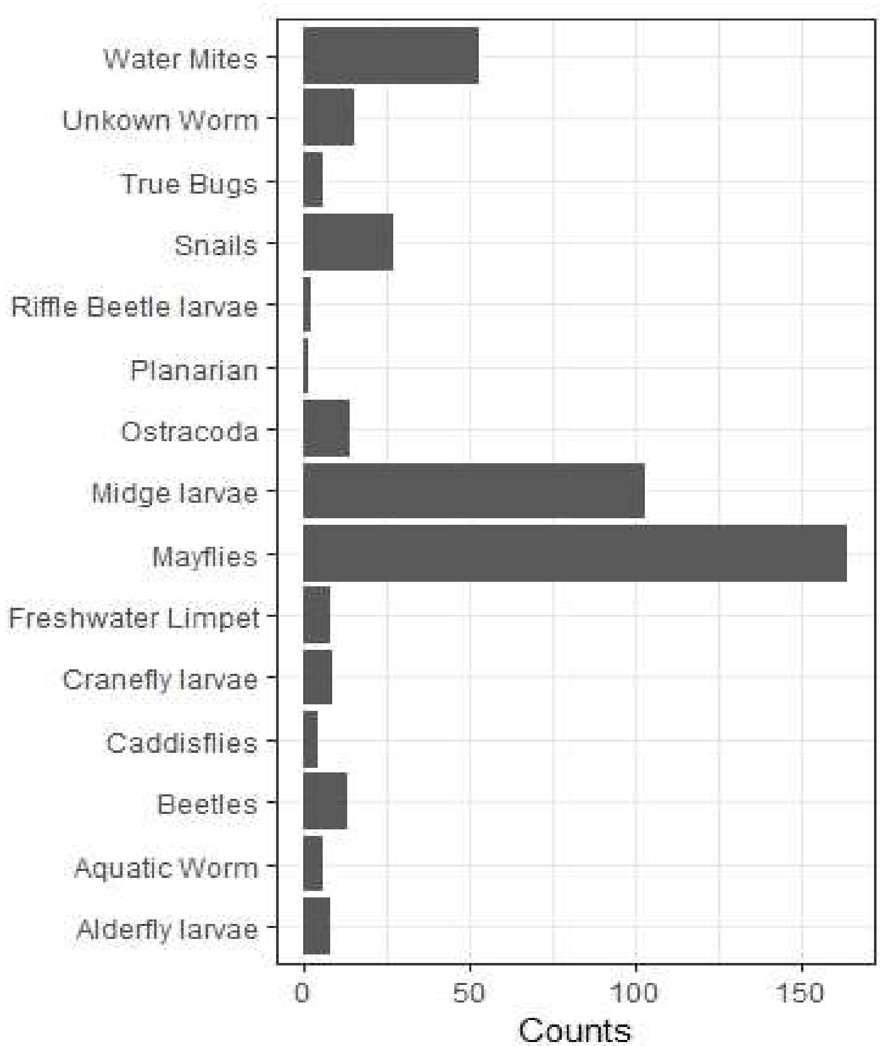

Figure 8. Benthic macroinvertebrates sampled using a kicknet, following methodology of the Canadian Aquatic Benthic Invertebrate Network.

7. Fishes

7.1. Introduction

To develop a baseline ecological survey of the Boggy River there are a number of factors that need to be accounted for. Among these factors are surveys of the biodiversity of the system. Biodiversity is often one of the first places biologists look when assessing the health of an ecosystem (National CABIN Science Forum 2017). The biodiversity that is supported by an ecosystem is able to exist due to a number of factors, including resource availability and river conditions (Bain 1988).

Fish are valuable to study for a number of reasons. Besides having significant economic and cultural value, fish are useful for understanding the general health of river ecosystems. This is especially true in Manitoba, which has been demonstrated to have the third highest fish diversity in Canada (Stewart and

Watkinson 2014). The quantities of different fish species is useful for determining the overall biodiversity of the river. Additionally, surveys can offer a clear understanding of which species can thrive in a given ecosystem, identifying both invasive and at risk species (Stanfield 2017). The species diversity of an ecosystem can be a clear indicator of an ecosystem's health, as it demonstrates an ability to provide for a variety of species (National CABIN Science Forum 2017).

During our observations, we were able to get a clear look at species diversity and quantity of fishes. These observations could offer some indication of which species are present in the Boggy River and in approximately what quantities. As previously discussed, such factors are crucial for understanding species diversity and by extension, overall ecosystem health. The sizes of sampled individuals help indicate what life stages of observed species can be found within the river (Stanfield 2017). We considered smaller unidentifiable fish as juveniles, and larger fish would have corresponded to any number of species.

Over time, it will be important to continue to sample the sizes of individuals, as changes may indicate which life stages and species of fish depend more on this habitat. This may vary based on season or changes occurring in the ecosystem over extended periods of time (Stanfield 2017). If by performing the exact same collection process we find fewer individuals, it may suggest that resources are lacking. Changes in these observations would allow us to see if the supportive capabilities of the river are improving or faltering. These observations can be supported by understanding the abiotic conditions that different species need to survive (Bain et al. 1988).

From data that we gathered, we would expect to observe a healthy river ecosystem based on the diversity of fish species. A large variety would indicate that the Boggy River would be able to support a great diversity of species. Additionally, the sizes of the observed fish should indicate the Boggy River is home to fish at variable life stages. Findings that show limited diversity would raise some concerns about the health of the river, and indicate that there is something preventing fish from thriving in the Boggy River.

7.2 Methods

In order to take a representative sample of the fish diversity of the Boggy River, our team used minnow seines to collect fish. We collected fish in two groups spanning the width of the river so we could cover a larger area, thereby ensuring a more thorough collection. One person held the net at either end at the poles. The weighted end of the net and end poles were held so they were always touching the bottom of the river. The net was scooped from the bottom after a long run or immediately after being caught on submerged logs or branches. Once the nets were brought out of the water we collected and identified all of the fish.

We measured the total length of each individual. After being measured, fish were placed in a petri dish and weighed. After being weighed the fish were identified and verified by consulting Stewart and Watkinson's *The Freshwater Fishes of Manitoba* (2014). Fish were then placed into designated buckets based on species.

Any fish we could not immediately identify was photographed and set aside to be reassessed. These photos were analyzed later and their species concluded. All of this was recorded on data sheets.

After recording the mass, total length, and identification of each individual, the fish were released back into the Boggy River.

7.3 Results and Discussion

Our fish sample resulted in 118 individuals that represented seven species: shorthead redhorse, rock bass, common shiner, longnose dace, blackside darter, johnny darter, and brook stickleback (Figure 9). In addition, there were 71 juveniles that were unidentifiable due to size though appeared to be common shiners. The most prominent species was the common shiner, *Notropis cornutus,* followed by blackside darter, *Percina maculata,* and longnose dace, *Rhinichthys cataractae.* The weights ranged from just over 2 g to under 0.1 g (Table 4) and length of these fishes ranged from 2.1 cm to over 12 cm (Table 5). All species found were known to be in this watershed and our results were expected for this area and habitat type.

Common shiners are very well known and are commonly found in rivers as well as some shore waters of lakes (Stewart and Watkinson 2014). They are more generalist than the other species found, which may explain the large numbers and size distribution. Common shiners are also schooling fish that swim in the middle of the water column, unlike darters, dace, and redhorse, which tend to stay on or close to the riverbed. It may have been the case that when seining, our nets were best designed to catch mid column schooling fish resulting in the abundance of common shiners. The other fishes sampled were also known to be found in this area and use small rivers as habitat. Rock bass was the most surprising fish found, as the sediment was silty clay not gravel or boulders as is considered the normal habitat for this species, yet these fish tend to use fallen trees and other macrophyte cover as shelter. It is quite possible that the bass found were the young of year and the mature bass came into this smaller river to nest. There was a rocky area downstream of our sampling reach with many larger boulders in the river, which too may have explained the observation of rock bass.

Our results tell us that there was fish diversity in the river, which relates back to the overall diversity and health of the ecosystem. Over time, this baseline record of fishes will help to determine if there are changes in fish species composition and overall biodiversity over time.

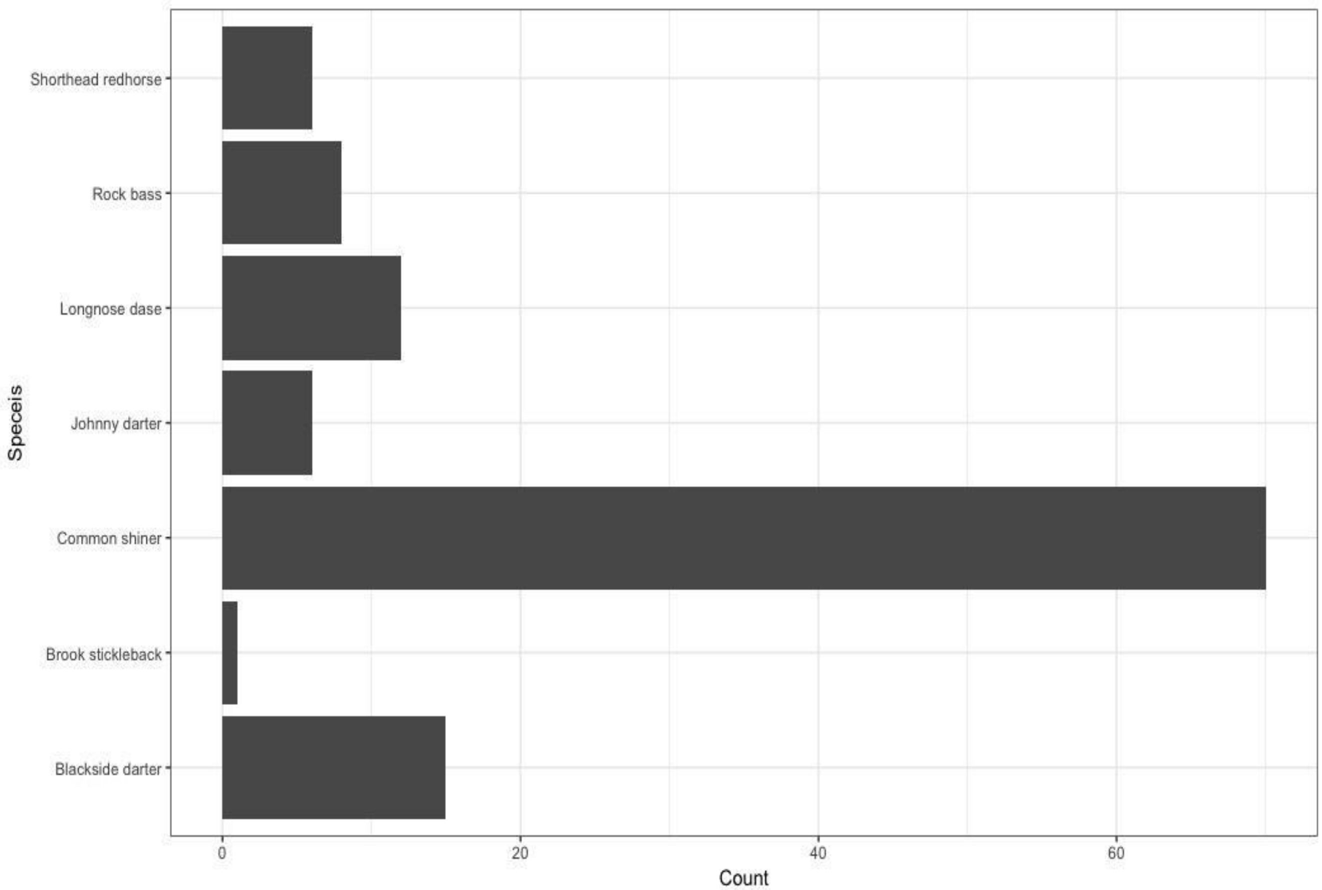

Figure 9. Fish count caught in the minnow seine over all 10 transects by species.

Table 4. Mean, standard error, minimum, and maximum fish weight (g) by species.

Species	Mean Weight (g) [1]	Min Weight (g) [2]	Max Weight (g)	Standard Error [3]
Blackside darter	0.71	< 0.1	2.2	0.17
Brook stickleback	0.40	0.4	0.4	NA
Rock bass	0.30	< 0.1	0.3	NA
Common shiner	2.06	0.3	15.5	0.30
Longnose dace	1.10	0.4	1.8	0.11
Shorthead redhorse	0.70	0.4	1.2	0.13
Johnny darter	1.03	<0.1	1.2	0.09

[1]Weights for two blackside darter, seven rock bass, and three johnny darter were less than 0.1, too small to be read on the scale, so they were not included in calculating the mean.

[2]Weights for two blackside darter, seven rock bass, and three johnny darter were less than 0.1, too small to be read on the scale, so the minimum weight was recorded as <0.1.

[3]There was only one weight recorded for brook stickleback and rock bass so the standard error was not calculated.

Table 5. Mean, standard error, minimum, and maximum fish weight (g) by species.

Species	Mean Length (cm)	Min Length (cm)	Max Length (cm)	Standard Error [1]
Blackside darter	3.91	2.9	6.3	0.26
Brook stickleback	3.50	3.5	3.5	NA
Rock bass	2.19	1.2	2.7	0.17
Common shiner	5.79	3.3	12.5	0.23
Longnose dace	4.98	4.4	5.6	0.13
Shorthead redhorse	4.08	3.4	5.1	0.23
Johnny darter	3.75	2.5	5.3	0.47

[1]There was only one length recorded for brook stickleback so the standard error was not calculated.

8. Overall Discussion

8.1 Bank Stability

The 100 m sampling reach of this baseline survey included a bend in the river to the left, with erosion occurring on the right bank. This is displayed by the high bank angle and undercuts on the right bank observed at transects 7 and 8. This erosion is a result of the natural meandering movement of a river over time. This can present some concerns when rivers encroach on places utilized by humans, such as land that holds roads or buildings. The more extreme erosion that is seen at transects 7 and 8 could be connected to the lack of bankside vegetation seen along the right side of the bank. The lack of plant material could allow for erosion to occur in the river in high amounts as evidenced by the noticeably greater undercuts and bank angles at certain points. This erosion could be promoted by the observed lack of plant material, which uses root systems to hold sediments together, preventing them from being washed away (Jeffery et al. 2008).

Classification of bank stability according to OSAP can be found in Table 6. The first category for classifying the stability of a bank is bank angle. Our results of the bank angle measurements show all angles to be less than 45° with the exception of transects 7 and 8 on the right bank. Therefore, in this sampling reach, the bank is almost always categorized as a “deposition zone.” This category has a gentle slope and the substrate is usually materials that have been deposited by the river. On the other hand, the bank at transect 8 would be classified as an “eroding bank.” This classification has a bank angle greater than 45º, substrate that is erodible, and has other characteristics such as an undercut of at least 5 cm, and little to no vegetation. The measurements collected for transect 8 had an angle of 56º, silt substrate, no vegetation, and an undercut of 5.8 cm. The bank stability for transect 7, although the undercut is less than 5 cm, is classified as an eroding bank because it shows recent signs of erosion (see Table 6). The measurements collected were an angle of 52º, silt substrate, no vegetation, and undercutting of 4.5 cm. This may be a natural consequence of the curve of the river at these transects. Alternatively, the differing results at transects 7 and 8 could have resulted from a localized disturbance, such as rain water entering the river system. This could result in the increased in erosion at these particular locations (Longoni et al. 2016). Observation over time will help to determine which of these is more likely, and therefore whether any intervention is necessary.

Table 6. Classification of Bank Stability (recreated from OSAP manual, S4.M1: page 9)

Bank Stability Categories	Interface between Water and Bank	Bank Soil/Substrate	Characteristics of Bank
“Eroding Bank”	Steep, >45°	Erodible materials	Undercut (by at least 5 cm) or shows signs of recent slumping (e.g. no or little vegetation present)
“Vulnerable Bank”	Steep, >45°	Erodible materials	Shows no recent signs of erosion (e.g. undercuts or slumping) and protected by a mat of live vegetation
“Protected Bank”	Steep, >45°	Non-erodible materials (e.g. rock, boulders or hardened clay)	Vegetation may or may not be present, includes banks armoured by humans
“Deposition zone”	Gentle, <45°	Generally, materials deposited by the river during flood conditions	Point bars inside bends of streams

8.2 Vegetation and Stream Flow

The morphology of a stream is influenced by various abiotic and biotic characteristics and their interactions, including occurrence of macrophytes, channel woody debris, stream velocity, substrate, light, and nutrient status. The presence of woody debris in the channel seems to be inversely related to the presence of macrophyte cover. It could be that woody debris is preventing access to either space or sunlight. With dead woody material that is more difficult to be broken down, the space available to river plant material could be severely lessened. This could also be restricting their access to light resources, though this may not be as much of an influencer depending of the photosynthetic needs of river macrophytes. According to Franklin et al. (2008), although the minimal light at this location impacts lack of macrophytes, it is also possible that at higher flow times of the year, higher water velocity could be removing biomass faster than it grows.

Our macrophyte results show a larger biomass on the right side of the bank; vegetation was noted in 8 transects out of 10. No macrophytes were found in the center of the stream at observation point 3 in all transects. Observation point 3 on all transects has the highest mean velocity, corresponding to 0.045 m/s; this correlated with the absence of vegetation. Franklin et al. (2008) says that, while the combination of light, substrate, and nutrient status control the status of macrophytes, it is stream discharge and velocity that have the largest effect. The working mechanism deals with biomass loss and gain. It is important to consider that while observation point 3 on the transects has the highest mean velocity, this measurement is when the river is near its annual low. It is expected that this result will exist when the river is higher with larger velocity and discharge. It should be noted that the stream velocity itself is impacted by woody debris, which impacts factors such as macrophyte presence.

River morphology is impacted by the presence of woody debris. Woody debris is sufficient enough to significantly impact the flow of water, and therefore its morphology. We have been able to observe that the width of the river remains fairly consistent, suggesting a consistent flow of water. The large amounts of woody material could be influencing this by regulating the rate at which water is able to flow through the system. Woody debris would could inhibit the flow of water, thereby regulating the amount of water flowing through the river at any given point. Regulating stream flow has also been known to limit the effects of erosion, therefore the presence of woody debris could be good for the health of the river system (Wayne et al 2011).

8.3 Fish and Benthic Macroinvertebrate Populations

Fishes and benthic macroinvertebrates are effective biological indicators of a river ecosystem's health. The results of the Boggy River fish and benthic samples show a relatively large diversity of species. As mentioned in sections 6.3 and 7.3, this indicates a healthy stream. The benthic macroinvertebrates that were present included disturbance-sensitive taxa, indicating that the habitat is relatively free of toxic pollutants and has experienced minimal human disturbance. The results for the benthic invertebrate are closely tied to the channel flow, as they are dependent on the flow to remain consistent and at the same strength allowing nutrient to be brought downstream and provide habitat.

It is not surprising that a high diversity of benthic invertebrates are found alongside many fishes. The benthic invertebrates make up a significant portion of many fish diets, which helps to explain this association, and demonstrates a more complex food web with many predator-prey relationships, and redundancies that increase the resilience of the system.

The variability in the numbers of different fish species observed could have been due to their dependence on different areas in the water column. As discussed, fish have habitat preferences that lead to them live in different parts of the water column. It could be that the biodiversity that we observed is related to the variability in channel depths observed. The same can be said for changes observed in water velocity. (Mark et al.

1988). There was also a sizeable amount of woody debris present in the channel, providing habitat for both benthic invertebrates and fishes. Both instream vegetation and woody debris play an important part in fish habitat. Interestingly, there were many juvenile fish present in our sample. This indicates that the habitat created by factors such as vegetation and woody debris is a good nursery location for young fishes. The Boggy River, which seems to be a relatively healthy ecosystem, could be an essential location for the growth of juvenile fishes within the larger watershed.

9. Recommendations

9.1 Future Monitoring

For future monitoring, it would be beneficial to continue to monitor water temperature and chemistry, in the fall (as we did) and also during the summer. It would be useful to know if the temperature of the river is increasing; looking for a long-term trend could be important for climate change monitoring. Major increases in temperature along with low flow and shallow depth can be hard on fish species because it leads to low oxygen levels. Some species may be more vulnerable than others, and will be more strongly negatively affected with major changes in the climate. The fish species would also be affected by varying pH levels.

The watershed surrounding the Boggy River contains minimal agricultural land. However, if this were to change, there would be concern that chemical runoff from agricultural inputs could change the river's pH. Agriculture fertilizers change soil and water pH by increasing the acidity through dissociation of the particular fertilizers and the release of hydrogen ions (Mosaic n.d.). The pH of the stretch of the Boggy River that holds our interest was measured at 7.8 and 7.6, slightly above neutral. These existing measurements are of no concern to the river's health, though the river's pH should continue to be monitored. If there is any substantial change in pH, even if it is within habitat tolerance, interventions should take place.

Presently, the left bank of the sampling reach is classified as a "deposition zone;" it does not need any extensive intervention measures. It is recommended that these areas of bank be monitored, although they are not vulnerable or eroding banks, because other areas in this stretch of the river exhibit severe erosion. For the right bank between transects 7 and 8 of the sampling reach, the bank is much steep with evidence of some erosion and undercutting. If this erosion acclerates and the bank becomes increasingly unstable, the following intervention measures are suggested. One recommendation is the use of vegetation to increase bank stability. Vegetation offers the best long-term protection for slope erosion, but lesser protection for shallow mass-movement (Johnston and Stypula 1993). The limitations of using plants is that the roots can actually weaken bank structure under some circumstances, and large trees have a risk of toppling over. This is why vegetation selection is important. For this stretch of the Boggy River it is recommended that grasses, such as those found on the left bank, be planted. Installation guidelines can be found in Guidelines for Bank Stabilization Projects in the Riverine Environments of King County (Johnston and Stypula 1993). There still remains the problem of the steep vertical bank angle where vegetation would not easily be implemented. A rehabilitation measure that could be used here is a riprap design. A riprap design places rocky material along shorelines to prevent erosion. This restoration would be more extensive than vegetation stabilization, so we suggest that vegetation be installed, and the bank monitored for changes before proceeding to this more invasive approach.

Fish populations, including juvenile fishes should also be monitored. Juvenile fishes are impacted by habitat variability and hydraulic flow (Freeman et al. 2001). Juvenile fishes are more commonly found in streams when the habitat is more stable and flow is lower; this is constant with the large number of juvenile fish this study sampled. Freeman et al.'s study noted seasonal spawning species are impacted when stream regulation changes velocity (2001). Since this is a baseline study of the Boggy River, more measurements should be taken over the years to see if the species, and sizes of the fishes, changes before any interventions like velocity changes occur. At the moment, the fishes sampled do not suggest concern for the river's health. We also recommend that fish samples be taken at different times of the year to observe which species change with the seasons. Additionally, we recommend that larger species also be monitored. Larger fishes were not monitored in this study because of the limitations of the minnow seines we used; we recommend the use of additional fish monitoring equipment, such as fyke nets, to monitor larger bodied fishes to give a more complete picture of fish species diversity in the Boggy River.

9.2 Future Studies

There are a number of possibilities of future studies to strengthen and develop our understanding of the Boggy River. As A Rocha continues to interact with the river, we recommend further research in the following areas: a further reach sampling, a retrospective study of past changes, and a comparison of present conditions observed in this baseline study with previous work in the area by Clarke in 1996, which covered a portion of the Boggy River. Comparing Clarke's (1996) results to this study could be beneficial in understanding any changes in the morphology of the river, the velocity of the water, and the fish biodiversity.

In future studies it would be beneficial to observe differences that could be caused by increased inputs from falling debris and any added salt from the road and bridge during the winter months. These inputs could affect the water chemistry and could have a negative impact on the ecosystem.

10. Conclusions

While this baseline ecological survey indicates that the Boggy River has experienced little human disturbance in the recent past, it is important to continue to monitor the river regularly for any changes. This baseline ecological survey provides a reference point for future observations to be compared to. As A Rocha begins environmental stewardship and education programming beside the Boggy River, there is a chance that human impacts on the watershed could increase. Changes in observations would indicate disturbance, and assist managers in deciphering how to best manage and protect the river.

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12. Appendices

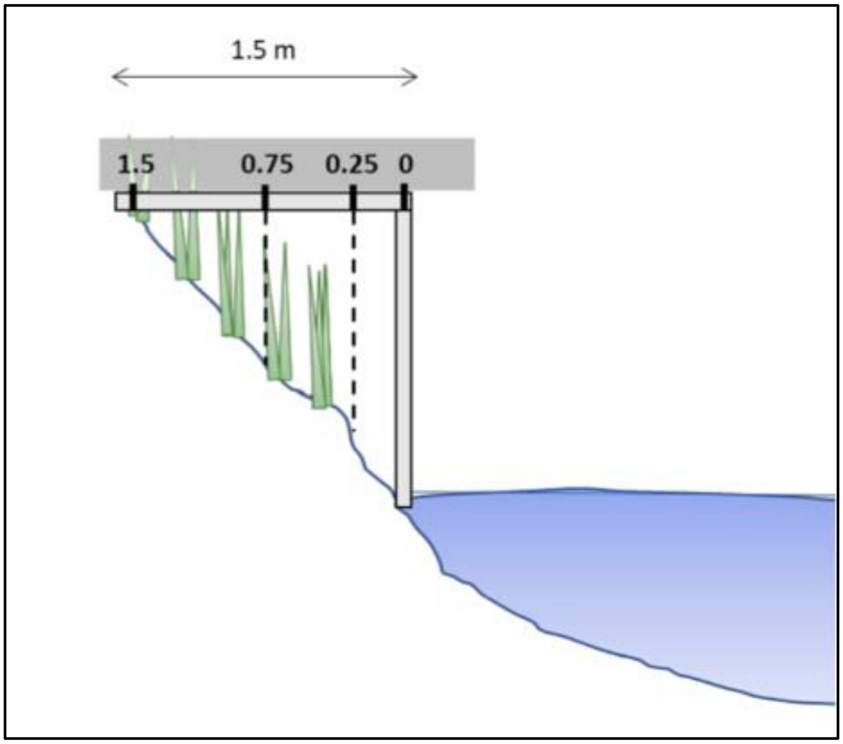
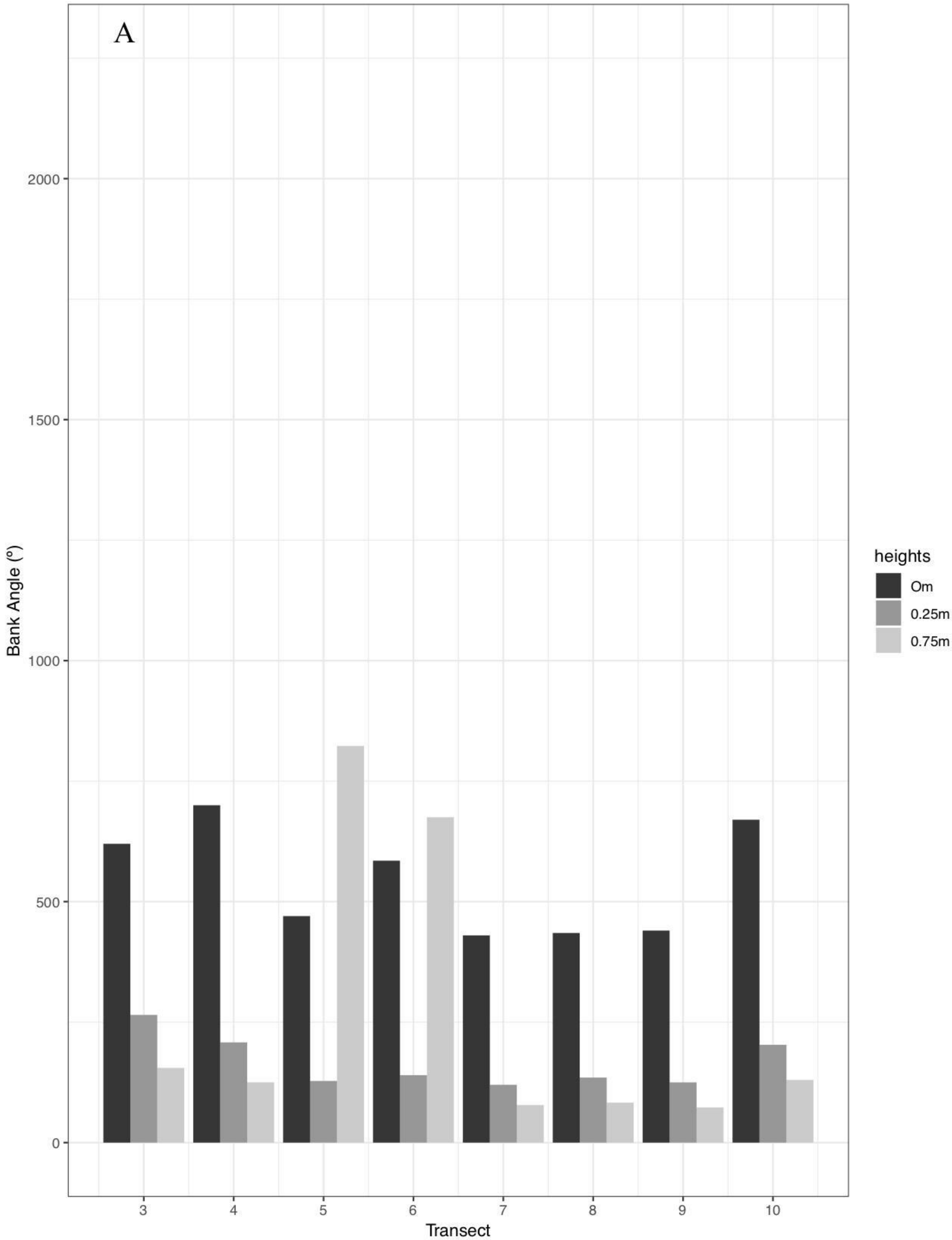


Figure 1. Spacing of measurement of bank angle. Adapted from Ontario Stream Assessment Protocol (2017).


A
2000
1500
1000
500
0
Bank Angle (°)
3
4
5
6
7
8
9
10
Transect
heights
Om
0.25m
0.75m

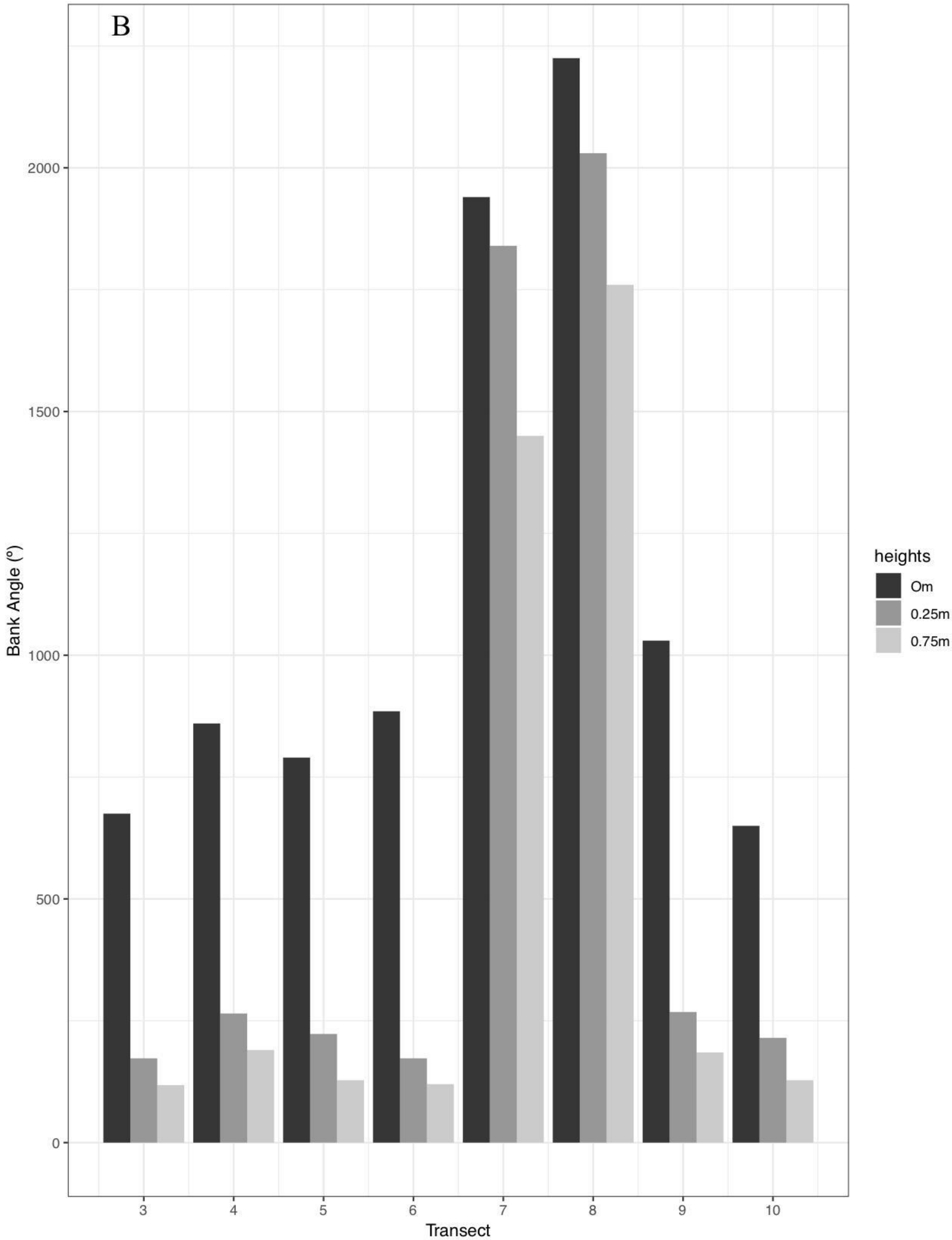


Figure 2. Height measurements of bank angle for both sides of the river, A) left side, and B) right side.