# Lower Fraser River Juvenile Fish Habitat Suitability Criteria

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## ABSTRACT

Rempel, L.L., Healey K., and Lewis, F.J.A. 2012. Lower Fraser River juvenile fish habitat suitability criteria. Can. Tech. Rep. Fish. Aquat. Sci. 2991: ix + 73 p.

This report presents life-stage specific habitat suitability criteria (HSC) for six species of juvenile fish in the lower Fraser River gravel reach, British Columbia: Chum (*Oncorhynchus keta*), Sockeye (*O. nerka*) and Chinook (*O. tshawytscha*) Salmon, Mountain Whitefish (*Propsopium williamsoni*), Rainbow Trout (*O. mykiss*), and Mountain Sucker (*Catostomus platyrhynchus*). Criteria for suitable depth, velocity and substrate are presented. HSC can be used to predict the amount of suitable habitat under different flow and habitat conditions, and are therefore a useful tool to support fisheries managers and regulatory decision-making. Our HSC are derived from an extensive dataset of field sampling that targeted juvenile rearing habitat associated with gravel bars in this large, turbid river. As such, these are the types of habitats in other systems to which the HSC may be applied. Our suitability criteria for all species analyzed match reasonably well with existing curves published in the literature. Moreover, habitat suitability compared between the main and secondary channels in the Fraser River revealed very little difference in channel-specific suitability criteria. HSC are presented graphically in the report and are available as an electronic Appendix.

## RÉSUMÉ

Rempel, L.L., Healey, K., and Lewis, F.J.A. 2012. Lower Fraser River juvenile fish habitat suitability criteria. Can. Tech. Rep. Fish. Aquat. Sci. 2991: ix + 73 p.

Le présent rapport fait état des critères d'admissibilité de l'habitat (CAH) selon le stade de vie pour six espèces de juvéniles dans le passage de gravier du bas Fraser, en Colombie-Britannique : le saumon kéta (*Oncorhynchus keta*), le saumon rouge (*O. nerka*) le saumon quinnat (*O. tshawytscha*), le ménomini de montagnes (*Propsopium williamsoni*), la truite arc-en-ciel (*O. mykiss*) et le meunier des montagnes (*Catostomus platyrhynchus*). Le rapport présente les critères acceptables pour ce qui est de la profondeur, la vélocité et le substrat. Les CAH peuvent être utilisés pour prédire la superficie d'habitat convenable selon différentes conditions touchant le flux et l'habitat. Ils sont donc un outil pratique pour appuyer les gestionnaires des pêches et les décideurs. Nos CAH sont élaborés à partir d'un vaste ensemble de données recueillies au moyen de l'échantillonnage sur le terrain ciblant les habitats de juvéniles associés à des bancs de gravier dans cette grande rivière trouble. Ainsi, c'est à ce type d'habitat que les CAH peuvent être appliqués dans d'autres systèmes. Après analyse, nos critères d'admissibilité pour toutes les espèces correspondent raisonnablement bien aux graphiques déjà publiés dans la littérature scientifique. En outre, une comparaison de l'admissibilité de l'habitat entre les branches principale et secondaires du fleuve Fraser a révélé que les critères d'admissibilité propres à chaque branche varient très peu entre eux. Les CAH sont présentés sous forme de graphiques dans le présent rapport et sont disponibles en tant qu'annexe électronique.

# 1 INTRODUCTION

The Fraser River drains approximately 233,000 km$^2$ of south-central British Columbia. The mainstem river is unregulated and annual flooding due to snowmelt (referred to as freshet) occurs in spring. The upper basin is relatively steep and laden with post-glacial sediment deposits that are mobilized during annual freshet. A sharp decline in gradient in the lower river basin at Hope forces the deposition of much of this sediment load. A large volume of predominantly gravel-sized sediment is deposited between the towns of Hope and Mission on an annual basis during freshet (Figure 1). Consequently, this 60-km reach of Fraser River is referred to as the *gravel reach*. The *sand reach*, along which the river bed is predominantly sand, is located downstream of Mission to the Strait of Georgia at Vancouver.

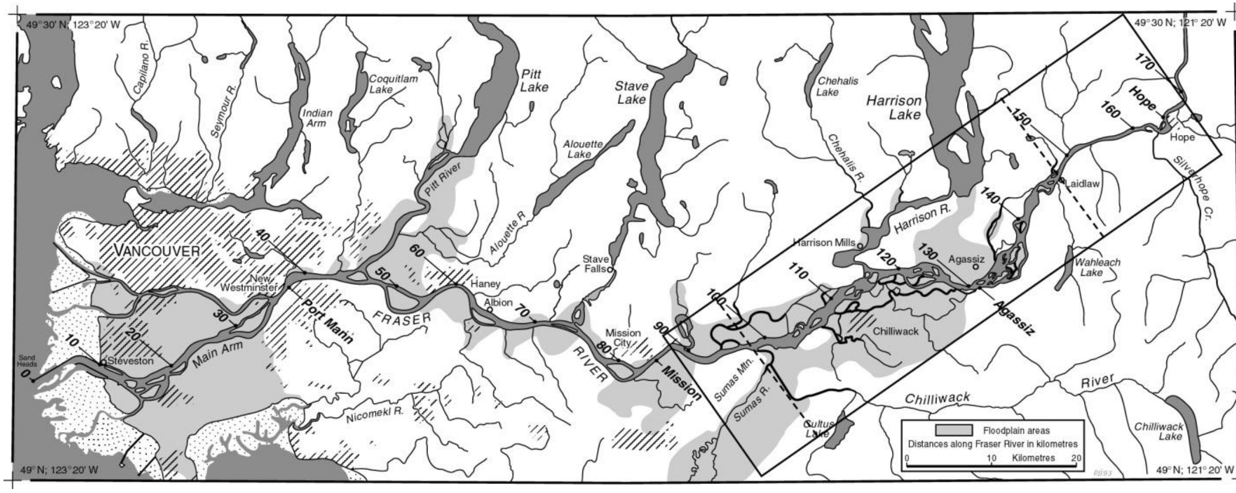


Figure 1. Location map of the lower Fraser River including the gravel reach (inset box) from Hope to Mission.

Sediment deposition in the gravel reach creates a complex pattern of gravel bars and vegetated islands around which the river flows. Prominent gravel bars are exposed at low water levels when the river's flow is mostly concentrated in the main channel. With the onset of freshet, gravel bars become submerged and the network of secondary and seasonal channels delivers flow, sediment and nutrients to productive habitat types across the active channel zone. The location and form of these bars and islands are constantly changing as a result of the river's natural erosion and deposition processes during freshet. It is these same processes that create and maintain fish habitat of exceptionally high quality. Average peak freshet at Hope is 8,766 m$^3$/s (Water Survey of Canada Station 08MF005) and mean annual flow is 3,410 m$^3$/s.

The habitat complexity afforded by the network of gravel bars, islands and channels supports a diverse fish community (Rosenau and Angelo 2007). At least 28 species representing 9 families are found in the gravel reach; this reach of Fraser River is more species-rich than all upstream reaches (Rempel 2004, Northcote and Larkin 1989). Five species are considered *at risk* by the Province of British Columbia: White Sturgeon, Mountain Sucker, Cutthroat Trout, Bull Trout, Dolly Varden (http://www.env.gov.bc.ca/atrisk/index.html). White Sturgeon is listed as *endangered* by the Committee on the Status of Endangered Wildlife in Canada (http://www.cosewic.gc.ca/eng/sct5/index_e.cfm).

Fish species of greatest cultural, commercial and recreational importance in the gravel reach are Chinook, Chum, Coho, Pink and Sockeye Salmon, Cutthroat, Steelhead and Rainbow Trout, and White Sturgeon. Significant numbers of Pink Salmon spawn within the main channel in odd years and small numbers of Chum Salmon spawn annually. Some juvenile Chum Salmon rear briefly in mainstem habitats before migrating downstream whereas newly emerged Pink Salmon migrate directly to the estuary. River-type Sockeye Salmon rear in slack-water habitats of the gravel reach year-round. Some are believed to spend a year or more in riverine habitats but the majority likely rear only for up to a few months before migrating to the estuary. Large numbers of Chinook Salmon rear in the Fraser River gravel reach for up to one year before ocean migration. Genetic analyses indicate that these fish originate predominantly from the middle Fraser Basin (~75%), particularly the Stuart and Nechako Rivers, and also commonly from the Raft and Clearwater Rivers of the North Thompson basin (~15%, Rempel 2004). White Sturgeon reside in the gravel reach throughout the year and side channel use for spawning has been documented (Perrin et al. 2003a, Liebe and Sykes 2010).

The Fraser River gravel reach and its surrounding floodplain are under increasing development pressure. Over 100 km of highly productive floodplain side channels have been isolated from the mainstem by dyking and flow control structures (Rosenau and Angelo 2000). More than 63 km of bankline have been armoured with riprap and an additional 32 km have been hardened to protect railways (Ham 2005). Riparian vegetation has been cleared from river bank and floodplain areas, and wetlands have been drained and isolated for agriculture. Both the industrial need for aggregate and flood concerns have resulted in the removal of at least 6.2 million $m^3$ of sediment from within the active channel of the gravel reach since 1964 (Weatherly and Church 1999). The sediment removal rate has averaged 130,000 $m^3$/yr since 1964 but the recent extraction rate since 2008 (254,000 $m^3$/yr) is much larger as a consequence of BC's Sediment Management Program that carries out instream gravel removal for flood protection (http://www.pep.bc.ca/floods/fraser_sediment_prog.html). With this increasing pressure, federal and provincial fisheries managers need the best available information on habitat requirements of the species and life stages in the gravel reach to support decision-making and ensure the protection and sustainability of Fraser River fisheries.

This report examines the habitat requirements of select populations of juvenile fish in the Fraser River gravel reach and presents life-stage specific habitat suitability criteria (HSC). Coupled with information about the physical habitat and flow dynamics, HSC can be used to evaluate the ecological consequences to fish from flow and habitat related changes. They are therefore a useful tool to support regulatory decision-making. In the case of gravel removal, Fisheries & Oceans Canada (DFO) is using HSC to estimate the amount of useable rearing habitat for juvenile fish at sites where gravel removal is proposed. Using a 2-D hydraulic model (e.g., River2D©), the change in useable habitat area can be predicted based on the removal design in order to estimate the extent of harmful alteration, disruption or destruction of fish habitat (HADD) likely to be caused by the removal. If gravel removal is authorized under the *Fisheries Act*, then annual site surveys and habitat modeling with HSC can be used to estimate habitat change at the site due to annual freshet in order to determine the duration of HADD and track habitat recovery.

The development of reliable HSC typically requires large amounts of field data that describe the locations and habitat characteristics where individual fish do and do not occur. This sort of information is especially difficult to acquire for large rivers because standard field sampling methods developed for small streams are not feasible. Moreover, the inherent variability in fish distributions requires a significant and costly sampling effort. An extensive dataset was fortuitously available from a juvenile fish sampling program between 1999 and 2001 of the Fraser River gravel reach (Rempel 2004). The present study made use of this dataset to develop HSC specific to fish populations in the gravel reach, which may then be used to support fish habitat decision-making for the lower Fraser River and other, similar systems.

Field sampling targeted juvenile rearing habitat associated with gravel bars in the active channel zone and as such, these are the habitats to which the HSC should be applied. HSC are developed for several life stage classes of five species: Chum (*Oncorhynchus keta*), Sockeye (*O. nerka*) and Chinook (*O. tshawytscha*) Salmon, Mountain Whitefish (*Propsopium williamsoni*), Rainbow Trout (*O. mykiss*), and Mountain Sucker (*Catostomus platyrhynchus*). Specific study objectives were to 1) determine appropriate life stage classes for species based on length data; 2) calculate depth, velocity and substrate habitat suitability scores for each life stage class of species; and 3) create habitat suitability criteria for each life stage class of species.

# 2 METHODS

## 2.1 HABITAT CLASSIFICATION

The objective of the original sampling program (Rempel 2004) was to identify species-habitat associations in the gravel reach of Fraser River. A secondary objective was to evaluate the effects of sediment removal from gravel bars on fish and fish habitat. Sampling occurred over three years (1999-2001) in all seasons. One product of the study was a habitat classification that identifies physically distinct habitat types and channel types associated with gravel bars, islands and river banks (Table 1). The habitat types occur ubiquitously throughout the gravel reach, typically on the scale of 100 $m^2$ units, and are characterized by particular velocity, depth and substrate conditions. The habitat classification was the basis for stratified fish sampling between 1999 and 2001 to identify species-habitat associations. A full discussion of the habitat classification can be found in Church et al. (2000) and Rempel (2004).

Figure 2 shows a schematic of alluvial habitat types and channel types associated with gravel bars. These alluvial habitat types, meaning habitats formed by river processes, were prioritized for stratified fish sampling and correspond with the channel zone where juvenile fish productivity is likely to be highest (Beechie et al. 2005). Each habitat type was sampled approximately in proportion to its occurrence at a gravel bar site. Hence, common habitat types (e.g., bar edge) were sampled with greater frequency than uncommon ones (e.g., eddy pool) and all habitat types were not sampled with equal effort. Because each fish sample was collected from within the boundaries of a physically distinct habitat unit, we believe these fish collection data are suitable for habitat suitability analysis and that any confounding effect on the fish collection data of within-unit habitat variation is minimized. We acknowledge that juvenile fish may use some non-alluvial habitats (e.g., rip rap, bedrock) for rearing but these habitats were not included in our analysis because field data were unavailable.

Table 1. Habitat and channel types in the gravel reach of Fraser River (from Rempel 2004).

| Habitat Type | Definition |
|---|---|
| **Riffle (RI)*** | High-gradient area of shallow, fast water flowing over well-sorted substrate. The flow is rough. Common at bar heads. |
| **Bar Head (BH)*** | Upstream end of a gravel bar. Surface substrate is characteristically coarse and flow velocity is usually high. |
| **Bar Edge (BE)*** | Any length of bar edge not occurring at the head or tail of a bar that is oriented parallel to the flow and subject to constant and consistent flow forces. Bank slope is variable and a range of velocities and substrate types is possible. |
| **Bar Tail (BT)*** | Downstream end of a gravel bar, usually with moderate flow velocity. Surface substrate consists of gravels and occasionally sand. |
| **Eddy Pool (EP)*** | Area bounded by fast, rough water that creates a back eddy in the lee of the flow. Common on the inside edge of riffles and at the upstream end of some bar head habitats. Bank slope is invariably steep and the substrate is usually embedded cobble. |
| **Open Nook (ON)*** | Shallow indentation along a bar edge of reduced velocity and variable substrate that is openly connected to the channel with no sedimentary barrier (unlike channel nook). An ephemeral habitat that may disappear with a relatively small change in water level. |
| **Channel Nook (CN)*** | Dead-end channel or narrow embayment of standing water. Substrate is usually sand/silt and embedded gravel. |
| **Bay (BA)*** | Semi-enclosed area with no flow velocity and fine substrate. Occurs on the lee side of large, crescent-shaped sediment deposits. |
| **Vegetation (VG)^** | Area of flooded island or bank vegetation where velocity is reduced and substrate is relatively fine. Submerged only at very high flow. |
| **Cut Bank (CB)^** | Eroding bank of fine sediment that is steeply sloped or vertical. Dense riparian vegetation is often present. Large woody debris is common and flow is variable. |
| **Rock Bank (RB)+** | Natural rock bank that is invariably steep. The water is deep immediately offshore and currents are either fast or form a back eddy. |
| **Artificial Bank (AB) +** | Bank of riprap or rubble rock that is invariably steep. The water is usually deep and fast immediately offshore, particularly at high flow. |
| **Channel Type** | |
| **Main** | Channel conveys flow year-round and includes the thalweg. Bed material consists mostly of clean gravels with a low proportion of fine sediment. |
| **Side** | Channel conveys flow during freshet but may have little or no flow during winter. Wetted habitats at the lower end of the channel persist year-round. Bed material contains a low to moderate amount of fine sediment at the upstream end, and moderate to high amount at the downstream end. |
| **Summer** | Channel is seasonally inundated during freshet only and often intersects diagonally across bar tops. Bed material contains a high proportion of fine sediment. |

* alluvial habitat targeted for sampling by Rempel (2004)

^ alluvial habitat not sampled by Rempel (2004)

\+ non-alluvial habitat type

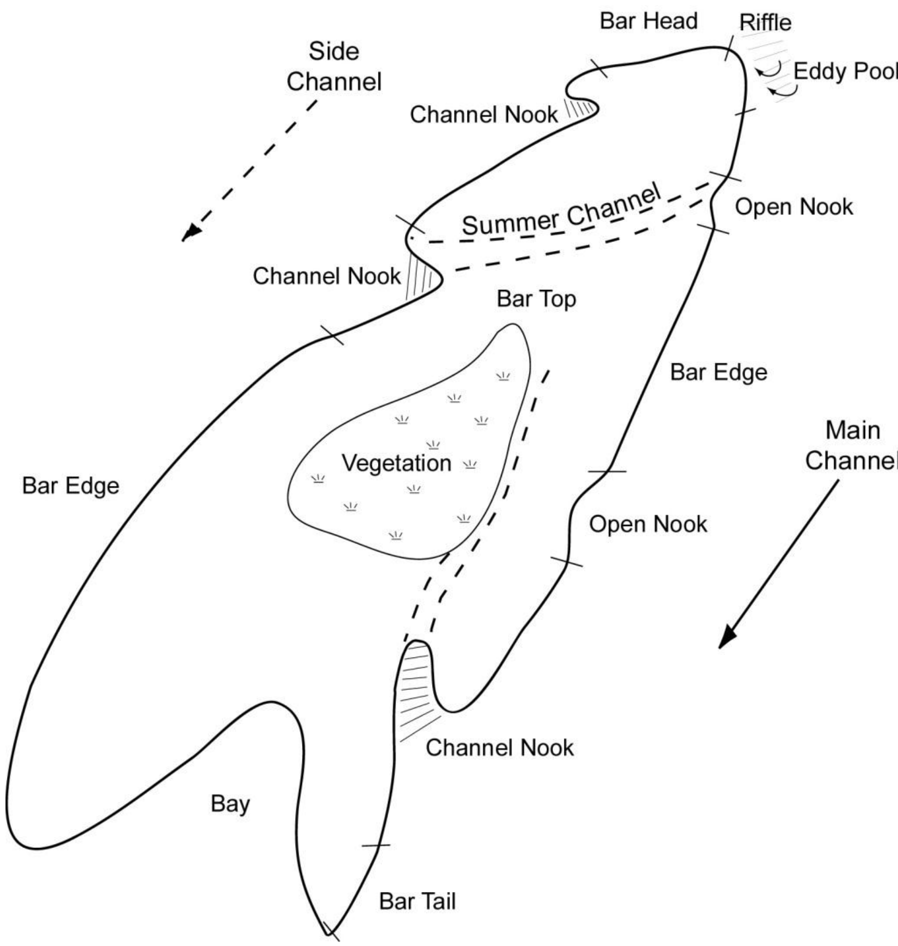


Figure 2. Illustration of channel types and alluvial habitat types in the Fraser River gravel reach (from Rempel 2004).

## 2.2 FISH SAMPLING

Juvenile fish were collected within alluvial habitat units using a variety of sampling gear: beach seine, electrofisher, gillnet, and minnow trap. All sampling methods were used extensively in year one (1999) whereas the beach seine was used principally in subsequent years (2000-2001) because it was effective in most habitats. Both gillnet and minnow trap data were excluded from habitat suitability analyses due to relatively high sampling bias. The mesh size of gillnet panels tends to bias the size of fish captured and the species- and size-related biases of minnow traps are well documented (e.g., Layman and Smith 2001). Hence, the absence of particular size classes and species from gillnet or trap samples does not necessarily indicate that the habitat is unsuitable.

Beach seining was carried out in all habitat types and although capture efficiency was not estimated, we acknowledge that it may have varied depending on several factors including habitat type, fish species, fish size, time of year, and time of day. Each of these factors may underestimate some species as fish either evade the net or escape through its mesh. Some authors recommend attempting to quantify this bias and applying a correction factor to catch data (e.g., Parsley *et al*. 1989). However, Holland-Bartels and Dewey (1997) showed that corrections to compensate for gear bias and environmental conditions are difficult and the error of the adjusted data remains high.

In the Fraser River, we expect that turbidity during most months of sampling minimized beach seine sampling bias related to physical differences between habitat types and species-specific traits. Turbidity decreases the reactive distance of fish (Sweka and Hartman 2001), and Gregory and Levings (1989) showed that turbidity in Fraser River reduced the encounter rate between predacious adult fish and juvenile Chinook Salmon. Gregory and Levings (1989) also reviewed evidence that fish living in turbid water are active throughout the day and benefit from turbidity providing protective cover, which reduces the risk of occupying near-shore areas. This is consistent with results of Rempel (2004) that show summer fish density in daytime beach seines was similar or higher than at night, whereas winter density with clear water averaged almost 5 times higher at night.

Fish sampling by Rempel (2004) used a large beach seine (30 x 3.5 m, 9mm mesh) deployed by boat, and a smaller and highly versatile seine (12.5 x 2 m, 6 mm mesh) was deployed by wading from shore. Its major limitation was that sampling extended to depths less than 1.2 m, the maximum depth one can safely wade in chest waders. Electrofishing with a Smith-Root backpack unit occurred primarily in shallow riffle habitats. Sampling effort by gear type is presented in Table 2. Beach seine sampling sites are shown in Figure 3 through Figure 5.

Table 2. Fish sampling effort and catch summary for the Fraser River gravel reach, 1999-2001. Both gillnet and minnow trap data were excluded from habitat suitability analyses due to potential sampling bias.

| Sampling Gear | # Events | Total Fish | Total Area ($m^2$) | Total Time (hr) |
|---|---|---|---|---|
| **Beach Seine (30 x 3.5 m)** | 27 | 2,155 | 13,109 | - |
| **Beach Seine (12.5 x 2 m)** | 933 | 50,263 | 328,691 | - |
| **Beach Seine (all)** | 960 | 52,418 | 341,800 | - |
| **Electrofisher** | 20 | 456 | 2491 | - |
| **Gillnet** | 61 | 719 | - | 351 |
| **Minnow Trap** | 534 | 1091 | - | 11,480 |
| **TOTAL** | **1575** | **54,684** | **344,291** | **11,831** |

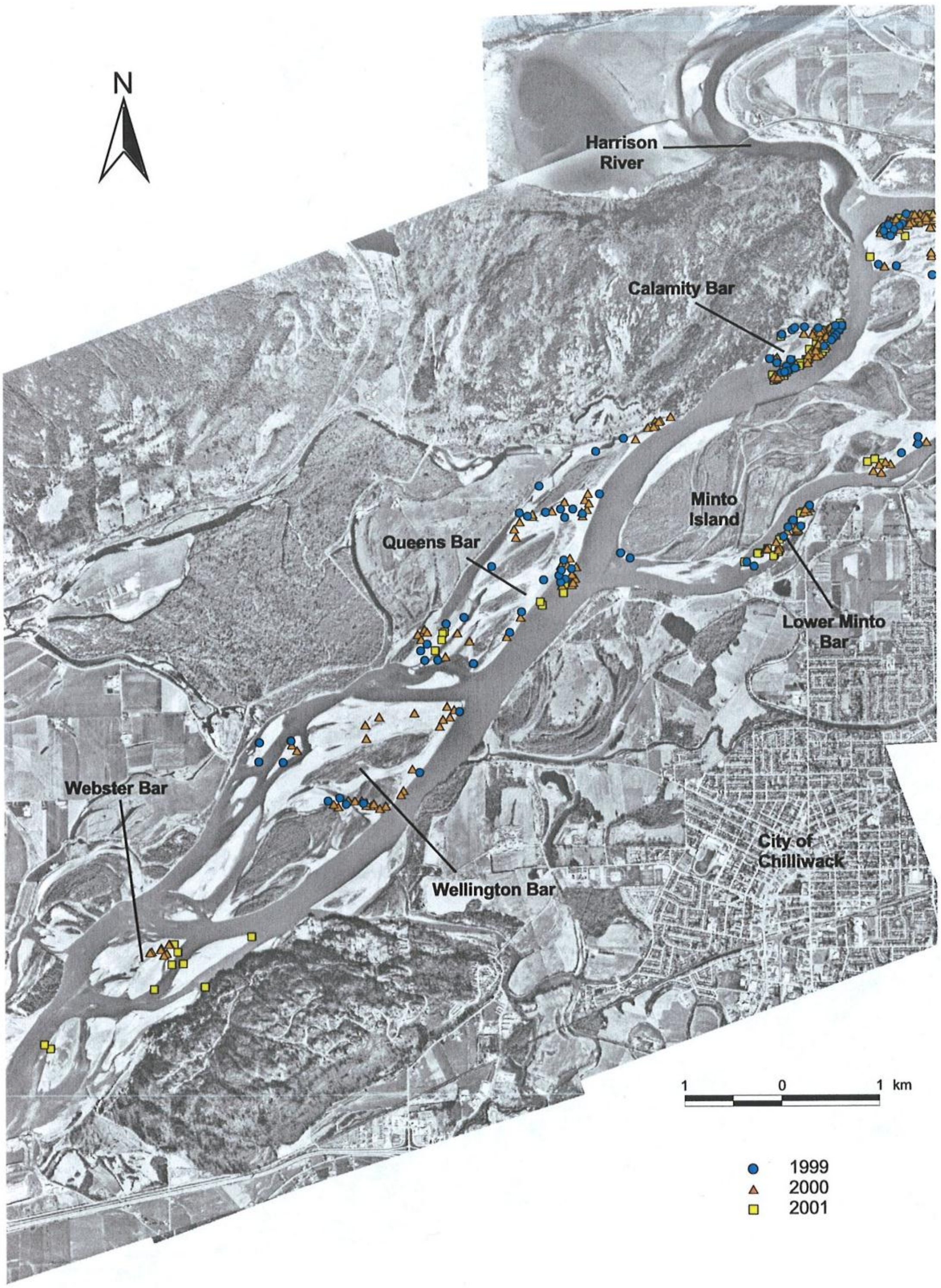


Figure 3. Beach seine sampling sites in the lower gravel reach of Fraser River.


Figure 4. Beach seine sampling sites in the middle gravel reach of Fraser River.

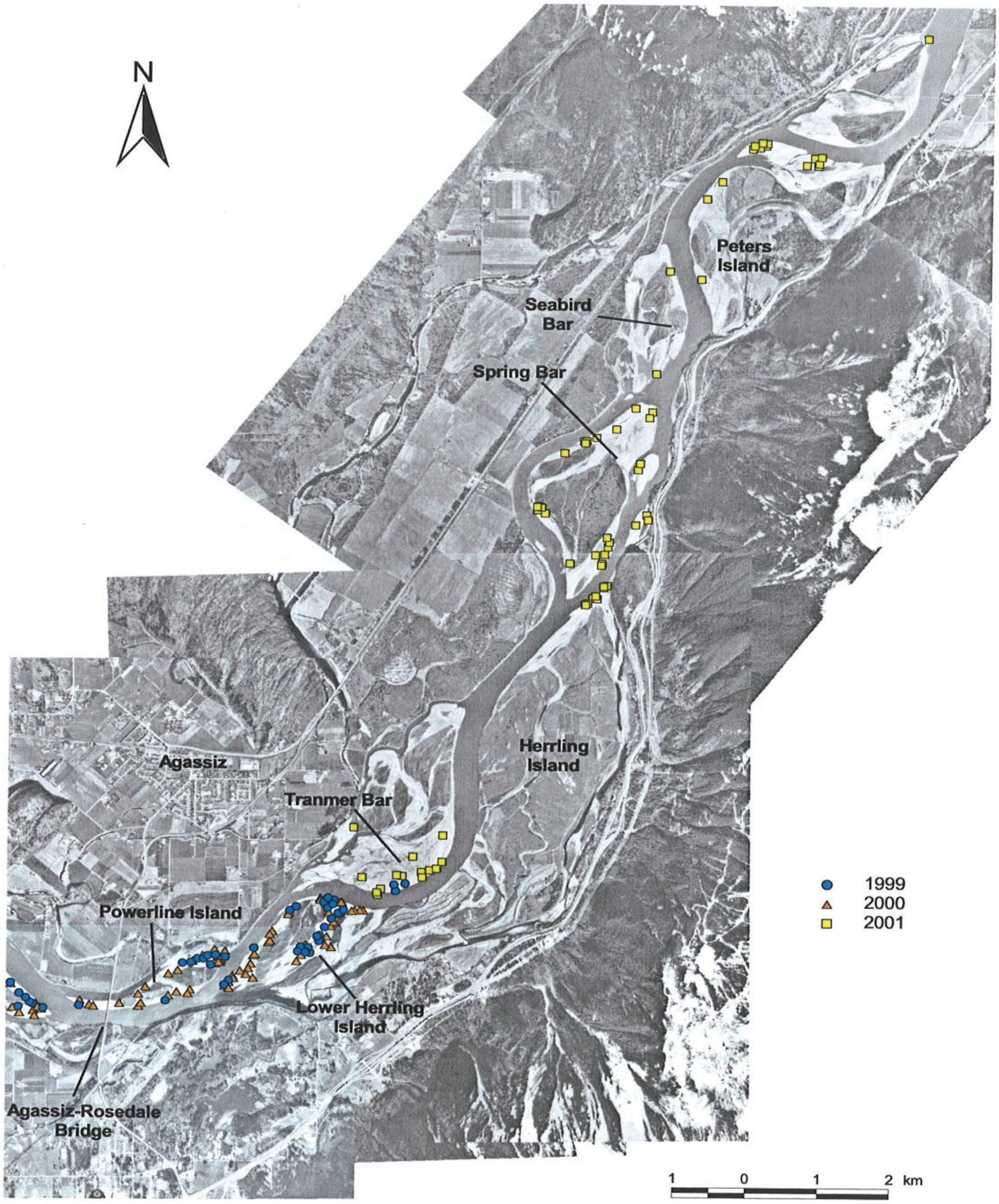


Figure 5. Beach seine sampling sites in the upper gravel reach of Fraser River.

## 2.3 FISH PROCESSING

Captured fish were immediately transferred to holding buckets containing fresh river water for processing. All fish were identified to species (McPhail and Carveth 1994) by the lead author and counted. Voucher specimens were routinely collected for species verification by Dr. G.R. Haas (formerly of BC Ministry of Environment). Species identification remained uncertain for very small fish (usually <20 mm). All anadromous fish and a minimum of 15 fish representing each non-anadromous species were measured for fork length (mm) and weighed to the nearest 0.1 g. Of the 54,684 fish collected by various methods over three years of sampling, 26,771 (49%) were measured for fork length and 11,533 (21%) were weighed. Fish were returned to the river at the point of collection promptly after processing.

## 2.4 HABITAT SURVEYS

Observations and measurements were made of the physical characteristics within habitat units where fish sampling occurred. Water depth and velocity at 6/10 depth from the surface were measured at nine locations within the sampled area using a graduated wading rod and Marsh-McBirney electromagnetic velocity meter. The 9 locations corresponded to the nearshore, midpoint and most offshore extent of sampling along 3 transects positioned at the upstream, midpoint, and downstream boundaries of the sampled area. The surface sediment was classified for degree of embeddedness and percent representation by major grain size classes: sand (<2 mm), gravel (2-64 mm), cobble (64-128 mm), and large cobble (>128 mm). Embeddedness refers to the degree to which dominant gravels or cobbles are embedded in the surrounding matrix material (Bunte and Abt 2001). The slope angle of the bar edge was estimated and nearby vegetation was noted. Water temperature at the mid-point in the seine area was measured using a hand-held thermometer.

## 2.5 SPECIES SELECTION

All species known to reside in the gravel reach of Fraser River are listed in Table 3. Of the 24 species collected by beach seine and electrofisher, 6 were chosen for habitat suitability analysis: Chum, Sockeye and Chinook Salmon, Mountain Whitefish, Rainbow Trout, and Mountain Sucker (Table 3). Species selection for habitat suitability analysis was based on data availability and management priorities.

Table 3. Fish species in the Fraser River gravel reach, 3-letter code assigned for this study, and number of records of fish in beach seine and electrofishing hauls, 1999-2001. Species selected for habitat suitability analysis are highlighted in grey.

| Family | Species | Common name | Code | # Fish |
|---|---|---|---|---|
| **Acipenseridae** | *Acipenser transmontanus* | White Sturgeon [R] | WST | - |
| **Salmonidae** | *Prosopium williamsoni* | Mountain Whitefish | MWF | 712 |
| | *Salvelinus confluentus* | Bull Trout [B] | BUL | 1 |
| | *S. malma* | Dolly Varden [B] | DOL | 1 |
| | *Oncorhynchus clarki* | Cutthroat Trout [B] | CUT | 50 |
| | *O. gairdneri* | Rainbow Trout/Steelhead | RBT | 111 |
| | *O. gorbuscha* | Pink Salmon | PIN | 122 |
| | *O. keta* | Chum Salmon | CHU | 1237 |
| | *O. kisutch* | Coho Salmon | COH | 9 |
| | *O. nerka* | Sockeye Salmon | SOC | 219 |
| | *O. tshawytscha* | Chinook Salmon | CHI | 5925 |
| **Cyprinidae** | *Hybognathus hankinsoni* | Brassy Minnow | BRA | 3 |
| | *Mylocheilus caurinus* | Peamouth Chub | PEA | 2072 |
| | *Ptychocheilus oregonensis* | Northern Pikeminnow | NPM | 1134 |
| | *Rhinichthys cataractae* | Longnose Dace | LND | 2448 |
| | *R. falcatus* | Leopard Dace | LED | 3791 |
| | *Richardsonius balteatus* | Redside Shiner | RSS | 3023 |
| **Catostomidae** | *Catostomus macrocheilus* | Largescale Sucker | LGS | 1376 |
| | *C. platyrhynchus* | Mountain Sucker [B] | MTS | 1583 |
| | *C. columbianus* | Bridgelip Sucker | BLS | 1 |
| **Gasterosteidae** | *Gasterosteus aculeatus* | Threespine Stickleback | TSS | 887 |
| | *G. aculeatus trachurus* | Marine Stickleback | MSB | 570 |
| **Cottidae** | *Cottus aleuticus* | Coastrange Sculpin | CRS | 172 |
| | *C. asper* | Prickly Sculpin | PRS | 535 |
| **Petromyzontidae** | Lampetra sp. | unidentified lamprey | LAM | 2 |
| | *Lampetra ayresi* | River Lamprey[+] | LAM | - |
| | *L. richardsoni* | Western Brook Lamprey[+] | LAM | - |
| | *L. tridentata* | Pacific Lamprey[+] | LAM | - |
| **Osmeridae** | *Thaleichthys pacificus* | Eulachon[B] * | nc | - |

R: red-listed, B: blue-listed (provincial listing)
+ presence documented in Northcote and Larkin (1989)
* presence upstream of Agassiz documented by Perrin et al. (2003b)
nc: not captured in this study

Below is a brief description of the freshwater life history of each of the six species, focusing on the young-of-year (YOY) and juvenile life stages, and their general habitat requirements. This information is pretext to statistically deriving HSC and applying professional judgment to evaluate if they are reasonable against available biological information.

### 2.5.1 Chinook Salmon

There are two distinct types of Chinook Salmon (*Oncorhynchus tshawytscha*) in the Fraser River (Healey 1983, Healey 1991). Stream-type Chinook arrive as subyearlings (0+) to the gravel reach from upriver spawning locations and rear for one year before migrating downstream to the Pacific Ocean. Ocean-type Chinook typically migrate to sea within the first three months of life and have only a brief residence time in the gravel reach.

Ocean-type fry may migrate to estuary environments as early as April at a size of 30 to 45 mm, or as late as June as fingerlings ranging in size from 50 to 75 mm (Healey 1991). In contrast, stream-type fish grow slower and normally migrate seaward as 1+ fish in the early spring of their second year. Average size of 1+ smolts ranges from 65 to 135 mm based on studies in several British Columbia, Oregon and Washington rivers, as reported by Healey (1991).

Previous studies suggest juvenile Chinook Salmon associate with gravel-cobble substrates over a range of depth and flow conditions. They are rarely found in slack-water habitats (Healey 1991). They use cover for protection from predators except in turbid conditions (Gregory 1993), such as the Fraser River gravel reach, where perceived predation risk is reduced and young-of-the-year Chinook move about more freely (Gregory and Northcote 1993). In the gravel reach, they feed predominantly on aquatic invertebrates and other fish (Rempel 2004, Appendix G). In addition to fish parts, Ephemeroptera, Trichoptera and Chironomidae were the most common invertebrate groups found by Rempel (2004) in Chinook stomachs in summer (n=461) whereas Chironomidae and Plecoptera were most common in winter (n=62).

### 2.5.2 Chum Salmon

Newly emergent Chum Salmon (*O. keta*) fry are believed to migrate to the ocean within a few weeks after emergence, and then rear in nearshore estuary environments for weeks to several months before moving to open ocean (Salo 1991). Some populations reportedly migrate downstream in the early nighttime hours and show aggregation or schooling behavior in daylight, with little downstream movement (Salo 1991). Salo (1991) reports that Fraser River chum are generally distributed across the entire river throughout the migratory spring season. Rempel (2004) collected Chum Salmon fry in the gravel reach in a range of habitats and the average percent body weight as stomach was higher than for fry of all other species sampled (16% of body weight, n=34). This suggests that Chum actively feed and therefore rear in the gravel reach, albeit for only a brief period. Chum were caught as early as February 9$^{th}$ and as late as May 9$^{th}$, with the majority caught in early April in bar edge, channel nook and bay habitats. Chum Salmon fry foraged predominantly on chironomids and zooplankton in the gravel reach (Rempel 2004).

### 2.5.3 Sockeye Salmon

Similar to Chinook, anadromous Sockeye Salmon (*O. nerka*) in the Fraser River exhibit multiple life history types (Wood et al. 1987). The most common form are lake-type Sockeye that spawn in stream gravels and newly emerged fry move into a nursery lake for 1 to 2 years of freshwater rearing before downstream migration to sea. More rare are river-type Sockeye that rear in streams and rivers for 1 to 2 years, and sea-type Sockeye that migrate directly to estuaries as fry and then to sea in their first summer. One sea-type population on the Harrison River migrates as young fry to the estuary in April/May (Gregory and Levings 1989), whereas river-type populations in the Stikine River rear in side channels and sloughs for a year (Wood et al. 1987, Burgner 1991).

The presence of juvenile Sockeye Salmon year-round in the Fraser River gravel reach indicates one or more river-type populations use the reach for rearing. Genetic analysis of fish captured in off-channel habitats near Hope (Morrison et al. 2011) were predominantly Late Stuart and Stellako populations (Dr. M. Rosenau, BCIT, pers. comm.). Relatively little is known about the habitat use of 0+ river-type Sockeye, although they are consistently associated with slack-water habitats along river margins, and in sloughs, backwaters and off-channel habitats (Murphy et al. 1989, McPhail 2007). In the Fraser River gravel reach where 219 Sockeye were captured, all were found in slack-water channel nook and bay habitats (Rempel, 2004).

In 22 juvenile Sockeye stomachs collected between June and September (1999-2001) in the gravel reach, adult dipterans including chironomids, as well as terrestrial insects were dominant (Rempel 2004). Chironomid nymphs were the dominant taxonomic group in winter (n=11).

### 2.5.4 Rainbow Trout / Steelhead

*O. mykiss* in the Lower Fraser River may either be part of the southern interior group of anadromous Steelhead, or freshwater residents. Both typically reach a length of about 100 mm in their first summer of growth (McPhail 2007). Smolting in Steelhead can occur as early as 1+ and at <150 mm (Peven et al. 1994), but is more often in the second or third year of stream life. For the purpose of this report, all *O. mykiss* are referred to as Rainbow Trout.

Both Rainbow Trout and Steelhead fry occupy similar habitats. They select shallow depths <20 cm over small gravel substrates as newly emerged fry, and then move into deeper and faster flowing habitats as they grow (Roberge et al. 2002). Yearlings and larger juveniles are associated with large substrates and relatively deep (>60 cm) and fast flows (>60 cm/s). Rainbow Trout collected by Rempel (2004) were found in a range of habitat types including eddy pools and bar tails, but were absent from habitats with low velocity such as channel nooks.

A variety of food items were found in the stomachs of 13 juvenile Rainbow Trout collected in summer months by Rempel (2004). These included terrestrial insects and both adult and nymph forms of Ephemeroptera, Tricoptera and Diptera.

### 2.5.5 Mountain Whitefish

Mountain Whitefish, *Prosopium williamsoni*, exhibit three life histories: lake-type fish reside in lakes for their entire life cycle; river-type fish are associated with streams and lakes; and an adfluvial life history moves between lakes and rivers. Presumably in the gravel reach of Fraser River, Mountain Whitefish are of the river-type and/or adfluvial life history.

According to McPhail (2007), newly emerged fry are small (16-20 mm total length) and utilize low-velocity areas along the river margins. By late summer, 0+ fish reach a size of 60-100 mm. Juveniles generally avoid riffles and backwaters, and are more often found in glides and runs (Porter and Rosenfeld 1999). McPhail (2007) indicates they are associated with water 0.5 to 1.0 m deep, coarse substrates and moderate current (0.25-0.60 m/s). Following the habitat classification of Rempel (2004), juveniles were found in habitats with flow (bar head, bar edge, bar tail, open nook), but not in slack-water habitats.

Sampling by Rempel (2004) found juveniles feed predominantly on aquatic nymphs of Ephemeroptera and Chironomidae in summer months (n=43), and almost exclusively on Chironomidae in winter (n=31).

### 2.5.6 Mountain Sucker

Mountain sucker, *Catostomus platyrhynchus*, are considered *at-risk* in British Columbia and their BC distribution is limited to the Fraser River gravel reach, the North Thompson River in the region of Heffley, and the Similkameen River system from above Princeton to the US border

(McPhail 2007). In the lower Fraser River, young-of-the-year (YOY) fish average 35 mm by mid-September and 65 mm by the end of their second growing season (1+). Habitat suitability for BC populations is not well described. YOY are believed to inhabit shallow habitats with moderate velocity, and then move into deeper and slower habitat as juveniles. Sampling by Rempel (2004) found fish <100 mm most commonly in flat bar edge and bar tail habitat, and fish >100 mm associated with bar tail habitat.

Mountain sucker are principally herbivores and their specialized mouth and lower jaw suggests they feed by scraping periphyton off rocks in clear rivers (McPhail 2007). They also ingest material directly off the substrate in turbid waters. Of 30 Mountain Sucker examined for stomach contents by Rempel (2004), the majority were feeding exclusively on algae and plant material. A very low proportion had 1-2 invertebrate items in the stomach.

# 3 DATA ANALYSIS

## 3.1 LIFE STAGE CLASSES

We developed life-stage specific HSC because habitat suitability is known to differ among life stages of fish species. Life stage is related to fish size and so length-frequency histograms were plotted for each of the five fish species to identify life stage classes based on distinct modes on the histogram. This was relatively straightforward because fish sampling targeted juveniles and there is generally good separation by fish length among early year classes compared to adult fish. We stratified the data by season (winter/spring, summer, fall) to improve our resolution of distinct life stage classes. Once preliminary length-life stage classes were identified from the histograms, they were compared to available literature for validation.

We also evaluated the relationship between life stage classes and habitat velocity as a preliminary check for differentiated habitat use among life stage classes. If habitat use changes with life stage, then life stage class breaks should generally match up with differences in habitat velocity among areas sampled for fish. Habitat velocity for each set was calculated as the average of up to 9 velocity measurements made in the fishing area. Velocity was plotted as a function of fish length, and a curve was fit to these data using a locally weighted regression (LOESS) to identify overall trends in the length-velocity relationship.

## 3.2 HABITAT DATA PROCESSING

Our dataset contains 980 fishing hauls by beach seine and electrofisher in the Fraser River gravel reach, and their associated habitat data. Of these habitat data, our interest for HSC analysis was substrate, depth and velocity data. For substrate, each fishing set is associated with an estimate of the average percent coverage of major substrate size classes (sand, gravel, cobble, large cobble). We used the dominant size class (highest percent coverage) as the representative substrate for each fishing set area, and no further data processing was required.

For both depth and velocity, each fishing set is associated with up to nine values. A preliminary data screening first was performed by calculating the averages and standard deviations of depths and velocities for each set. Five sets with zero or near-zero depth or velocity standard deviations were discarded as standard deviations of such low magnitude are more likely due to a lack of measurements than to a constant depth or velocity across the entire set.

In the absence of individual-based microhabitat use data, we assumed fish do not discriminate habitat suitability within a fishing set area, i.e., depth/velocity use within a set is equivalent to availability. The next step in our analysis was to determine representative depths and velocities for each fishing set. If a single depth or velocity value is used to represent each fishing set (such as the averages of the nine depth and velocity measurements), then all fish within each set area are assumed to be using the same habitat, and the habitat suitability curves will be biased toward these depths and velocities. To overcome this bias, we assumed a probability distribution of depths and velocities within each fishing set, and conducted habitat suitability analysis on these continuous distributions, rather than discrete depth and velocity values.

We tested the distribution of depth and velocity measurements at each site for normality using the Shapiro-Wilks test. The depth distributions for 102 of 968 sets (10.5%) were not normal at a significance level of 0.05 (Figure 6). This departure from normality is not considered significant given the expected 5% rejection rate, and the fact that most non-normal samples were those with identical depth values among the nine depths measured for a particular fishing set.

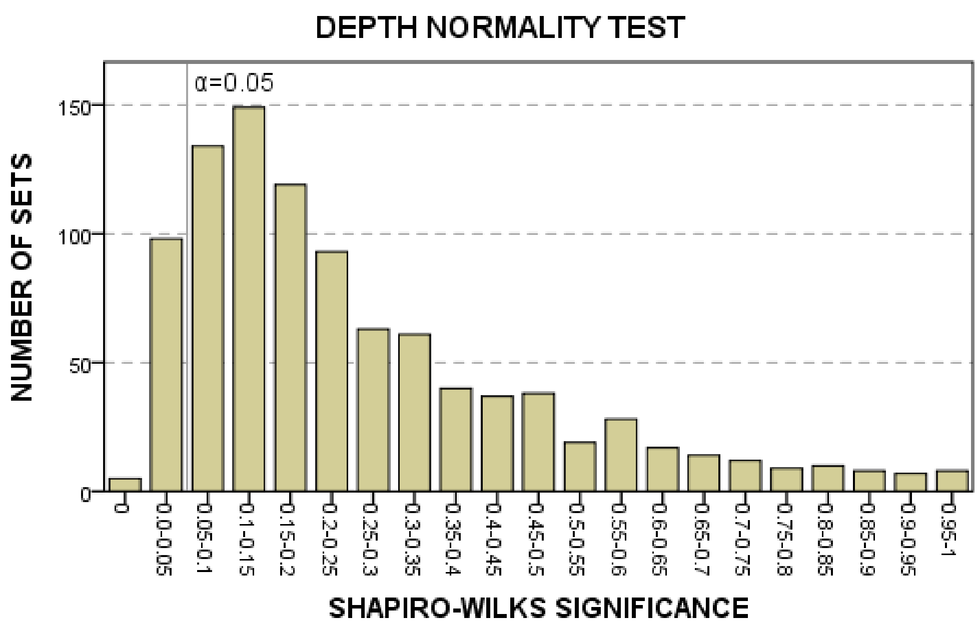


Figure 6. Histogram of Shapiro-Wilks significance results for the test of normality for depth distributions within fishing sets. Low values (<0.05) indicate a significant departure from normality.

For velocity, there are 134 data sets with zero velocity and representing slackwater habitat. The velocity distributions of these sets were treated as discrete distributions. Of the remaining 834 sets, 190 (22.8%) also have velocity distributions that show a departure from normality by the Shapiro-Wilks test (Figure 7). Some of these fishing sets have a non-normal test result due to repeated values, as was the case for depth, and some of the sets have skewed velocity data. Similar to depth, we have assumed that the departure from normality is due to these sampling issues and that velocities in these sets are truly normally distributed according to the sampled mean and standard deviations. All velocity data were treated as positive for the analysis and because a normal distribution was assumed, the frequency distributions were truncated at zero and the positive portions scaled so that the total area under each distribution curve was equal to 1 (i.e., each set is equally weighted for the analysis).

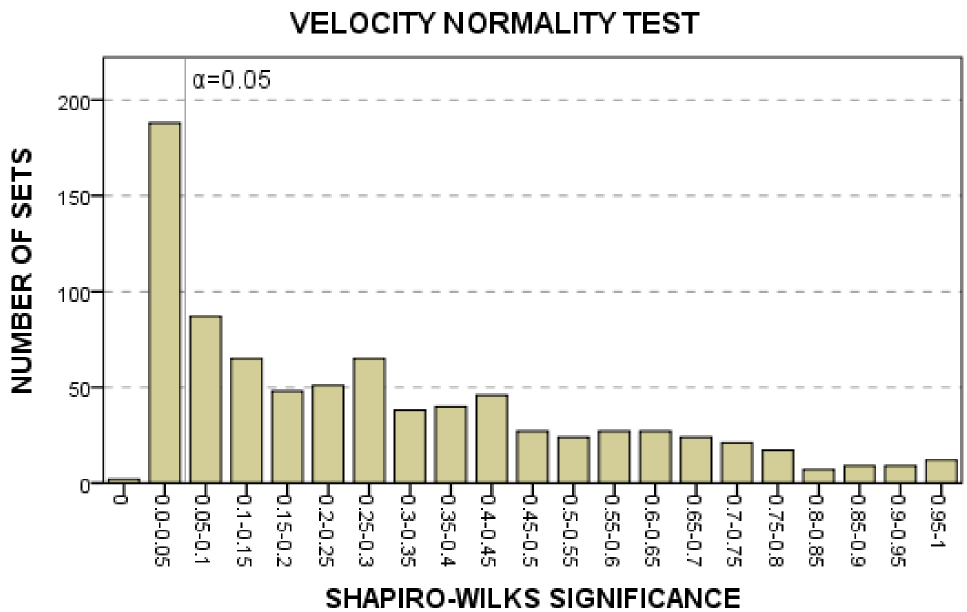


Figure 7. Histogram of Shapiro-Wilks significance results for the test of normality for velocity distributions within fishing sets. Low values (<0.05) indicate a significant departure from normality.

We evaluated possible bias toward shallow habitats in the data set because the field sampling program targeted shallow rearing habitat associated with gravel bars. To do this, overall frequency distributions for depth and velocity were tabulated from the observed data and then compared to the depth/velocity probability distributions within each set. There is reasonably good agreement between the observed and estimated depth and velocity relative frequencies (Figure 8), which supports the assumption of normally distributed data.

Black reference lines in Figure 8 indicate the expected frequency distribution if all depths and velocities were sampled with equal effort. It appears that shallow (10 to 50 cm) and low-velocity (<30 cm/s) sites were sampled more frequently than deeper and high-velocity sites. This unbalanced sampling effort must be considered in data analysis and the development of habitat suitability criteria. However, underestimating deeper and faster habitats in the dataset is not believed to be overly consequential to our HSC because we have limited our analysis to depths <100 cm and velocities <100 cm/s, and habitats beyond these values are unlikely to support large numbers of juvenile fish for rearing.

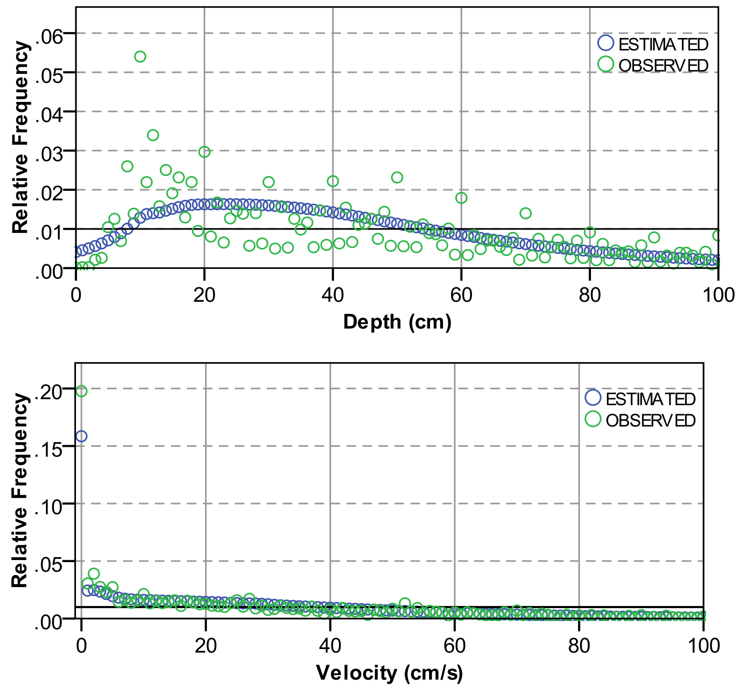


Figure 8. Observed (green) and estimated (blue) relative frequencies of depth and velocity based on fish sampling in the Fraser River gravel reach. The black reference lines at 0.01 indicate the frequency distribution if depths and velocities were sampled with equal effort.

## 3.3 HABITAT SUITABILITY CRITERIA

Fundamentally, habitat suitability criteria are intended to represent a functional relationship between an independent variable (e.g., depth, velocity) and the response of a species and life stage to a gradient of the independent variable expressed over a scale of 0.0 (unsuitable) to 1.0 (highly suitable). There are various types of HSC and different methods available to derive them. Overall, it is imperative that the final functional relationship matches with the known biology of the target species and life stage. Some degree of professional experience and judgment is almost always applied to evaluate this match.

Suitability curves are broadly categorized into several types (Bovee et al. 1998):

- Category I Curves: Curves are based either on available literature sources or professional experience and judgment. The latter curves are usually developed by face-to-face group discussion or the Delphi method. Category I curves are a common solution when field data are unavailable, or when the field sampling design does not conform to the requirements of higher curve categories. Verification studies comparing Category I curves to subsequently developed Category II curves have shown good agreement (Bovee 1986).
- Category II Curves: Curves are based on some type of frequency analysis of field data representing the habitat conditions where fish are observed. These curves are sometimes termed 'utilization functions' because they do not consider the relative

availability of all habitat conditions. A variety of curve-fitting techniques may be applied to the field data.

- Category III Curves: These curves are termed ‘preference curves’ or ‘suitability curves’ because they attempt to correct for habitat availability bias in the utilization function by factoring out the influence of limited habitat choice. These curves are established by dividing the probability of a habitat type being used by its availability, and normalizing the results for a maximum habitat suitability of 1.0. They are most difficult to derive because quantifying the relative availability of all habitat conditions is challenging, and the output is subject to some interpretation. Also, they are the most data-intensive of all curves.
- Category II ½ Curves: Curves are statistically-based functions (either utilization or suitability functions) that are derived by equal area sampling or other approaches that specifically incorporate habitat availability in the sampling design.

For our study, field sampling was carried out in proportion to available habitat because sampling sites were first classified according to habitat type and common habitat types were sampled more frequently than rare ones. Therefore, we generated Category II utilization curves for substrate, water depth and velocity. The substrate utilization curves were considered final; however, we applied professional judgment to the depth and velocity utilization curves, correcting for availability bias and incorporating biological knowledge, to arrive at final Category I criteria. Statistically-generated utilization curves for depth and velocity are in APPENDIX A. Final criteria are presented in Section 4.2 and APPENDIX B.

The following is a description of how HSC were developed for depth and velocity. An example is presented in Figure 9 using water depth. Habitat availability and use curves were derived using the estimated depth and velocity frequency distributions for each fishing set. To obtain these distributions, we first assumed depths and velocities within a given set $\mathbf{i}$ were normally distributed according to the sample means and standard deviations:

$$f_i\left(d;\ \bar{d}_i\ [\![,\sigma^2_{d_i}\right)]\!]^* = Normal\left(\bar{d}_i,\sigma^2_{d_i}\right) \quad g_i\left(v;\ [\![\bar{v}_i,\sigma^2_{v_i}\right)]\!]^* = Normal\left(\bar{v}_i,\sigma^2_{v_i}\right)$$

where $f_i^*$ and $g_i^*$ are the depth and velocity distributions as a function of depth $\mathbf{d}$ and velocity $v$, $\bar{\mathbf{d}}_\mathbf{i}$ and $\bar{\mathbf{v}}_\mathbf{i}$ are the mean depth and velocity measured in set $\mathbf{i}$, and $\sigma_{\mathbf{d_i}}$ and $\sigma_{\mathbf{v_i}}$ are the standard deviation of the depth and velocity measurements, respectively. For sets with all measured velocities equal to zero, we assumed the velocity distribution is the probability mass function $f_i(\mathbf{0}) = 1, f_i(v) = 0\ for\ v \neq \mathbf{0}$ .

We limited our analysis to depths and velocities between 0 and 100 cm and 100 cm/s, respectively, by truncating the distributions at 0 and 100. Because the truncated distributions are not valid probability densities (the area under them does not necessarily integrate to 1), each distribution was rescaled by constant scaling factors $c_{di}$ and $c_{vi}$, obtained from calculating the cumulative distribution functions between 0 and 100:

$$\frac{\mathbf{1}}{c_{di}} = \int_{\mathbf{0}}^{\mathbf{100}} Normal\left(\bar{d}_i,\sigma^{\mathbf{2}}_{d_i}\right) \qquad \frac{\mathbf{1}}{c_{vi}} = \int_{\mathbf{0}}^{\mathbf{100}} Normal\left(\bar{v}_i,\sigma^{\mathbf{2}}_{v_i}\right)$$

Within the study ranges, depths and velocities are distributed according to:

$$f_i(d) = c_{di}Normal\left(\bar{d}_i,\sigma^{\mathbf{2}}_{d_i}\right) \quad 0 \le d \le 100 \qquad f_i(v) = c_{vi}Normal\left(\bar{v}_i,\sigma^{\mathbf{2}}_{v_i}\right) \quad 0 \le v \le 100$$

If $A_i$ is the area of set $i$ , and $n_i$ the number of fish in a given life history caught in set $i$ , then the areal distribution of depths and velocities within set $\mathbf{i}$ is given by

$$Area_i(d) = A_i c_{di} Normal\left(\bar{d}_i, \sigma^2_{d_i}\right) \qquad Area_i(v) = c_{vi} Normal\left(\bar{v}_i, \sigma^2_{v_i}\right) \qquad 0 \le d,v \le 100$$

Similarly, assuming the fish are uniformly distributed throughout each set, the density of fish within the set as a function of depth $\rho_i(d)$ and velocity $\rho_i(v)$ is distributed according to

$$\rho_i(d) = \frac{n_i}{A_i} c_{di} Normal\left(\bar{d}_i, \sigma^2_{d_i}\right) \qquad \rho_i(v) = \frac{n_i}{A_i} c_{vi} Normal\left(\bar{v}_i, \sigma^2_{v_i}\right) \qquad 0 \le d,v \le 100$$

The distributions $Area_i(d)$ and $Area_i(v)$ are proportional to the velocity and depth availability within the set, and $\rho_i(d)$ and $\rho_i(v)$ represent the velocity and depth habitat use within the set.

The overall distribution of available depths and velocities over *m* sets was then obtained by summing the distributions of all sets:

$$Availability^*(d) = \sum_{i=1}^{m} Area_i(d) \qquad Availability^*(v) = \sum_{i=1}^{m} Area_i(v) \qquad 0 \le d,v \le 100$$

The overall habitat use over *m* sets was given via summation of the habitat use distributions of each set:

$$Use^*(d) = \sum_{i=1}^{m} \rho_i(d) \qquad Use^*(v) = \sum_{i=1}^{m} \rho_i(v) \qquad 0 \le d,v \le 100$$

The use and availability functions were then divided by their respective maximum values to normalize the functions on a scale of 0 to 1.0.

We compared these statistically-derived use and availability functions to generate final habitat suitability criteria. The utilization functions are automatically biased by habitat availability due to the sampling design of Rempel (2004); hence, we compared them with the availability functions as an added verification step for generating the final HSC. We also considered and attempted to correct for the potential influence of unequal sampling effort across available depths and velocities, the truncation of values at 100, and the limited sample size of some species (e.g., Rainbow Trout, n=111). Hence, this final step of HSC development for depth and velocity incorporated some professional judgment, which is typical for many HSC analyses (Bovee 1986). The statistically-derived utilization and availability criteria for depth and velocity are included as APPENDIX A to this report. Final HSC are presented below in Section 4.2 and in APPENDIX B. For substrate, the statistically-derived utilization curves are presented in Section 4.2 and these criteria are considered final.

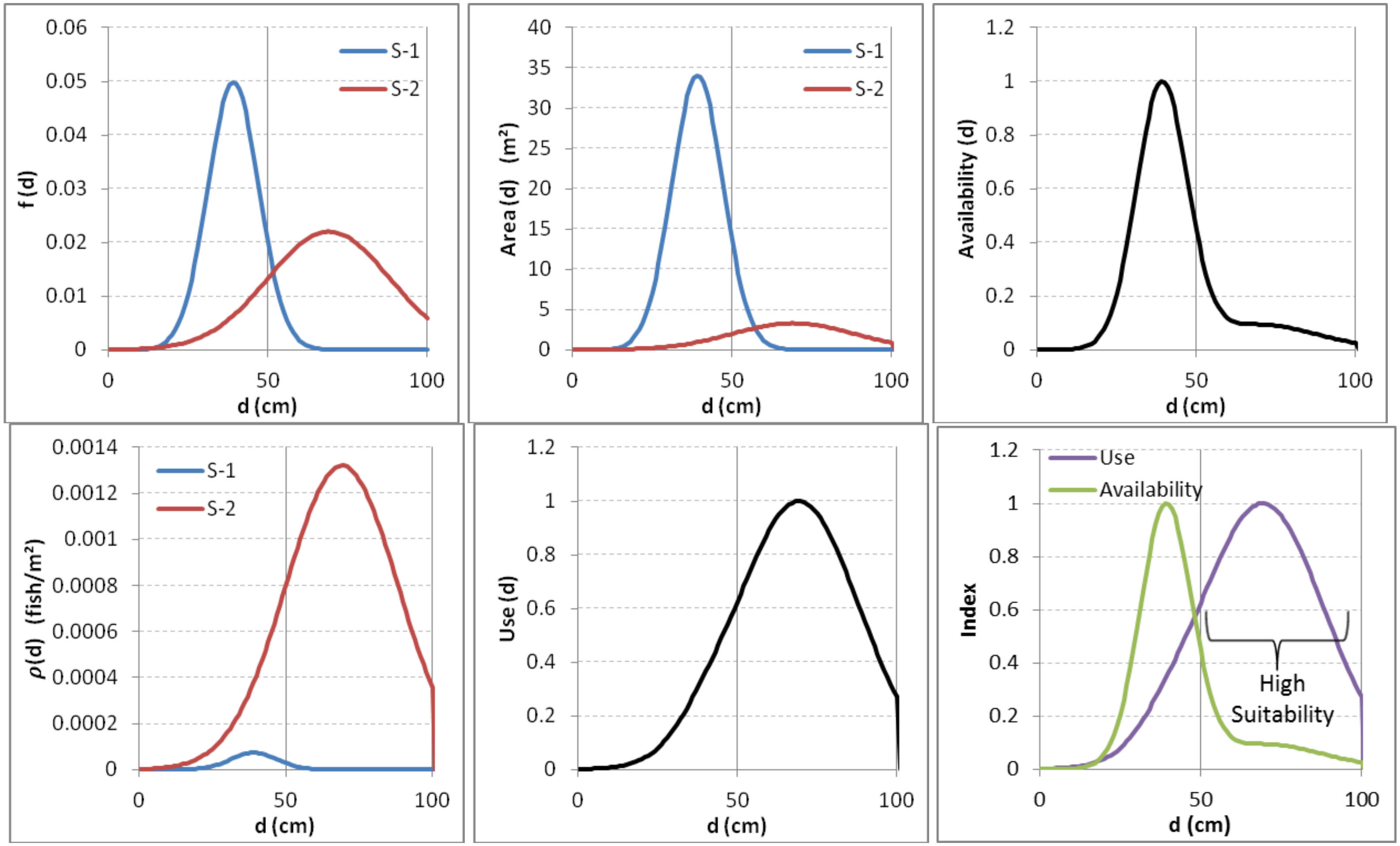


Figure 9. Example HSC calculations to determine suitable depth for juvenile Mountain Sucker (MTS) based on two fishing sets (S). S-1 (684-$m^2$ area fishing set, mean depth 39.2 cm ± 8.0) caught 1 MTS. S-2 (150-$m^2$ area, mean depth 69.2 cm ± 19.1) caught 9 MTS. 1) Top left: Probability distribution functions (PDFs) are calculated for both sets. 2) Top middle: Each PDF is weighted by set area. 3) Top right: Set areas are combined and normalized to obtain an index of habitat availability. 4) Bottom left: PDFs are weighted by fish density to obtain an index of habitat use. 5) Bottom middle: Density distributions are averaged and normalized. 6) Bottom right: Use is compared to availability to derive HSC.

The following are published habitat suitability curves we compared against our HSC for the Fraser River gravel reach.

- Addley et al. (2003): Category I curves for Mountain Whitefish that were derived from professional judgment and produced for the South Saskatchewan River basin in Alberta.
- Bovee (1978): Category I curves for Mountain Whitefish that are based on existing literature and professional judgment.
- Hale et al. (1985): Category I curves for Chum Salmon that are based on existing literature and professional judgment, and not field-tested.
- Hoffman et al. (2002): Category III suitability curves for Mountain Whitefish in the Kootenai River, Montana-Idaho, USA.
- Raleigh et al. (1984): Category I curves for Rainbow Trout that are based on existing literature and professional judgment, and not field-tested.
- Raleigh et al. (1986): Category I curves for Chinook Salmon that are based on existing literature and professional judgment.
- Ptolemy (2001): Excel spreadsheet of Category I curves provided by Mr. R. Ptolemy, BC Ministry of Environment. The curves are derived from a Delphi process for water use planning (WUP), with input from various professionals, government agencies and BC Hydro. The WUP habitat suitability dataset is specific to British Columbia and focused on clear-water streams and rivers.
- USFWS (1985): Category I curves for Chinook Salmon published by the US Fish and Wildlife Service, as cited in Raleigh et al. (1986).

No existing habitat suitability functions were found for Sockeye 0+, nor for all age classes of Mountain Sucker.

## 3.4 HABITAT SUITABILITY BY CHANNEL TYPE

The habitat classification by Rempel (2004) identifies three channel types in the gravel reach within which fish sampling occurred: main, side and summer (Table 1). Supplementary to our primary objective of developing HSC for the Fraser River gravel reach, we evaluated the influence of channel type on habitat suitability by deriving channel-specific HSC. HSC were calculated for depth and velocity based on a weighted average as described above, except these averages were calculated for each channel type rather than for all channel types combined. Species with good representation of data across channel types were analyzed; these were Chinook Salmon 0+ (stream type), Chum Salmon, and Mountain Sucker 1+/2+. The sample size of fishing sets by channel type is presented in Table 4. Minor number disagreements between total fish and the sum of channel types are due to some missing channel type information in the dataset.

Table 4. Number of fish by life stage class collected in each of three channel types. Species-life stages selected for channel analysis are highlighted in grey.

| Life Stage | Total Fish | Channel Type | | |
|---|---|---|---|---|
| | | Main | Side | Summer |
| Chinook Salmon 0+ Stream / Ocean Type | 1564 | 1108 | 376 | 80 |
| Chinook Salmon 0+ Stream Type | 3810 | 2444 | 795 | 557 |
| Chinook Salmon 1+ Stream Type | 489 | 447 | 36 | 0 |
| Chum Salmon 0+ | 1237 | 762 | 344 | 131 |
| Sockeye Salmon 0+ | 209 | 87 | 80 | 42 |
| Rainbow Trout 0+ | 59 | 37 | 15 | 7 |
| Rainbow Trout 1+ | 42 | 27 | 7 | 7 |
| Mountain Whitefish 0+ | 483 | 271 | 141 | 69 |
| Mountain Whitefish 1+ | 205 | 125 | 67 | 8 |
| Mountain Whitefish 2+ | 62 | 29 | 2 | 0 |
| Mountain Sucker 0+ | 124 | 31 | 79 | 14 |
| Mountain Sucker 1+ / 2+ | 961 | 623 | 184 | 152 |
| Mountain Sucker 3+ | 512 | 343 | 98 | 55 |

# 4 RESULTS

## 4.1 LIFE STAGE CLASSES

### *4.1.1 Chinook Salmon*

Histogram plots of Chinook Salmon lengths by season suggest that stream-type fish are dominant in the gravel reach because juvenile Chinook are caught year-round. We identified two distinct life stage classes in spring (Figure 10). Subyearlings (0+) are ≤55 mm and likely a mix of both stream- and ocean-type Chinook. Fish >55 m in spring are stream-type yearlings (1+) that will migrate to sea (Figure 10). Fish >55 m and captured in summer and fall are stream-type subyearlings (0+), since the unimodality of the plots indicates 1+ fish do not spend a second winter in freshwater. Our length breaks generally correspond with those identified by McPhail (2007) and Healey (1991).

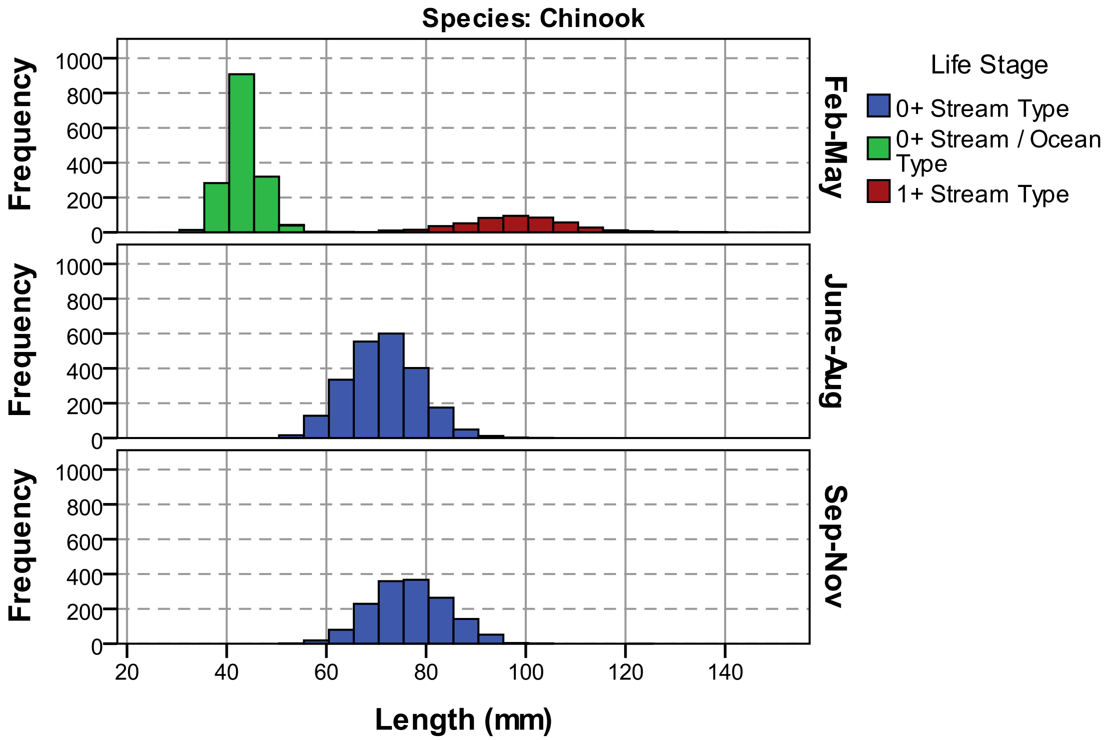


Figure 10. Seasonal length frequency distributions of juvenile Chinook Salmon in the Fraser River gravel reach between 1999 and 2001.

There is a slight trend of increasing velocity with Chinook length from 40 to 80 mm (Figure 11). This corresponds well with the life stage class break at 55 cm seen in Figure 11 between spring and summer/fall 0+ fish. The larger 1+ Chinook don't appear to differentiate velocity from summer and fall 0+ fish, although differences in depth suitability may be apparent in later HSC analysis below.

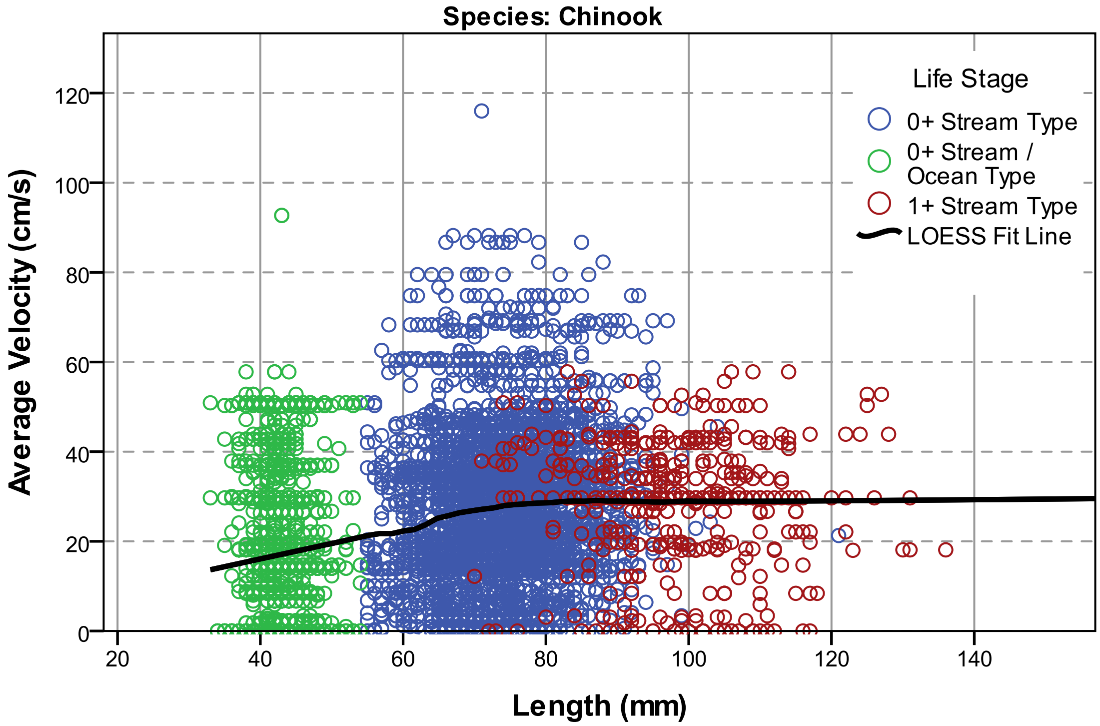


Figure 11. Relationship between velocity and fish length for juvenile Chinook Salmon in the Fraser River gravel reach.

### *4.1.2 Chum Salmon*

Chum Salmon 0+ caught in the Fraser River gravel reach ranged in length from 23 to 61 mm. These 0+ fish were captured during their migration to the ocean in spring, as confirmed by the unimodality of the length histogram (Figure 12).

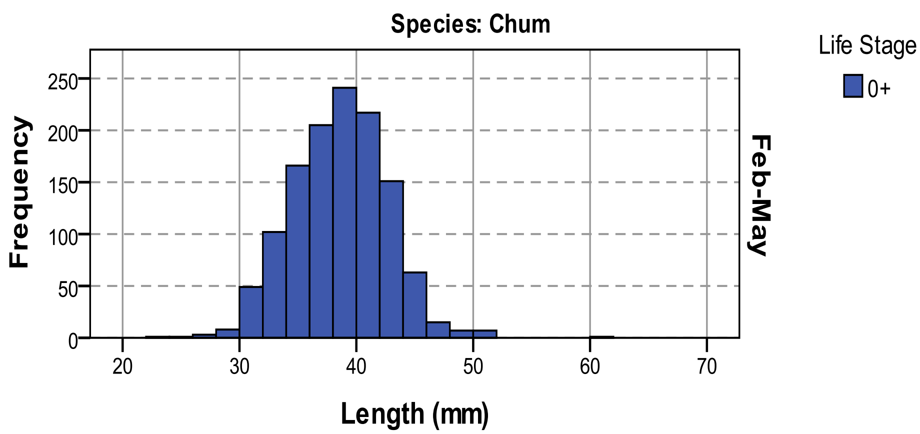


Figure 12. Seasonal length frequency distribution of 0+ Chum Salmon in the Fraser River gravel reach between 1999 and 2001.

### *4.1.3 Sockeye Salmon*

Stream-type Sockeye were captured in each of the spring, summer and fall seasons (Figure 13). The bimodal distribution in spring indicates two age classes present, with most 1+ fish likely being stream-type but possibly mixed with some lake-type sockeye on their downstream migration to the ocean. Relatively few 1+ Sockeye were captured overall. The 0+ fish captured in April/May are possibly a combination of stream-type fish and the ocean-type Harrison River stock out-migrating to sea (see section on Methods 2.5.3). We defined 0+ Sockeye in our study as ≤75 mm in spring and ≤100 m in summer and fall. This is consistent with Scott and Crossman (1973) stating YOY are generally <106 mm in length. We opted not to generate separate HSC functions for 0+ and 1+ fish due to the relatively low sample size of 1+ fish.

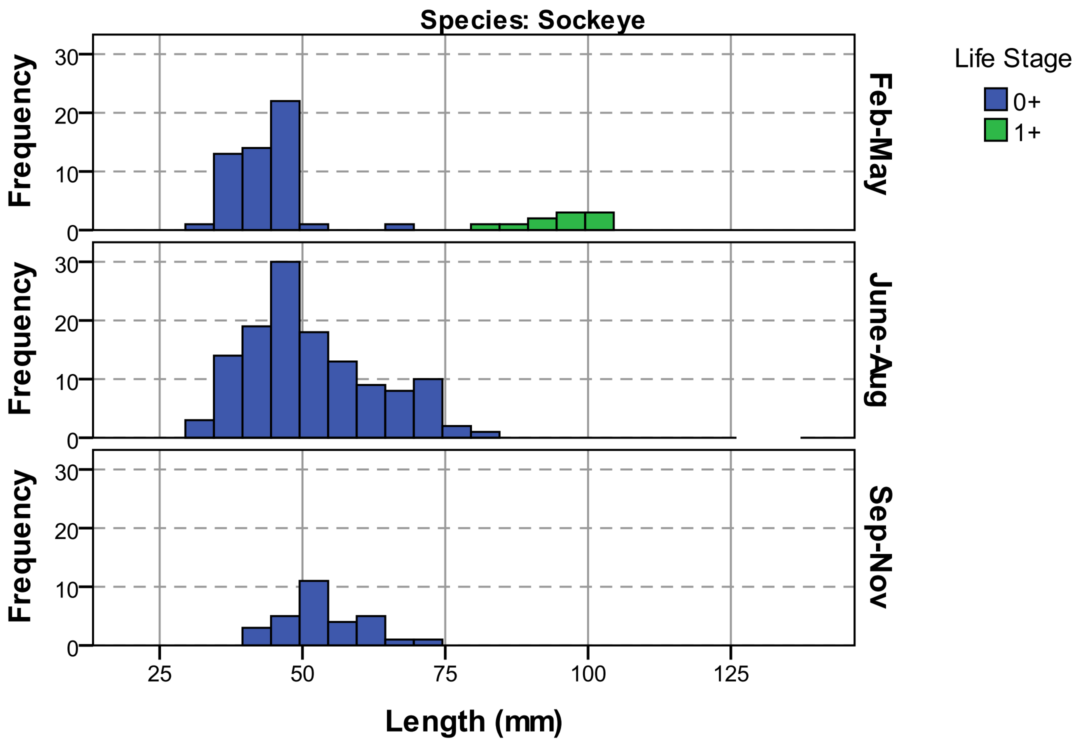


Figure 13. Seasonal length frequency distributions of Sockeye Salmon in the Fraser River gravel reach between 1999 and 2001.

There appears to be no relationship between velocity and juvenile Sockeye Salmon length (Figure 14), and the majority of fish were captured in <20 cm/s flow. The few fish caught in velocities >40 cm/s may include some spring ocean-type fish that were opportunistically using faster flows for their out-migration to sea.

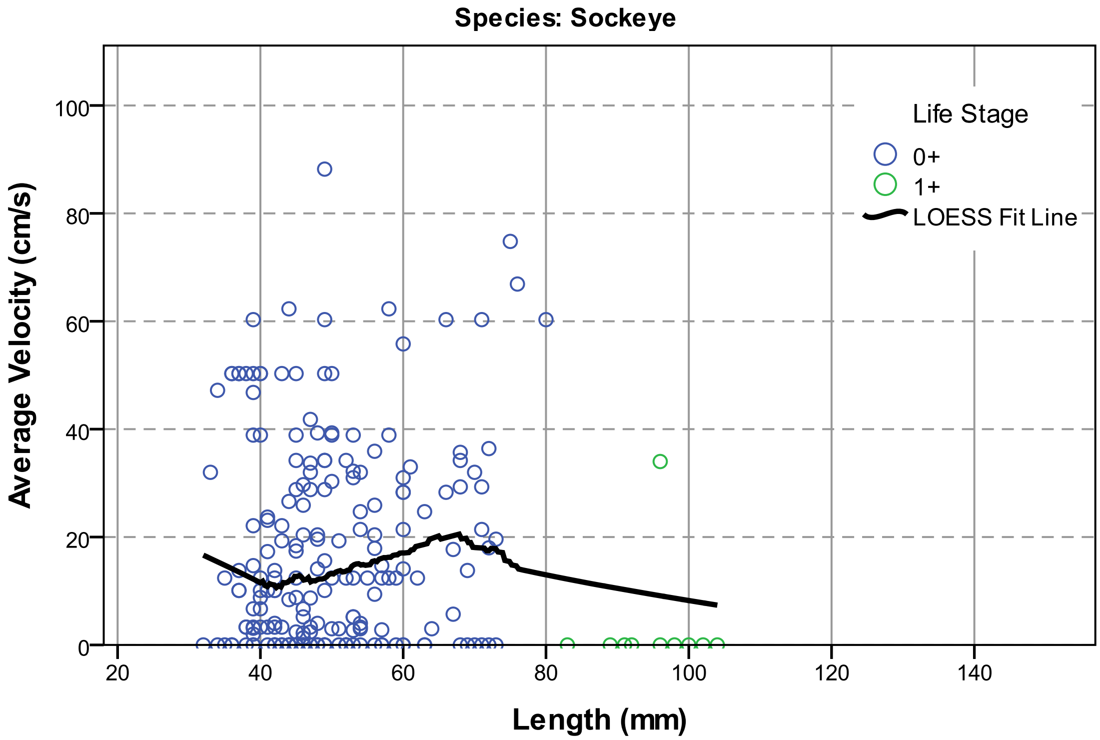


Figure 14. Relationship between velocity and fish length for juvenile Sockeye Salmon in the Fraser River gravel reach.

### *4.1.4 Rainbow Trout / Steelhead*

A relatively small number of Rainbow Trout (n=111) was captured at Fraser River gravel bars. The length histogram shows separation between 0+ and 1+ fish at approximately 90 mm (Figure 15). This is consistent with McPhail (2007) stating that fish reach about 100 mm in their first summer of growth. Because there are few fish longer than 90 mm, the separation between 1+ and 2+ fish is not clear. We estimate this boundary at 200 mm and consider 90-200 mm fish as 1+ for the purpose of HSC analysis. There is no clear trend between velocity and length for juvenile Rainbow Trout (Figure 16).

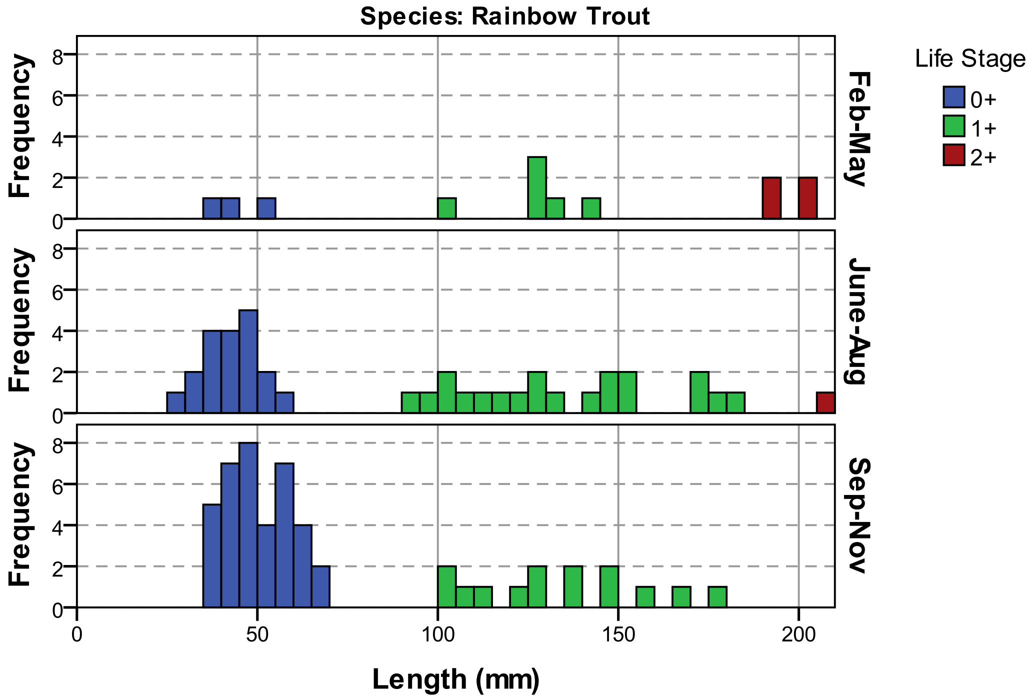


Figure 15. Seasonal length frequency distributions of Rainbow Trout in the Fraser River gravel reach between 1999 and 2001.

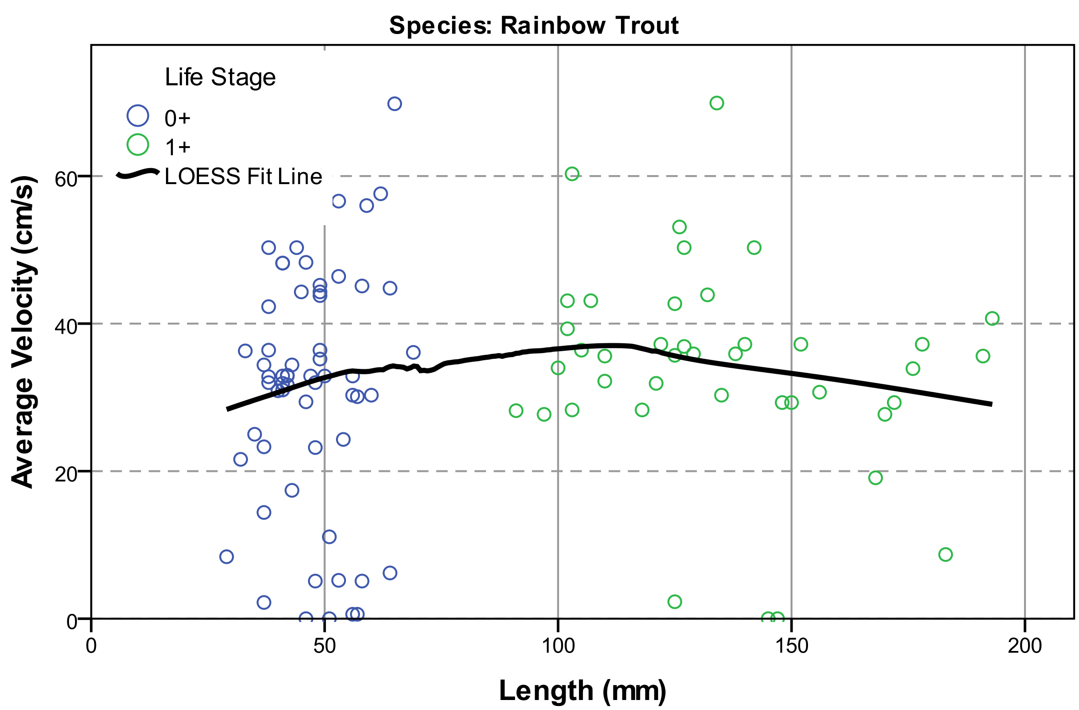


Figure 16. Relationship between velocity and fish length for Rainbow Trout in the Fraser River gravel reach.

#### *4.1.5 Mountain Whitefish*

The seasonal length histograms identify three distinct life stage classes of Mountain Whitefish in the gravel reach (Figure 17). In spring, the separation between 0+ and +1 fish is at roughly 90 mm and the separation between 1+ and 2+ fish is at 160 mm. These size breaks shift slightly in the summer and fall, with separation between 0+ and 1+ at 110 mm and separation between 1+ and 2+ fish at 200 mm. This is consistent with data presented by McPhail showing fry are 60 to 100 mm in length by late summer (McPhail 2007).

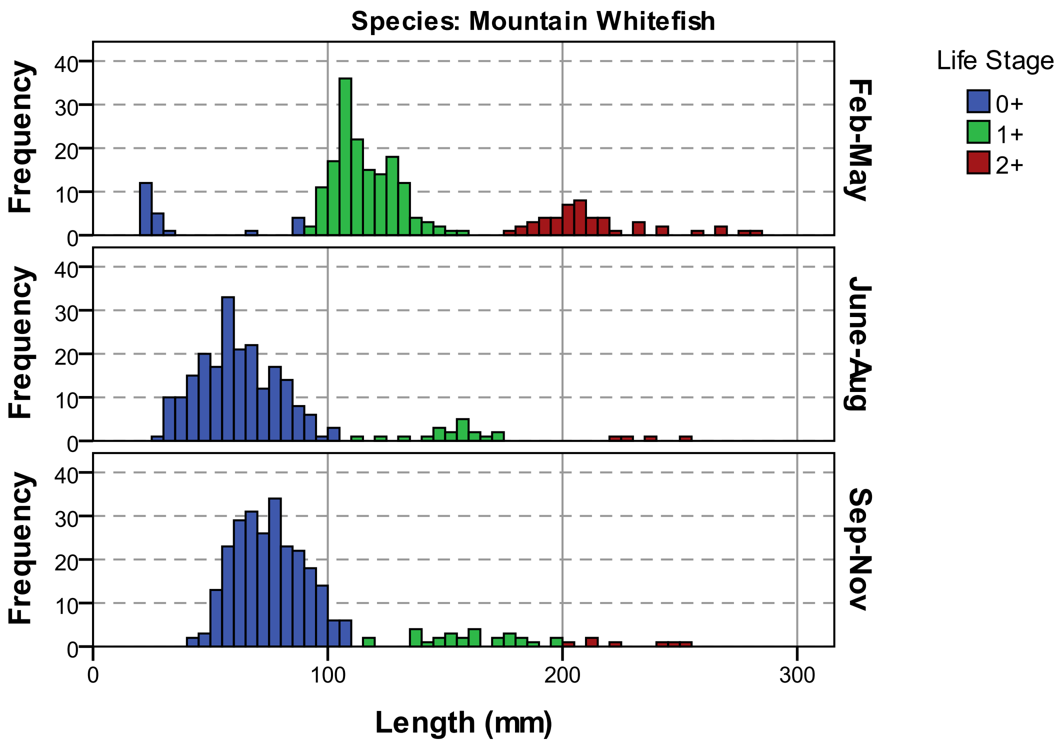


Figure 17. Seasonal length frequency distribution of Mountain Whitefish in the Fraser River captured between 1999 and 2001.

There is a weak trend of increasing habitat velocity with length for Mountain Whitefish (Figure 18). Whereas some of the 1+ fish between 100 and 150 mm were found in zero-velocity habitats, all of the larger 2+ fish were found in habitats with flow.

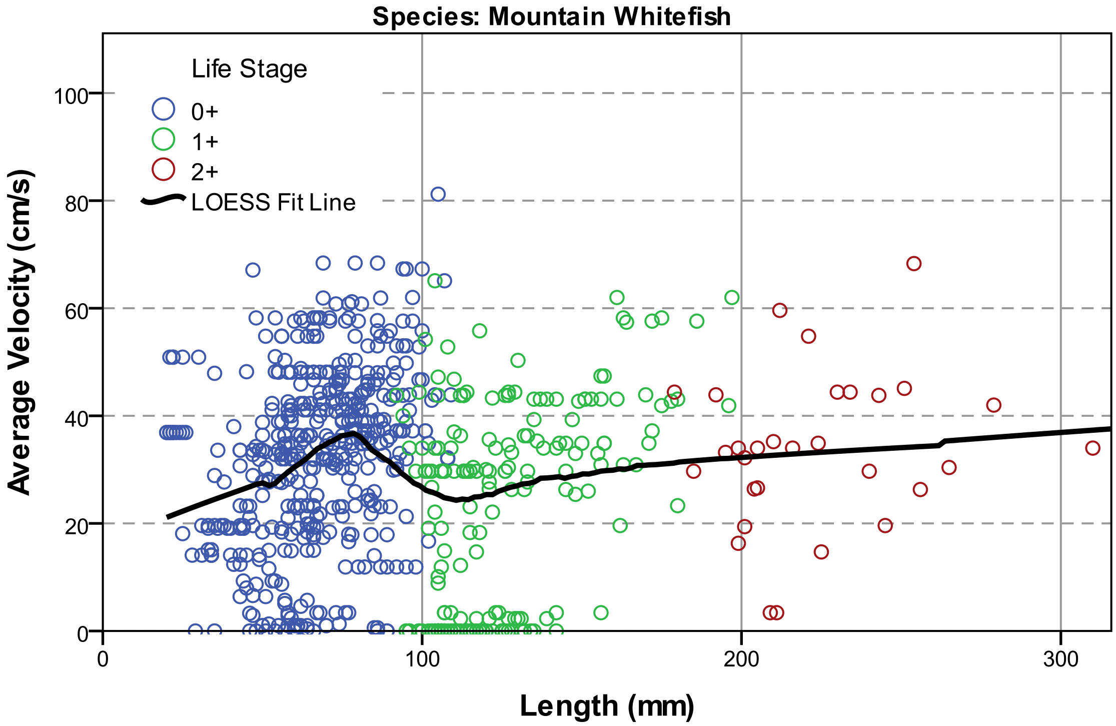


Figure 18. Relationship between habitat velocity and fish length for Fraser River Mountain Whitefish.

### *4.1.6 Mountain Sucker*

McPhail (2007) and Scott and Crossman (1973, from Hauser 1969) each present growth information for Mountain Sucker in the Fraser River and Flathead Creek, respectively (Table 5). Seasonal length histograms for Fraser River fish show one mode between 20 and 50 mm that we expect are 0+ fish (Figure 19). Additional modes are less clear due to decreased growth rate with age. Referring to data of McPhail (2007) and Hauser (1969) in Table 5, we believe 1+ and 2+ fish group together as a single mode between 50 and 115 mm (Figure 19), and 3+ fish are >135 mm.

Table 5. Mountain Sucker length information from Flathead Creek (Hauser 1969) and the Fraser River (McPhail 2007), and proposed life stage classes for the Fraser River gravel reach. All values in mm.

| Age | Mean Length | | Fraser River Gravel Reach | | |
|---|---|---|---|---|---|
| | Hauser | McPhail | Histogram Mode | Minimum | Maximum |
| 0+ | - | 35 | 30 | 0 | 50 |
| 1+ | 93 | 65 | 75 | 50 | 95 |
| 2+ | 117 | - | 105 | 95 | 115 |
| 3+ | 131 | - | 125 | 115 | 135 |

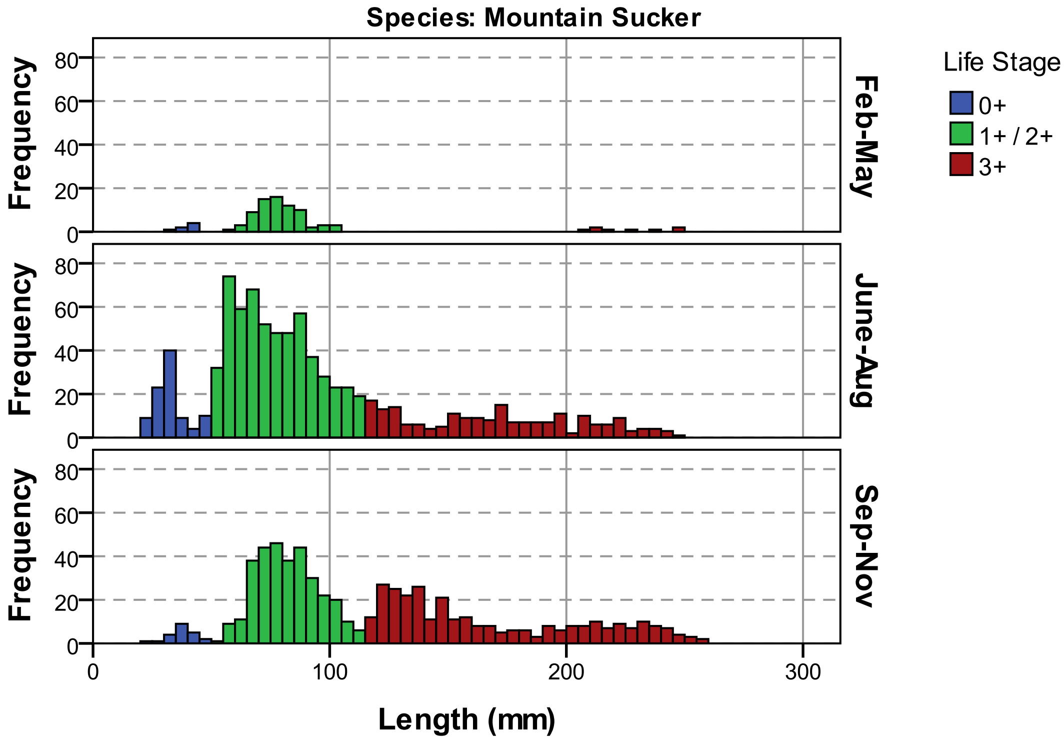


Figure 19. Seasonal length frequency distributions of Mountain Sucker in the Fraser River gravel reach between 1999 and 2001.

There is a positive relationship between Mountain Sucker length and average velocity up to 120 mm in size (Figure 20). This relationship supports the grouping of 1+ and 2+ fish for HSC analysis since the life stages are not discernable by size and there is no apparent differentiation in habitat use based on velocity. Subsequently, we refer to 0+ fish as fry, 1+/2+ fish as juveniles, and 3+ fish as adults.

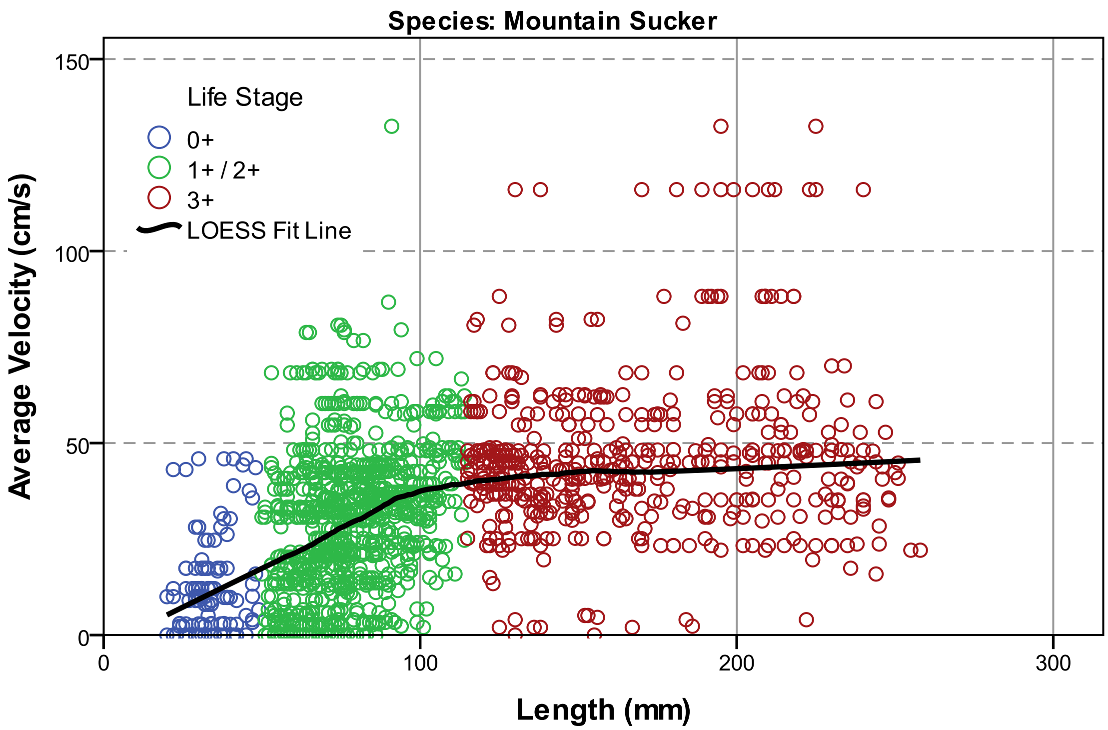


Figure 20. Relationship between velocity and fish length for Mountain Sucker in the Fraser River gravel reach.

## 4.2 HABITAT SUITABILITY CRITERIA

Fraser River gravel reach HSC data are described and presented graphically below, and are available in tabular form as APPENDIX B to this report. These finalized curves are developed from the statistically-derived utilization and availability curves (APPENDIX A) that were reviewed and then modified based on professional judgment (see Section 3.3. for further details).

### *4.2.1 Chinook Salmon*

**Chinook 0+ Stream/Ocean-Type** – A wide range of depths were suitable for 0+ stream/ocean-type Chinook Salmon captured in spring (Figure 21). The wide depth suitability may be reflective of both shallow water use by stream-type fry and a broader distribution of migrating ocean-type fish. Depth suitability for Fraser gravel reach fish is similar to the WUP curve for Chinook fry, except that suitability declines past 80 cm for Fraser fish (Figure 21). Suitable velocity for Fraser fish is also similar to the WUP curve and identifies low velocity habitat up to 35 cm/s as highly suitable. Maximum suitability extends to lower velocities for Fraser fish (5 cm/s) compared to the WUP curve (Figure 21). Substrate use is highest over cobble habitat, and equally modest over sand and gravel substrates.

**Chinook 0+ Stream-Type** –Suitable depths for stream-type Chinook Salmon captured from June through the fall months is narrower in range (20-50 cm) compared to younger stream/ocean-type fish caught in spring. Suitable water velocity is nearly identical for the two types of Fraser Chinook, which both show high utilization of low velocity habitat <35 cm/s

(Figure 22). Substrate use by stream-type Fraser Chinook 0+ is similar to other published data sources and shows increasing suitability with substrate size (Figure 22).

**Chinook 1+ Stream Type** – The most suitable depth range for 1+ Chinook Salmon captured in winter/spring months is deeper compared to 0+ fish, and extends beyond 100 cm (Figure 23). These 1+ fish also use higher velocity habitats compared to 0+ fish and suitability extends to 55 cm/s, which is similar to the WUP curve (Figure 23). Substrate use by Fraser Chinook 1+ increases with substrate size and the suitability criteria are highly similar to the WUP criteria (Figure 23).

### *4.2.2 Chum Salmon*

Chum fry in the Fraser River show high utilization of depths equal to or greater than 40 cm (Figure 24), which is consistent with reporting by Salo (1991) that Fraser River chum are generally distributed across the entire river throughout the migratory spring season. Despite the wide depth distribution, a narrower range of low velocity habitat is most suitable to Fraser Chum (Figure 24), which is consistent with the Type II curve proposed by Hale et al. (1985). Substrate use is highest for cobble habitats, followed by sand and then gravel (Figure 24).

### *4.2.3 Sockeye Salmon*

Sockeye Salmon fry in the gravel reach avoid very shallow water and most suitable habitats are between 35 and 55 cm (Figure 25). Sockeye show high utilization of stagnant and low velocity habitats <10 cm/s (Figure 25), and in fact all fish caught by Rempel (2004) in the Fraser River gravel reach were found in channel nook and bay habitat units that characteristically have no flow. Similar to Chum Salmon, substrate suitability for Sockeye fry is highest for sand and cobble substrates (Figure 25). We expect that velocity is the primary driver of habitat suitability for stream-type Sockeye and low velocity habitats characteristically are either sandy or a cobble-sand mix.

### *4.2.4 Rainbow Trout / Steelhead*

**Rainbow Trout 0+** – For Rainbow Trout fry, there is good agreement between the Fraser HSC and WUP curves for both depth and velocity. The Rainbow Trout sample size of Rempel (2004) was relatively low (n=111); hence, we have adopted the WUP curves as the final HSC for 0+ Rainbow Trout in the Fraser River gravel reach. Fry show highest use of shallow and low velocity habitats over gravel-sized substrate (Figure 26).

**Rainbow Trout 1+** – For Fraser River Rainbow Trout yearlings, depth suitability is similar though slightly shallower compared to the WUP Delphi curve (Figure 27). Suitability also tapers off beyond 90 cm depth for Fraser fish. Velocity suitability is maximal between 30 and 55 cm/s, which is greater than for 0+ Rainbow and similar to the WUP Delphi curve. There is good agreement in substrate utilization between the Fraser River data and all comparable data in the literature, with increasing use of larger substrates (Figure 27).

### *4.2.5 Mountain Whitefish*

**Mountain Whitefish 0+** – Peak habitat suitability for Mountain Whitefish fry in the Fraser River is between 20-30 cm depth and 20-60 cm/s velocity (Figure 28). Velocity suitability agrees well with data presented by Addley et al. (2003), whereas Fraser River depth suitability has a narrower and shallower range. Curves presented by Bovee (1978) indicate higher use of slower velocity and deeper water compared to the Fraser River data. For the Fraser, substrate use by Mountain Whitefish fry is highest over gravel, and similarly modest for sand and cobble (Figure 28).

**Mountain Whitefish 1+** – Yearling Mountain Whitefish in the Fraser River use moderate depths ranging between 30 and 65 cm (Figure 29). This range matches Alberta data reported by Addley (2003), but is a notably narrower range. Fraser River fish also use a narrower range of velocity between 30-50 cm/s compared to Addley (2003), but both depth and velocity suitability match well with curves presented by Bovee (1978). Mountain Whitefish 1+ have highest use of gravel substrate, reduced use of sand compared to 0+ fish, and increased use of cobble (Figure 29).

**Mountain Whitefish 2+** – Depth suitability for age 2+ Mountain Whitefish is maximal for depths equal to or greater than 50 cm (Figure 30), and use of shallow habitats less than 20 cm depth is low. Depth suitability is nearly identical to that reported by Addley (2003), and comparable to Bovee (1978). For these references, we have compared Fraser River 2+ fish to the "adult" size class reported by the authors. Maximum velocity suitability is from 40 to 60 cm/s in the Fraser River, which matches well with both Addley (2003) and Bovee (1978). Consistent with the younger age classes, 2+ Mountain Whitefish are predominantly associated with gravel substrate and minimally use sandy habitats (Figure 30).

### *4.2.6 Mountain Sucker*

**Mountain Sucker 0+** – Young-of-the-year Mountain Sucker are <50 mm fork length and fish show high use of shallow (10-25 cm) and low velocity (5-15 cm/s) habitats (Figure 31). Substrate use is primarily over gravel habitats, with low suitability for sandy and cobble sites.

**Mountain Sucker 1/2+** – Fraser River 1+ and 2+ Mountain Sucker range in size from 50 to 115 mm fork length. A broader range of velocities is suitable for these larger fish compared to 0+ fry but maximum depth suitability is relatively narrow, from 15 to 40 cm (Figure 32). Fish are not associated with sandy habitat whereas gravel and cobble sites have high use in the Fraser gravel reach.

**Mountain Sucker 3+** – Maximum depth and velocity suitability for age 3+ Mountain Sucker are notably higher for these larger fish >115 mm fork length compared to the younger size classes. Suitable habitat extends beyond 100 cm depth and 100 cm/s velocity (Figure 33). Consistent with younger size classes, fish are not associated with sandy habitat whereas gravel and cobble sites have high use by 3+ Mountain Sucker (Figure 33).

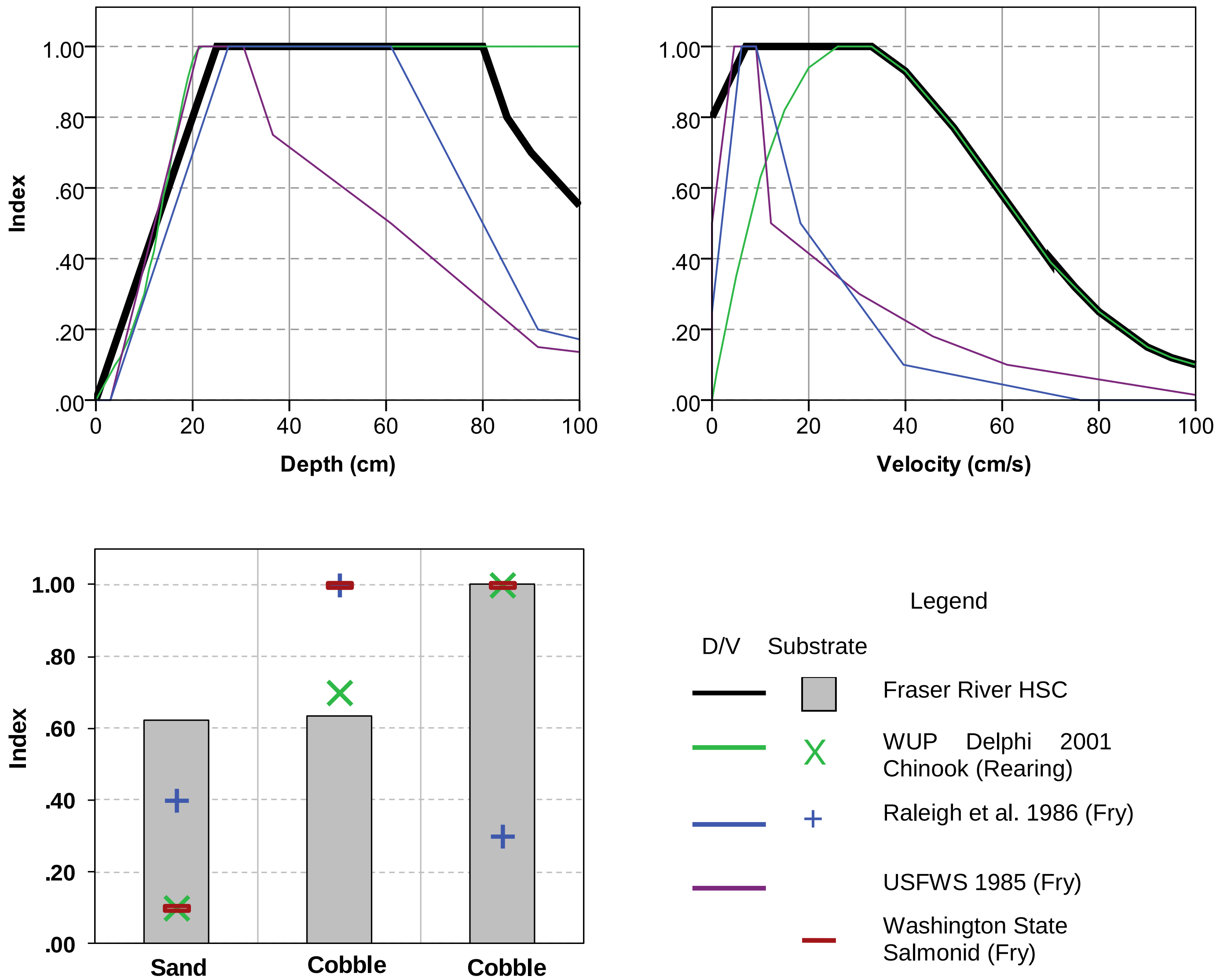


Figure 21. Chinook Salmon 0+ (stream/ocean-type) HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=1564).

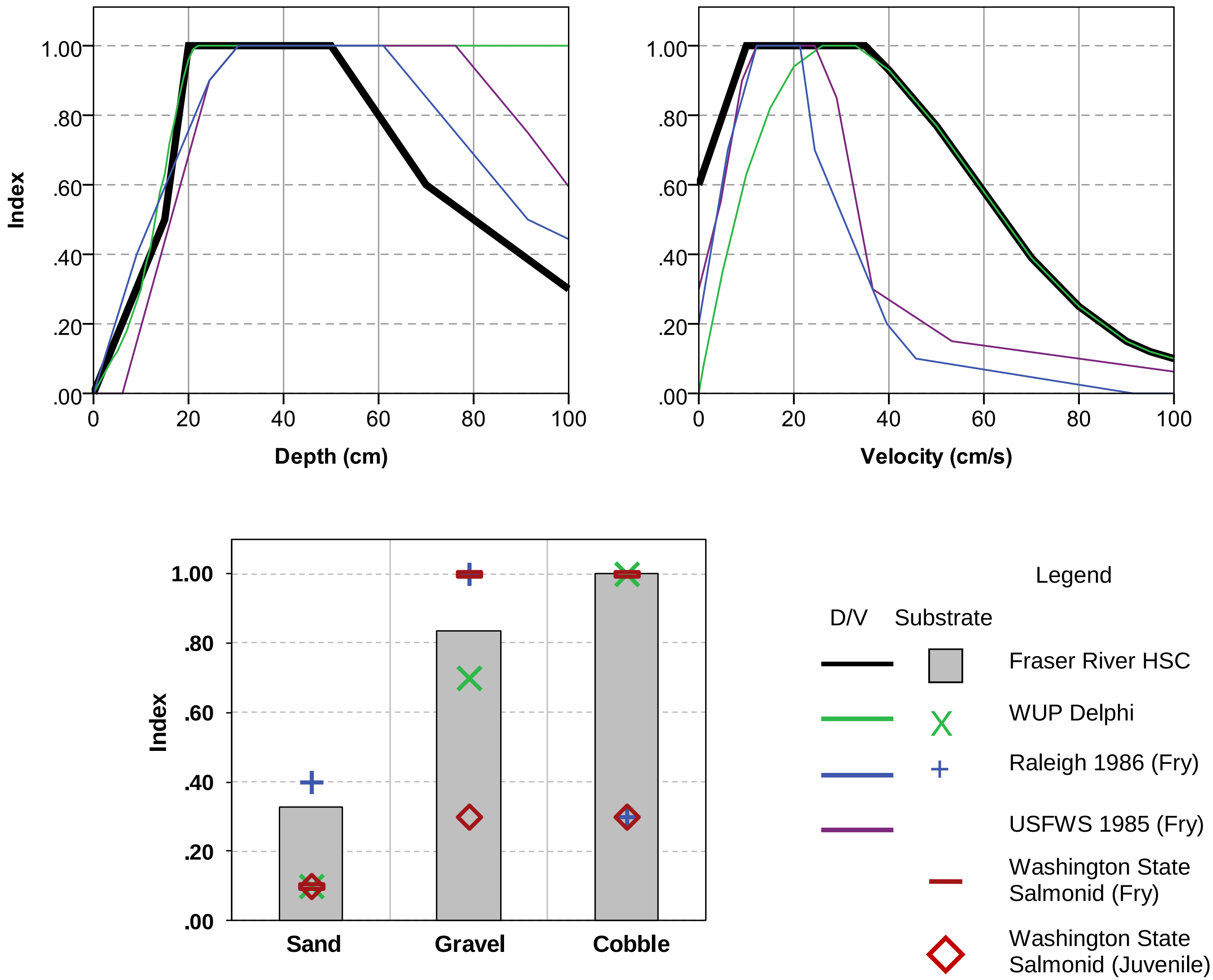


Figure 22. Chinook Salmon 0+ (stream-type) HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=3810).

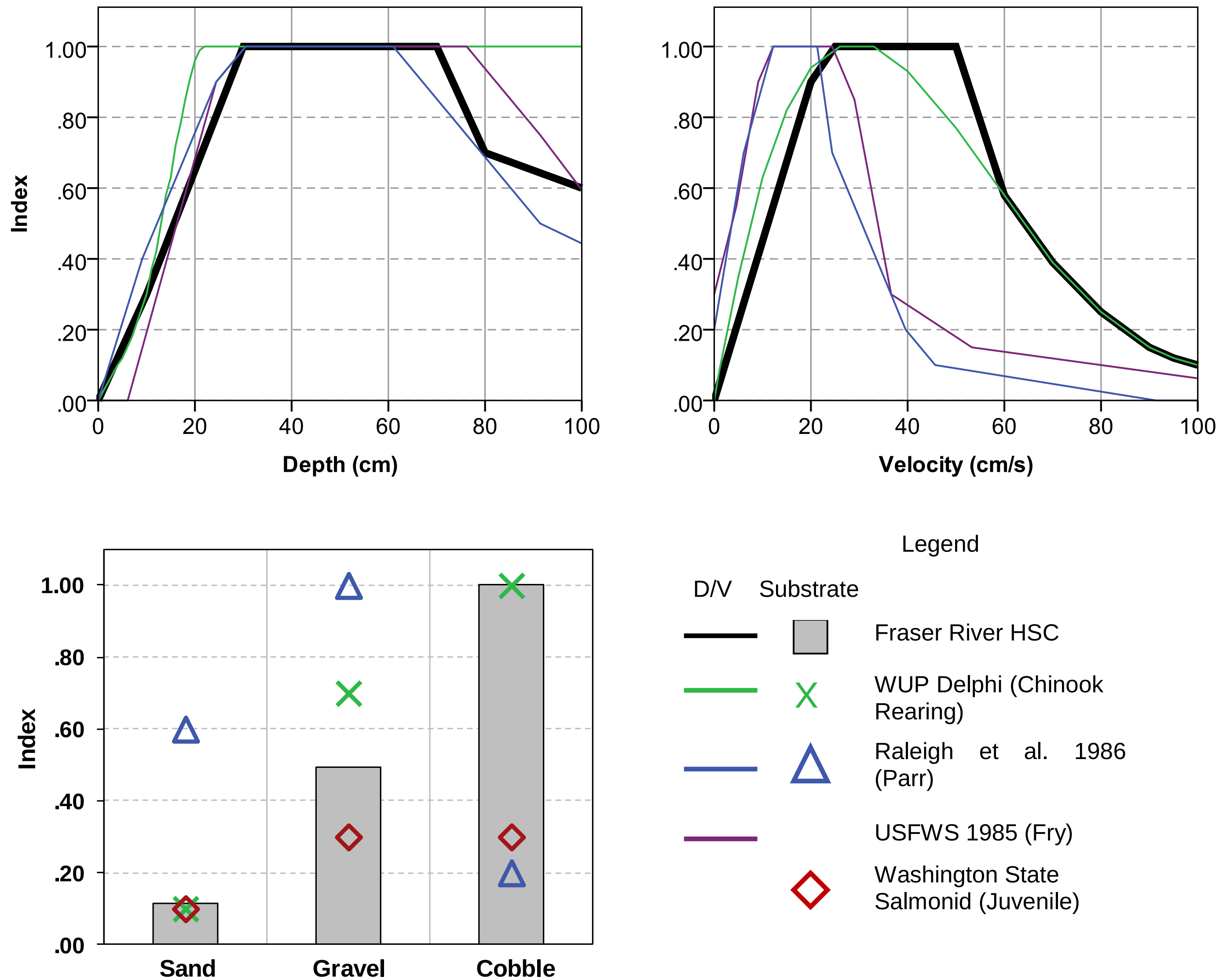


Figure 23. Chinook Salmon 1+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=489).

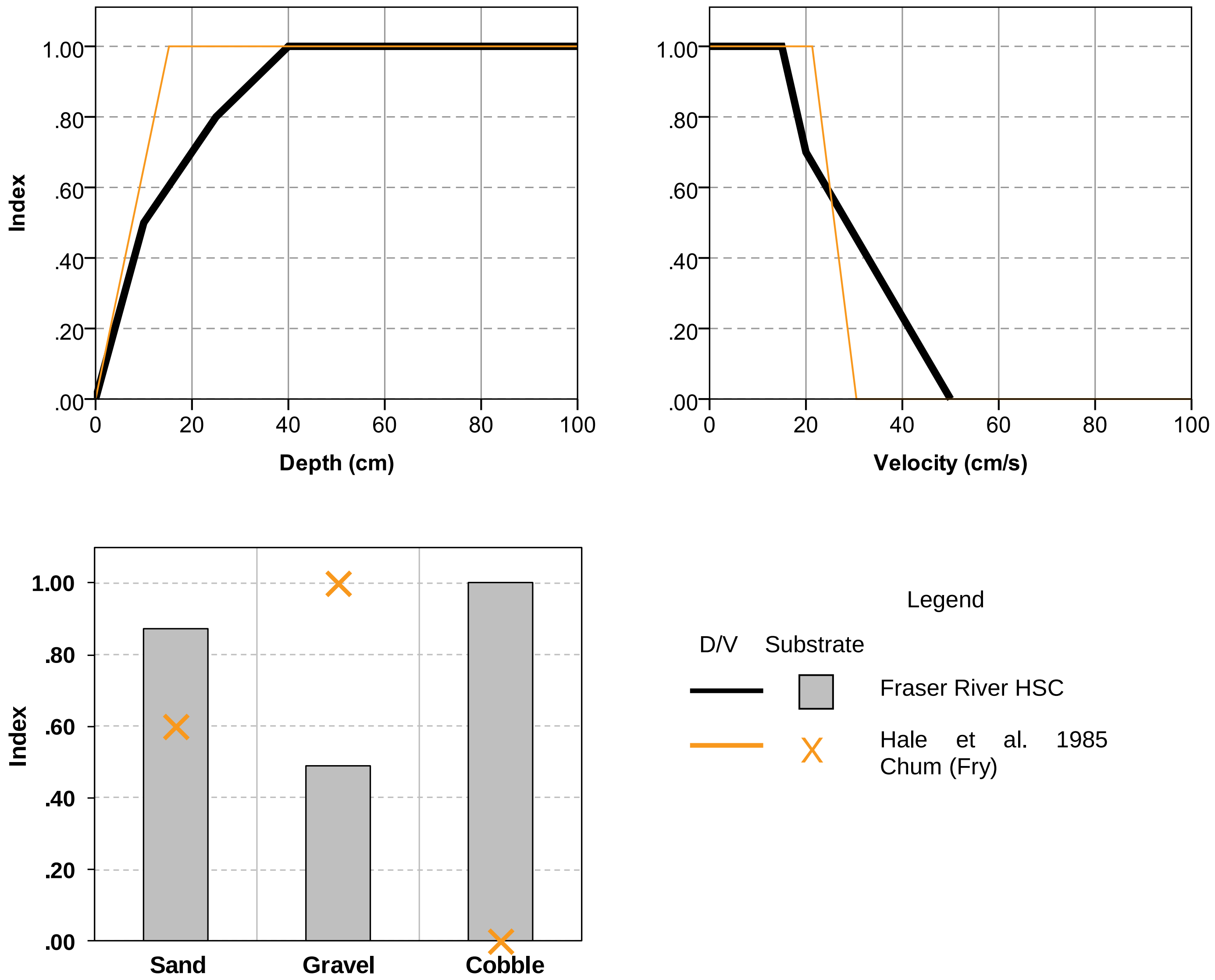


Figure 24. Chum Salmon 0+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=1237).

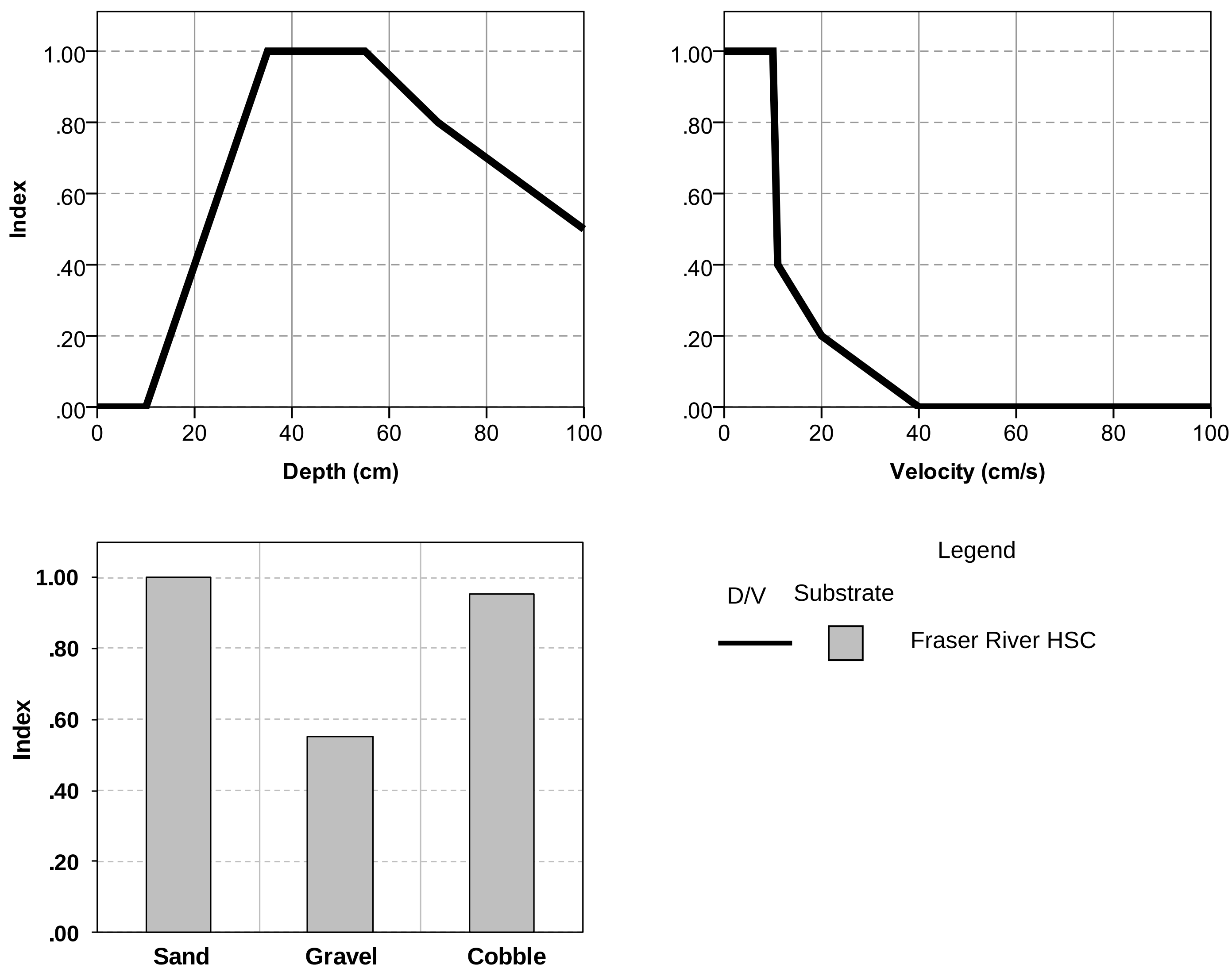


Figure 25. Sockeye Salmon 0+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=219).

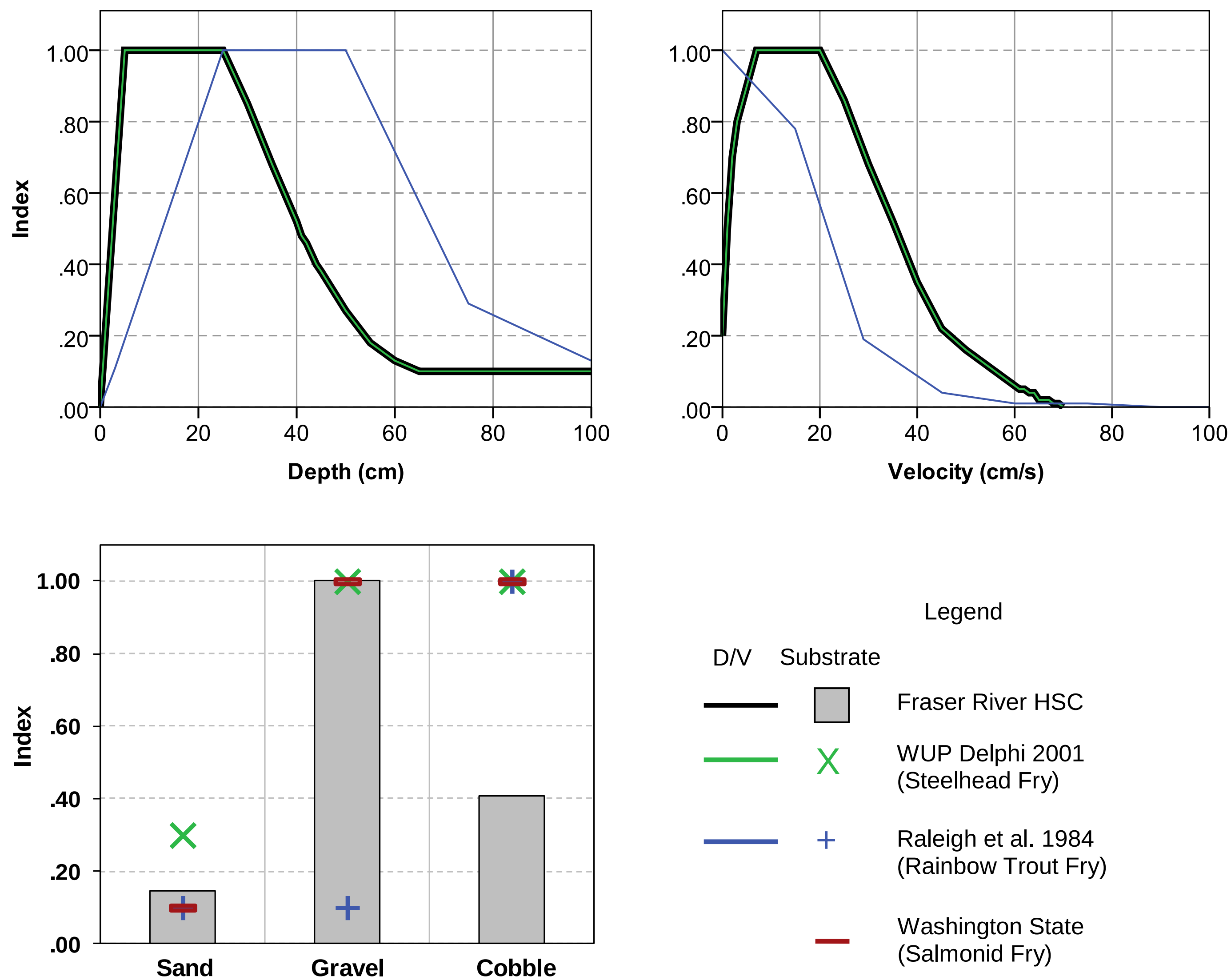


Figure 26. Rainbow Trout 0+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=59).

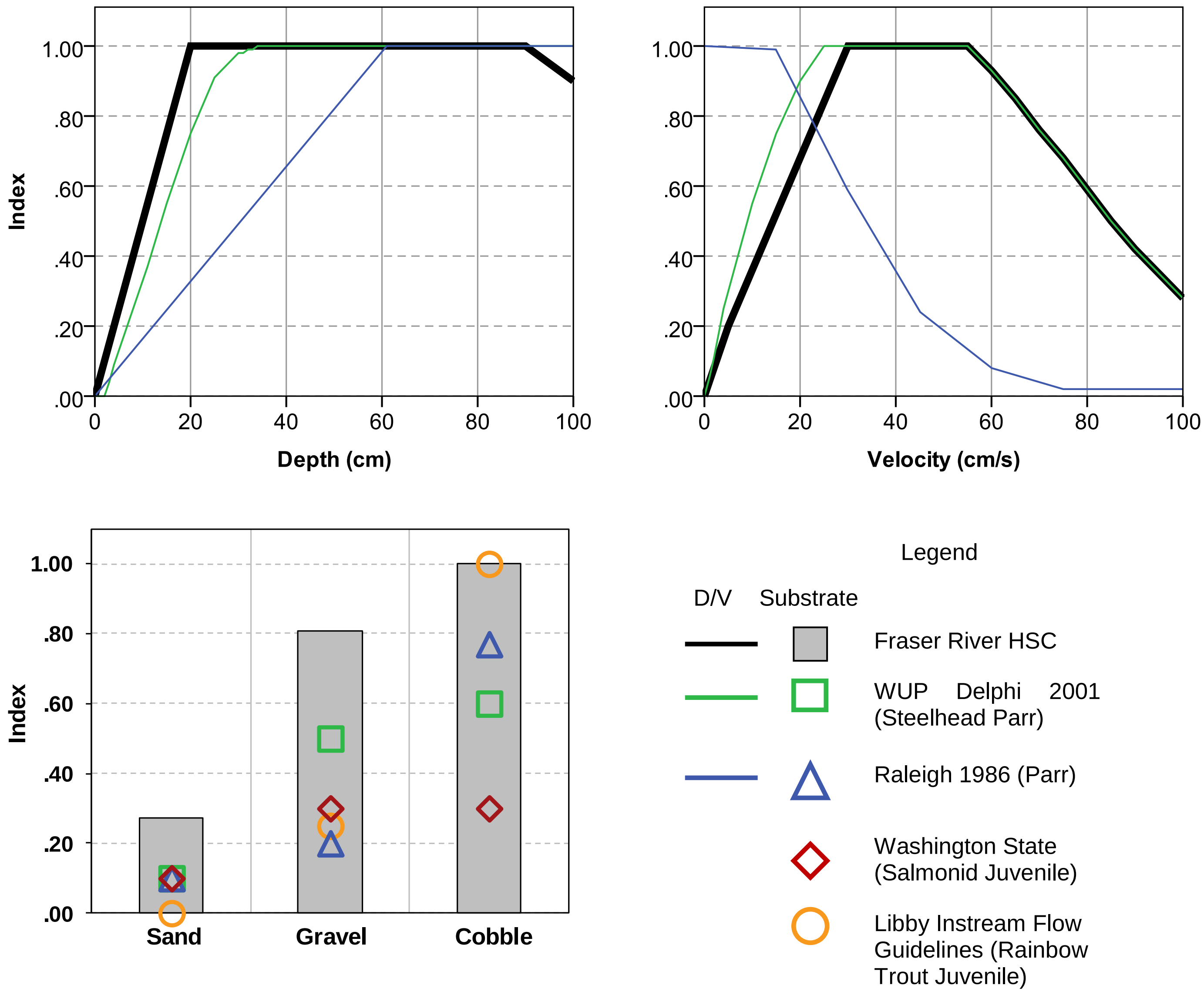


Figure 27. Rainbow Trout 1+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=42).

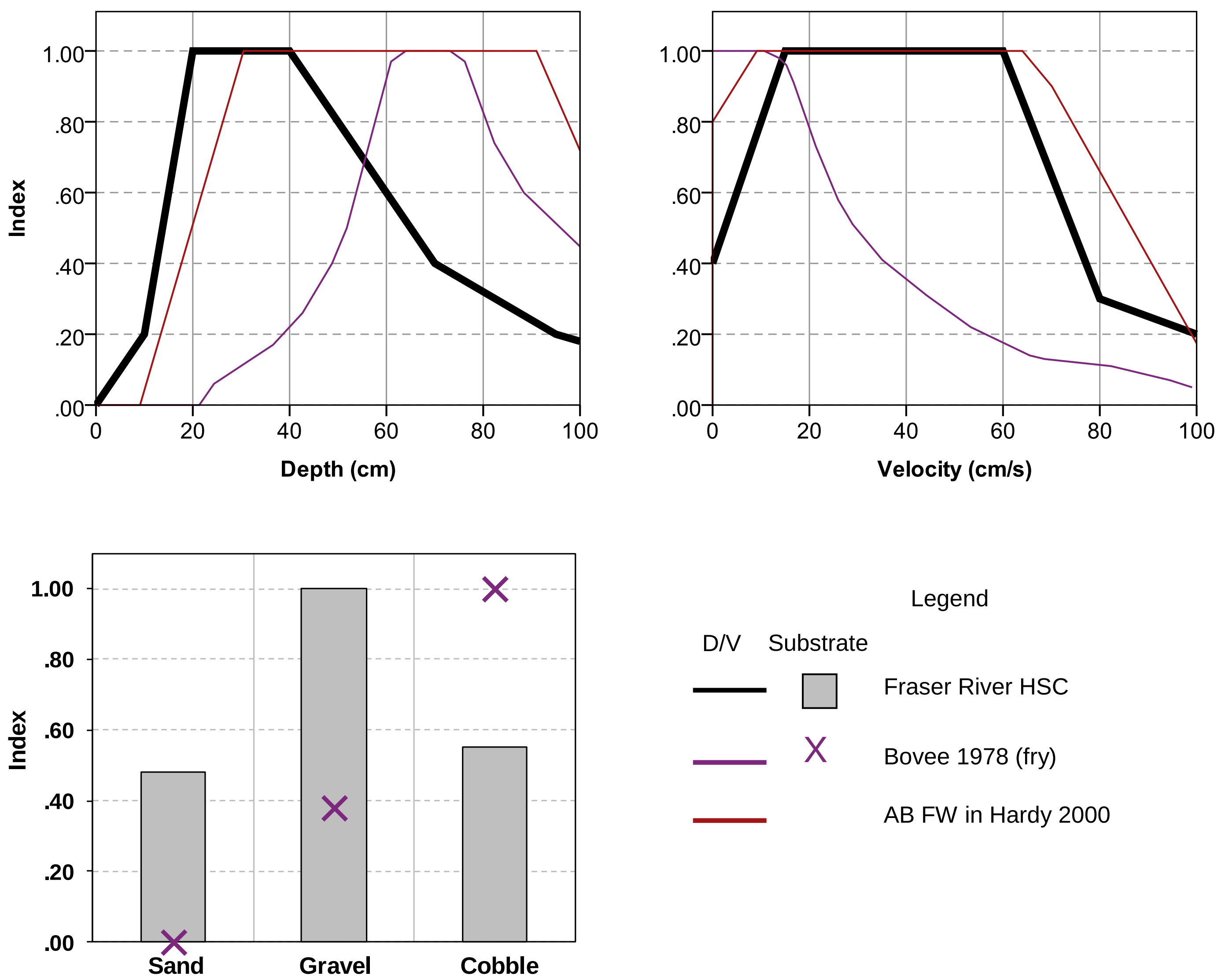


Figure 28. Mountain Whitefish 0+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=483).

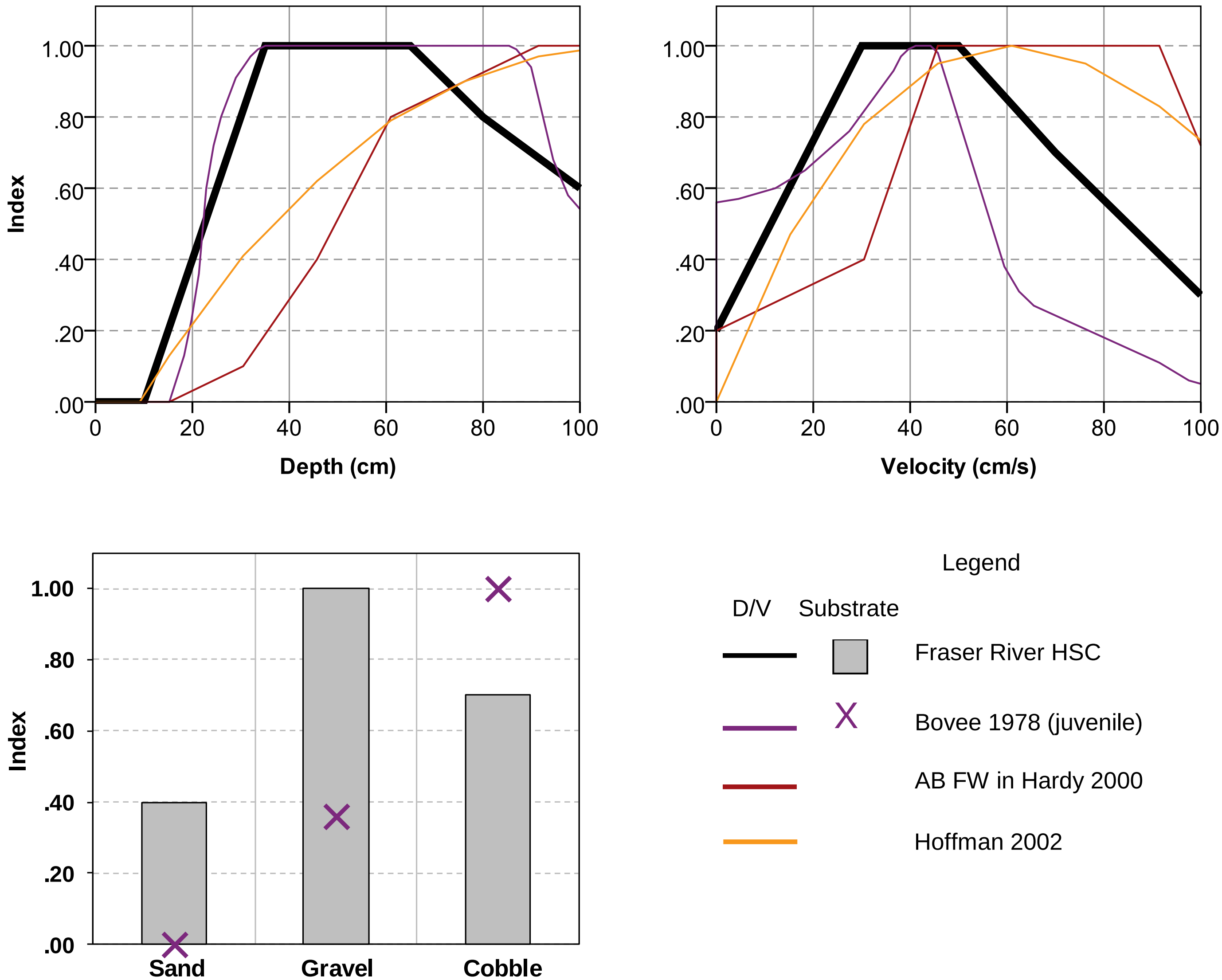


Figure 29. Mountain Whitefish 1+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=205).

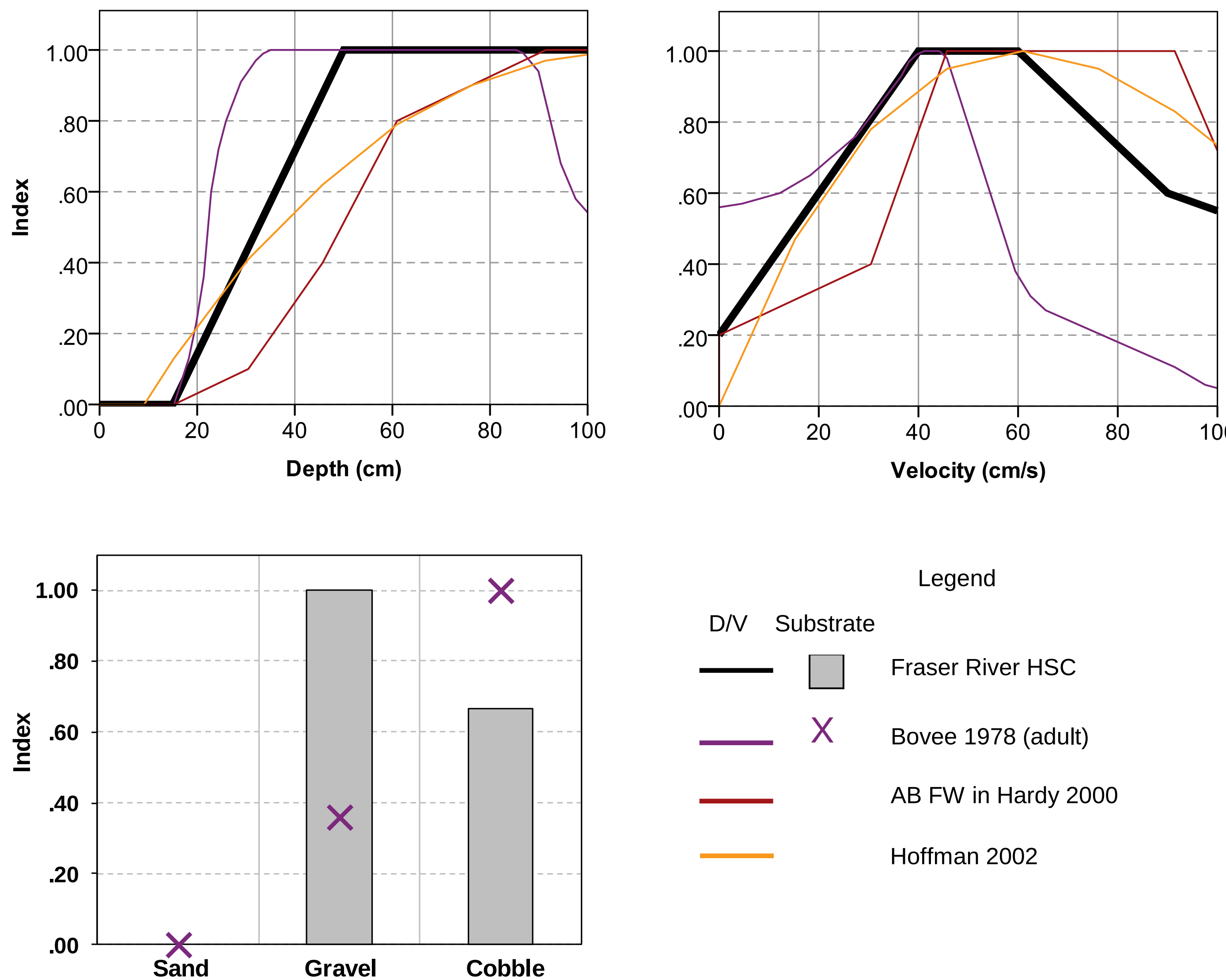


Figure 30. Mountain Whitefish 2+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=62).

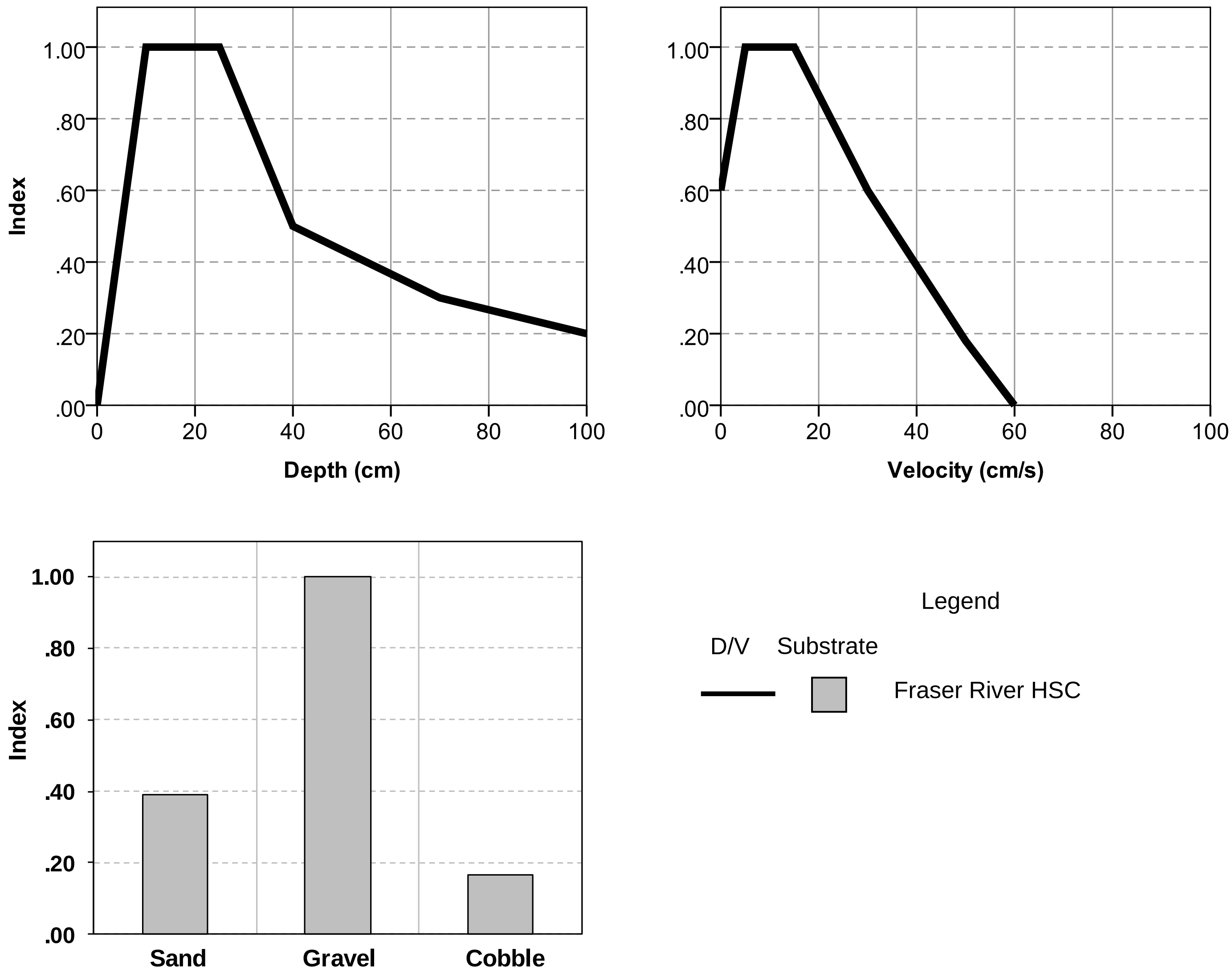


Figure 31. Mountain Sucker 0+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=124).

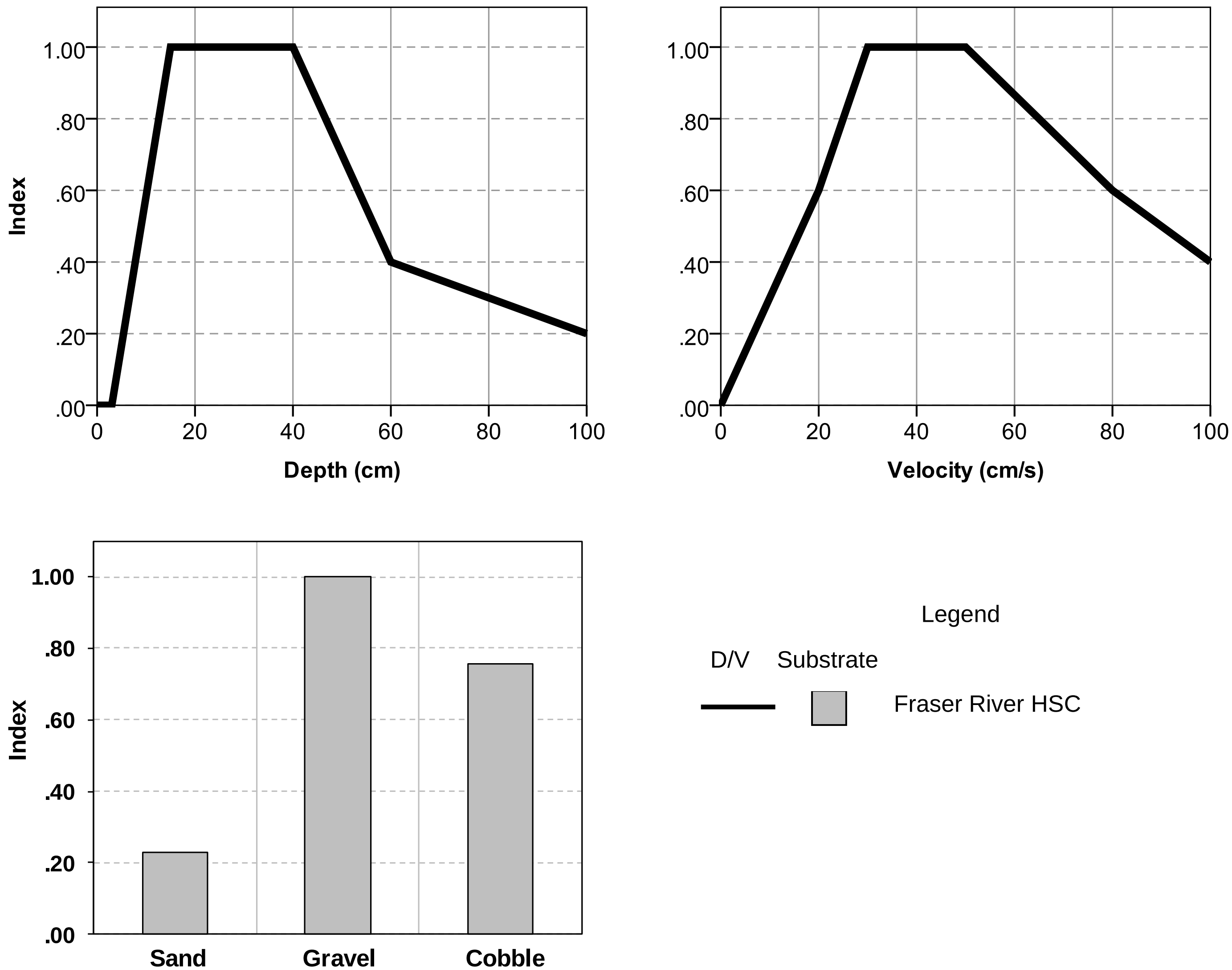


Figure 32. Mountain Sucker 1+/2+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=961).

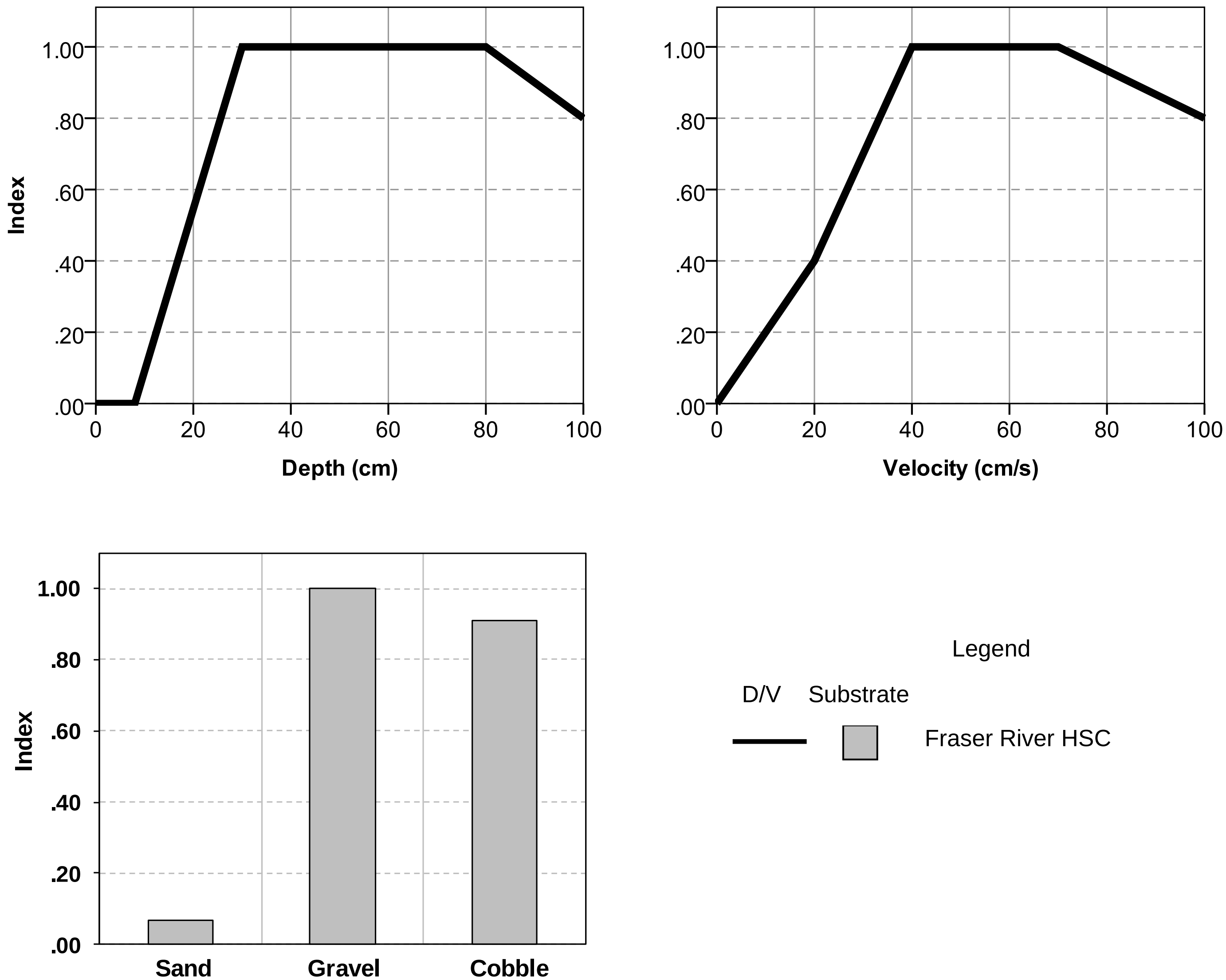


Figure 33. Mountain Sucker 3+ HSC curves for depth (top left), velocity (top right) and substrate (bottom left) in the Fraser River gravel reach (n=512).

# 5 HABITAT SUITABILITY BY CHANNEL TYPE

Fish sampling occurred within three channel types of the Fraser River gravel reach: main, side and summer channels. We generated channel-specific availability curves for depth and velocity in order to evaluate general differences in habitat characteristics among channel types, and to assist in the interpretation of channel-specific HSC curves.

The availability curves reveal that sampling sites in summer channels have more shallow habitat <20 cm available compared to sites in the main and side channels, and sampling sites had roughly twice as much zero-velocity habitat in summer and side channels (Figure 34). Side channel sampling sites are most similar to main channel sites in terms of depth availability, but more similar to summer channels in terms of velocity. The convergence of main and side channel depth and velocity availability at the outer limit of each plot reflects the physical limitations of sampling in these channels where maximum channel depth exceeds 100 cm.

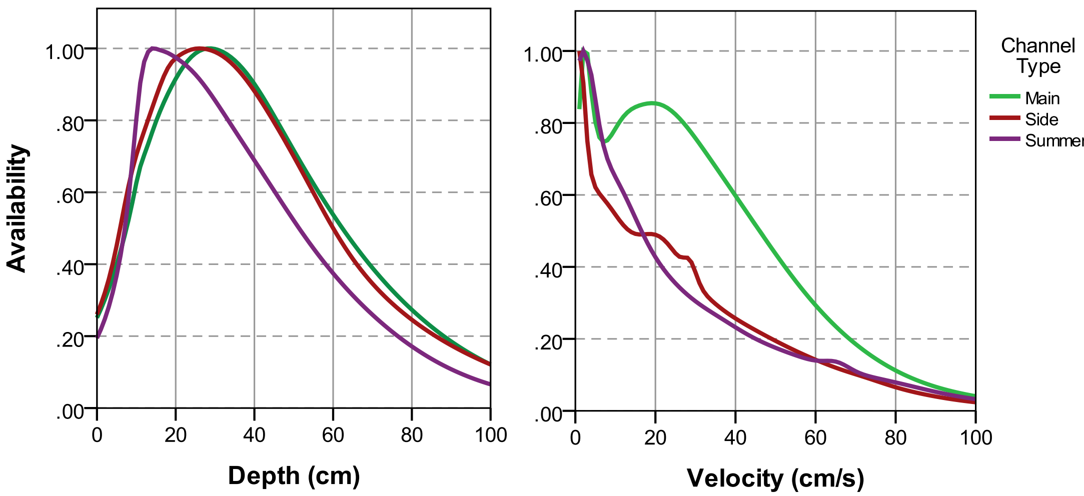


Figure 34. Depth and velocity availability in main, side, and summer channel types of the Fraser River gravel reach.

### *5.1.1 Chinook Salmon 0+*

The majority of Chinook Salmon 0+ (stream-type) were collected in the main channel (64%). Both the main and side channel depth suitability functions match the composite channel curve, with maximum suitability between 15 and 40 cm (Figure 35). Suitability in summer channels extends to deeper habitats (60 cm), which reflects the lower availability of deep-water habitat in these channels (Figure 34).

Just as for depth, velocity suitability in side channels matches the composite channel suitability function (Figure 35). In the main channel, highest suitability is shifted to slightly higher velocity habitat than the composite curve, and suitability in summer channels is very broad.

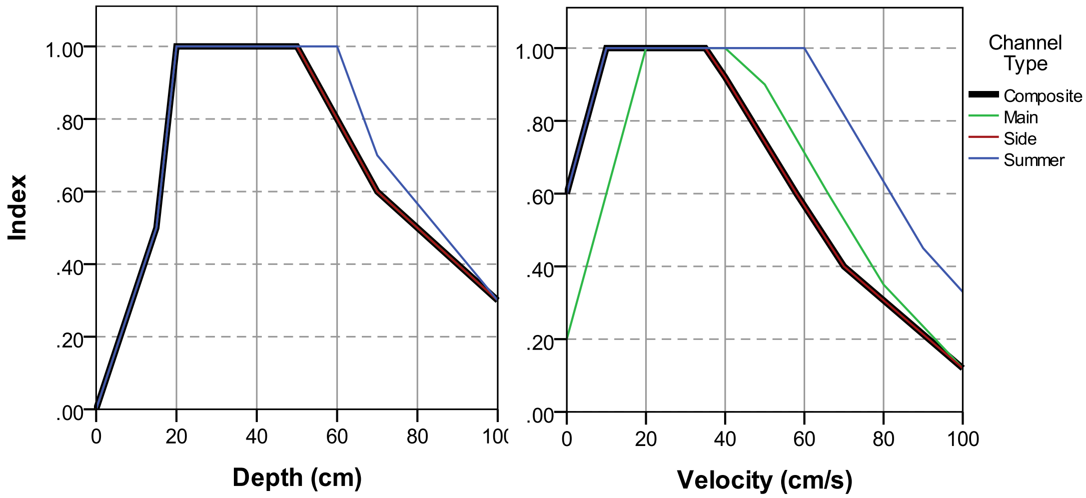


Figure 35. Chinook Salmon 0+ (stream-type) HSC curves for depth and velocity in main, side and summer channels of the Fraser River gravel reach. ‘Composite’ refers to all channel types combined.

### *5.1.2 Chum Salmon 0+*

The majority of Chum Salmon 0+ were collected in the main channel (62%) where the depth suitability function matches the composite channel curve, with maximum suitability extending from 40 cm to >100 cm (Figure 36). The suitability functions for side and summer channels are very similar, except that maximum suitability only extends to 80 cm and 60 cm, respectively, before declining. Both the composite and main channel suitability velocity functions match, just as for depth, and the side and summer channels also match but modest suitability extends into higher velocity habitat (Figure 36).

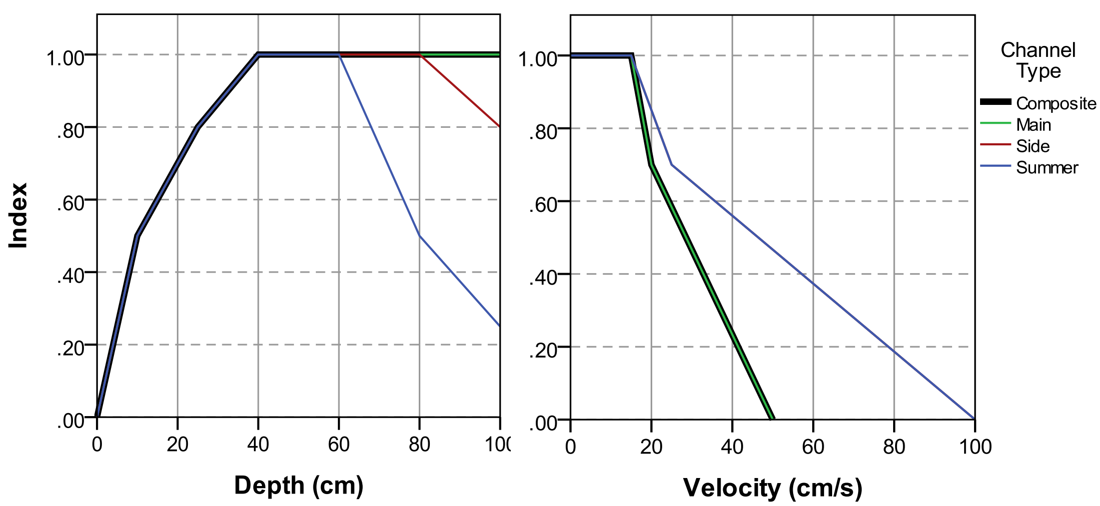


Figure 36. Chum Salmon 0+ HSC curves for depth and velocity in main, side and summer channels of the Fraser River gravel reach. ‘Composite’ refers to all channel types analyzed together.

### 5.1.3 Mountain Sucker 1+/2+

For both depth and velocity, the composite channel curve of Mountain Sucker 1+/2+ matches habitat suitability in each of the main and side channels whereas summer channel suitability is shifted to slightly deeper depths and higher velocities (Figure 37).

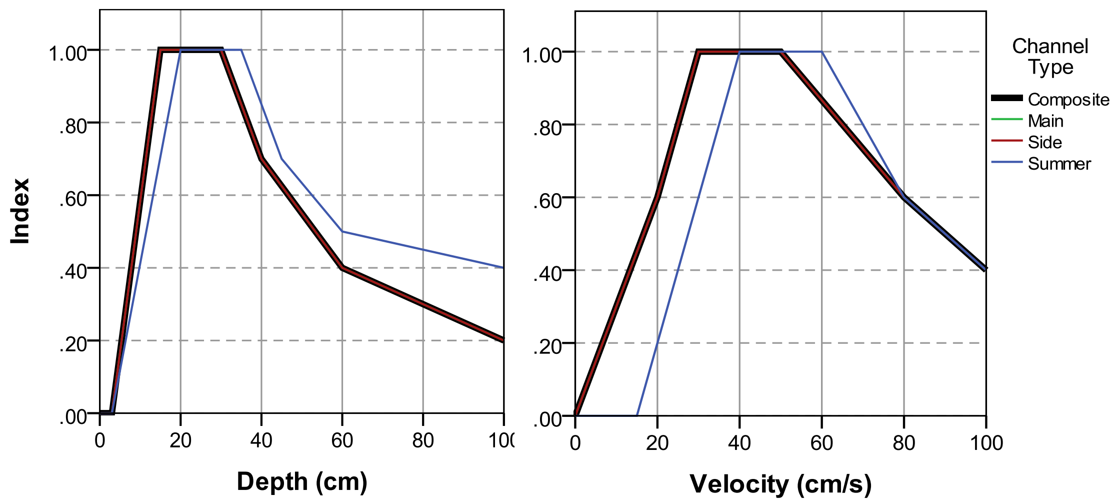


Figure 37. Mountain Sucker 1+/2+ HSC curves for depth and velocity in main, side and summer channels of the Fraser River gravel reach. 'Composite' refers to all channel types analyzed together.

## 6 DISCUSSION

The ecological integrity of the gravel reach is under increasing pressure from floodplain development and flood protection measures, and fisheries resource managers need tools to assess the impacts of these activities and make regulatory decisions. One useful tool is hydraulic habitat modeling to predict the change in availability of suitable fish habitat under different development scenarios. This application of habitat modeling depends on reliable habitat suitability criteria (HSC) that are relevant to the local populations of species and life stages likely to be affected. Most suitability criteria in the literature are either developed with field data from small, clear-water streams or are developed for generic application based on available literature and professional judgment. None have been developed for British Columbia species in large channels and turbid water conditions. These conditions characterize the Fraser River gravel reach, and many other coastal rivers in British Columbia.

We analyzed an extensive set of juvenile fish and habitat data collected from gravel bar habitats in the active channel zone of the Fraser River gravel reach. From these data, we have developed habitat suitability criteria for juvenile life stages of six species (Chinook, Chum and Sockeye Salmon, Mountain Whitefish, Rainbow Trout, and Mountain Sucker). Our HSC describe suitable water depth, velocity and substrate conditions where juveniles of these species are most likely to occur. We consider our criteria to be Category II utilization functions for substrate, and Category I utilization functions for water depth and velocity because professional judgment was applied to the statistically-derived utilization functions, which corrected for sampling limitations of the source data.

In order to derive reliable habitat suitability criteria, Bovee (1986) recommends a minimum of 150 to 200 observations for every species and life stage of interest. Our dataset consisted of 960 beach seine and 20 electrofisher observations that collected 9,787 fish representing the 6 species analyzed. Our dataset far exceeded Bovee's (1986) minimum sample size recommendation to produce reliable HSC for 5 of our 6 species of juvenile fish. For the one species with a relatively low sample size, Rainbow Trout, we have adopted the WUP Delphi curves (Ptolemy, 2001). For all other species and life stages, we have generated new curves based on Fraser River field data. We believe our curves for river-type Sockeye Salmon and Mountain Sucker are the first suitability criteria presented in the literature for these species. River-type Sockeye is a less common life history type about which the habitat requirements are not well known (Heifetz et al. 1989), and which is of increasing conservation and management interest. Mountain Sucker is considered at-*risk* by the Province of British Columbia and DFO has begun consultation on the federal listing of Mountain Sucker under the *Species At Risk Act* (SARA).

For most species and life stages we analyzed, the Fraser-specific HSC are reasonably similar to other published suitability curves. The similarity among curves was especially high for velocity, and only for two species were there notable differences. Low velocity habitat <20 cm/s has higher suitability for Fraser Chinook 0+ fish compared to the WUP Delphi curve (Ptolemy, 2001), and Fraser Mountain Whitefish 1+ have a narrower and lower velocity range of maximum suitability compared to other available sources. Comparing depth suitability, stream-type Chinook 0+ in the Fraser River have a narrower suitability range in shallow water from 20 to 50 cm, as do Mountain Whitefish 0+ with a shallow and narrow suitability from 20 to 40 cm. Yearling Mountain Whitefish 1+ also have a relatively narrow and shallow maximum suitability range from 35 to 65 cm. We attribute the high utilization of shallow habitats to the natural turbidity in the Fraser River gravel reach, which exceeds 20 NTU from March through September each year, and which provides cover for juvenile fish in shallow habitat. The effectiveness of turbidity as cover for juvenile salmonids is well documented (Gregory and Levings 1989, Sweka and Hartman 2001). We acknowledge the potential that sampling bias towards shallow depths may have partly influenced these results, but for the juvenile life stages we analyzed, the potential depth bias is not considered significant.

Substrate suitability is a more difficult habitat index to compare among studies because of the variety of methods to measure substrate and report their size characteristics. The standard scale of measure to report on sediment data is the Wentworth Scale (Bunte and Abt 2001) and size measures are expressed in millimeters or ø (phi), or else rolled up into Wentworth-based categories. For data expressed in inches or categorically (e.g., sand, gravel, cobble), we converted them, as best we could with sometimes limited information, to the Wentworth Scale for comparison with Fraser data.

How substrate measurements are collected in the field may also greatly affect results. Visual, qualitative assessment may produce reliable results if carried out by a professional with local experience. However, characteristics such as stone shape, lithology and imbrication will influence size measurements and these characteristics are likely to differ among streams (Bunte and Abt 2001); hence, local experience on one stream does not necessarily transfer to other systems. Quantitative assessments produce the most reliable size measurements but because they require more field time to measure individual stones, they are not always carried out.

Keeping in mind these possible sources of variation in substrate suitability data, the Fraser suitability criteria compare reasonably well to other data sources. Ocean/stream-type Chinook 0+ use sandy habitats in greater proportion to other studies, and 0+/1+ Mountain Whitefish have higher use of both sandy and gravel habitats. Comparatively higher use of sandy habitats in the Fraser River gravel reach is not surprising given the prevalence of surface sand deposits throughout the gravel reach. On average, sand makes up approximately 30% of the sub-surface bed material in the reach (Church et al. 2001), but surface sand representation at a particular site can be higher. Sandy-gravel and sandy-cobble sites are common and these habitats would be classified as sand-dominant for our analysis of substrate use, even though some of these habitats may have a high sub-dominant proportion of stones present. Photograph examples of sandy-gravel and sandy-cobble sites are shown in Figure 38.

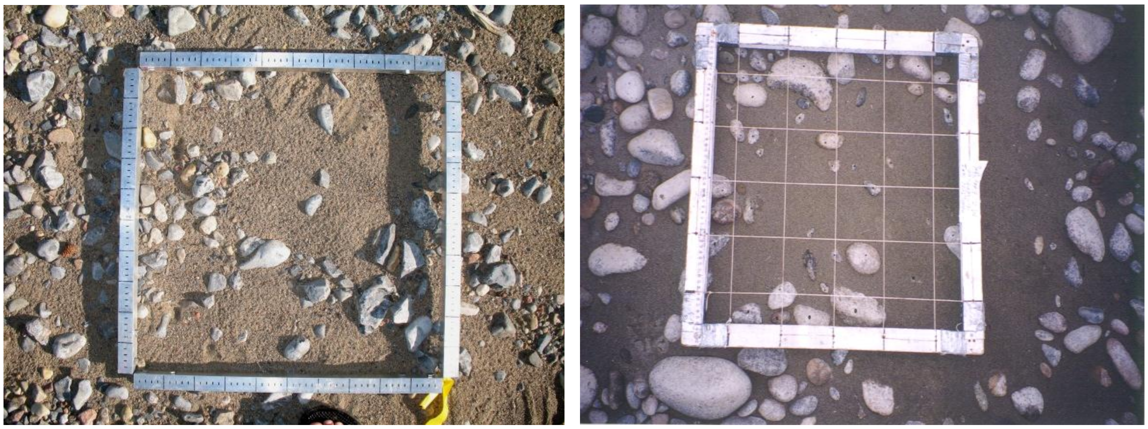

Figure 38. Examples of sandy-gravel (left) and sandy-cobble (right) substrate. The quadrat area in each photograph is 0.25 $m^2$.

For juvenile Chum Salmon, as an example, we expect that the high use of sand and cobble substrate in the Fraser River is correlated with the high preference for low velocity habitat. During spring months when discharge is relatively high and Chum are migrating, these habitats are often characterized by sandy-cobble or sandy-gravel substrate similar to photographs in Figure 38.

Our comparison of channel-specific suitability curves revealed only small differences among channel types for juvenile fish. This suggests that suitable habitat for these species is available and of similar character among channel types, and there is no added value of separating fish catch data by channel type because the composite curves match reasonably well to the channel-specific curves. This result may not apply to all large, multi-thread rivers where habitat quality is degraded or channel engineering has significantly modified secondary channel and floodplain areas. But for the Fraser River, where both channel processes and a modest amount of side channel and floodplain habitat remain intact, the differences in channel type do not appear important. We expect there may be larger differences among channel types for adult fish, and caution should be exercised when applying HSC for adults in large, multi-channel rivers.

In closing, we present the following recommendations for consideration. We recommend additional sampling of river-type Sockeye Salmon and Rainbow Trout to increase the sample size of fish observations and further refine the Fraser River HSC presented herein. Many non-game species have a large sample size in Rempel's (2004) dataset (Table 3), from which additional habitat criteria may be developed. Habitat use information for White Sturgeon would be highly valuable for fisheries managers and for protecting critical habitat of this endangered species in the gravel reach. Although the Fraser River Sturgeon Conservation Society has led several recent studies of juvenile habitat use (Glova et al. 2008, Glova et al. 2009, Glova et al.

2010), the data are not conducive to statistically generating habitat suitability criteria. Future White Sturgeon habitat studies may include modified field methods for more quantitative habitat assessment; however, the low capture rate of juvenile sturgeon will remain problematic for establishing habitat suitability criteria.

## 7 ACKNOWLEDGEMENTS

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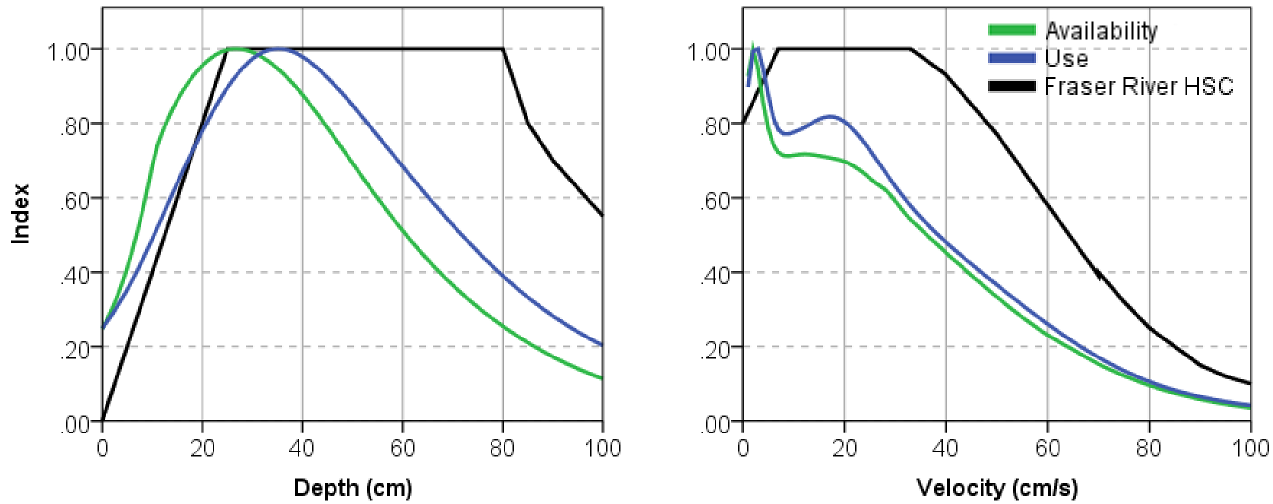
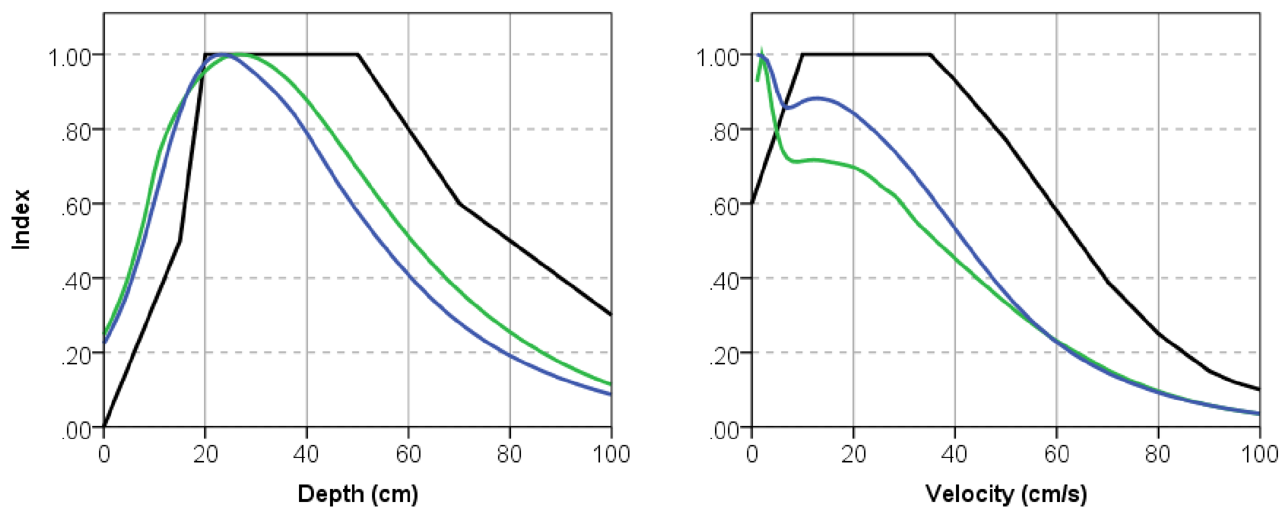
# 9 APPENDIX A

Statistically-derived habitat availability and utilization functions overlaid by the final habitat suitability criteria for juvenile life stages of fish species in the Fraser River gravel reach.

a) Chinook Salmon 0+ Stream/Ocean-Type




b) Chinook Salmon 0+ Stream-Type



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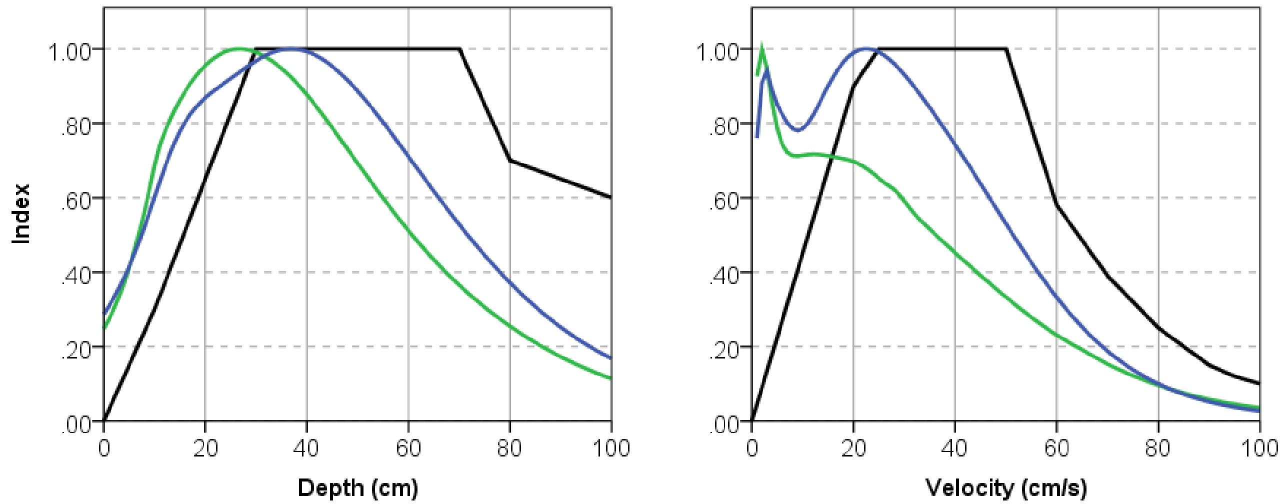
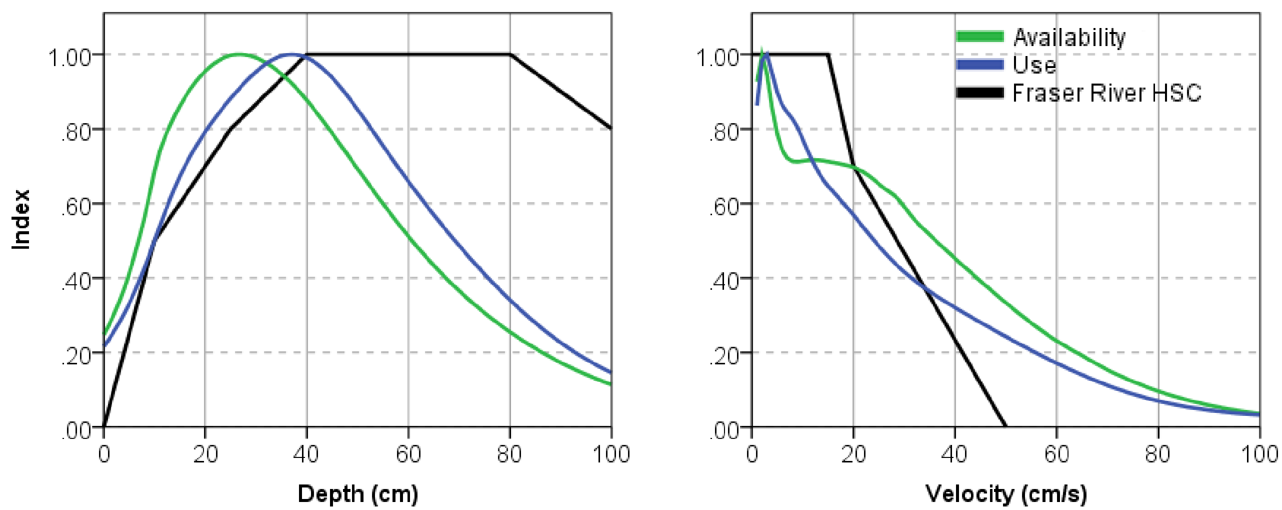
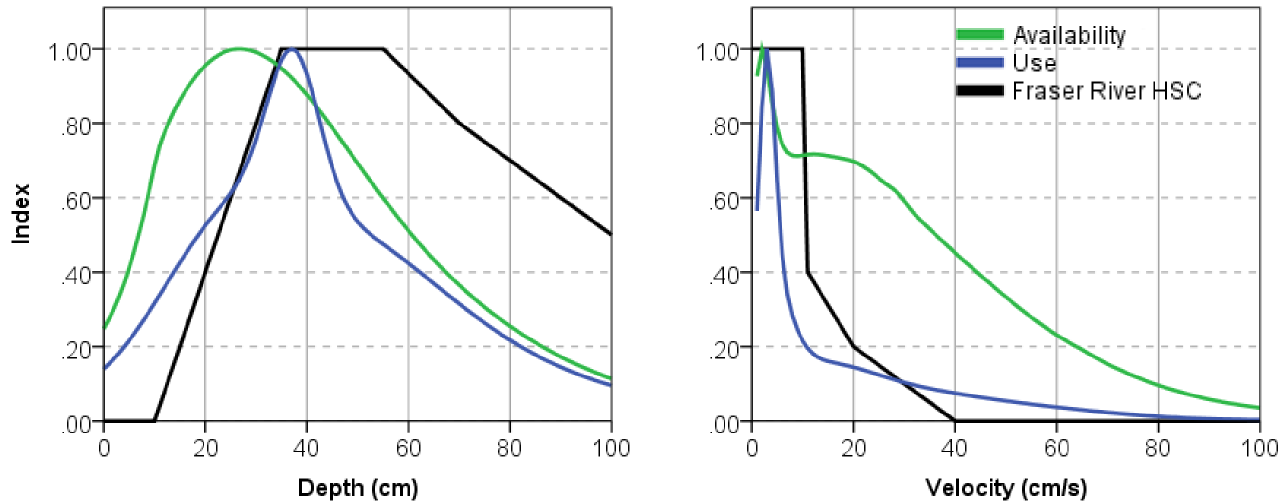


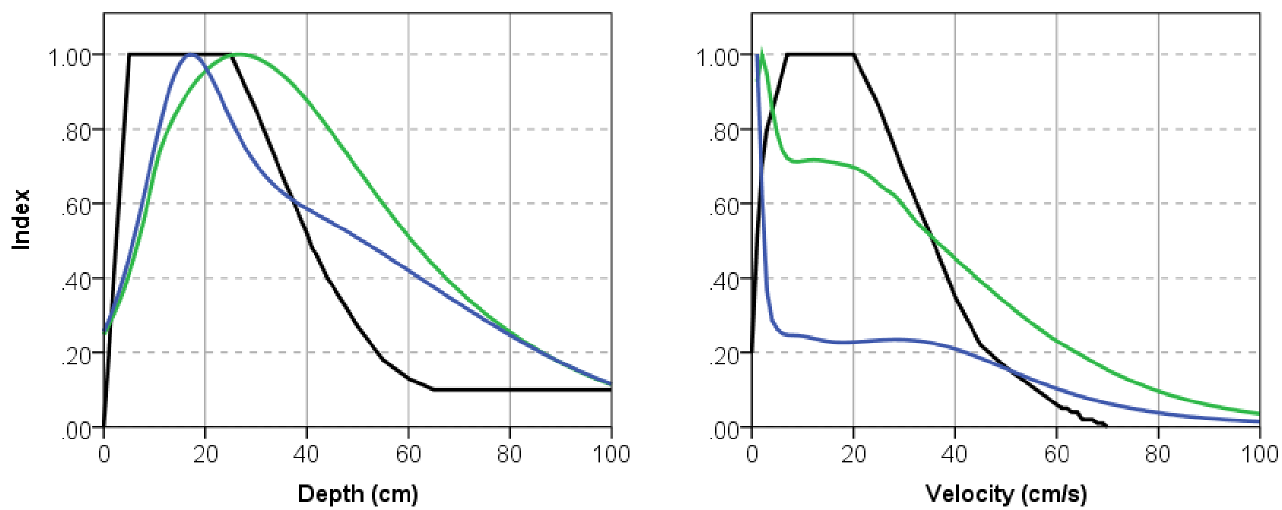

d) Chum Salmon 0+



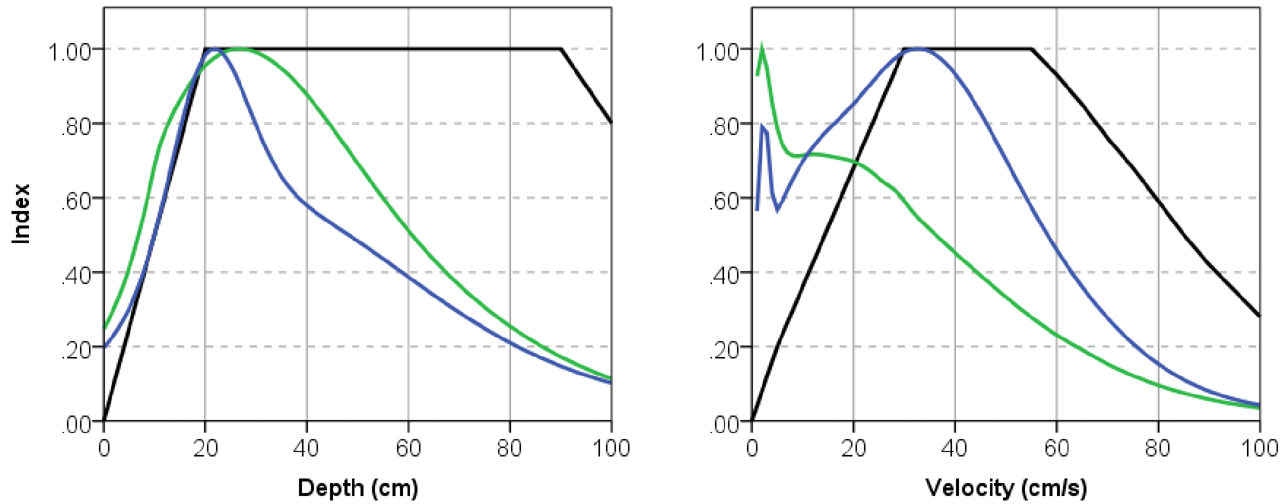
e) Sockeye Salmon 0+



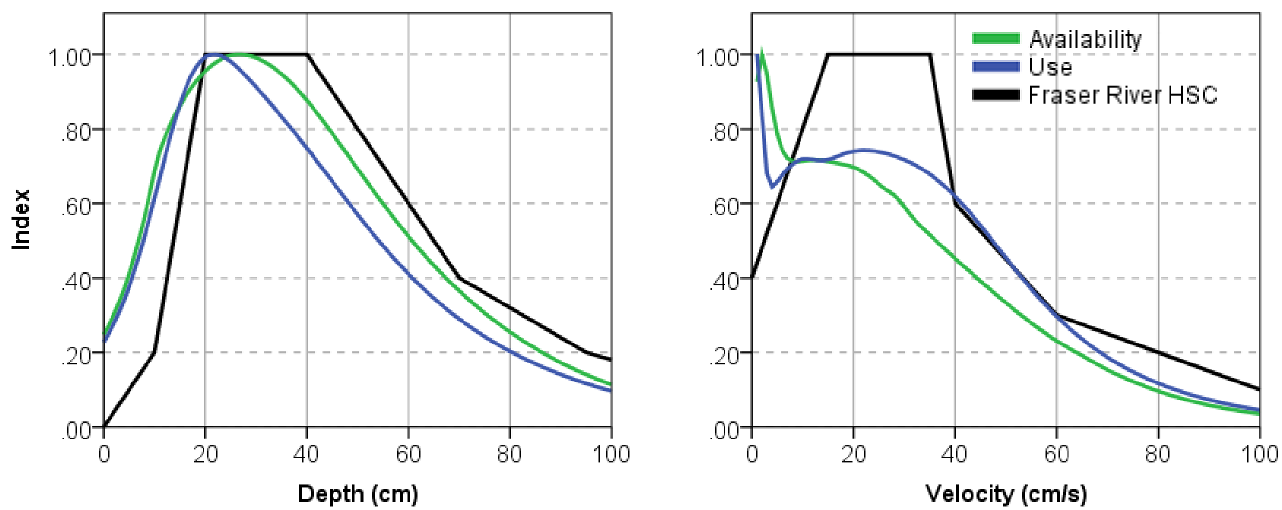

f) Rainbow Trout 0+



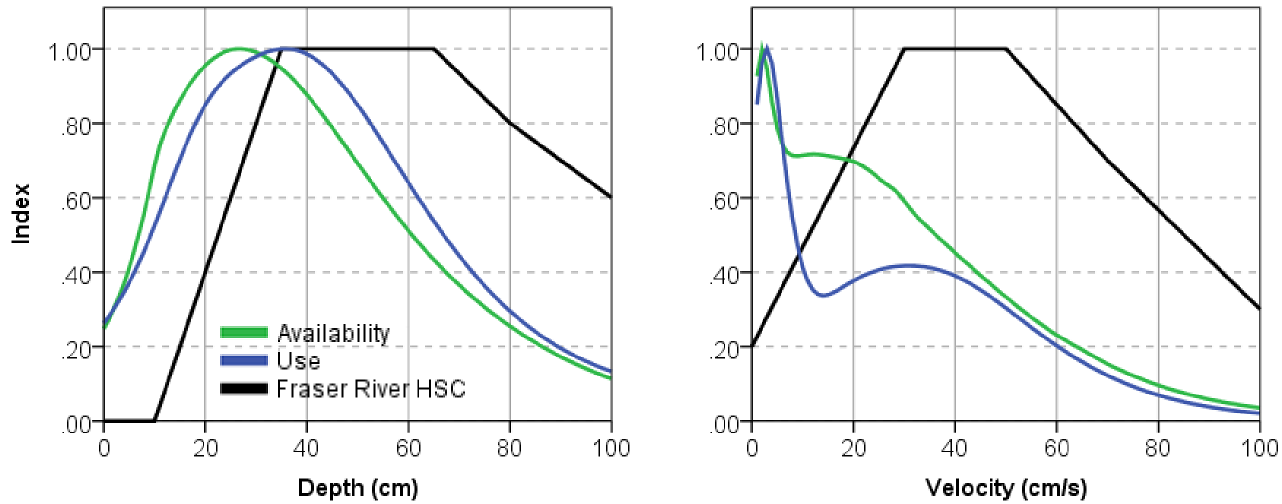
g) Rainbow Trout 1+



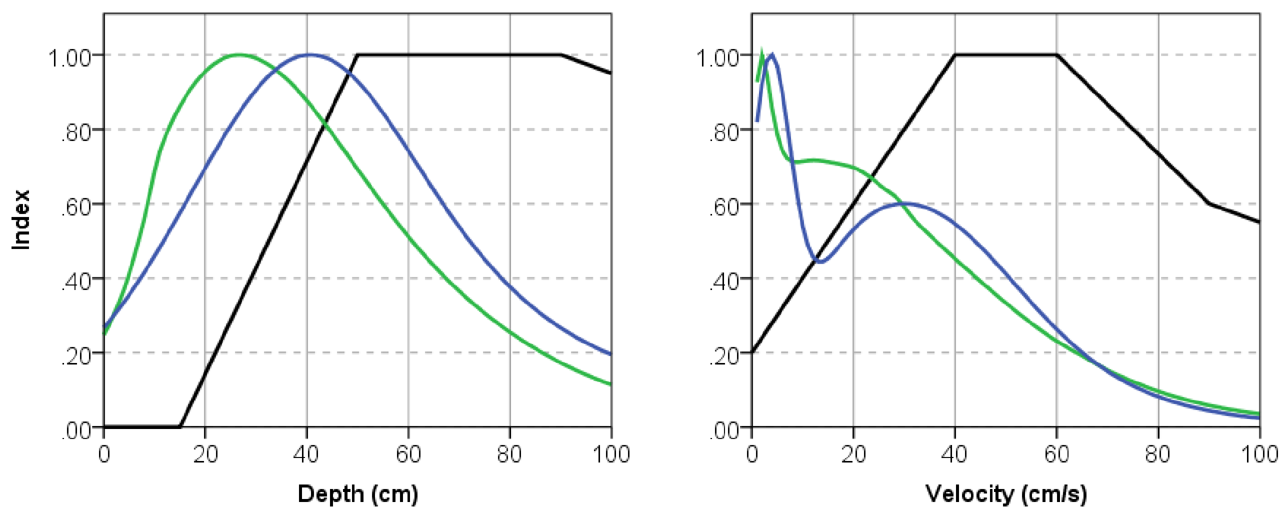

h) Mountain Whitefish 0+



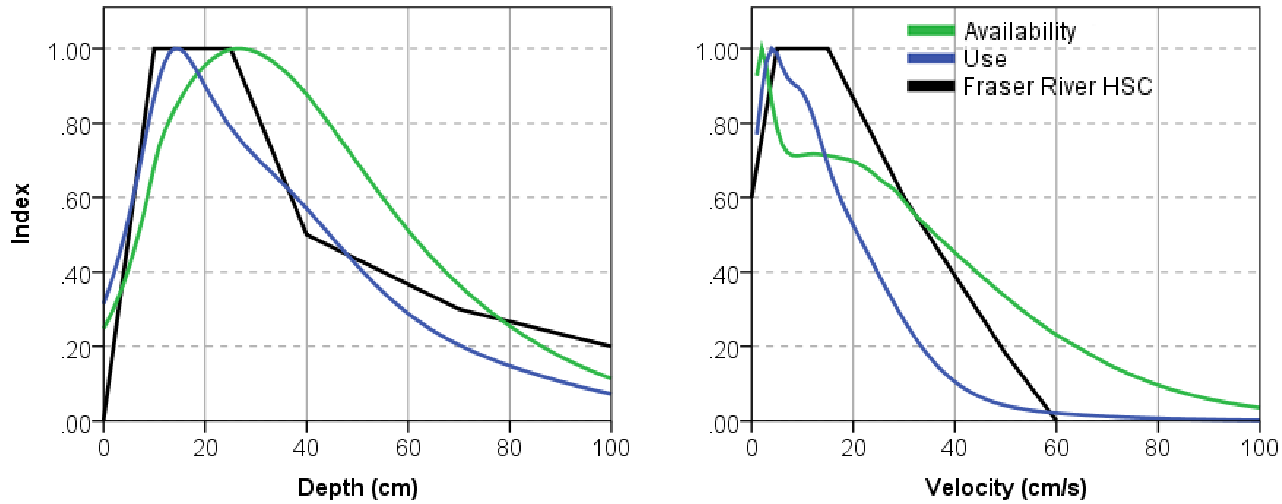
i) Mountain Whitefish 1+



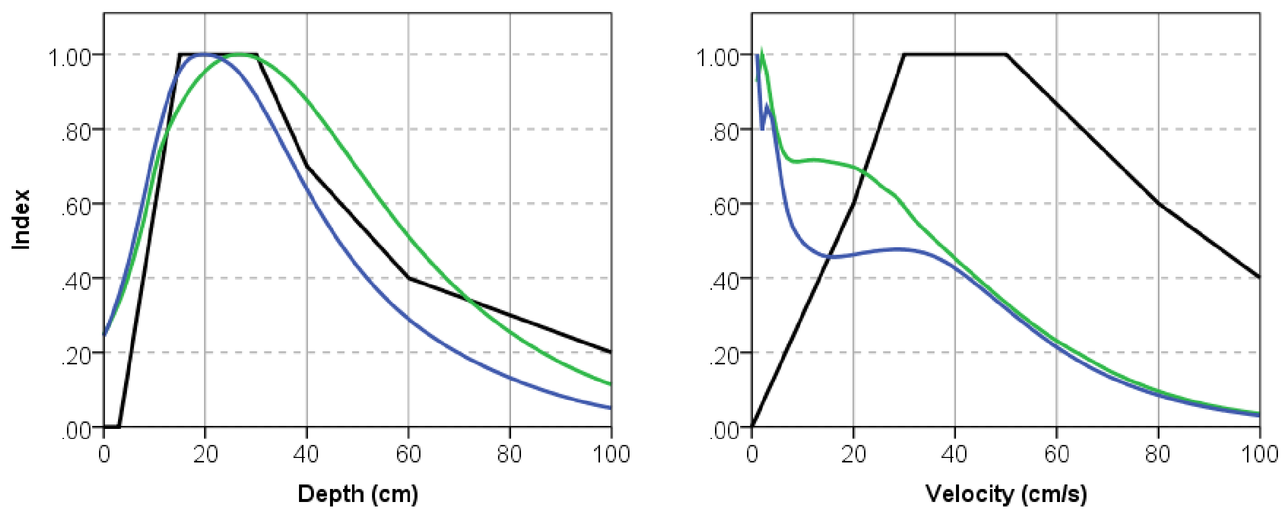

j) Mountain Whitefish 2+



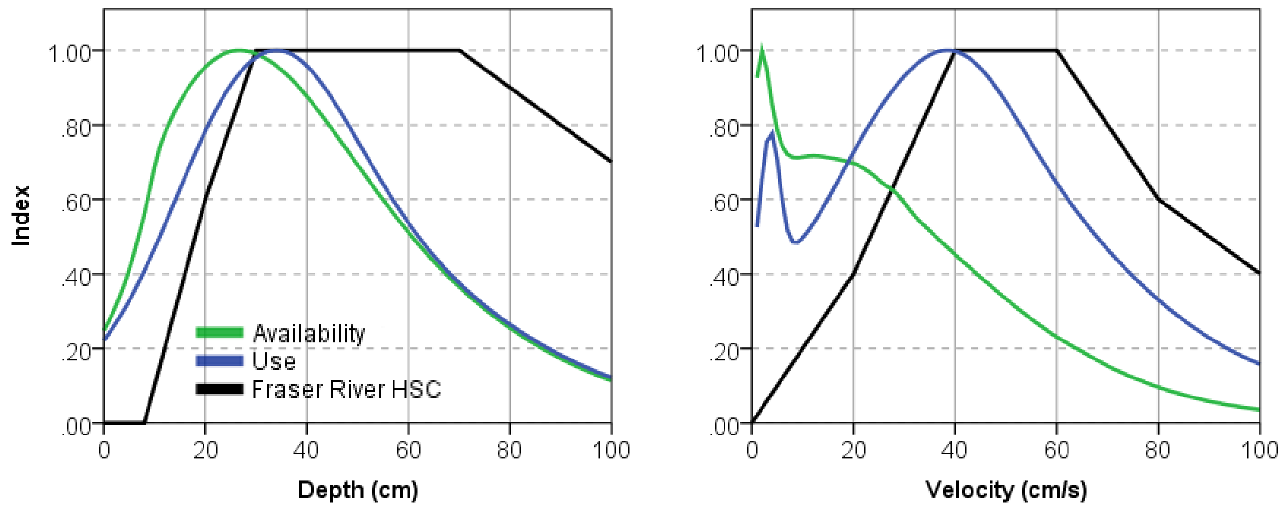
k) Mountain Sucker 0+




l) Mountain Sucker 1+/2+



m) Mountain Sucker 3+



# 10 APPENDIX B

Final habitat suitability criteria for juvenile life stages of fish species in the Fraser River gravel reach.

| Depth / Velocity (cm / cm $s^{-1}$) | Depth: Chinook 0+ Stream-Ocean Type | Velocity: Chinook 0+ Stream-Ocean Type | Depth: Chinook 0+Stream Type | Velocity: Chinook 0+Stream Type | Depth: Chinook 1+ Stream Type | Velocity: Chinook 1+ Stream Type | Depth: Chum 0+ | Velocity: Chum 0+ | Depth: Sockeye 0+ | Velocity: Sockeye 0+ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.80 | 0.00 | 0.60 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 | 1.00 |
| 1 | 0.04 | 0.83 | 0.03 | 0.64 | 0.03 | 0.05 | 0.05 | 1.00 | 0.00 | 1.00 |
| 2 | 0.08 | 0.86 | 0.07 | 0.68 | 0.06 | 0.09 | 0.10 | 1.00 | 0.00 | 1.00 |
| 3 | 0.12 | 0.89 | 0.10 | 0.72 | 0.09 | 0.14 | 0.15 | 1.00 | 0.00 | 1.00 |
| 4 | 0.16 | 0.91 | 0.13 | 0.76 | 0.12 | 0.18 | 0.20 | 1.00 | 0.00 | 1.00 |
| 5 | 0.20 | 0.94 | 0.17 | 0.80 | 0.15 | 0.23 | 0.25 | 1.00 | 0.00 | 1.00 |
| 6 | 0.24 | 0.97 | 0.20 | 0.84 | 0.18 | 0.27 | 0.30 | 1.00 | 0.00 | 1.00 |
| 7 | 0.28 | 1.00 | 0.23 | 0.88 | 0.21 | 0.32 | 0.35 | 1.00 | 0.00 | 1.00 |
| 8 | 0.32 | 1.00 | 0.27 | 0.92 | 0.24 | 0.36 | 0.40 | 1.00 | 0.00 | 1.00 |
| 9 | 0.36 | 1.00 | 0.30 | 0.96 | 0.27 | 0.41 | 0.45 | 1.00 | 0.00 | 1.00 |
| 10 | 0.40 | 1.00 | 0.33 | 1.00 | 0.30 | 0.45 | 0.50 | 1.00 | 0.00 | 1.00 |
| 11 | 0.44 | 1.00 | 0.37 | 1.00 | 0.34 | 0.50 | 0.52 | 1.00 | 0.04 | 0.40 |
| 12 | 0.48 | 1.00 | 0.40 | 1.00 | 0.37 | 0.54 | 0.54 | 1.00 | 0.08 | 0.38 |
| 13 | 0.52 | 1.00 | 0.43 | 1.00 | 0.41 | 0.59 | 0.56 | 1.00 | 0.12 | 0.36 |
| 14 | 0.56 | 1.00 | 0.47 | 1.00 | 0.44 | 0.63 | 0.58 | 1.00 | 0.16 | 0.33 |
| 15 | 0.60 | 1.00 | 0.50 | 1.00 | 0.48 | 0.68 | 0.60 | 1.00 | 0.20 | 0.31 |
| 16 | 0.64 | 1.00 | 0.60 | 1.00 | 0.51 | 0.72 | 0.62 | 0.94 | 0.24 | 0.29 |
| 17 | 0.68 | 1.00 | 0.70 | 1.00 | 0.55 | 0.77 | 0.64 | 0.88 | 0.28 | 0.27 |
| 18 | 0.72 | 1.00 | 0.80 | 1.00 | 0.58 | 0.81 | 0.66 | 0.82 | 0.32 | 0.24 |
| 19 | 0.76 | 1.00 | 0.90 | 1.00 | 0.62 | 0.86 | 0.68 | 0.76 | 0.36 | 0.22 |
| 20 | 0.80 | 1.00 | 1.00 | 1.00 | 0.65 | 0.90 | 0.70 | 0.70 | 0.40 | 0.20 |
| 21 | 0.84 | 1.00 | 1.00 | 1.00 | 0.69 | 0.92 | 0.72 | 0.68 | 0.44 | 0.19 |
| 22 | 0.88 | 1.00 | 1.00 | 1.00 | 0.72 | 0.94 | 0.74 | 0.65 | 0.48 | 0.18 |
| 23 | 0.92 | 1.00 | 1.00 | 1.00 | 0.76 | 0.96 | 0.76 | 0.63 | 0.52 | 0.17 |
| 24 | 0.96 | 1.00 | 1.00 | 1.00 | 0.79 | 0.98 | 0.78 | 0.61 | 0.56 | 0.16 |
| 25 | 1.00 | 1.00 | 1.00 | 1.00 | 0.83 | 1.00 | 0.80 | 0.58 | 0.60 | 0.15 |

| Depth / Velocity (cm / cm s$^{-1}$) | Depth: Chinook 0+ Stream-Ocean Type | Velocity: Chinook 0+ Stream-Ocean Type | Depth: Chinook 0+Stream Type | Velocity: Chinook 0+Stream Type | Depth: Chinook 1+ Stream Type | Velocity: Chinook 1+ Stream Type | Depth: Chum 0+ | Velocity: Chum 0+ | Depth: Sockeye 0+ | Velocity: Sockeye 0+ |
|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 1.00 | 1.00 | 1.00 | 1.00 | 0.86 | 1.00 | 0.81 | 0.56 | 0.64 | 0.14 |
| 27 | 1.00 | 1.00 | 1.00 | 1.00 | 0.90 | 1.00 | 0.83 | 0.54 | 0.68 | 0.13 |
| 28 | 1.00 | 1.00 | 1.00 | 1.00 | 0.93 | 1.00 | 0.84 | 0.51 | 0.72 | 0.12 |
| 29 | 1.00 | 1.00 | 1.00 | 1.00 | 0.97 | 1.00 | 0.85 | 0.49 | 0.76 | 0.11 |
| 30 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.87 | 0.47 | 0.80 | 0.10 |
| 31 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.88 | 0.44 | 0.84 | 0.09 |
| 32 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.89 | 0.42 | 0.88 | 0.08 |
| 33 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.91 | 0.40 | 0.92 | 0.07 |
| 34 | 1.00 | 0.99 | 1.00 | 1.00 | 1.00 | 1.00 | 0.92 | 0.37 | 0.96 | 0.06 |
| 35 | 1.00 | 0.98 | 1.00 | 1.00 | 1.00 | 1.00 | 0.93 | 0.35 | 1.00 | 0.05 |
| 36 | 1.00 | 0.97 | 1.00 | 0.99 | 1.00 | 1.00 | 0.95 | 0.33 | 1.00 | 0.04 |
| 37 | 1.00 | 0.96 | 1.00 | 0.97 | 1.00 | 1.00 | 0.96 | 0.30 | 1.00 | 0.03 |
| 38 | 1.00 | 0.95 | 1.00 | 0.96 | 1.00 | 1.00 | 0.97 | 0.28 | 1.00 | 0.02 |
| 39 | 1.00 | 0.94 | 1.00 | 0.94 | 1.00 | 1.00 | 0.99 | 0.26 | 1.00 | 0.01 |
| 40 | 1.00 | 0.93 | 1.00 | 0.93 | 1.00 | 1.00 | 1.00 | 0.23 | 1.00 | 0.00 |
| 41 | 1.00 | 0.91 | 1.00 | 0.91 | 1.00 | 1.00 | 1.00 | 0.21 | 1.00 | 0.00 |
| 42 | 1.00 | 0.90 | 1.00 | 0.90 | 1.00 | 1.00 | 1.00 | 0.19 | 1.00 | 0.00 |
| 43 | 1.00 | 0.88 | 1.00 | 0.88 | 1.00 | 1.00 | 1.00 | 0.16 | 1.00 | 0.00 |
| 44 | 1.00 | 0.87 | 1.00 | 0.87 | 1.00 | 1.00 | 1.00 | 0.14 | 1.00 | 0.00 |
| 45 | 1.00 | 0.85 | 1.00 | 0.85 | 1.00 | 1.00 | 1.00 | 0.12 | 1.00 | 0.00 |
| 46 | 1.00 | 0.83 | 1.00 | 0.83 | 1.00 | 1.00 | 1.00 | 0.09 | 1.00 | 0.00 |
| 47 | 1.00 | 0.82 | 1.00 | 0.82 | 1.00 | 1.00 | 1.00 | 0.07 | 1.00 | 0.00 |
| 48 | 1.00 | 0.80 | 1.00 | 0.80 | 1.00 | 1.00 | 1.00 | 0.05 | 1.00 | 0.00 |
| 49 | 1.00 | 0.79 | 1.00 | 0.79 | 1.00 | 1.00 | 1.00 | 0.02 | 1.00 | 0.00 |
| 50 | 1.00 | 0.77 | 1.00 | 0.77 | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 0.00 |
| 51 | 1.00 | 0.75 | 0.98 | 0.75 | 1.00 | 0.96 | 1.00 | 0.00 | 1.00 | 0.00 |
| 52 | 1.00 | 0.73 | 0.96 | 0.73 | 1.00 | 0.92 | 1.00 | 0.00 | 1.00 | 0.00 |
| 53 | 1.00 | 0.71 | 0.94 | 0.71 | 1.00 | 0.87 | 1.00 | 0.00 | 1.00 | 0.00 |
| 54 | 1.00 | 0.69 | 0.92 | 0.69 | 1.00 | 0.83 | 1.00 | 0.00 | 1.00 | 0.00 |
| 55 | 1.00 | 0.67 | 0.90 | 0.67 | 1.00 | 0.79 | 1.00 | 0.00 | 1.00 | 0.00 |

| Depth / Velocity (cm / cm s$^{-1}$) | Depth: Chinook 0+ Stream-Ocean Type | Velocity: Chinook 0+ Stream-Ocean Type | Depth: Chinook 0+Stream Type | Velocity: Chinook 0+Stream Type | Depth: Chinook 1+ Stream Type | Velocity: Chinook 1+ Stream Type | Depth: Chum 0+ | Velocity: Chum 0+ | Depth: Sockeye 0+ | Velocity: Sockeye 0+ |
|---|---|---|---|---|---|---|---|---|---|---|
| 56 | 1.00 | 0.66 | 0.88 | 0.66 | 1.00 | 0.75 | 1.00 | 0.00 | 0.99 | 0.00 |
| 57 | 1.00 | 0.64 | 0.86 | 0.64 | 1.00 | 0.71 | 1.00 | 0.00 | 0.97 | 0.00 |
| 58 | 1.00 | 0.62 | 0.84 | 0.62 | 1.00 | 0.66 | 1.00 | 0.00 | 0.96 | 0.00 |
| 59 | 1.00 | 0.60 | 0.82 | 0.60 | 1.00 | 0.62 | 1.00 | 0.00 | 0.95 | 0.00 |
| 60 | 1.00 | 0.58 | 0.80 | 0.58 | 1.00 | 0.58 | 1.00 | 0.00 | 0.93 | 0.00 |
| 61 | 1.00 | 0.56 | 0.78 | 0.56 | 1.00 | 0.56 | 1.00 | 0.00 | 0.92 | 0.00 |
| 62 | 1.00 | 0.54 | 0.76 | 0.54 | 1.00 | 0.54 | 1.00 | 0.00 | 0.91 | 0.00 |
| 63 | 1.00 | 0.52 | 0.74 | 0.52 | 1.00 | 0.52 | 1.00 | 0.00 | 0.89 | 0.00 |
| 64 | 1.00 | 0.50 | 0.72 | 0.50 | 1.00 | 0.50 | 1.00 | 0.00 | 0.88 | 0.00 |
| 65 | 1.00 | 0.48 | 0.70 | 0.48 | 1.00 | 0.48 | 1.00 | 0.00 | 0.87 | 0.00 |
| 66 | 1.00 | 0.47 | 0.68 | 0.47 | 1.00 | 0.47 | 1.00 | 0.00 | 0.85 | 0.00 |
| 67 | 1.00 | 0.45 | 0.66 | 0.45 | 1.00 | 0.45 | 1.00 | 0.00 | 0.84 | 0.00 |
| 68 | 1.00 | 0.43 | 0.64 | 0.43 | 1.00 | 0.43 | 1.00 | 0.00 | 0.83 | 0.00 |
| 69 | 1.00 | 0.41 | 0.62 | 0.41 | 1.00 | 0.41 | 1.00 | 0.00 | 0.81 | 0.00 |
| 70 | 1.00 | 0.39 | 0.60 | 0.39 | 1.00 | 0.39 | 1.00 | 0.00 | 0.80 | 0.00 |
| 71 | 1.00 | 0.38 | 0.59 | 0.38 | 0.97 | 0.38 | 1.00 | 0.00 | 0.79 | 0.00 |
| 72 | 1.00 | 0.36 | 0.58 | 0.36 | 0.94 | 0.36 | 1.00 | 0.00 | 0.78 | 0.00 |
| 73 | 1.00 | 0.35 | 0.57 | 0.35 | 0.91 | 0.35 | 1.00 | 0.00 | 0.77 | 0.00 |
| 74 | 1.00 | 0.33 | 0.56 | 0.33 | 0.88 | 0.33 | 1.00 | 0.00 | 0.76 | 0.00 |
| 75 | 1.00 | 0.32 | 0.55 | 0.32 | 0.85 | 0.32 | 1.00 | 0.00 | 0.75 | 0.00 |
| 76 | 1.00 | 0.31 | 0.54 | 0.31 | 0.82 | 0.31 | 1.00 | 0.00 | 0.74 | 0.00 |
| 77 | 1.00 | 0.29 | 0.53 | 0.29 | 0.79 | 0.29 | 1.00 | 0.00 | 0.73 | 0.00 |
| 78 | 1.00 | 0.28 | 0.52 | 0.28 | 0.76 | 0.28 | 1.00 | 0.00 | 0.72 | 0.00 |
| 79 | 1.00 | 0.26 | 0.51 | 0.26 | 0.73 | 0.26 | 1.00 | 0.00 | 0.71 | 0.00 |
| 80 | 1.00 | 0.25 | 0.50 | 0.25 | 0.70 | 0.25 | 1.00 | 0.00 | 0.70 | 0.00 |
| 81 | 0.96 | 0.24 | 0.49 | 0.24 | 0.70 | 0.24 | 1.00 | 0.00 | 0.69 | 0.00 |
| 82 | 0.92 | 0.23 | 0.48 | 0.23 | 0.69 | 0.23 | 1.00 | 0.00 | 0.68 | 0.00 |
| 83 | 0.88 | 0.22 | 0.47 | 0.22 | 0.69 | 0.22 | 1.00 | 0.00 | 0.67 | 0.00 |
| 84 | 0.84 | 0.21 | 0.46 | 0.21 | 0.68 | 0.21 | 1.00 | 0.00 | 0.66 | 0.00 |
| 85 | 0.80 | 0.20 | 0.45 | 0.20 | 0.68 | 0.20 | 1.00 | 0.00 | 0.65 | 0.00 |

| Depth / Velocity (cm / cm $s^{-1}$) | Depth: Chinook 0+ Stream-Ocean Type | Velocity: Chinook 0+ Stream-Ocean Type | Depth: Chinook 0+Stream Type | Velocity: Chinook 0+Stream Type | Depth: Chinook 1+ Stream Type | Velocity: Chinook 1+ Stream Type | Depth: Chum 0+ | Velocity: Chum 0+ | Depth: Sockeye 0+ | Velocity: Sockeye 0+ |
|---|---|---|---|---|---|---|---|---|---|---|
| 86 | 0.78 | 0.19 | 0.44 | 0.19 | 0.67 | 0.19 | 1.00 | 0.00 | 0.64 | 0.00 |
| 87 | 0.76 | 0.18 | 0.43 | 0.18 | 0.67 | 0.18 | 1.00 | 0.00 | 0.63 | 0.00 |
| 88 | 0.74 | 0.17 | 0.42 | 0.17 | 0.66 | 0.17 | 1.00 | 0.00 | 0.62 | 0.00 |
| 89 | 0.72 | 0.16 | 0.41 | 0.16 | 0.66 | 0.16 | 1.00 | 0.00 | 0.61 | 0.00 |
| 90 | 0.70 | 0.15 | 0.40 | 0.15 | 0.65 | 0.15 | 1.00 | 0.00 | 0.60 | 0.00 |
| 91 | 0.68 | 0.14 | 0.39 | 0.14 | 0.65 | 0.14 | 1.00 | 0.00 | 0.59 | 0.00 |
| 92 | 0.67 | 0.14 | 0.38 | 0.14 | 0.64 | 0.14 | 1.00 | 0.00 | 0.58 | 0.00 |
| 93 | 0.65 | 0.13 | 0.37 | 0.13 | 0.64 | 0.13 | 1.00 | 0.00 | 0.57 | 0.00 |
| 94 | 0.64 | 0.13 | 0.36 | 0.13 | 0.63 | 0.13 | 1.00 | 0.00 | 0.56 | 0.00 |
| 95 | 0.62 | 0.12 | 0.35 | 0.12 | 0.63 | 0.12 | 1.00 | 0.00 | 0.55 | 0.00 |
| 96 | 0.61 | 0.12 | 0.34 | 0.12 | 0.62 | 0.12 | 1.00 | 0.00 | 0.54 | 0.00 |
| 97 | 0.59 | 0.11 | 0.33 | 0.11 | 0.62 | 0.11 | 1.00 | 0.00 | 0.53 | 0.00 |
| 98 | 0.58 | 0.11 | 0.32 | 0.11 | 0.61 | 0.11 | 1.00 | 0.00 | 0.52 | 0.00 |
| 99 | 0.56 | 0.10 | 0.31 | 0.10 | 0.61 | 0.10 | 1.00 | 0.00 | 0.51 | 0.00 |
| 100 | 0.55 | 0.10 | 0.30 | 0.10 | 0.60 | 0.10 | 1.00 | 0.00 | 0.50 | 0.00 |

| Depth / Velocity (cm / cm s$^{-1}$) | Depth: Rainbow Trout 0+ | Velocity: Rainbow Trout 0+ | Depth: Rainbow Trout 1+ | Velocity: Rainbow Trout 1+ | Depth: Mountain Whitefish 0+ | Velocity: Mountain Whitefish 0+ | Depth: Mountain Whitefish 1+ | Velocity: Mountain Whitefish 1+ | Depth: Mountain Whitefish 2+ | Velocity: Mountain Whitefish 2+ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.20 | 0.00 | 0.20 |
| 1 | 0.20 | 0.50 | 0.05 | 0.04 | 0.02 | 0.44 | 0.00 | 0.23 | 0.00 | 0.22 |
| 2 | 0.40 | 0.7 | 0.10 | 0.08 | 0.04 | 0.48 | 0.00 | 0.25 | 0.00 | 0.24 |
| 3 | 0.60 | 0.8 | 0.15 | 0.12 | 0.06 | 0.52 | 0.00 | 0.28 | 0.00 | 0.26 |
| 4 | 0.80 | 0.85 | 0.20 | 0.16 | 0.08 | 0.56 | 0.00 | 0.31 | 0.00 | 0.28 |
| 5 | 1.00 | 0.9 | 0.25 | 0.20 | 0.10 | 0.60 | 0.00 | 0.33 | 0.00 | 0.30 |
| 6 | 1.00 | 0.95 | 0.30 | 0.23 | 0.12 | 0.64 | 0.00 | 0.36 | 0.00 | 0.32 |
| 7 | 1.00 | 1.00 | 0.35 | 0.26 | 0.14 | 0.68 | 0.00 | 0.39 | 0.00 | 0.34 |
| 8 | 1.00 | 1.00 | 0.40 | 0.30 | 0.16 | 0.72 | 0.00 | 0.41 | 0.00 | 0.36 |
| 9 | 1.00 | 1.00 | 0.45 | 0.33 | 0.18 | 0.76 | 0.00 | 0.44 | 0.00 | 0.38 |
| 10 | 1.00 | 1.00 | 0.50 | 0.36 | 0.20 | 0.80 | 0.00 | 0.47 | 0.00 | 0.40 |
| 11 | 1.00 | 1.00 | 0.55 | 0.39 | 0.28 | 0.84 | 0.04 | 0.49 | 0.00 | 0.42 |
| 12 | 1.00 | 1.00 | 0.60 | 0.42 | 0.36 | 0.88 | 0.08 | 0.52 | 0.00 | 0.44 |
| 13 | 1.00 | 1.00 | 0.65 | 0.46 | 0.44 | 0.92 | 0.12 | 0.55 | 0.00 | 0.46 |
| 14 | 1.00 | 1.00 | 0.70 | 0.49 | 0.52 | 0.96 | 0.16 | 0.57 | 0.00 | 0.48 |
| 15 | 1.00 | 1.00 | 0.75 | 0.52 | 0.60 | 1.00 | 0.20 | 0.60 | 0.00 | 0.50 |
| 16 | 1.00 | 1.00 | 0.80 | 0.55 | 0.68 | 1.00 | 0.24 | 0.63 | 0.03 | 0.52 |
| 17 | 1.00 | 1.00 | 0.85 | 0.58 | 0.76 | 1.00 | 0.28 | 0.65 | 0.06 | 0.54 |
| 18 | 1.00 | 1.00 | 0.90 | 0.62 | 0.84 | 1.00 | 0.32 | 0.68 | 0.09 | 0.56 |
| 19 | 1.00 | 1.00 | 0.95 | 0.65 | 0.92 | 1.00 | 0.36 | 0.71 | 0.11 | 0.58 |
| 20 | 1.00 | 1.00 | 1.00 | 0.68 | 1.00 | 1.00 | 0.40 | 0.73 | 0.14 | 0.60 |
| 21 | 1.00 | 0.97 | 1.00 | 0.71 | 1.00 | 1.00 | 0.44 | 0.76 | 0.17 | 0.62 |
| 22 | 1.00 | 0.94 | 1.00 | 0.74 | 1.00 | 1.00 | 0.48 | 0.79 | 0.20 | 0.64 |
| 23 | 1.00 | 0.92 | 1.00 | 0.78 | 1.00 | 1.00 | 0.52 | 0.81 | 0.23 | 0.66 |
| 24 | 1.00 | 0.89 | 1.00 | 0.81 | 1.00 | 1.00 | 0.56 | 0.84 | 0.26 | 0.68 |
| 25 | 1.00 | 0.86 | 1.00 | 0.84 | 1.00 | 1.00 | 0.60 | 0.87 | 0.29 | 0.70 |
| 26 | 0.97 | 0.82 | 1.00 | 0.87 | 1.00 | 1.00 | 0.64 | 0.89 | 0.31 | 0.72 |
| 27 | 0.94 | 0.79 | 1.00 | 0.90 | 1.00 | 1.00 | 0.68 | 0.92 | 0.34 | 0.74 |
| 28 | 0.91 | 0.75 | 1.00 | 0.94 | 1.00 | 1.00 | 0.72 | 0.95 | 0.37 | 0.76 |
| 29 | 0.88 | 0.72 | 1.00 | 0.97 | 1.00 | 1.00 | 0.76 | 0.97 | 0.40 | 0.78 |
| 30 | 0.85 | 0.68 | 1.00 | 1.00 | 1.00 | 1.00 | 0.80 | 1.00 | 0.43 | 0.80 |
| 31 | 0.82 | 0.65 | 1.00 | 1.00 | 1.00 | 1.00 | 0.84 | 1.00 | 0.46 | 0.82 |
| 32 | 0.78 | 0.62 | 1.00 | 1.00 | 1.00 | 1.00 | 0.88 | 1.00 | 0.49 | 0.84 |

| Depth / Velocity (cm / cm $s^{-1}$) | Depth: Rainbow Trout 0+ | Velocity: Rainbow Trout 0+ | Depth: Rainbow Trout 1+ | Velocity: Rainbow Trout 1+ | Depth: Mountain Whitefish 0+ | Velocity: Mountain Whitefish 0+ | Depth: Mountain Whitefish 1+ | Velocity: Mountain Whitefish 1+ | Depth: Mountain Whitefish 2+ | Velocity: Mountain Whitefish 2+ |
|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 0.75 | 0.58 | 1.00 | 1.00 | 1.00 | 1.00 | 0.92 | 1.00 | 0.51 | 0.86 |
| 34 | 0.71 | 0.55 | 1.00 | 1.00 | 1.00 | 1.00 | 0.96 | 1.00 | 0.54 | 0.88 |
| 35 | 0.68 | 0.52 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.57 | 0.90 |
| 36 | 0.65 | 0.49 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.60 | 0.92 |
| 37 | 0.62 | 0.45 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.63 | 0.94 |
| 38 | 0.58 | 0.42 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.66 | 0.96 |
| 39 | 0.55 | 0.38 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.69 | 0.98 |
| 40 | 0.52 | 0.35 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.71 | 1.00 |
| 41 | 0.48 | 0.32 | 1.00 | 1.00 | 0.98 | 1.00 | 1.00 | 1.00 | 0.74 | 1.00 |
| 42 | 0.46 | 0.30 | 1.00 | 1.00 | 0.96 | 1.00 | 1.00 | 1.00 | 0.77 | 1.00 |
| 43 | 0.43 | 0.27 | 1.00 | 1.00 | 0.94 | 1.00 | 1.00 | 1.00 | 0.80 | 1.00 |
| 44 | 0.40 | 0.25 | 1.00 | 1.00 | 0.92 | 1.00 | 1.00 | 1.00 | 0.83 | 1.00 |
| 45 | 0.38 | 0.22 | 1.00 | 1.00 | 0.90 | 1.00 | 1.00 | 1.00 | 0.86 | 1.00 |
| 46 | 0.36 | 0.21 | 1.00 | 1.00 | 0.88 | 1.00 | 1.00 | 1.00 | 0.89 | 1.00 |
| 47 | 0.34 | 0.20 | 1.00 | 1.00 | 0.86 | 1.00 | 1.00 | 1.00 | 0.91 | 1.00 |
| 48 | 0.31 | 0.18 | 1.00 | 1.00 | 0.84 | 1.00 | 1.00 | 1.00 | 0.94 | 1.00 |
| 49 | 0.29 | 0.17 | 1.00 | 1.00 | 0.82 | 1.00 | 1.00 | 1.00 | 0.97 | 1.00 |
| 50 | 0.27 | 0.16 | 1.00 | 1.00 | 0.80 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 51 | 0.25 | 0.15 | 1.00 | 1.00 | 0.78 | 1.00 | 1.00 | 0.99 | 1.00 | 1.00 |
| 52 | 0.23 | 0.14 | 1.00 | 1.00 | 0.76 | 1.00 | 1.00 | 0.97 | 1.00 | 1.00 |
| 53 | 0.22 | 0.13 | 1.00 | 1.00 | 0.74 | 1.00 | 1.00 | 0.96 | 1.00 | 1.00 |
| 54 | 0.20 | 0.12 | 1.00 | 1.00 | 0.72 | 1.00 | 1.00 | 0.94 | 1.00 | 1.00 |
| 55 | 0.18 | 0.11 | 1.00 | 1.00 | 0.70 | 1.00 | 1.00 | 0.93 | 1.00 | 1.00 |
| 56 | 0.17 | 0.10 | 1.00 | 0.99 | 0.68 | 1.00 | 1.00 | 0.91 | 1.00 | 1.00 |
| 57 | 0.16 | 0.09 | 1.00 | 0.97 | 0.66 | 1.00 | 1.00 | 0.90 | 1.00 | 1.00 |
| 58 | 0.15 | 0.08 | 1.00 | 0.96 | 0.64 | 1.00 | 1.00 | 0.88 | 1.00 | 1.00 |
| 59 | 0.14 | 0.07 | 1.00 | 0.94 | 0.62 | 1.00 | 1.00 | 0.87 | 1.00 | 1.00 |
| 60 | 0.13 | 0.06 | 1.00 | 0.93 | 0.60 | 1.00 | 1.00 | 0.85 | 1.00 | 1.00 |
| 61 | 0.12 | 0.05 | 1.00 | 0.91 | 0.58 | 0.96 | 1.00 | 0.84 | 1.00 | 0.99 |
| 62 | 0.12 | 0.05 | 1.00 | 0.90 | 0.56 | 0.93 | 1.00 | 0.82 | 1.00 | 0.97 |
| 63 | 0.11 | 0.04 | 1.00 | 0.88 | 0.54 | 0.89 | 1.00 | 0.80 | 1.00 | 0.96 |
| 64 | 0.11 | 0.04 | 1.00 | 0.87 | 0.52 | 0.86 | 1.00 | 0.79 | 1.00 | 0.95 |
| 65 | 0.10 | 0.02 | 1.00 | 0.85 | 0.50 | 0.82 | 1.00 | 0.77 | 1.00 | 0.93 |
| 66 | 0.10 | 0.02 | 1.00 | 0.83 | 0.48 | 0.79 | 0.99 | 0.76 | 1.00 | 0.92 |

| Depth / Velocity (cm / cm $s^{-1}$) | Depth: Rainbow Trout 0+ | Velocity: Rainbow Trout 0+ | Depth: Rainbow Trout 1+ | Velocity: Rainbow Trout 1+ | Depth: Mountain Whitefish 0+ | Velocity: Mountain Whitefish 0+ | Depth: Mountain Whitefish 1+ | Velocity: Mountain Whitefish 1+ | Depth: Mountain Whitefish 2+ | Velocity: Mountain Whitefish 2+ |
|---|---|---|---|---|---|---|---|---|---|---|
| 67 | 0.10 | 0.02 | 1.00 | 0.81 | 0.46 | 0.75 | 0.97 | 0.74 | 1.00 | 0.91 |
| 68 | 0.10 | 0.01 | 1.00 | 0.80 | 0.44 | 0.72 | 0.96 | 0.73 | 1.00 | 0.89 |
| 69 | 0.10 | 0.01 | 1.00 | 0.78 | 0.42 | 0.68 | 0.95 | 0.71 | 1.00 | 0.88 |
| 70 | 0.10 | 0.00 | 1.00 | 0.76 | 0.40 | 0.65 | 0.93 | 0.70 | 1.00 | 0.87 |
| 71 | 0.10 | 0.00 | 1.00 | 0.74 | 0.39 | 0.61 | 0.92 | 0.69 | 1.00 | 0.85 |
| 72 | 0.10 | 0.00 | 1.00 | 0.73 | 0.38 | 0.58 | 0.91 | 0.67 | 1.00 | 0.84 |
| 73 | 0.10 | 0.00 | 1.00 | 0.71 | 0.38 | 0.54 | 0.89 | 0.66 | 1.00 | 0.83 |
| 74 | 0.10 | 0.00 | 1.00 | 0.70 | 0.37 | 0.51 | 0.88 | 0.65 | 1.00 | 0.81 |
| 75 | 0.10 | 0.00 | 1.00 | 0.68 | 0.36 | 0.47 | 0.87 | 0.63 | 1.00 | 0.80 |
| 76 | 0.10 | 0.00 | 1.00 | 0.66 | 0.35 | 0.44 | 0.85 | 0.62 | 1.00 | 0.79 |
| 77 | 0.10 | 0.00 | 1.00 | 0.64 | 0.34 | 0.40 | 0.84 | 0.61 | 1.00 | 0.77 |
| 78 | 0.10 | 0.00 | 1.00 | 0.63 | 0.34 | 0.37 | 0.83 | 0.59 | 1.00 | 0.76 |
| 79 | 0.10 | 0.00 | 1.00 | 0.61 | 0.33 | 0.33 | 0.81 | 0.58 | 1.00 | 0.75 |
| 80 | 0.10 | 0.00 | 1.00 | 0.59 | 0.32 | 0.30 | 0.80 | 0.57 | 1.00 | 0.73 |
| 81 | 0.10 | 0.00 | 1.00 | 0.57 | 0.31 | 0.30 | 0.79 | 0.55 | 1.00 | 0.72 |
| 82 | 0.10 | 0.00 | 1.00 | 0.55 | 0.30 | 0.29 | 0.78 | 0.54 | 1.00 | 0.71 |
| 83 | 0.10 | 0.00 | 1.00 | 0.54 | 0.30 | 0.29 | 0.77 | 0.53 | 1.00 | 0.69 |
| 84 | 0.10 | 0.00 | 1.00 | 0.52 | 0.29 | 0.28 | 0.76 | 0.51 | 1.00 | 0.68 |
| 85 | 0.10 | 0.00 | 1.00 | 0.50 | 0.28 | 0.28 | 0.75 | 0.50 | 1.00 | 0.67 |
| 86 | 0.10 | 0.00 | 1.00 | 0.48 | 0.27 | 0.27 | 0.74 | 0.49 | 1.00 | 0.65 |
| 87 | 0.10 | 0.00 | 1.00 | 0.47 | 0.26 | 0.27 | 0.73 | 0.47 | 1.00 | 0.64 |
| 88 | 0.10 | 0.00 | 1.00 | 0.45 | 0.26 | 0.26 | 0.72 | 0.46 | 1.00 | 0.63 |
| 89 | 0.10 | 0.00 | 1.00 | 0.44 | 0.25 | 0.26 | 0.71 | 0.45 | 1.00 | 0.61 |
| 90 | 0.10 | 0.00 | 1.00 | 0.42 | 0.24 | 0.25 | 0.70 | 0.43 | 1.00 | 0.60 |
| 91 | 0.10 | 0.00 | 0.98 | 0.41 | 0.23 | 0.25 | 0.69 | 0.42 | 1.00 | 0.60 |
| 92 | 0.10 | 0.00 | 0.96 | 0.39 | 0.22 | 0.24 | 0.68 | 0.41 | 1.00 | 0.59 |
| 93 | 0.10 | 0.00 | 0.94 | 0.38 | 0.22 | 0.24 | 0.67 | 0.39 | 1.00 | 0.59 |
| 94 | 0.10 | 0.00 | 0.92 | 0.36 | 0.21 | 0.23 | 0.66 | 0.38 | 1.00 | 0.58 |
| 95 | 0.10 | 0.00 | 0.90 | 0.35 | 0.20 | 0.23 | 0.65 | 0.37 | 1.00 | 0.58 |
| 96 | 0.10 | 0.00 | 0.88 | 0.34 | 0.20 | 0.22 | 0.64 | 0.35 | 1.00 | 0.57 |
| 97 | 0.10 | 0.00 | 0.86 | 0.32 | 0.19 | 0.22 | 0.63 | 0.34 | 1.00 | 0.57 |
| 98 | 0.10 | 0.00 | 0.84 | 0.31 | 0.19 | 0.21 | 0.62 | 0.33 | 1.00 | 0.56 |
| 99 | 0.10 | 0.00 | 0.82 | 0.29 | 0.18 | 0.21 | 0.61 | 0.31 | 1.00 | 0.56 |
| 100 | 0.10 | 0.00 | 0.80 | 0.28 | 0.18 | 0.20 | 0.60 | 0.30 | 1.00 | 0.55 |

| Depth / Velocity (cm / cm $s^{-1}$) | Depth: Mountain Sucker 0+ | Velocity: Mountain Sucker 0+ | Depth: Mountain Sucker 1/2+ | Velocity: Mountain Sucker 1/2+ | Depth: Mountain Sucker 3+ | Velocity: Mountain Sucker 3+ |
|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.60 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 0.10 | 0.68 | 0.00 | 0.03 | 0.00 | 0.02 |
| 2 | 0.20 | 0.76 | 0.00 | 0.06 | 0.00 | 0.04 |
| 3 | 0.30 | 0.84 | 0.00 | 0.09 | 0.00 | 0.06 |
| 4 | 0.40 | 0.92 | 0.08 | 0.12 | 0.00 | 0.08 |
| 5 | 0.50 | 1.00 | 0.17 | 0.15 | 0.00 | 0.10 |
| 6 | 0.60 | 1.00 | 0.25 | 0.18 | 0.00 | 0.12 |
| 7 | 0.70 | 1.00 | 0.33 | 0.21 | 0.00 | 0.14 |
| 8 | 0.80 | 1.00 | 0.42 | 0.24 | 0.00 | 0.16 |
| 9 | 0.90 | 1.00 | 0.50 | 0.27 | 0.05 | 0.18 |
| 10 | 1.00 | 1.00 | 0.58 | 0.30 | 0.09 | 0.20 |
| 11 | 1.00 | 1.00 | 0.67 | 0.33 | 0.14 | 0.22 |
| 12 | 1.00 | 1.00 | 0.75 | 0.36 | 0.18 | 0.24 |
| 13 | 1.00 | 1.00 | 0.83 | 0.39 | 0.23 | 0.26 |
| 14 | 1.00 | 1.00 | 0.92 | 0.42 | 0.27 | 0.28 |
| 15 | 1.00 | 1.00 | 1.00 | 0.45 | 0.32 | 0.30 |
| 16 | 1.00 | 0.97 | 1.00 | 0.48 | 0.36 | 0.32 |
| 17 | 1.00 | 0.95 | 1.00 | 0.51 | 0.41 | 0.34 |
| 18 | 1.00 | 0.92 | 1.00 | 0.54 | 0.45 | 0.36 |
| 19 | 1.00 | 0.89 | 1.00 | 0.57 | 0.50 | 0.38 |
| 20 | 1.00 | 0.87 | 1.00 | 0.60 | 0.55 | 0.40 |
| 21 | 1.00 | 0.84 | 1.00 | 0.64 | 0.59 | 0.43 |
| 22 | 1.00 | 0.81 | 1.00 | 0.68 | 0.64 | 0.46 |
| 23 | 1.00 | 0.79 | 1.00 | 0.72 | 0.68 | 0.49 |
| 24 | 1.00 | 0.76 | 1.00 | 0.76 | 0.73 | 0.52 |
| 25 | 1.00 | 0.73 | 1.00 | 0.80 | 0.77 | 0.55 |
| 26 | 0.97 | 0.71 | 1.00 | 0.84 | 0.82 | 0.58 |
| 27 | 0.93 | 0.68 | 1.00 | 0.88 | 0.86 | 0.61 |
| 28 | 0.90 | 0.65 | 1.00 | 0.92 | 0.91 | 0.64 |
| 29 | 0.87 | 0.63 | 1.00 | 0.96 | 0.95 | 0.67 |
| 30 | 0.83 | 0.60 | 1.00 | 1.00 | 1.00 | 0.70 |
| 31 | 0.80 | 0.58 | 1.00 | 1.00 | 1.00 | 0.73 |
| 32 | 0.77 | 0.56 | 1.00 | 1.00 | 1.00 | 0.76 |

| Depth / Velocity (cm / cm $s^{-1}$) | Depth: Mountain Sucker 0+ | Velocity: Mountain Sucker 0+ | Depth: Mountain Sucker 1/2+ | Velocity: Mountain Sucker 1/2+ | Depth: Mountain Sucker 3+ | Velocity: Mountain Sucker 3+ |
|---|---|---|---|---|---|---|
| 33 | 0.73 | 0.54 | 1.00 | 1.00 | 1.00 | 0.79 |
| 34 | 0.70 | 0.52 | 1.00 | 1.00 | 1.00 | 0.82 |
| 35 | 0.67 | 0.50 | 1.00 | 1.00 | 1.00 | 0.85 |
| 36 | 0.63 | 0.47 | 1.00 | 1.00 | 1.00 | 0.88 |
| 37 | 0.60 | 0.45 | 1.00 | 1.00 | 1.00 | 0.91 |
| 38 | 0.57 | 0.43 | 1.00 | 1.00 | 1.00 | 0.94 |
| 39 | 0.53 | 0.41 | 1.00 | 1.00 | 1.00 | 0.97 |
| 40 | 0.50 | 0.39 | 1.00 | 1.00 | 1.00 | 1.00 |
| 41 | 0.49 | 0.37 | 0.97 | 1.00 | 1.00 | 1.00 |
| 42 | 0.49 | 0.35 | 0.94 | 1.00 | 1.00 | 1.00 |
| 43 | 0.48 | 0.33 | 0.91 | 1.00 | 1.00 | 1.00 |
| 44 | 0.47 | 0.31 | 0.88 | 1.00 | 1.00 | 1.00 |
| 45 | 0.47 | 0.29 | 0.85 | 1.00 | 1.00 | 1.00 |
| 46 | 0.46 | 0.26 | 0.82 | 1.00 | 1.00 | 1.00 |
| 47 | 0.45 | 0.24 | 0.79 | 1.00 | 1.00 | 1.00 |
| 48 | 0.45 | 0.22 | 0.76 | 1.00 | 1.00 | 1.00 |
| 49 | 0.44 | 0.20 | 0.73 | 1.00 | 1.00 | 1.00 |
| 50 | 0.43 | 0.18 | 0.70 | 1.00 | 1.00 | 1.00 |
| 51 | 0.43 | 0.16 | 0.67 | 0.99 | 1.00 | 1.00 |
| 52 | 0.42 | 0.14 | 0.64 | 0.97 | 1.00 | 1.00 |
| 53 | 0.41 | 0.13 | 0.61 | 0.96 | 1.00 | 1.00 |
| 54 | 0.41 | 0.11 | 0.58 | 0.95 | 1.00 | 1.00 |
| 55 | 0.40 | 0.09 | 0.55 | 0.93 | 1.00 | 1.00 |
| 56 | 0.39 | 0.07 | 0.52 | 0.92 | 1.00 | 1.00 |
| 57 | 0.39 | 0.05 | 0.49 | 0.91 | 1.00 | 1.00 |
| 58 | 0.38 | 0.04 | 0.46 | 0.89 | 1.00 | 1.00 |
| 59 | 0.37 | 0.02 | 0.43 | 0.88 | 1.00 | 1.00 |
| 60 | 0.37 | 0.00 | 0.40 | 0.87 | 1.00 | 1.00 |
| 61 | 0.36 | 0.00 | 0.40 | 0.85 | 1.00 | 1.00 |
| 62 | 0.35 | 0.00 | 0.39 | 0.84 | 1.00 | 1.00 |
| 63 | 0.35 | 0.00 | 0.39 | 0.83 | 1.00 | 1.00 |
| 64 | 0.34 | 0.00 | 0.38 | 0.81 | 1.00 | 1.00 |
| 65 | 0.33 | 0.00 | 0.38 | 0.80 | 1.00 | 1.00 |
| 66 | 0.33 | 0.00 | 0.37 | 0.79 | 1.00 | 1.00 |

| Depth / Velocity (cm / cm $s^{-1}$) | Depth: Mountain Sucker 0+ | Velocity: Mountain Sucker 0+ | Depth: Mountain Sucker 1/2+ | Velocity: Mountain Sucker 1/2+ | Depth: Mountain Sucker 3+ | Velocity: Mountain Sucker 3+ |
|---|---|---|---|---|---|---|
| 67 | 0.32 | 0.00 | 0.37 | 0.77 | 1.00 | 1.00 |
| 68 | 0.31 | 0.00 | 0.36 | 0.76 | 1.00 | 1.00 |
| 69 | 0.31 | 0.00 | 0.36 | 0.75 | 1.00 | 1.00 |
| 70 | 0.30 | 0.00 | 0.35 | 0.73 | 1.00 | 1.00 |
| 71 | 0.30 | 0.00 | 0.35 | 0.72 | 1.00 | 0.99 |
| 72 | 0.29 | 0.00 | 0.34 | 0.71 | 1.00 | 0.99 |
| 73 | 0.29 | 0.00 | 0.34 | 0.69 | 1.00 | 0.98 |
| 74 | 0.29 | 0.00 | 0.33 | 0.68 | 1.00 | 0.97 |
| 75 | 0.28 | 0.00 | 0.33 | 0.67 | 1.00 | 0.97 |
| 76 | 0.28 | 0.00 | 0.32 | 0.65 | 1.00 | 0.96 |
| 77 | 0.28 | 0.00 | 0.32 | 0.64 | 1.00 | 0.95 |
| 78 | 0.27 | 0.00 | 0.31 | 0.63 | 1.00 | 0.95 |
| 79 | 0.27 | 0.00 | 0.31 | 0.61 | 1.00 | 0.94 |
| 80 | 0.27 | 0.00 | 0.30 | 0.60 | 1.00 | 0.93 |
| 81 | 0.26 | 0.00 | 0.30 | 0.59 | 0.99 | 0.93 |
| 82 | 0.26 | 0.00 | 0.29 | 0.58 | 0.98 | 0.92 |
| 83 | 0.26 | 0.00 | 0.29 | 0.57 | 0.97 | 0.91 |
| 84 | 0.25 | 0.00 | 0.28 | 0.56 | 0.96 | 0.91 |
| 85 | 0.25 | 0.00 | 0.28 | 0.55 | 0.95 | 0.90 |
| 86 | 0.25 | 0.00 | 0.27 | 0.54 | 0.94 | 0.89 |
| 87 | 0.24 | 0.00 | 0.27 | 0.53 | 0.93 | 0.89 |
| 88 | 0.24 | 0.00 | 0.26 | 0.52 | 0.92 | 0.88 |
| 89 | 0.24 | 0.00 | 0.26 | 0.51 | 0.91 | 0.87 |
| 90 | 0.23 | 0.00 | 0.25 | 0.50 | 0.90 | 0.87 |
| 91 | 0.23 | 0.00 | 0.25 | 0.49 | 0.89 | 0.86 |
| 92 | 0.23 | 0.00 | 0.24 | 0.48 | 0.88 | 0.85 |
| 93 | 0.22 | 0.00 | 0.24 | 0.47 | 0.87 | 0.85 |
| 94 | 0.22 | 0.00 | 0.23 | 0.46 | 0.86 | 0.84 |
| 95 | 0.22 | 0.00 | 0.23 | 0.45 | 0.85 | 0.83 |
| 96 | 0.21 | 0.00 | 0.22 | 0.44 | 0.84 | 0.83 |
| 97 | 0.21 | 0.00 | 0.22 | 0.43 | 0.83 | 0.82 |
| 98 | 0.21 | 0.00 | 0.21 | 0.42 | 0.82 | 0.81 |
| 99 | 0.20 | 0.00 | 0.21 | 0.41 | 0.81 | 0.81 |
| 100 | 0.20 | 0.00 | 0.20 | 0.40 | 0.80 | 0.80 |