**Mactaquac Aquatic Ecosystem Study**
**Report Series 2018-033**

# PRELIMINARY FISH HABITAT AND COMMUNITY ASSESSMENT RELATED TO THE FUTURE OPTIONS OF THE MACTAQUAC GENERATING STATION

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**DISCLAIMER**

## LIST OF ACRONYMS

| | |
|---|---|
| CRI | Canadian Rivers Institute |
| DFO | Fisheries and Oceans Canada |
| MAES | Mactaquac Aquatic Ecosystem Study |
| MGS | Mactaquac Generating Station |
| NBP | New Brunswick Power |
| SJR | Saint John River |
| UNB | University of New Brunswick |
| ELOHA | Ecological Limits of Hydrologic Alteration |

## EXECUTIVE SUMMARY

This report provides an overview of how changes in flow relates to changes in the quantity and quality of physical habitat conditions for fish species in the downstream vicinity of the Mactaquac Generating Station (MGS). Flow scenarios considered in this report are based on potential effects of the Mactaquac Project options for removal or renewal of the hydropower facility.

The Saint John River (SJR) has a diverse fish community with 55 species. To evaluate the potential effects of flow induced habitat changes at the fish community level, this report focused on target fish species that represent distinct assemblages: Atlantic Salmon young-of-the-year and parr represent the cold-water guild; adult and juvenile Smallmouth Bass represent the warm-water fish guild; Cyprinids were represented by adult Common Shiner.

We surveyed four reaches (tailrace, islands, side channel, and main channel) downstream of the MGS to characterize fish assemblages. Surveys documented 29 species and 16 families. Species catch-per-unit-effort varied considerably throughout the study area and as a result, we focused on presence of species rather than metrics of relative abundance.

Habitat conditions were analyzed across a range of flows using a generalized, statistical hydraulic model. Low flow scenarios relevant to the Mactaquac Project options were investigated using a GIS-based habitat model. These models were used to predict areas of critical habitat for the target species. Results were reported as an index of habitat suitability or as weighted useable area. Both metrics can be plotted as a function of discharge to evaluate changes in habitat conditions for different flows.

Modeling results suggest that existing island habitats represent prime habitat conditions for most of the target species and are sensitive to changes during low flow periods. A decrease from low to minimum flow results in a considerable decline of preferred habitat for all target species. The suitable habitat in the side channel area consistently increased as discharge increased, i.e., the habitat transitions from stagnant conditions to a more dynamic system. Simulations across the flow range of all study areas except the side channel supersite show that habitat suitability for all target fish species typically has higher values at low to moderate flows; dropping when flow increases.

In summary, model predictions suggest that the quantity and quality of physical habitat for fishes respond, and are sensitive to changes in flow. A key finding is the importance of setting meaningful, ecological minimum flows during low-flow periods. We continue to improve and model the flow scenarios ranging from dam removal to the Ecological Limits of Hydrological Alteration (ELOHA)–derived flow regimes and the consequential effects on fishes and their habitats, as well as other organisms and their habitats.

# 1 INTRODUCTION

## 1.1 MACTAQUAC AQUATIC ECOSYSTEM STUDY (MAES)

This study was carried out as a part of the Mactaquac Aquatic Ecosystem Study (MAES), which is a whole-ecosystem study developed by the Canadian Rivers Institute (CRI) in partnership with New Brunswick Power (NBP) to assess the potential impacts of the Mactaquac Generating Station (MGS) on the Saint John River (SJR). The MGS, a 672 MW run-of-the-river hydroelectric facility, was constructed in 1968 and is now expected to reach the end of its service life by 2030 due to an alkali-aggregate reaction within concrete portions of the station. NBP identified four management options for the future of the MGS: repowering the station with a new powerhouse and spillway; rebuilding the spillway only; removing all parts of the facility allowing the river to follow its natural course; or, extending the service life to its intended 100-year lifespan. The latter option, known as Life Achievement, was selected as the preferred option in 2016.

## 1.2 HABITAT MODELLING

This report aims to link physical habitat characteristics with fish assemblages to predict the impact of altering flow conditions on the fish community in the SJR downstream of the MGS. Specifically, changes in the quantity and quality of useable area across a broad range of flows, as well as summer low flow conditions were evaluated.

Habitat simulation models are a widely used tool in river management worldwide. Physical habitat models have become increasingly popular in environmental flows assessments and are required by many regulatory agencies in North America and abroad (Tharme 2003; Linnansaari et al. 2013). These habitat models consist of a biological and hydraulic component based on the assumption that flow is a controlling variable of "optimum" physical habitat conditions that are defined by the biology of the target species (Karr 1991; Poff et al. 1997).

### 1.2.1 <u>Biological model:</u>

Physical-biota relationships (Conallin et al. 2010) are typically expressed as univariate, preference functions, which are combined to calculate a "habitat suitability index" (HSI) ranging from 0.0 (unsuitable) to 1.0 (most suitable) (Noack et al. 2013). Typically, the HSI is calculated as a ratio between the habitat use of individuals of the target species and the availability of habitat. Species preference curves are developed by observing the occurrence or abundance of species and the associated physical habitat parameters, typically velocity, depth, and substrate (Dunbar et al. 2012; Melcher et al. 2018). Ahmadi-Nedushan et al. (2006) provide a detailed review of statistical approaches to analyze species-environment associations and include both, univariate and multivariate functions.

### 1.2.2 <u>Hydraulic model:</u>

The flow properties that define the habitat requirements can be obtained with field measurements, statistical methods (Lamouroux et al. 1998), and/or hydrodynamic models (Tonina & Jorde 2013). Modelling approaches range from relatively simple 1D models to more complex 2D and 3D models. Hydrodynamic models consist of either a structured or unstructured grid mesh, where every cell contains information regarding hydraulic properties for simulated flows. For a detailed review regarding hydraulic modeling in ecohydraulic studies, refer to Tonina & Jorde (2013).

#### 1.2.3 Combining both components:

Habitat suitability values are generated for each parameter (e.g., $HSI_{velocity}$, $HSI_{depth}$, and $HSI_{substrate}$) and combined into a composite number applied to each cell of the hydraulic model (Linnansaari et al. 2013; Ahmadi-Nedushan et al. 2006). The composite suitability value is multiplied by the area of the cell with results generating a "Weighted Useable Area" (WUA). This metric can be calculated for various flow conditions and is considered a "habitat-discharge rating curve" or the amount suitable habitat as a function of flow (Dunbar et al. 2012; Linnansaari et al. 2013). The habitat-discharge rating curves are then used to evaluate potential effects of changes in flow conditions on the quality and availability of habitat.

#### 1.2.4 Generalized or statistical habitat models:

Generalized or statistical hydraulic-habitat models represent an alternative to hydraulic-habitat models (Lamouroux & Jowett 2005). Generalized models compute the change in flow properties statistically to generate an average distribution at a reach scale (Lamouroux et al. 1998; Lamouroux & Jowett 2005). The output is a WUA or a habitat suitability index. Given that the distributions of habitat parameters are average reach conditions, these models are spatially non-explicit (Linnansaari et al. 2013).

#### 1.2.5 Models Selected for this Study

In this report we use a statistical habitat model to simulate changes in habitat conditions across the flow range (STATHAB; http://www.irstea.fr/stathab) and a conventional habitat model to simulate changes between different low flow conditions (CASiMiR; http://www.casimir-software.de).

# 2 METHODS

## 2.1 STUDY AREA

With a catchment area of over 55,000 km$^2$, the SJR is one of the largest rivers in northeastern North America and has a relatively high diversity of fishes for a north temperate river; with 55 fish species documented (Linnansaari et al. 2017). This study focuses on a 20 km stretch downstream the MGS and includes four representative habitats (referred to as "supersites", tailrace, islands, side channel, and main channel; Figure 1).

## 2.2 FISH COMMUNITY SAMPLING

Fish community surveys were conducted during the 2015, 2016, and 2017 summer field seasons within the four supersite areas. Multiple gear types (boat electrofishing, seine netting and fyke netting) were used to survey the fish community within each supersite. This ensured that a wide range of habitat and species could be sampled. Surveys were conducted following the field protocol after Gautreau et al. (2015). Electrofishing effort was recorded as the number of seconds (usually 300-500 seconds) and catch-per-unit-effort (CPUE) was standardized among samples as fish per 100 shocking seconds. The fyke nets were set overnight (no longer than 24 hrs) and CPUE was standardized as fish per hour soak time. A bag seine (15 m long x 2 m height, mesh size of 0.6 cm with floats on the top line and a lead-weighted bottom line) was used to capture littoral species. The net was stretched out along the shore between two people. One end was pulled out as far as could be safely waded and looped back towards the stationary end to corral the fish in the net. Fishes were identified in the field, measured (total length – TL, cm; fork length – FL, cm; weight – WT, g), enumerated and released.

## 2.3 FISH – HABITAT ASSOCIATIONS

### 2.3.1 Species selection for simulations

#### a) Atlantic Salmon (*Salmo salar*)

Atlantic Salmon was selected as a representative of the cold-water fish guild. Preference curves for flow velocity, water depth and substrate particle size for salmon in lotic ecosystems were developed based on existing literature (Heggenes 1990; Armstrong et al. 2003). Habitat suitability curves were developed by Heggenes (1990), based on several published studies, for Atlantic Salmon young of the year (YOY) and parr (see Appendix). Note that the curves do not have optima equal to 1.0, as is the case for the other target species. The curves were calculated from the arithmetic means within ranges investigated in each study. Since habitat suitability curves from different studies were not identical, it resulted in optima less than 1.0. Preferred spawning habitat is usually a gravel-bottom riffle above or below a pool (Scott & Crosmann, 1973, Louhi 2008). Parr avoid still-water and utilize a relatively wide range of higher water velocities (Heggenes 1996).

#### b) Smallmouth Bass (*Micropterus dolomieu*)

Smallmouth Bass represented habitat requirements for guilds adapted to warm water temperatures. Suitability curves (see Appendix) for adults and YOY were selected from Aadland & Kuitunen (2006). Smallmouth Bass is an introduced species in the SJR, but can be considered 'naturalized' because it reproduces throughout the river upstream and downstream of the MGS (Canadian Rivers Institute 2011). The species requires a clean stone, rock, or gravel substrate for spawning (Scott & Crossman, 1973; Edwards, 1983).

#### c) Common Shiner (*Notropis cornutus*)

Common Shiner was selected to represent the diverse group of cyprinids found in the SJR (12 species). Aadland and Kuitunen (2006) described fish-habitat associations for the adult life stage of Common Shiner and proposed preference curves for different habitat variables (see Appendix). The Common Shiner typically prefers moderate velocities and unvegetated gravel to cobble bottom (Scott & Crossman, 1973; Trial et al., 1983).

## 2.4 HABITAT SIMULATION - STATHAB MODEL

### 2.4.1 Study Sites

The trailrace supersite was located immideately downstream of the MGS (Figure 1). It is characterized by moderate to high flow velocities (> 1 m/s), a deep channel, and coarse substrate. There is high sedimentation and high embeddedness. The effect of daily water level fluctuations related to the operation of the MGS is most pronounced in this supersite.

The side channel supersite is influenced by the Keswick River on the northwest of the study area (Figure 1). It is characterized by low velocities, high turbidity, fine substrates, abundant macrophyte vegetation, and moderate water depth.

The islands supersite has many islands which form heterogeneous habitat conditions with varying water depth, velocity, and substrate size class (Figure 1). This reach contains many gravel bars that are exposed at low flow conditions. A reach along the southern shore of Eqpahak Island was selected for the stathab modelling: it includes coarse substrates (gravel, pebble), a stronger current, and shallow to moderate water depths.

The main channel supersite is the site farthest downstream, and is characterized by a wide and deep channel (up to 850 m width), fine substrates, and low to moderate flow velocities (Figure 1).

We selected a 100 m reach from each supersite for use in the statistical hydraulic models. The selected reaches are shown in Figure 1 as the darker colouring within each supersite area. Table 1 provides an estimate of the total area that the 100 m reach represents within each supersite.

**Table 1: Total area of supersites which are represented by the simulated 100m reach at each study site**

| Study reach | Representative Area [$km^2$] |
|---|---|
| Main channel | 4.10 |
| Islands | 4.03 |
| Side channel | 1.33 |
| Tailrace | 3.00 |

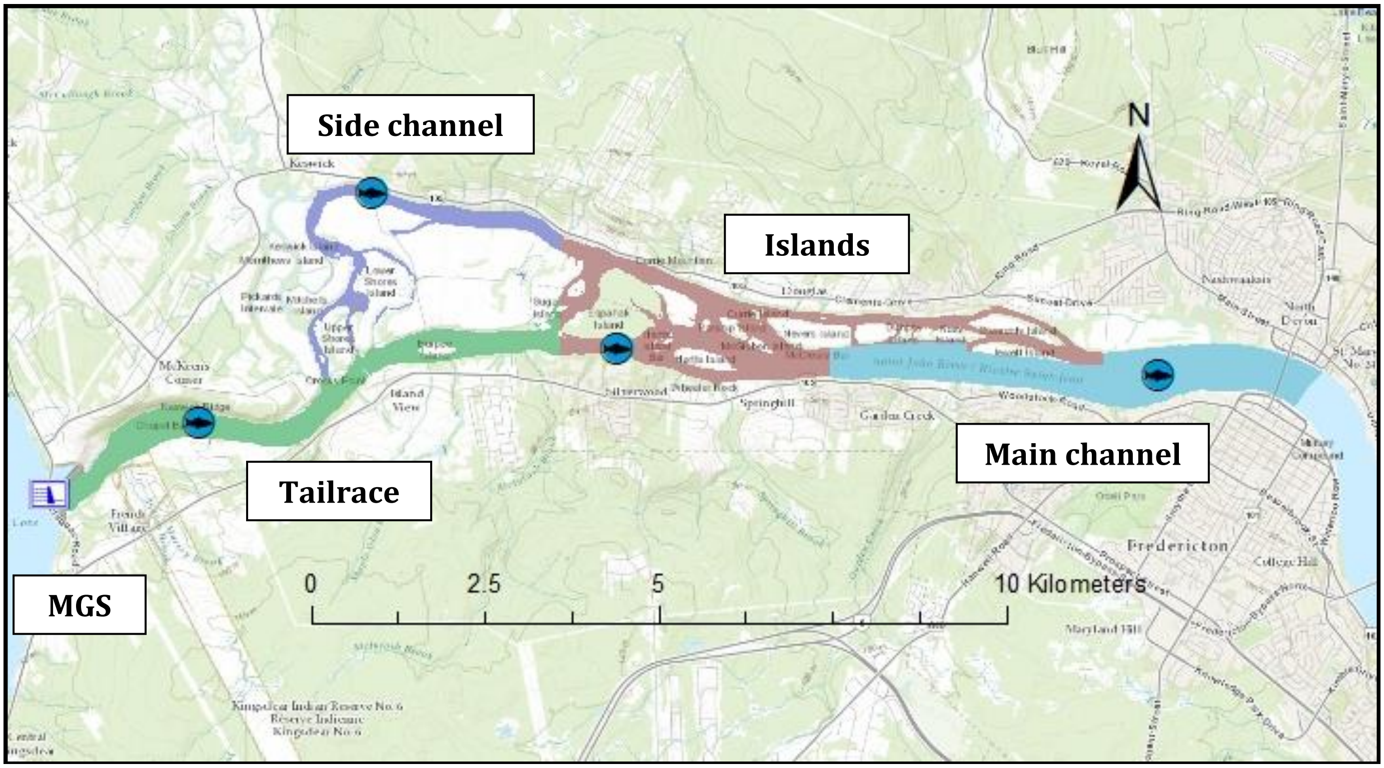


**Figure 1: Study area with representative study sites for the STATHAB model in the SJR. The four supersites (tailrace, islands, side channel, and main channel) are colored. Fish symbols show study reaches where transects were measured.**

### 2.4.2 STATHAB model

**Data requirements:**

The model requires the average depth and width of a river reach at more than two discharge levels, representing both high and low flow conditions. We used discharge data from the MGS as input for our model. A hydrodynamic model (Delft3D) was used to calculate the proportion of the flow in the study sites (Ndong et al. unpublished data). Depth and roughness was measured at 100 locations along 20 transects in the river reach.

**Methodology:**

Field sampling occurred within the four supersites at low and high flow conditions (Table 2). Water depth was measured with a Lowrance Echolot unit and substrate was sampled using an Ekman grab for soft river bottom or a sounding rod (Collins & Flotemersch 2014) for coarse river bottoms. Roughness by size class was visually assessed using the Wentworth scale (Gautreau et al. 2015b) Measurements were taken at five equidistant points on each transect. The coordinates of the river's edge for each transect were surveyed with a differential GPS (Topcon, Hiper Lite Plus) and imported into ArcMap (ArcGIS 10.0). The wetted width for each transect was calculated using the GIS measurement tool.

The statistical hydraulic model estimates the volumes and areas associated with velocity, depth, and substrate size classes within the studied reach. Preference functions for the target fish species (see Appendix) were used to calculate the habitat suitability indices for the species of interest within each reach.

**Table 2: Discharge at sites within the supersite area during transect measurements. Data is based on measurements taken at the Mactaquac Generating Station.**

| River Reach | Date | Q min [$m^3/s$] | Date | Q max [$m^3/s$] |
|---|---|---|---|---|
| Main channel | 28-Oct-15 | 268 | 12-May-16 | 1874 |
| Islands | 27-Oct-15 | 122 | 22-Jul-15 | 299 |
| Side channel | 28-Oct-15 | 5 | 12-May-16 | 470 |
| Tailrace | 27-Oct-15 | 218 | 23-Jul-15 | 759 |

## 2.5 LOW-FLOW SIMULATIONS – CASIMIR

Univariate preference functions were applied to Atlantic Salmon juveniles (parr and YOY), Smallmouth Bass, and Common Shiner (Appendix). CASiMiR is integrated in a GIS-environment which enables locating specific areas of interest, e.g. changes in habitat quality or suitability across flow ranges.

Velocity, depth and substrate particle size were measured as described above. Habitat suitability was calculated for each grid based on the corresponding species/life history preference curve (Appendix). For each cell, suitability indices for velocity, depth, and substrate particle size were combined to obtain an overall value of habitat suitability. We calculated the WUA as well as areas of the same suitability class defined as "avoided", "indifferent", or "preferred" (Linnansaari et al. 2010; Table 3)

We simulated habitats for three low flow conditions:

- Historic minimum flow (post Beechwood / pre MGS): 35 $m^3/s$ (1238 cfs).
- Current minimum flow at MGS: 65 $m^3/s$ (2300 cfs).
- Typical minimum flow: 176 $m^3/s$ (6203 cfs).

**Table 3: Classification of areas into three categories of suitability.**

| Suitability Index [-] | Category |
|---|---|
| 0-0.3 | avoided habitat |
| 0.31-0.70 | indifferent habitat |
| 0.71-1.0 | preferred habitat |

The "post Beechwood" time period refers to the time period after the completion of the large Beechwood Generating Station, but prior to the completion of the MGS. Beechwood is located 130 km upstream of MGS. The "typical" minimum flow refers to the lowest flow condition allowing for sustained turbine operation.

# 3 RESULTS

## 3.1 FISH COMMUNITY

Sampling effort varied among years and among supersites, but resulted in the collection of 12,649 fishes consisting of 29 species and 16 families (Table 4). The resulting fish community assemblages varied by river section and sampling method.

Boat electrofishing captured 26 species dominated by YOY Gaspereau (*Alosa sp)*, Yellow Perch (*Perca flavescens*), American Eel (*Anguilla rostrata*), and White Sucker (*Catostomus commersoni*) (Figure 2 and 3). Seining captured mainly small-bodied species, e.g., Banded Killifish and Fourspine Stickleback, or YOY of other species (Figure 4 and 5). Catches in fyke nets were dominated by Gaspereau and YOY Common Shiner. (Figure 6 and 7). The following figures illustrate mean species CPUE pooled among years. That is, all three years of catch data were combined to generate a single species estimate of CPUE for the time period 2015 to 2017.

**Table 4: Species captured from 2015 to 2017 using all gear types**

| Taxa | Scientific name | Code |
|---|---|---|
| **Acipenseridae** | | |
| Shortnose Sturgeon | *Acipenser brevirostrum* | SST |
| **Anguillidae** | | |
| American Eel | *Anguilla rostrata* | EEL |
| **Catostomidae** | | |
| Longnose Sucker | *Catostomus catostomus* | LNS |
| White Sucker | *Catostomus commersoni* | WHS |
| **Centrarchidae** | | |
| Pumpkinseed Sunfish | *Lepomis gibbosus* | PSF |
| Smallmouth Bass | *Micropterus dolomieui* | SMB |
| **Clupeidae** | | |
| Alewife | *Alosa pseudoharengus* | GASP |
| Blueback herring | *Alosa aestivalis* | GASP |
| **Cyprinidae** | | |
| Blacknose Dace | *Rhinichthys atratulus* | BND |
| Common Shiner | *Notropis cornutus* | CSH |
| Creek Chub | *Semiotilus atromaculatus* | CRC |
| Fallfish | *Semiotilus corporalis* | FLF |
| Golden Shiner | *Notemigonus cryosoleuca* | GSH |
| Lake Chub | *Couesius plumbeus* | LKC |
| **Esocidae** | | |
| Chain Pickerel | *Esox niger* | CHP |
| Muskellunge | *Esox masquinongy* | MUS |
| **Fundulidae** | | |
| Banded Killifish | *Fundulus diaphanus* | BKF |
| **Gasterosteidae** | | |
| Fourspine stickleback | *Apeltes quadracus* | 4SB |
| Threespine sticklebac | Gasterosteus aculeatus | 3SB |
| **Ictaluridae** | | |
| Brown Bullhead | *Ameiurus nebulosus* | BBH |
| **Lotidae** | | |
| Burbot | *Lota lota* | BUR |
| **Moronidae** | | |
| Striped Bass | *Morone saxatilis* | STB |
| White Perch | *Morone americana* | WHP |
| **Osmeridae** | | |
| Rainbow Smelt | *Osmerus mordax* | RSM |
| **Percidae** | | |
| Yellow Perch | *Perca flavescens* | YLP |
| **Petromyzontidae** | | |
| Sea Lamprey | *Petromyzon marinus* | SLP |
| **Salmonidae** | | |
| Atlantic Salmon | *Salmo salar* | ATS |
| Brook Trout | *Salvelinus fontinalis* | BKT |
| Rainbow Trout | *Oncorhynchus mykiss* | RBT |

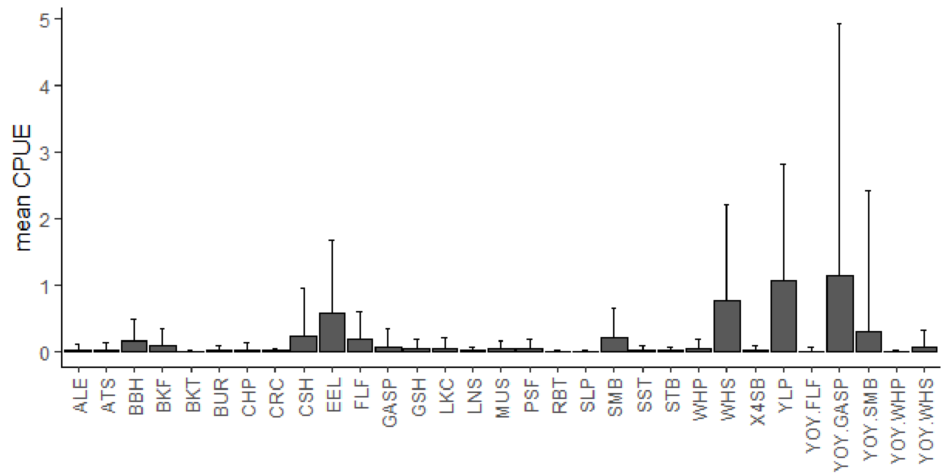


**Figure 2: Average catch per unit effort of species captured during boat electrofishing (catch / 100 s) surveys between 2015 and 2017, pooled among supersites and years (n = 26 species; see Table 4). Error bars represent one standard deviation about the mean.**

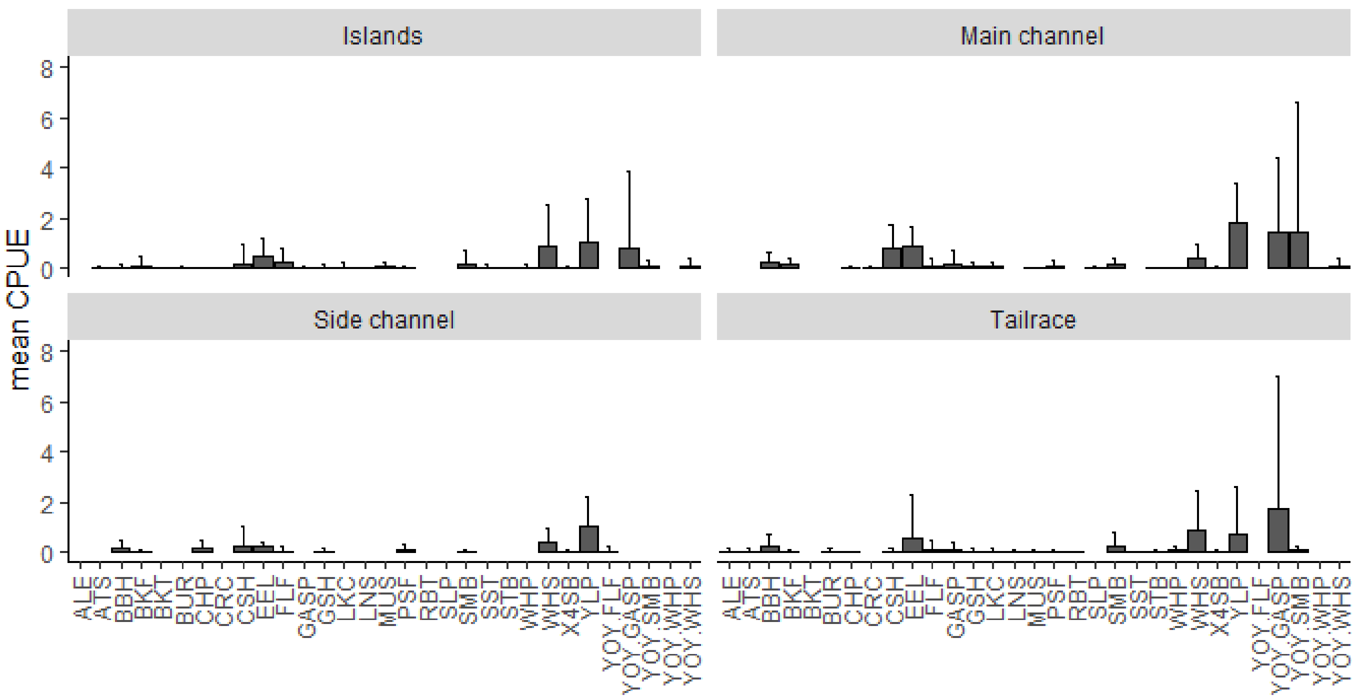


**Figure 3: Average catch per unit effort of species captured during boat electrofishing (catch / 100 s) surveys between 2015 and 2017, within each supersite and pooled among years (n = 26 species; see Table 4). Error bars represent one standard deviation about the mean.**

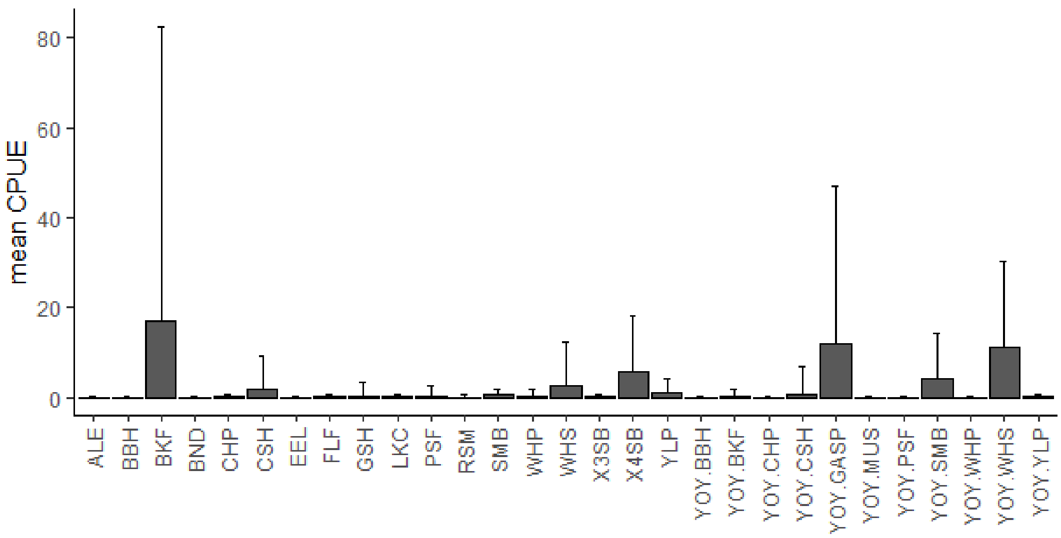


**Figure 4: Average catch per unit effort of species captured during seining (catch / net) surveys between 2015 and 2017, pooled among supersites and years (n = 20 species; see Table 4). Error bars represent one standard deviation about the mean.**

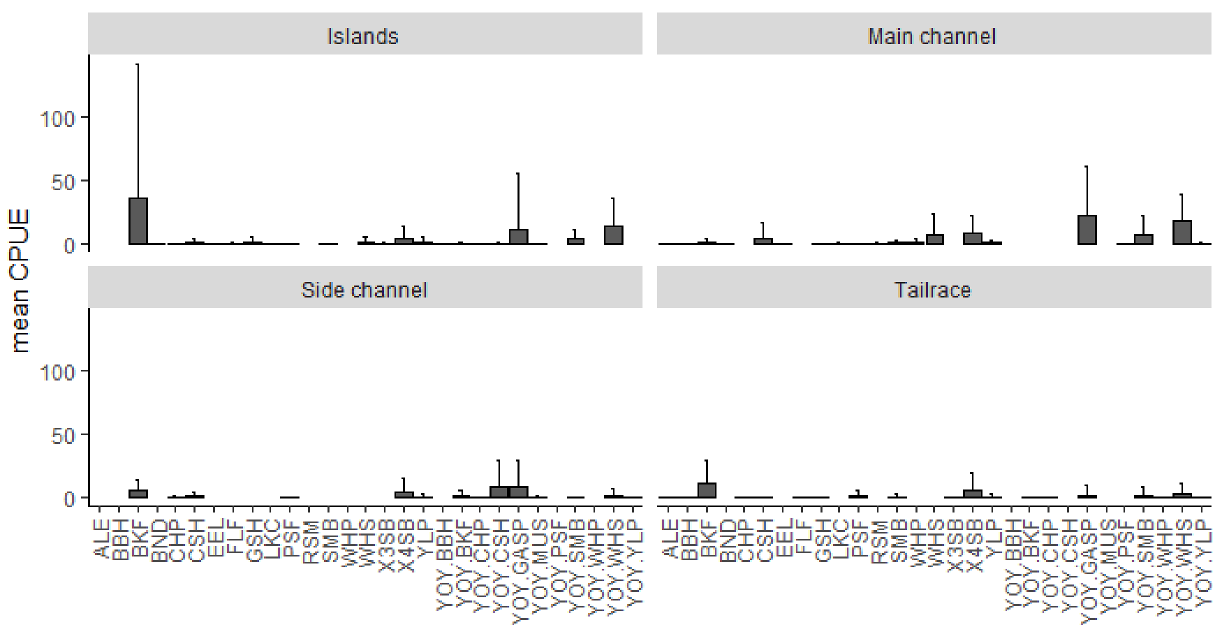


**Figure 5 Average catch per unit effort of species captured during seining (catch / net) surveys between 2015 and 2017, within each supersite and pooled among years (n = 20 species; see Table 4). Error bars represent one standard deviation about the mean.**

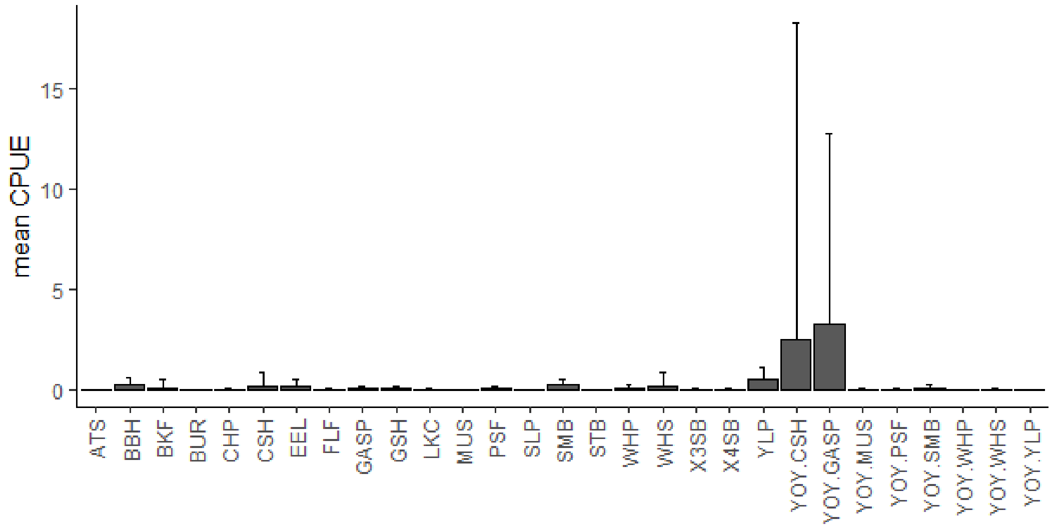


**Figure 6: Average catch per unit effort (fish per hour) of species captured in fyke net sets between 2015 and 2017, pooled among supersites and years (n = 21 species; see Table 4). Error bars represent one standard deviation about the mean.**

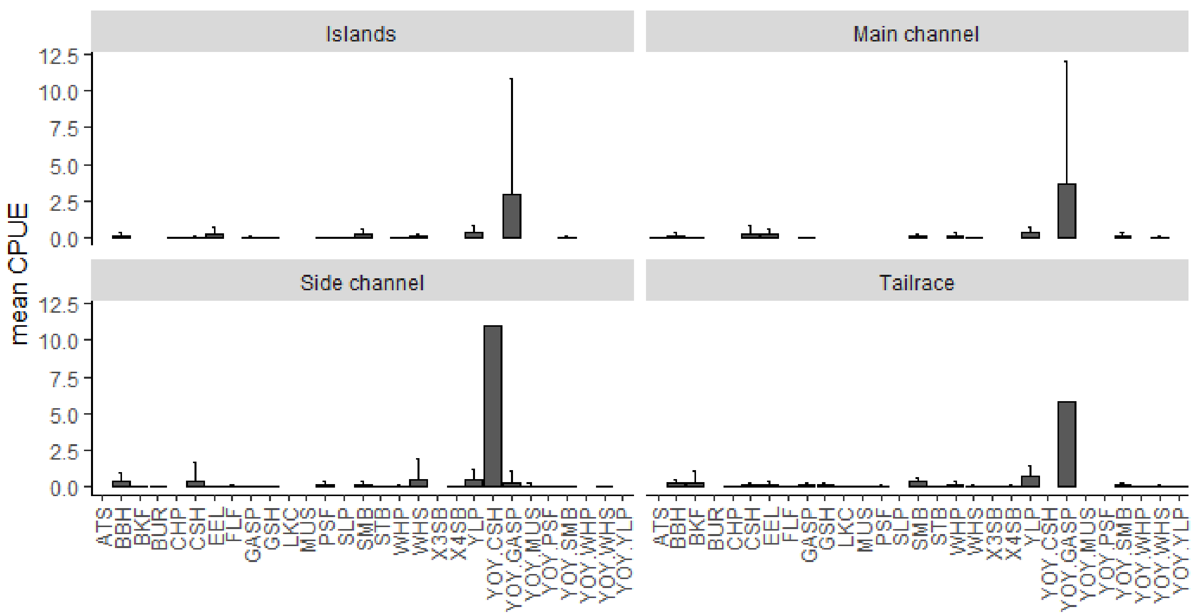


**Figure 7: Average catch per unit effort (fish per hour) of species captured in fyke net sets between 2015 and 2017, within each supersite and pooled among years (n = 21 species; see Table 4). Note that error bars for YOY Common Shiner (0.42 ±1.24) and YOY Gaspereau (5.82 ±14.87) at the supersites side channel and tailrace, respectively, were removed to facilitate interpretation of the graph. Error bars represent one standard deviation about the mean.**

## 3.2 HABITAT SIMULATIONS - STATHAB MODEL

The simulated habitat condition within the main channel ranges from a minimum flow of 250 $m^3/s$ to a maximum flow of 1900 $m^3/s$ (Table 2).

Habitat curves for both life stages of Atlantic Salmon show a slight increase in suitability with increasing discharge, followed by a plateau that remains relatively constant for higher flows (Figure 8). Overall, modelling results suggest that the main channel area seems not to be optimal habitat for salmon, as habitat suitability does not exceed a value of 0.5 at any discharge. Compared to Atlantic Salmon, suitability for Smallmouth Bass and Common Shiner are higher; however, suitability decreases with increasing flow (Figure 8).

The results for the islands (Figure 9) and tailrace (Figure 10) supersites show a similar pattern. While velocity and depth classes are more suitable during low flows (~218 $m^3/s$ at MGS; Table 2), the frequency of very high velocity classes (i.e. >1m/s) increases as a function of discharge which leads to a decrease in habitat quality. All target species show a similar negative response to high flows in these supersites (Figures 9 and 10). The decrease could also be due to an increase in deep water habitats outside of the optimum range of the target species.

The side channel supersite shows a different trend (Figure 11). Here, the quality of habitat is poor at low flows but is constantly increasing in response to higher flows (Table 2). The increase could be partially explained by a transition from stagnant flow conditions to an increase in higher velocity classes that favor the habitat requirements of the target species.

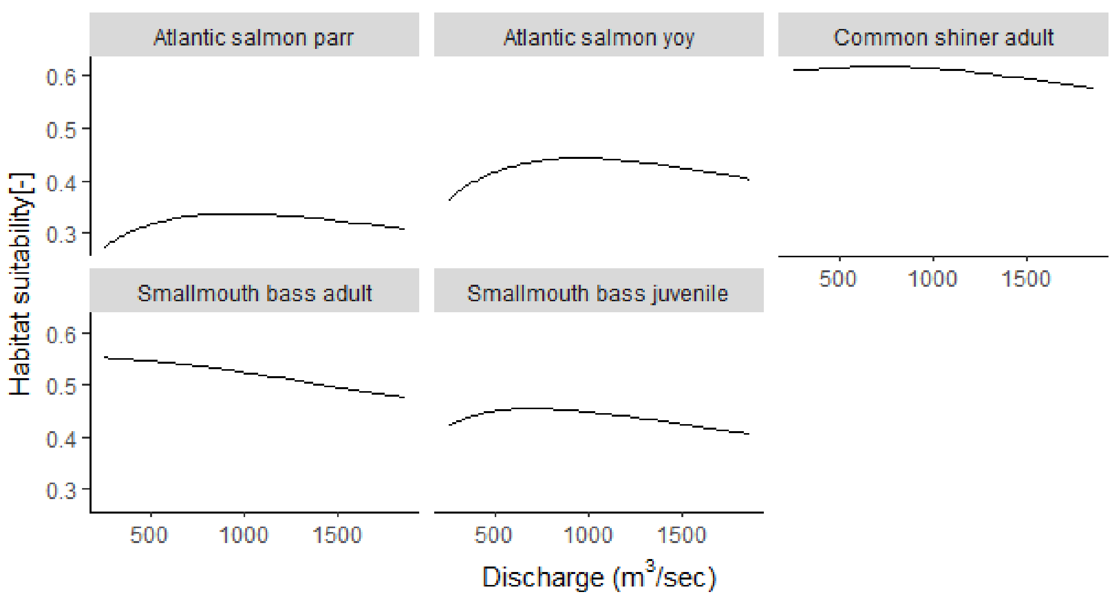


**Figure 8: Statistical habitat simulation of the main channel supersite for juvenile and adult Atlantic Salmon and Smallmouth Bass, and adult Common Shiner across the flow range. Habitat suitability ranges from 0 (poor conditions) to 1 (optimal conditions).**

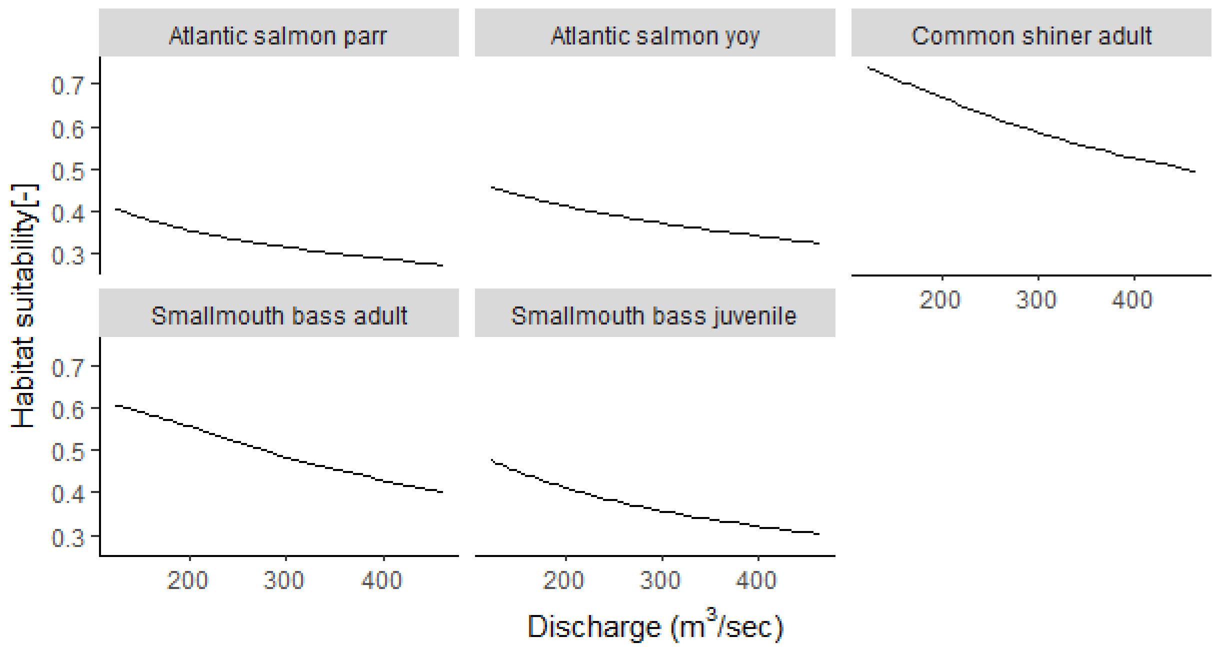


**Figure 9: Statistical habitat simulation of the islands supersite for juvenile and adult Atlantic Salmon and Smallmouth Bass, and adult Common Shiner across the flow range. Habitat suitability ranges from 0 (poor conditions) to 1 (optimal conditions).**

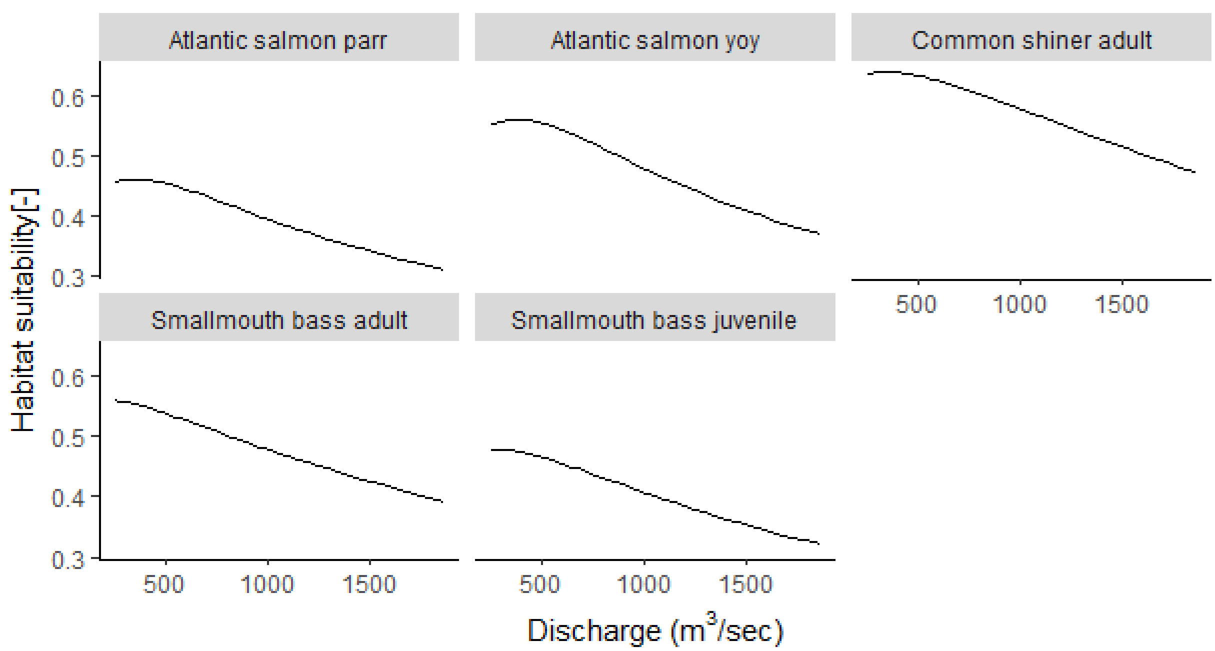


**Figure 10: Statistical habitat simulation of the tailrace for juvenile and adult Atlantic Salmon and Smallmouth Bass, and adult Common Shiner across the flow range. Habitat suitability ranges from 0 (poor conditions) to 1 (optimal conditions).**

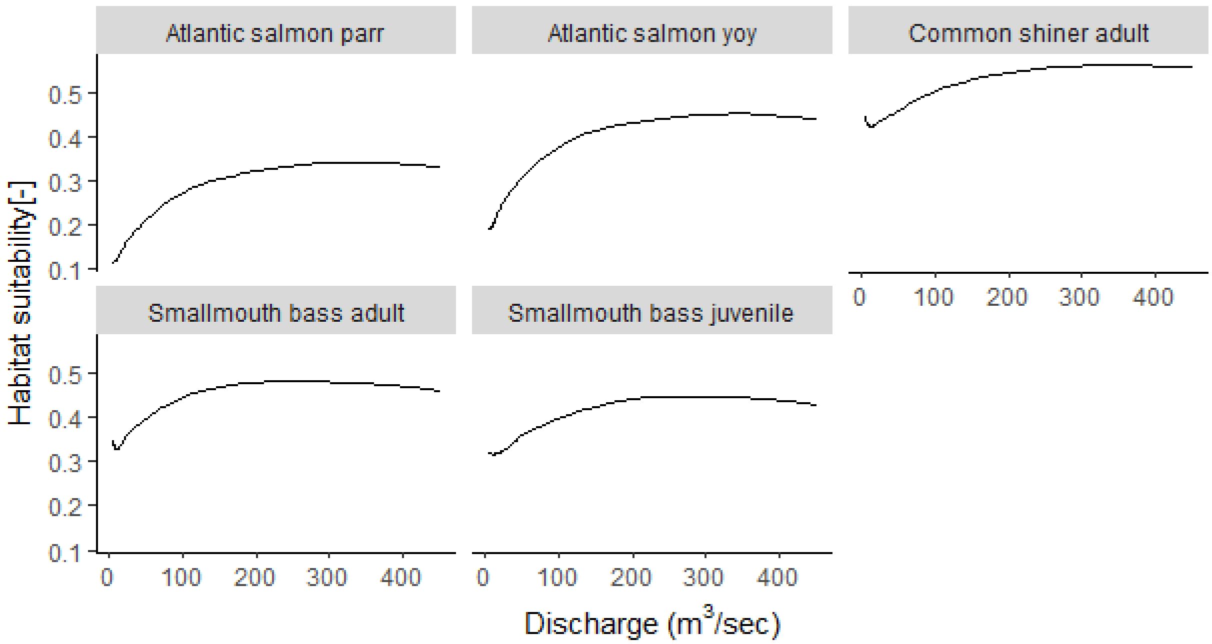


**Figure 11: Statistical habitat simulation of the side channel supersite for juvenile and adult Atlantic Salmon and Smallmouth Bass, and adult Common Shiner across the flow range. Habitat suitability ranges from 0 (poor conditions) to 1 (optimal conditions).**

## 3.3 LOW-FLOW SIMULATIONS – CASIMIR

### 3.3.1 Atlantic Salmon (*Salmo salar*)

Low-flow simulations for Atlantic Salmon identified areas around the islands supersite as the most suitable habitat for both life stages (see Figures 12 to 17). These areas are mainly associated with gravel and pebble substrate with varying velocity and depth conditions. Areas around the main channel and side channel supersites show poor habitat conditions for both life stages at each low-flow scenario. The low habitat suitability in these areas could be explained by the low flow velocities and fine substrate size classes (dominating substrate is silt and sand). Areas within the tailrace supersite show highest suitability around Burpee Island, which is characterized by a swift current and clean gravel and pebble substrate. When comparing the WUA for Atlantic Salmon between historic, current, and typically occurring minimum low-flow, there appears to be only minor changes in habitat quality for young of the year, while WUA for parr increases considerably (see Figure 18). With low quality habitat (i.e. HSI: 0.00-0.30), WUA generally increases for YOY and decreases for parr with higher flows (Figure 19). With moderate quality habitat (i.e. HIS: 0.31-0.70), WUA increases for parr but remains relatively constant for YOY (Figure 20). However, when considering the high quality habitat (i.e. HSI: 0.71-1.00), WUA increases with higher flows for both life stages (Figure 21).


**Figure 10~~12~~: Habitat simulation for Atlantic Salmon parr at historic low flow conditions of 35 m³/s. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**


**Figure 11~~13~~: Habitat simulation for Atlantic Salmon parr at current low flow conditions of 65 m³/s. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**

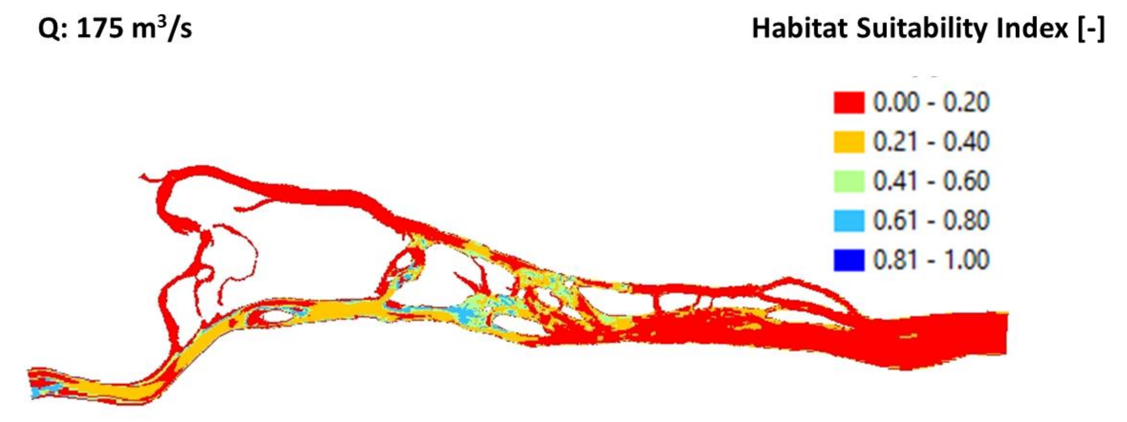


**Figure 12~~14~~: Habitat simulation for Atlantic Salmon parr at typical low flow conditions of 175 $m^3/s$. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**

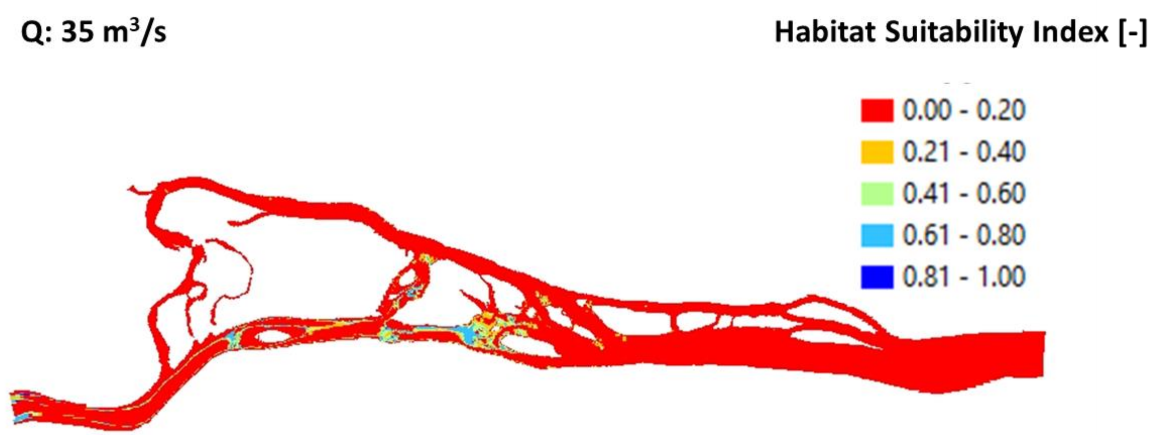


**Figure 13~~15~~: Habitat simulation for Atlantic Salmon (young of the year) at historic low flow conditions of 35 $m^3/s$. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**


**Figure 14~~16~~: Habitat simulation for Atlantic Salmon (young of the year) at current low flow conditions of 65 $m^3/s$. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**


**Figure 15~~17~~: Habitat simulation for Atlantic Salmon (young of the year) at typical low flow conditions of 175 $m^3/s$. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**

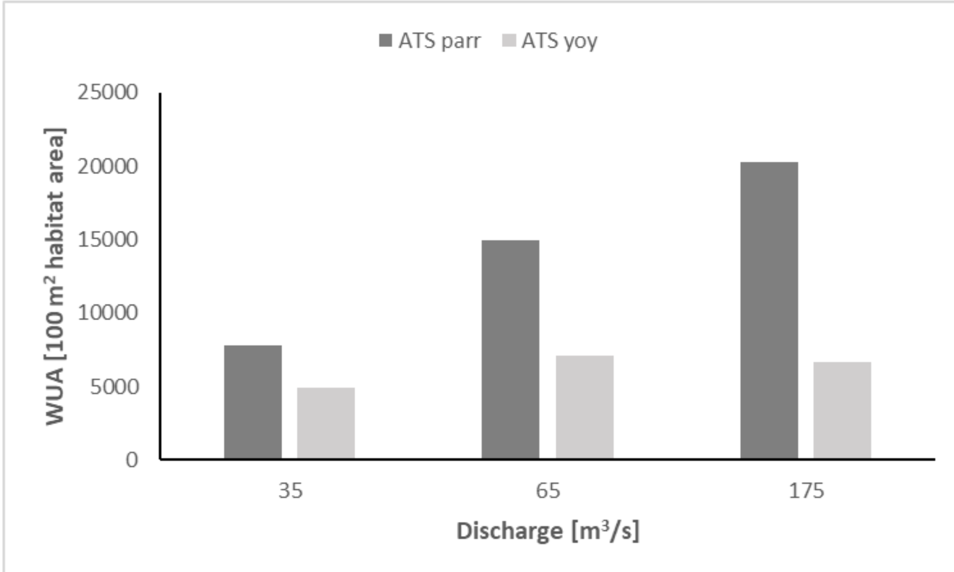


**Figure ~~18~~16: Weighted useable area [100m² habitat units] for Atlantic Salmon at three different low flow conditions. Dark bars: Atlantic Salmon parr; Light bars: Atlantic Salmon YOY**

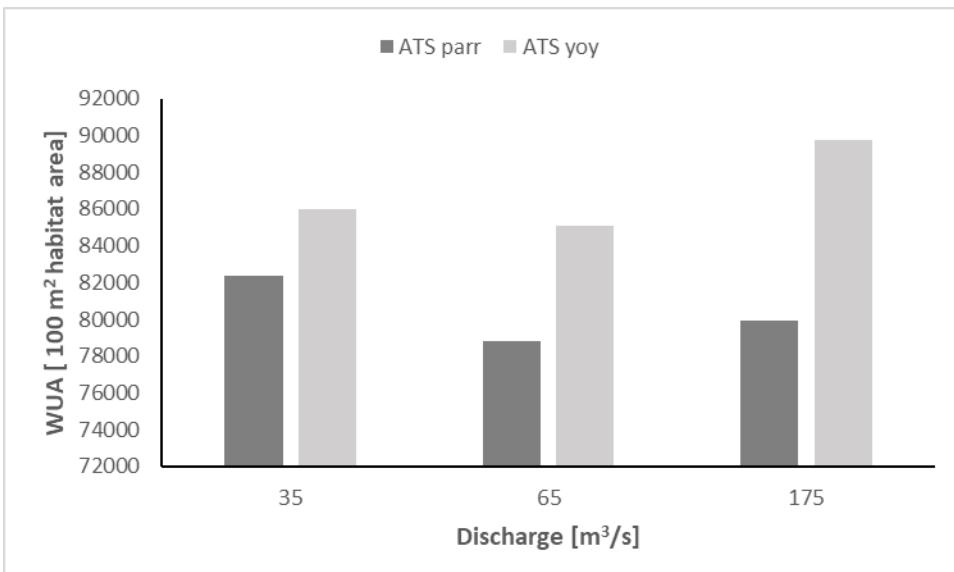


**Figure ~~19~~17: Avoided (SI: 0.00-0.30) Atlantic Salmon habitat at three low flow conditions. Dark bars: Atlantic Salmon parr; Light bars: Atlantic Salmon YOY**

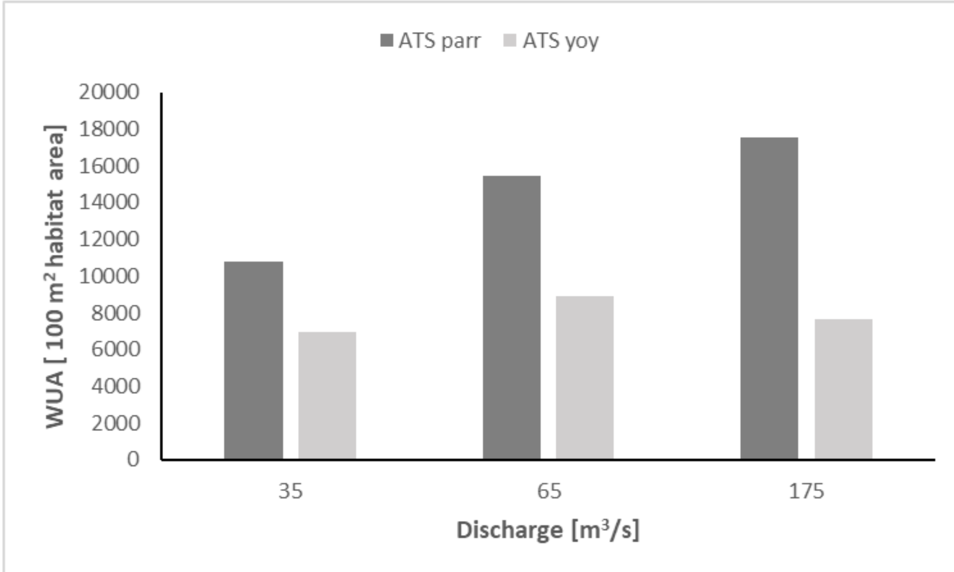


**Figure 18~~20~~: Indifferent (SI: 0.31-0.70) Atlantic Salmon habitat at three low flow conditions. Dark bars: Atlantic Salmon parr; Light bars: Atlantic Salmon YOY**

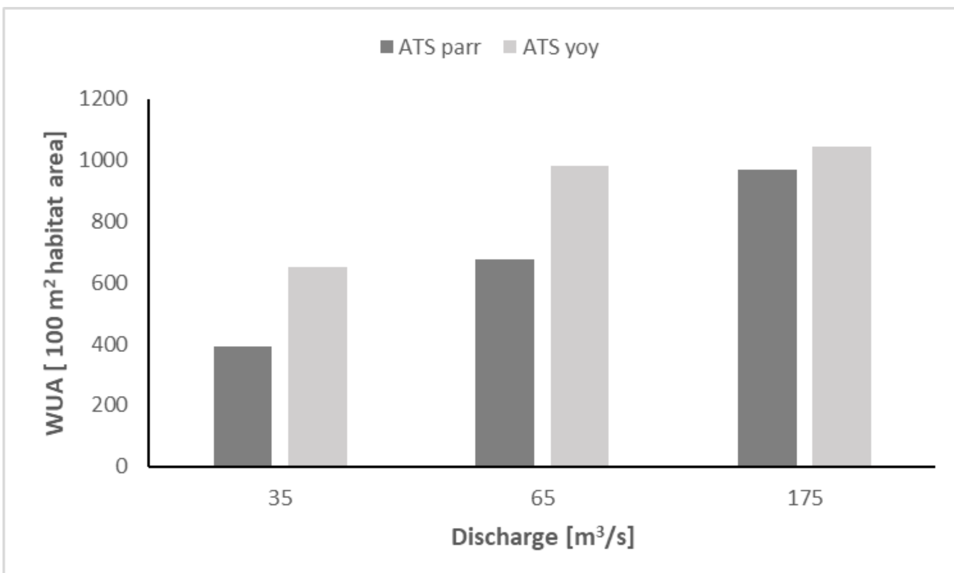


**Figure 19~~21~~: Preferred (SI: 0.71-1.00) Atlantic Salmon habitat at three low flow conditions. Dark bars: Atlantic Salmon parr; Light bars: Atlantic Salmon YOY**

### 3.3.2 Smallmouth Bass (*Micropterus dolomieu*)

Preferred Smallmouth Bass habitat at low-flows was identified primarily downstream of the tailrace supersite as well as around the islands supersite (see Figure 22 to 27). However, habitat quality at the islands supersite seems to be sensitive to a decrease in discharge from 175 (the typically occurring minimum low flow) to 35 $m^3$/s (historic minimum low flow). For both life stages the main channel supersite is characterized mainly by poor habitat suitability for historic low flow (35 $m^3$/s) and moderate suitability for higher flows. Modelling results suggest non-optimal conditions for both life stages within the side channel supersite habitat. There is an increase in WUA for both adult and juvenile Smallmouth Bass with increasing discharge (Figure 28). With low quality habitat (i.e. HIS: 0.00-0.30), WUA decreases for adult Smallmouth Bass with increasing discharge, whereas there is little change with the juveniles (Figure 29). In both the moderate and high quality sites, WUA for both adult and juvenile Smallmouth Bass increases with increasing discharge, however the increase is less pronounced in the juveniles (Figures 30 and 31; respectively).


**Figure 20~~22~~: Habitat simulation for Smallmouth Bass (adult) at historic low flow conditions of 35 m$^3$/s. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**

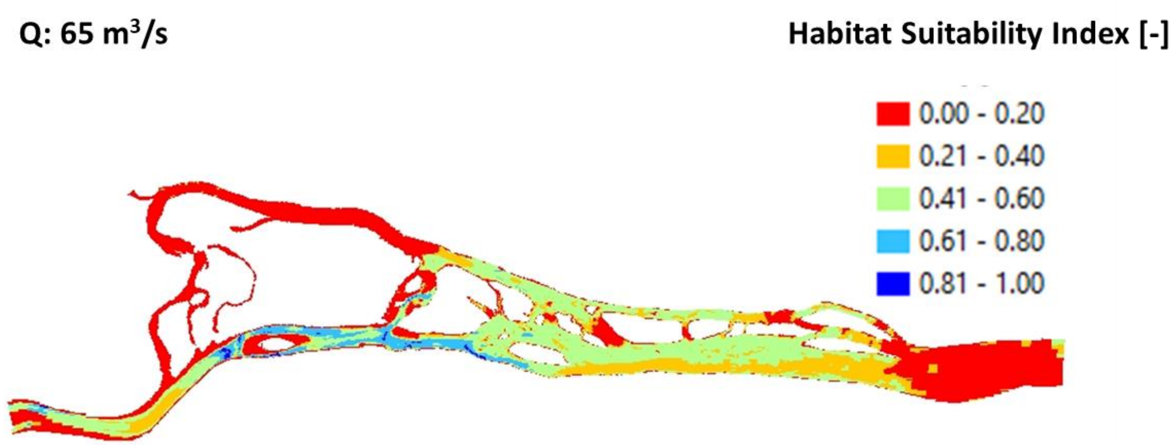


**Figure 21~~23~~: Habitat simulation for Smallmouth Bass (adult) at historic low flow conditions of 65 m$^3$/s. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.)**

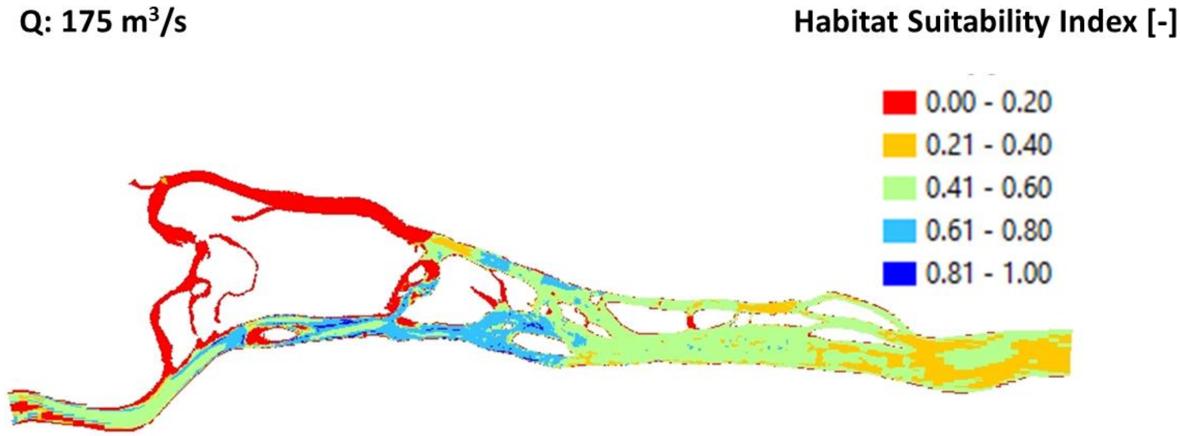


**Figure 22~~24~~: Habitat simulation for Smallmouth Bass (adult) at historic low flow conditions of 175 m$^3$/s. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.)**

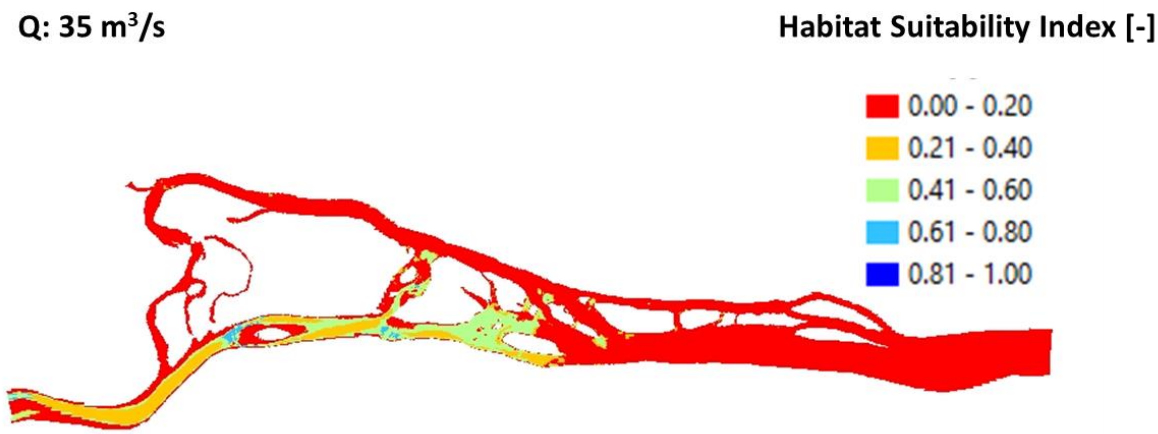


**Figure 23~~25~~: Habitat simulation for Smallmouth Bass (juvenile) at historic low flow conditions of 35 m$^3$/s. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.)**

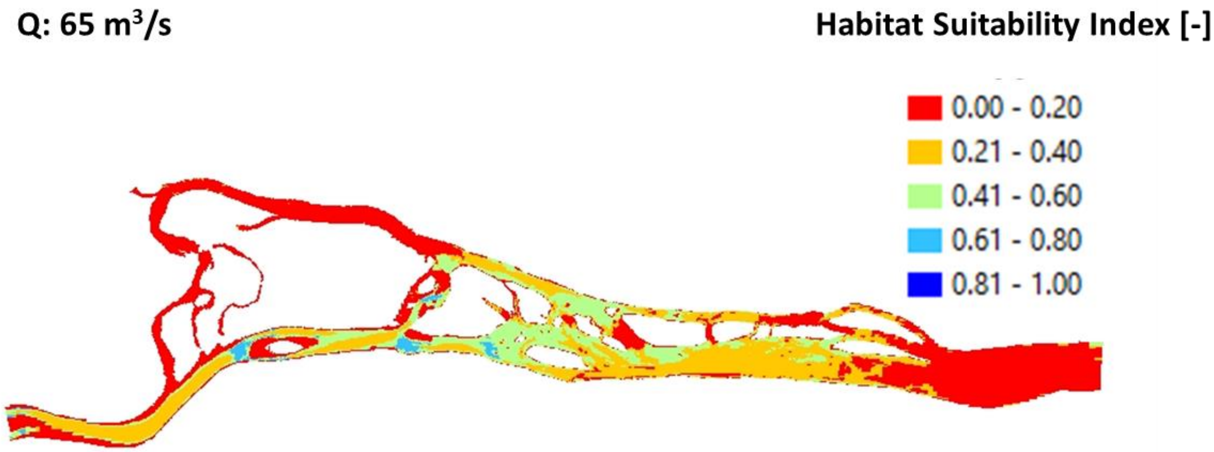


**Figure 24~~26~~: Habitat simulation for Smallmouth Bass (juvenile) at historic low flow conditions of 65 $m^3/s$. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.)**

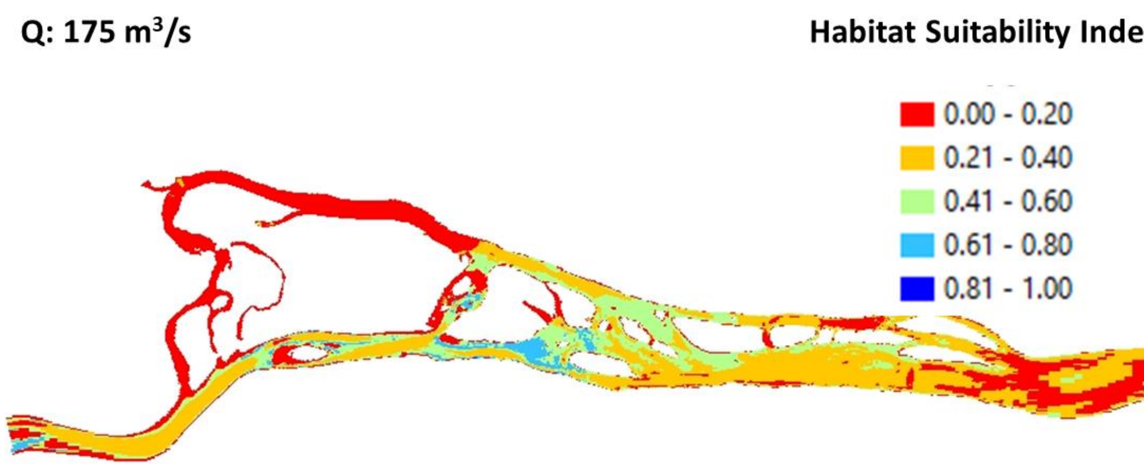


**Figure 25~~27~~ Habitat simulation for Smallmouth Bass (juvenile) at historic low flow conditions of 175 $m^3/s$. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.)**

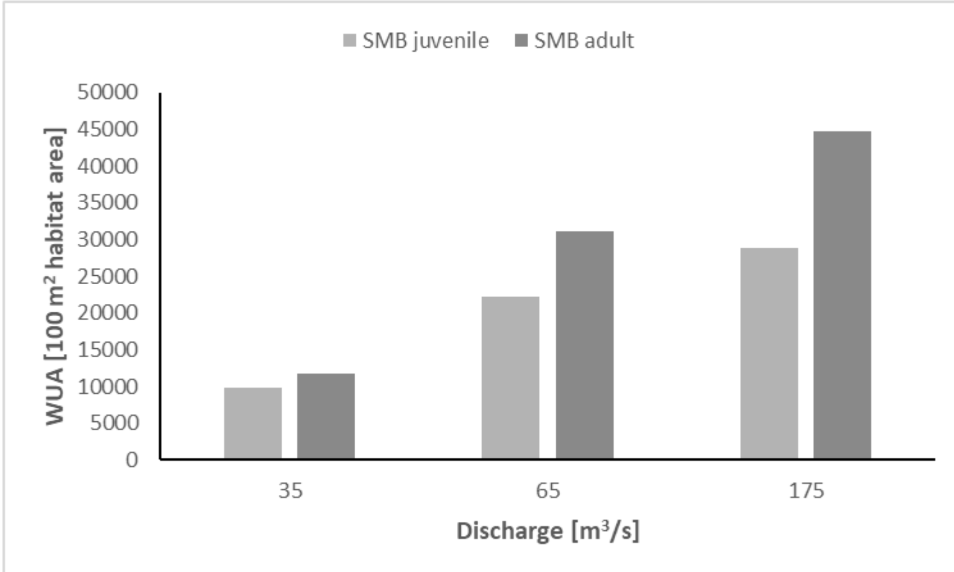


**Figure 26~~28~~: Weighted useable area [100m2 habitat units] for Smallmouth Bass at three different low flow conditions. Dark bars: Smallmouth Bass adult; Light bars: Smallmouth Bass juvenile**

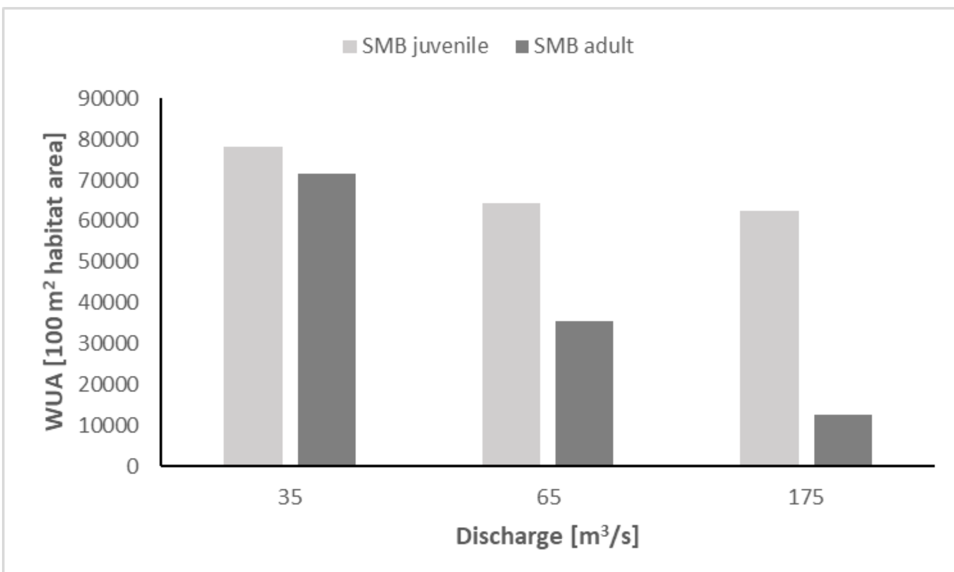


**Figure 27~~29~~: Avoided (SI: 0.0-0.30) Smallmouth Bass habitat at three low flow conditions. Dark bars: Smallmouth Bass adult; Light bars: Smallmouth Bass juvenile**

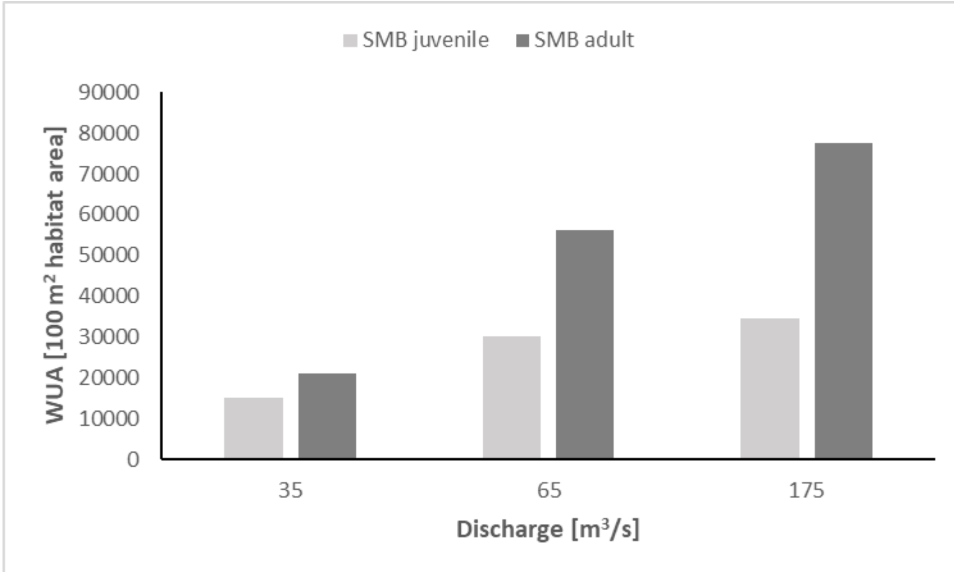


**Figure 28~~30~~: Indifferent (SI: 0.31-0.70) Smallmouth Bass habitat at three low flow conditions. Dark bars: Smallmouth Bass adult; Light bars: Smallmouth Bass juvenile**

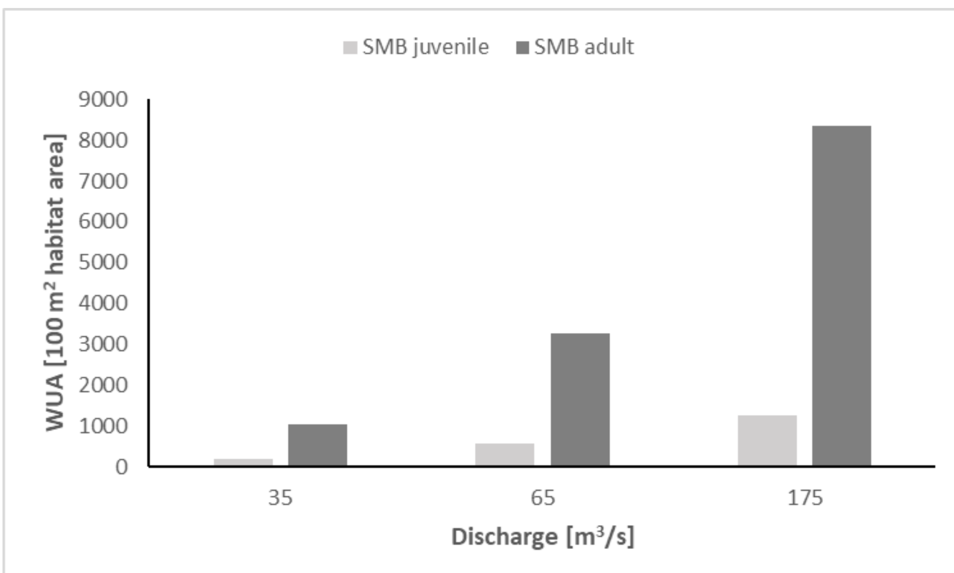


**Figure 29~~31~~: Preferred (SI: 0.71-1.0) Smallmouth Bass habitat at three low flow conditions. Dark bars: Smallmouth Bass adult; Light bars: Smallmouth Bass juvenile.**

### 3.3.3 Common Shiner (Notropis cornutus)

Modelling results for Common Shiner suggest that, similar to Atlantic Salmon and Smallmouth Bass, the downstream areas of the tailrace and island supersite habitat represent high quality habitat, even at the lowest considered flows (Figures 32 to 34). However, as discharge increases, habitat conditions seem to be suitable for almost the whole study area. Only areas within the side channel supersite seem to be sub-optimal (Figure 34), which is also the case for the other target species at all considered low flow scenarios. As with Atlantic Salmon and Smallmouth Bass, there is an increase in WUA with increasing discharge (Figure 35). In the low quality habitat, WUA decreases with increasing discharge (Figure 36), whereas in the moderate and high quality sites, there is a positive relationship between WUA discharge (Figures 37 and 38; respectively).

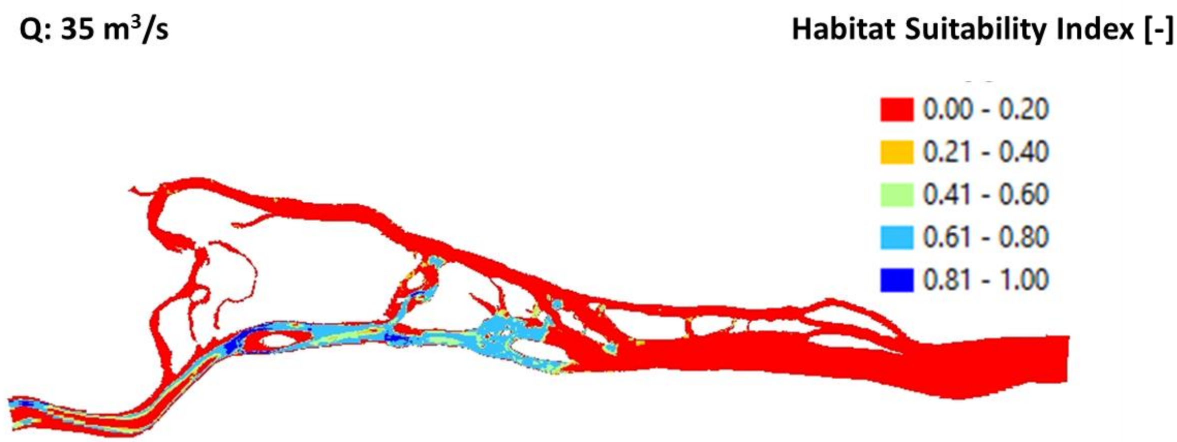


**Figure 30~~32~~: Habitat simulation for Common Shiner (adult) at historic low flow conditions of 35 m³/s. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**

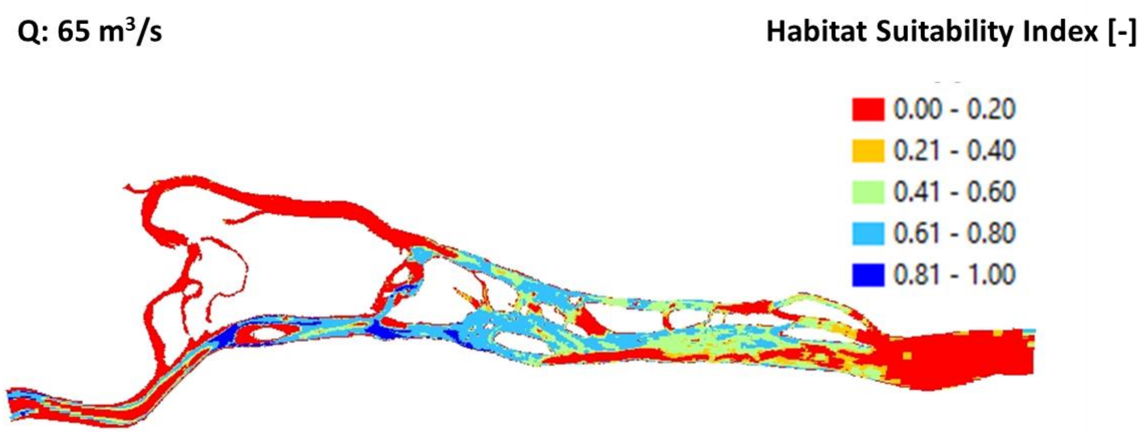


**Figure 31~~33~~: Habitat simulation for Common Shiner (adult) at historic low flow conditions of 65 m³/s. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**

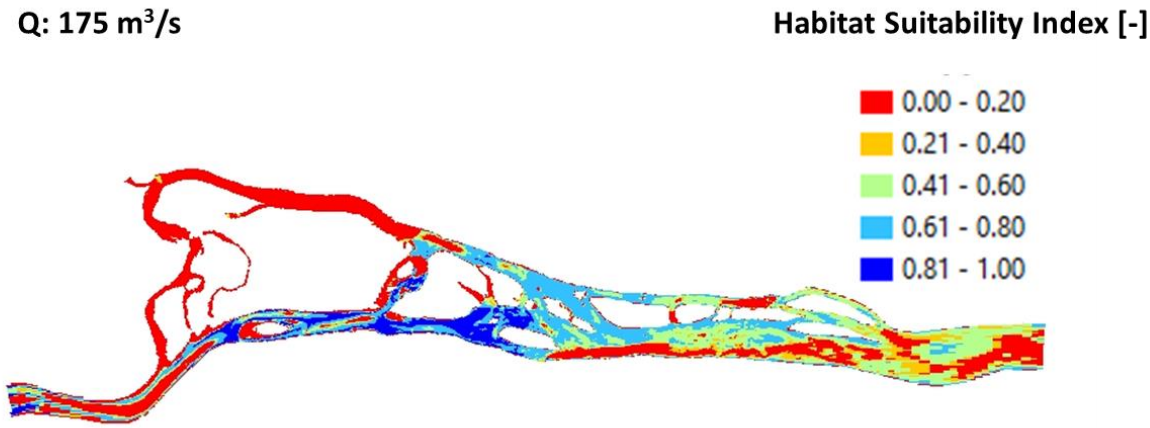


**Figure 32~~34~~: Habitat simulation for Common Shiner (adult) at historic low flow conditions of 175 m$^3$/s. Habitat suitability ranges from 0 (poor condition) to 1 (optimum condition) – see text for explanations.**

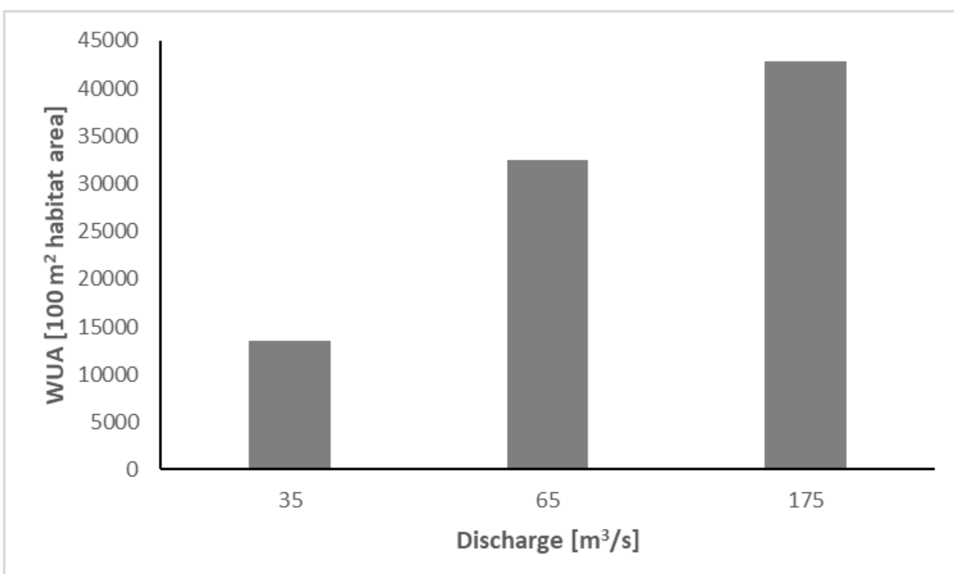


**Figure 33~~35~~: Weighted useable area [100m2 habitat units] for adult Common Shiner at three different low flow conditions.**

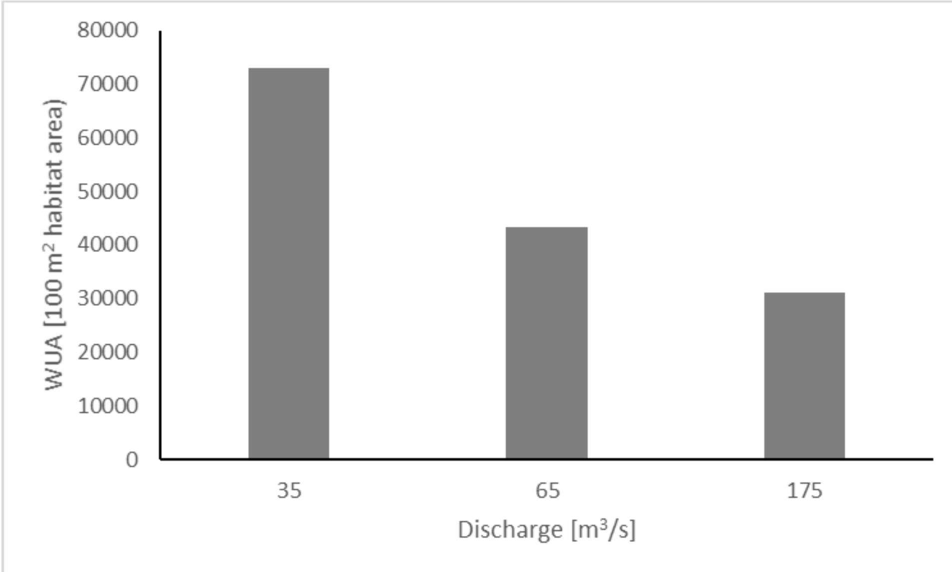


**Figure ~~34~~36: Avoided (SI:0.0-0.30) Common Shiner habitat at three low flow conditions.**

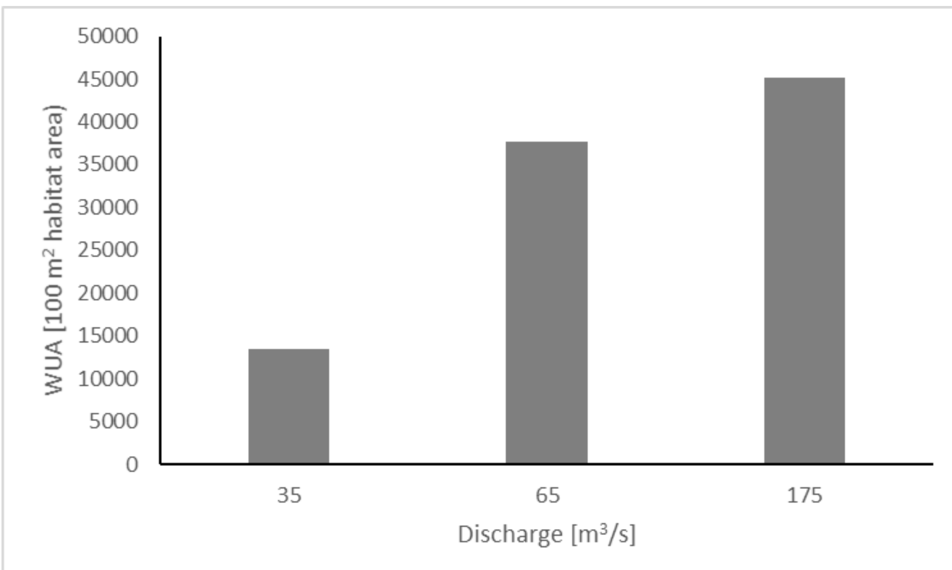


**Figure ~~35~~37: Indifferent (SI:0.31-0.7) Common Shiner habitat at three low flow conditions.**

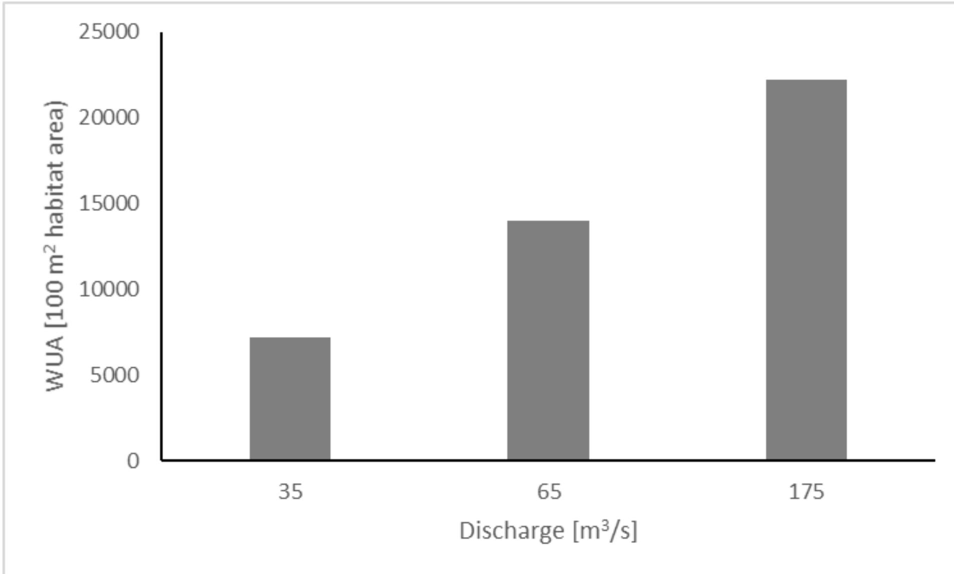


**Figure ~~38~~36: Preferred (SI:0.71-1.0) Common Shiner habitat at three low flow conditions.**

# 4 CONCLUSIONS AND IMPLICATIONS

## 4.1 FISH COMMUNITY IN SAINT JOHN RIVER

The results of the fish community surveys in this study are not intended to test for spatial patterns and differences in fish community composition. Rather this study presents, in a descriptive way, an overview of what species were captured, pooled among all three sampling years, in the modeled segment of the SJR downstream the MGS. A detailed analysis of community metrics and discussion of fish assemblages in the SJR downstream of MGS is forthcoming (Dolson-Edge et. al unpublished). Habitat conditions varied between supersites with fine substrates and dense aquatic vegetation (e.g. side vs. main channel) and supersites with coarse substrates, a higher level of embeddedness and scarce vegetation (e.g. tailrace). The island supersite represented intermediate conditions with gravel as the dominant substrate type and patchy, sparse aquatic vegetation. Some species, such as Yellow Perch or White Sucker, were abundant throughout the entire study area, which indicates that they can be classified as habitat generalists. Considering the identified spatial patterns within the study area, future surveys will investigate relationships between fish species presence and habitat types on a meso-scale (e.g. mesohabitat types: riffle, pool, glide or run). Linking meso-scale habitat to fish assemblages has shown promising results in the literature (Wilkes et al. 2016; Smith et al. 2016). This data can be used as a baseline to identify fish assemblages associated to specific mesohabitat types for modelling purposes.

Habitat parameters that were used in simulations included flow velocity, water depth and substrate particle size (Preference curves in Appendix). Results in section 1.10 and 1.11 represent a first habitat assessment for three target fish species. Future research utilizing a more holistic approach to evaluate fish assemblages would need to consider the effect of other factors (e.g. the presence or absence of macrophyte beds).

## 4.2 HABITAT SIMULATION ACROSS FLOW RANGE

Differences between preference curves of target species must be considered when analyzing habitat simulations, for both the whole flow range as well as the low-flow predictions. Preference curves of Atlantic Salmon do not have optima equal to 1.0, whereas Smallmouth Bass and Common Shiner do achieve optima of 1.0. Curves for salmon were calculated by Heggenes (1990) from the arithmetic means within ranges investigated in several studies. Since these curves were not identical it resulted in optima less than 1.0. Furthermore, curves of Smallmouth Bass and Common Shiner also cover a wider depth range (up to 3 m), in comparison to Atlantic Salmon (max depth: YOY=1 m; parr = 1.20 m). Consequently, habitat quality in areas deeper than the considered preference range is likely to be underestimated. These habitats can be important for juvenile life stages of Atlantic Salmon in large rivers (Linnansaari et al. 2010).

Simulations across the flow range of all study areas except the side channel supersite show that habitat suitability for all target fish species typically has higher values at low to moderate flows; dropping when flow increases. The availability of suitable habitat within the side channel supersite increases with increasing flow and reaches a plateau where it remains relatively constant. This stretch is characterized by stagnant flow conditions during low flows, which partly explains positive changes in habitat conditions as discharge increases.

When assessing habitat conditions, it is important to keep in mind that the habitat suitability index only represents the average habitat quality characteristic of a studied river reach. In order to evaluate the habitat availability and quality, it is essential to investigate the distribution of suitability classes (e.g. avoided, indifferent or preferred). For instance, a reach having a moderate HSI can either have many patches of moderate habitat suitability, or it may have some patches exhibiting excellent suitability scattered among mostly unsuitable areas. From the ecological perspective, the latter option would be the preferred situation. CASiMiR can identify the spatial distribution of these areas. The results are discussed in the following section 4.3.

## 4.3 LOW-FLOW SIMULATION-

Simulations at different low flow scenarios revealed changes in the spatial distribution of habitat conditions. Particularly fish habitat around the islands would be affected by a decrease in discharge from typically occurring low flows (176m$^3$/s) to historic low flows (35m$^3$/s), which generally results in a decrease in WUA as well as preferred habitat for the target fish species. However, a decrease in preferred habitat due to a low flow period does not necessarily involve a decline in fish population, since aquatic organisms are usually adapted to a natural flow regime that involve dynamic changes in habitat conditions (Lytle & Poff 2004). Since physical habitat models can only simulate a static relationship between habitat availability and flow, this temporal variability cannot be assessed with this tool. However, other methods exist, typically used in environmental flow studies, that take into account the ecological importance of flow variability (Poff et al. 2010; Linnansaari et al. 2013).

These predictions also highlight how sensitive habitat conditions change during the low-flow period, which represents a critical time in the development for many fish species (Bradford & Heinonen 2008). Thus, dam renewal options need to acknowledge the importance of setting ecologically meaningful minimum flows during a low-flow period.

Areas within the side and main channel supersites represent important habitat for species preferring low flow velocities and fine substrates. Since the side channel supersite is cut off from the main stem during low flow conditions, this area typically experiences stagnant flow conditions during summer months. The preference curves used in this study classify stagnant conditions (i.e. flow velocity ~0m/s) as unsuitable for all target species, which partly explains the low suitability indices for the simulated low flows. However, our fishing surveys show that this area is utilized by several species and life stages, which suggests that it is likely representing important habitat for fish. When comparing the low-flow modeling results for the side channel supersite, to the stathab model across the flow range, it is important to keep in mind that for the latter the lower discharge boundary (i.e. ~280 m$^3$/s at MGS) is still much higher than the "typically occurring low- flow scenario" simulated with the hydrodynamic model (i.e. 175 m$^3$/s). Consequently, frequencies of velocity and depth classes that lie within the suitable spectrum of the target species are higher in the stathab predictions. This partly explains why estimations of habitat suitability based from the statistical hydraulic model are more positive compared to the low-flow scenarios based on hydrodynamic modeling.

Habitat suitability in the tailrace increases with increasing discharge when comparing historic with current and typically occurring low flows. Substrate data at any reach within the modeled study area do not include information regarding the level of embeddedness, which would be particularly interesting at this supersite. For instance, even suitable habitat based on parameters such as flow velocity, water depth, and substrate particle size could be masked by a prominent level of embeddedness. Moreover, the tailrace supersite experiences increased water level fluctuations due to its proximity to the MGS. This is especially relevant for less mobile species (e.g., freshwater mussels) which cannot easily migrate to more stable environments (Layzer & Scott 2006).

Consequently, it will be important for future assessments to consider additional habitat characteristics (e.g., embeddedness, cover or water temperature) as well as habitat metrics (e.g., habitat persistence related to water level fluctuations) to better understand flow-ecology relationships. Overall, the quantification of physical habitat for different low-flow scenarios as well as predictions across the flow range, provide useful metrics (i.e. area of high quality habitat) that help evaluating and assessing environmental impacts on the SJR related to future options of the MGS.

## 4.1 UNCERTAINTIES

Habitat models are a useful tool in environmental management; however, there are several limitations when using this approach. For example, see Railsback (2016) for an interesting discussion about understanding flow-ecology relationships in habitat selection modelling. First, habitat availability does not represent habitat use, which means that the presence of suitable habitat conditions do not necessarily result in the presence of the species of interest (Linnansaari et al. 2013). Second, the issue of habitat scaling (i.e. micro-, meso-, or macro scale) needs to be considered when designing instream flow studies that are ecologically meaningful for the species of interest (Habersack et al. 2014). Furthermore, fish habitat selection varies not only among species and life stage but is also dependent on other factors such as the availability of food, temperature, or biotic interactions (e.g., competition) (Railsback 2016).

Despite the importance of habitat simulation models in river management, it is important to recognize that they can't be used alone to evaluate environmental impact scenarios and should be used in conjunction with other management tools. However, quantifying the physical habitat as a function of discharge is a necessary step in this process (Linnansaari et al. 2013).

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# 6 APPENDIX

## 6.1 PREFERENCE CURVES

Habitat conditions were simulated using preference curves from the literature.

- Atlantic Salmon: parr and YOY (Heggenes, 1990)
- Smallmouth Bass: adult and juvenile (Aadland & Kuitunen 2006)
- Common Shiner: adult (Aadland & Kuitunen 2006)

### 6.1.1 Atlantic Salmon (*Salmo salar*)

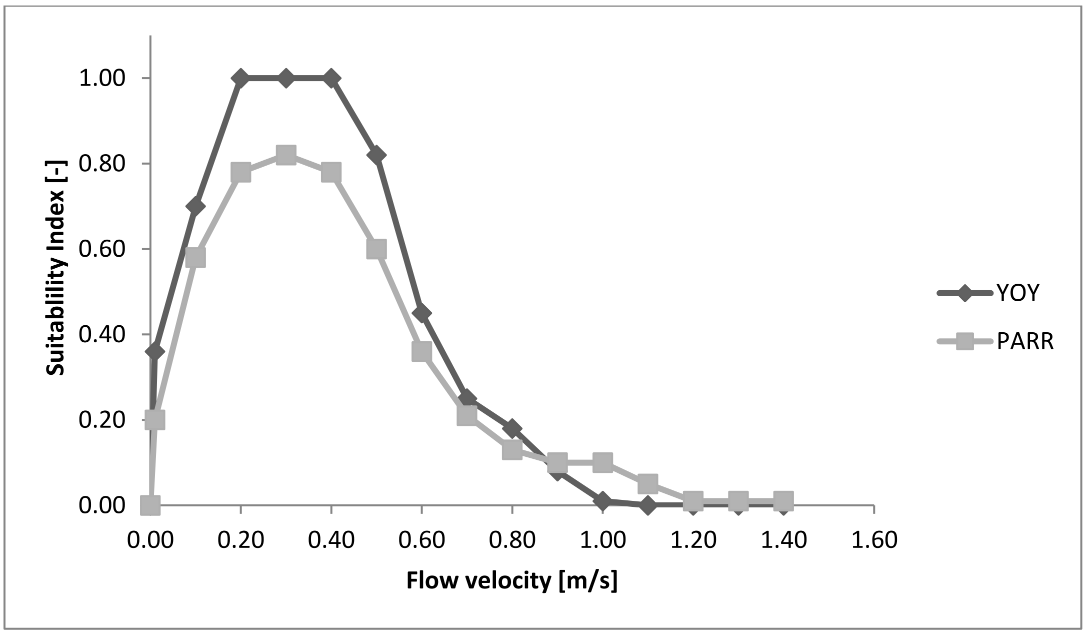


**Figure 37~~39~~: Habitat suitability curve for use of mean water velocities by Atlantic Salmon parr (bright line) and YOY (dark line).**

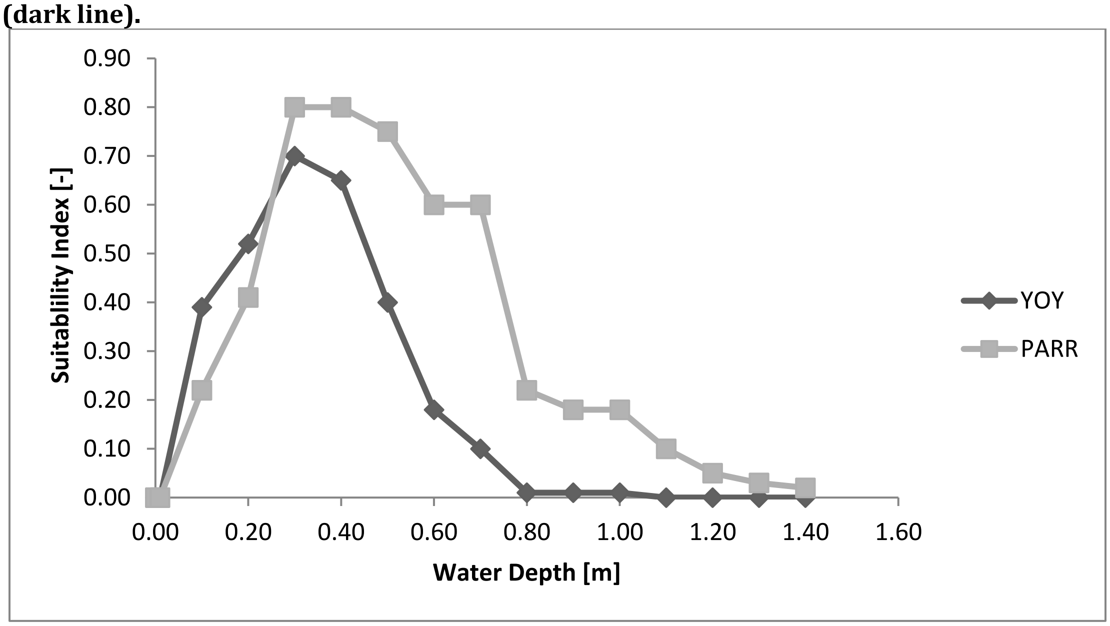


**Figure 38~~40~~: Habitat suitability curve for water depth by Atlantic Salmon parr (bright line) and YOY (dark line).**

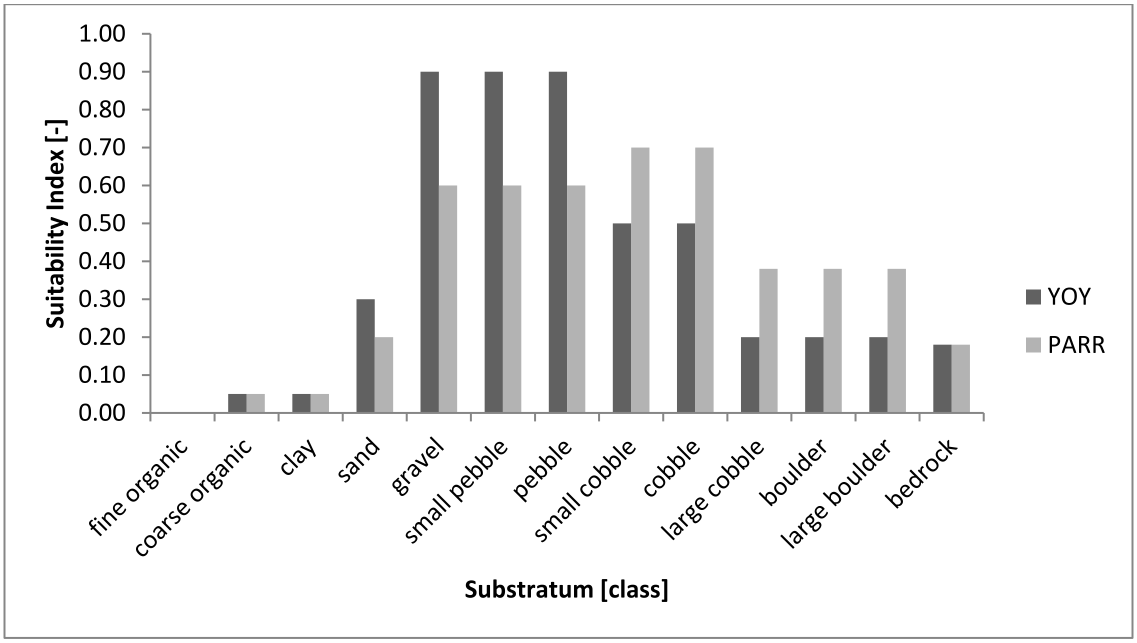


**Figure 39~~41~~: Habitat suitability curve for use of substratum particle sizes (Wentworth scale) by Atlantic Salmon parr (bright line) and YOY (dark line).**

### 6.1.2 Smallmouth Bass (*Micropterus dolomieu*)

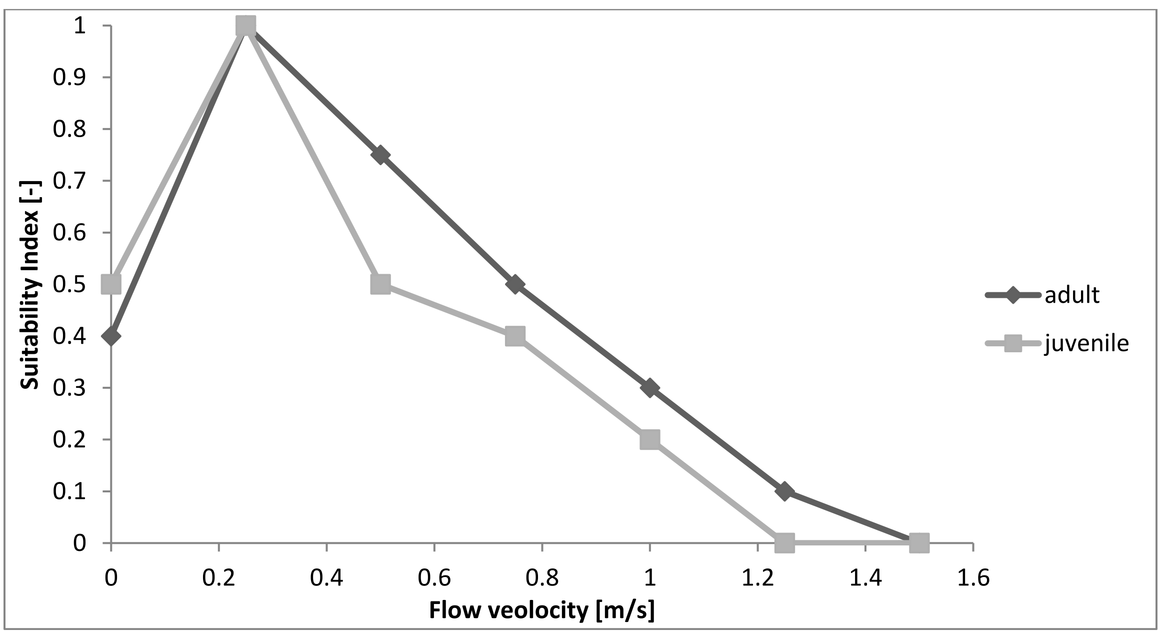


**Figure 40~~42~~: Habitat suitability curve for use of mean water velocities by Smallmouth Bass adult (dark line) and juvenile (bright line).**

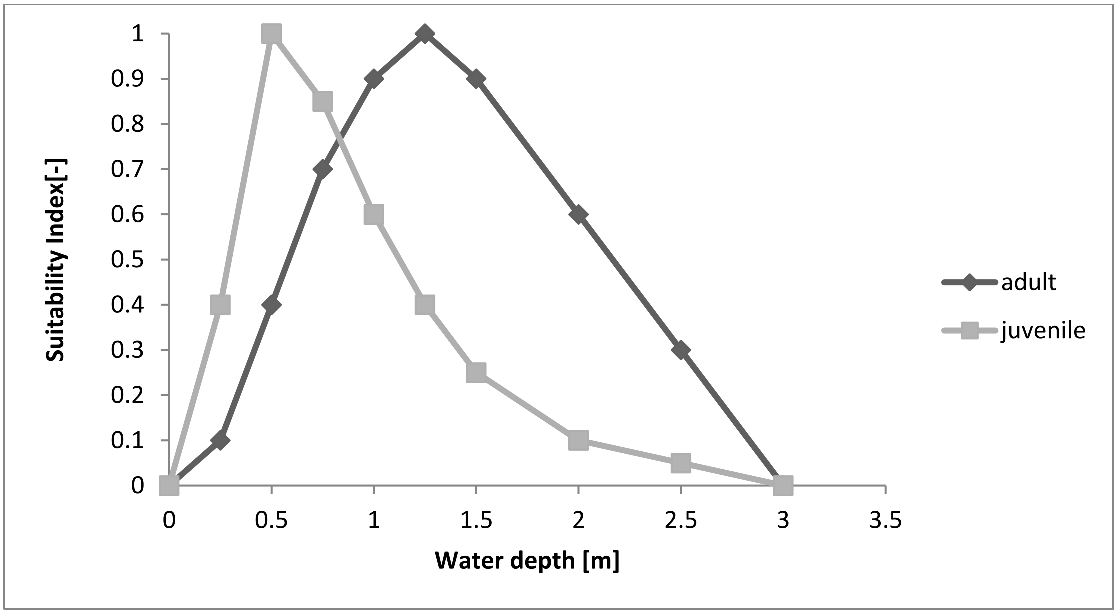


**Figure 41~~43~~: Habitat suitability curve for water depth by Smallmouth Bass adult (dark line) and juvenile (bright line).**

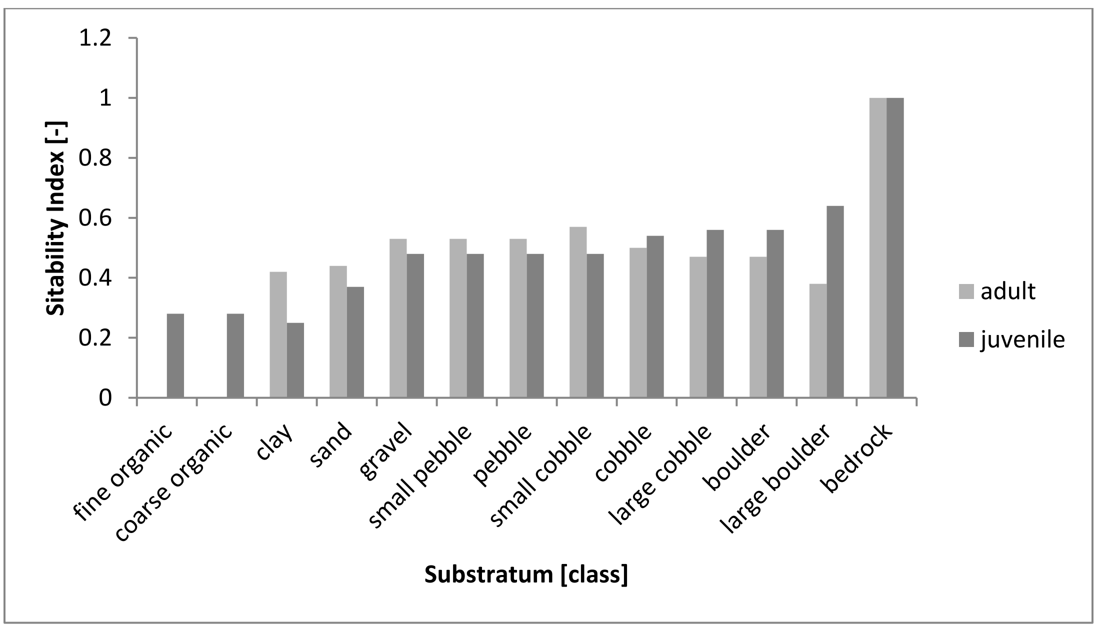


**Figure 42~~44~~: Habitat suitability curve for use of substratum particle sizes (Wentworth scale) by Smallmouth Bass adult (bright line) and juvenile (dark line).**

### 6.1.3 Common Shiner (Notropis cornutus)

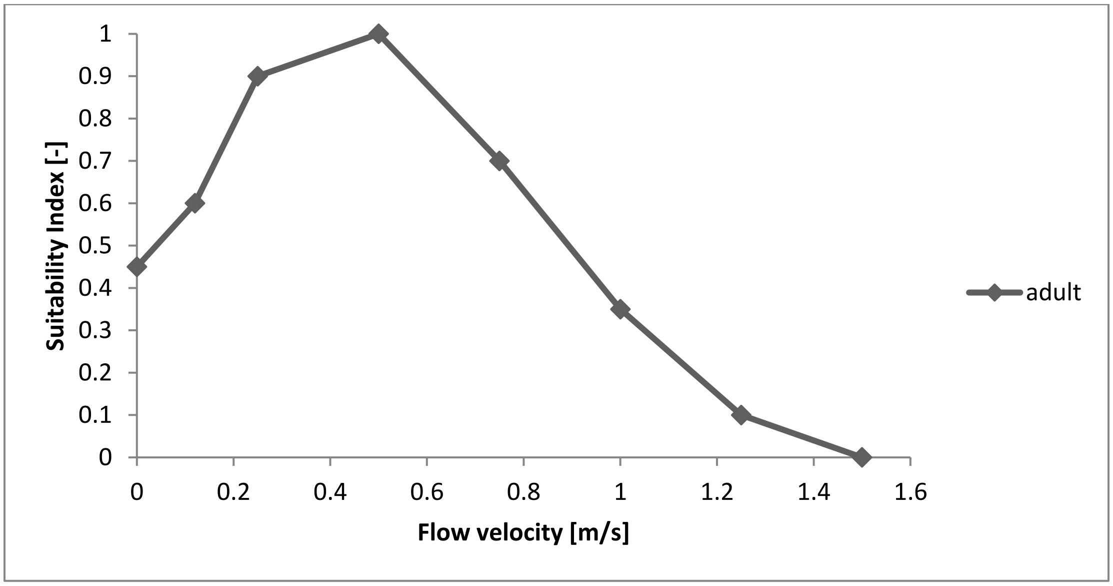


**Figure 43~~45~~: Habitat suitability curve for use of mean water velocities by Common Shiner adult**

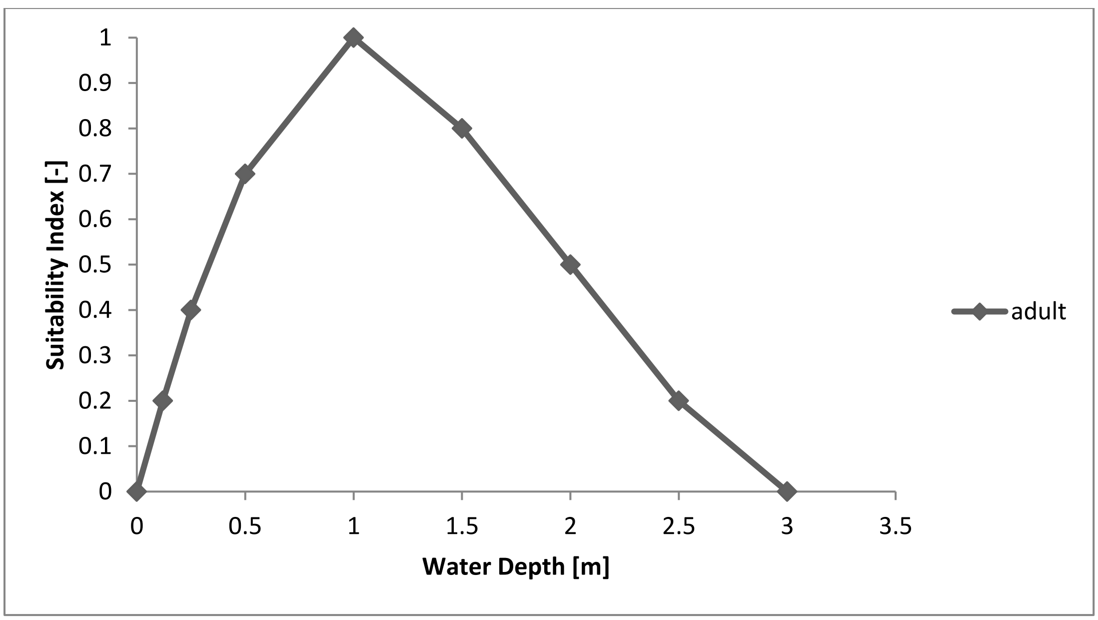


**Figure 44~~46~~: Habitat suitability curve for water depth by Common Shiner adult**

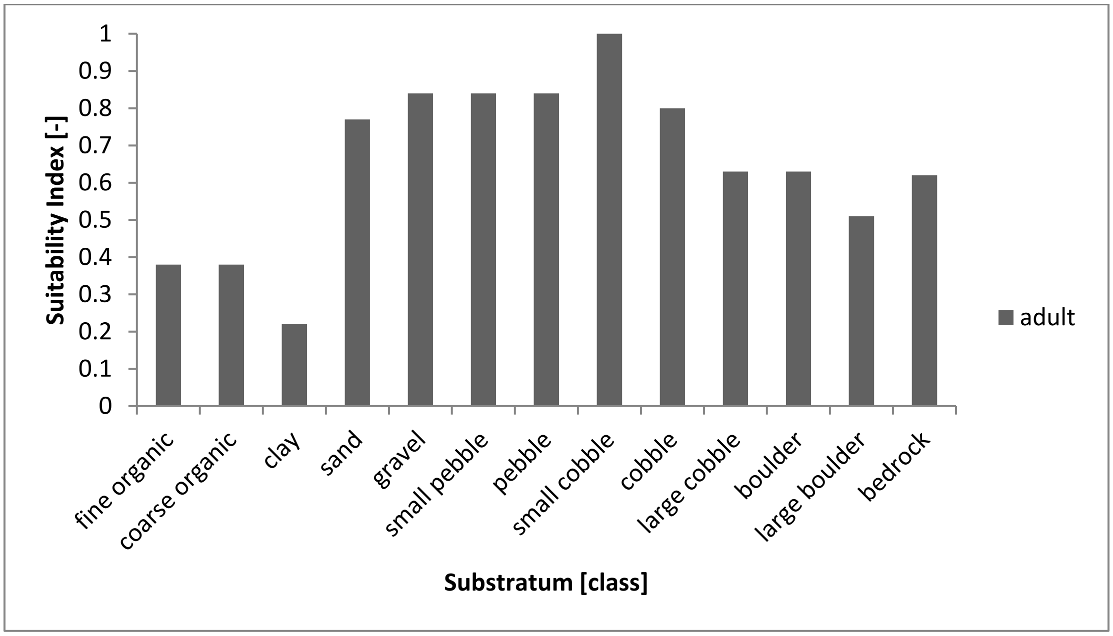


**Figure 45~~47~~: Habitat suitability curve for use of substratum particle sizes (Wentworth scale) by Common Shiner adult.**

## 6.2 SUBSTRATE MAP

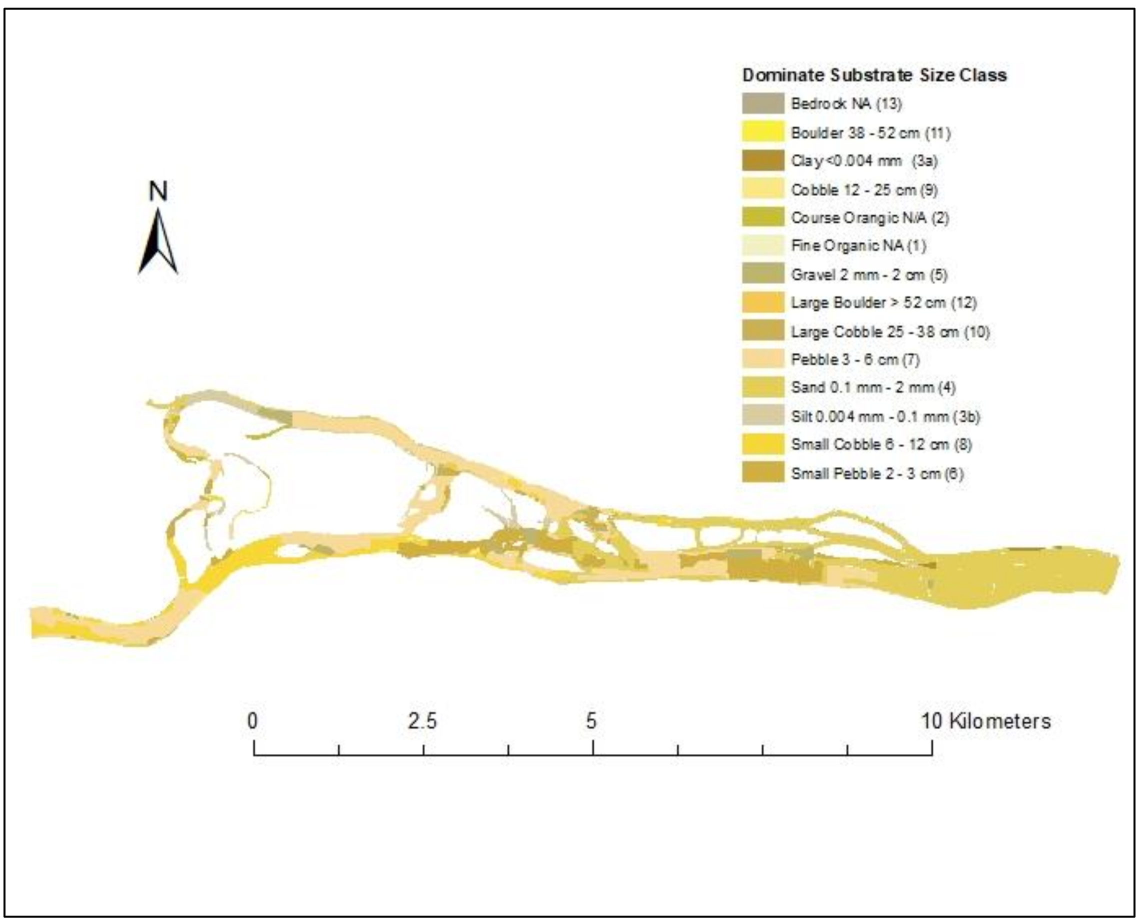


**Figure 46~~48~~: Mapped dominant substrate size classes across the study area**