Mapping Floodplain Fish Habitat in the Heart of the Fraser River and Restoration Options for Impacted Attributes on Selected Large Mid-Channel Islands

by

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Abstract

The purpose of this project is to develop an ecological restoration plan for degraded habitats on mid-channel islands in the lower Fraser River. The study focuses on Herrling, Carey, and Strawberry islands, large mid-channel islands located in the gravel reach between Mission and Hope, British Columbia. These islands are known to be critical off-channel rearing habitat for many fish species including the threatened White Sturgeon (*Acipenser transmontanus*) and interior and lower Fraser watershed Chinook Salmon (*Oncorhynchus tshawytscha*) populations. These islands are also home to many riparian plant and animal species. The flood-pulse concept (FPC) states that seasonal fluctuations in water levels for streams such as the Fraser River contribute substantially to the ecological function of the floodplain ecosystem where this phenomenon occurs. This often results in improved growth and survival rates for fish species that rely on a laterally-moving littoral zone of inundation. This phenomenon is thought by many to be the key to a properly functioning ecosystem in the lower Fraser River. Using a Digital Elevation Model (DEM) for the Fraser River between Hope and Mission, British Columbia, freshet flows (high water elevations) are presented to define the spatial extent of over-bank watering of Strawberry, Carey and Herrling islands. This over-bank watering provides lateral connectivity to floodplain islands. Based on extensive sampling in other studies, this lateral movement results in the creation of high-quality juvenile fish rearing habitat. A restoration plan is presented for those areas of Strawberry, Carey and Herrling islands degraded by recent land clearing for agriculture where they overlap sections defined as fish habitat from the spatial analysis.

Keywords: mid-channel islands; floodplain fish habitat; flood pulse concept; juvenile Chinook Salmon; lower Fraser River; White Sturgeon; gravel reach

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Introduction

World-wide, large river floodplains are a threatened-ecosystem habitat (Tockner et al., 2008). For the lower Fraser River, downstream of Hope, British Columbia, to the Salish Sea, it has been estimated that over 90% of floodplain areas have been lost since European settlement which began in the mid-1800's (Figure 1). Practices such as diking, bank armouring, alteration of channel and riparian areas at stream crossings, and draining of associated wetlands, has disconnected the main channel of the Fraser River from much of its floodplain (Levings, 2000). The lower Fraser River ecosystem is dominated by an interior freshet spring-flood pulse which, historically, inundated much of the valley bottom due to the substantial rise in water-surface elevation. The discharges (m^3/s) associated with the flood pulse have been historically at their highest in late May and early June (Figure 2).

The upper Fraser Valley portion of the lower Fraser River located between Hope and Mission, British Columbia, is known locally as the "Heart of the Fraser" and to fluvial geographers as the "gravel reach" (Rosenau and Angelo, 2007; Figure 1). Its floodplain had remained more-or-less stable since the expansion of diking which occurred after the 1948 Fraser River flood (Boyle, 2004). However, with the recent sale of Herrling, Carey, and Strawberry islands which were once part of Tree Farm License (TFL) #43, three of the last six identified remaining large mid-channel island complexes have been cleared, or are partially cleared, of vegetation. It is anticipated that more clearing of these gravel reach islands is proposed for the future and potentially, leveling, ditching, draining, armouring, diking, and bridge construction in conjunction with the development of intensive agriculture.

From a lower Fraser River ecosystem and fisheries sustainability perspective, these changes to the landscape are problematic. Students in the British Columbia Institute of Technology Fish, Wildlife, and Recreation program have, over the last decade, shown these habitats to be extensively used by various fish species including Sockeye *(Oncorhynchus nerka),* Coho *(Oncorhynchus kisutch),* and Chinook Salmon *(Oncorhynchus tshawytscha*) (Frake et al., 2009; Bailey et al., 2010; Morrison et al., 2011; Dubowits et al., 2012, Huard et al., 2013; Aleksich et al., 2014; Born et al., 2015;

Atkinson et al., 2017; Bondartchouk et al., 2018). The development of these islands will remove large areas of critical habitat for some stocks of fish, particularly Chinook Salmon.

To address the impact of clearing of these lower Fraser River islands, adequate inventory and assessment of the habitat characteristics, and an understanding of the function of these features needs to be undertaken. Thus, the goal of this Applied Research Project is to map floodplain rearing habitat at Strawberry, Carey and Herrling islands for fish, show how portions of these habitats have been degraded, define baseline ecological characteristics of the islands, and provide an ecological restoration plan for these degraded areas.

1.1. Mid-channel Islands

The gravel reach of the Fraser River located west of Hope and east of Mission, British Columbia, contains Holocene era post-glacial Salish and Fraser River sediments including sands, gravels and fines (Armstrong, 1981). This reach is dominated by coarse sediment deposition due to a reduction in channel gradient within the laterally moving main and side channels (Church and McLean, 1994). The active gravel layer in this reach is approximately 5 to 15 m deep (Armstrong, 1981) and comprises exceptional habitats for aquatic organisms, particularly spawning Pink Salmon (*Onchorhynchus gorbuscha*) (Rosenau and Angelo, 2007).

Fine sediment within the reach is deposited on the floodplain when overbank flows recede. Vegetated islands in the gravel reach are some of the only floodplain left and, therefore, fine sediment deposition is limited mainly to these sites with most of the rest transferred downstream. Island formation in the gravel reach of the Fraser River and the sediment transfer associated with this process are a key to maintaining both aquatic and riparian habitats (Ham and Church, 2002).

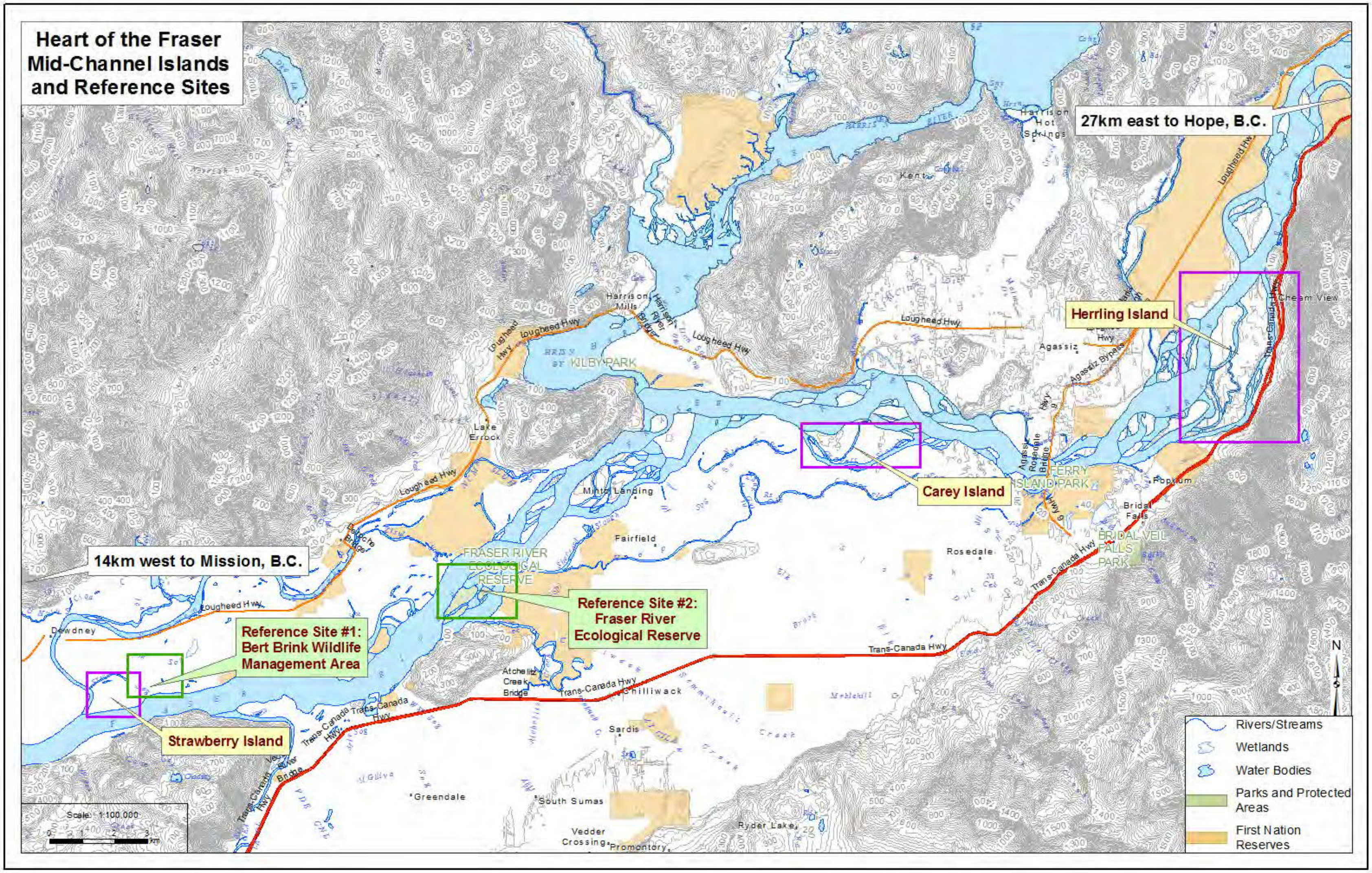

Figure 1. Locations of Strawberry, Carey, and Herrling islands between Hope and Mission, British Columbia. Map: Lori Bartsch January 2019

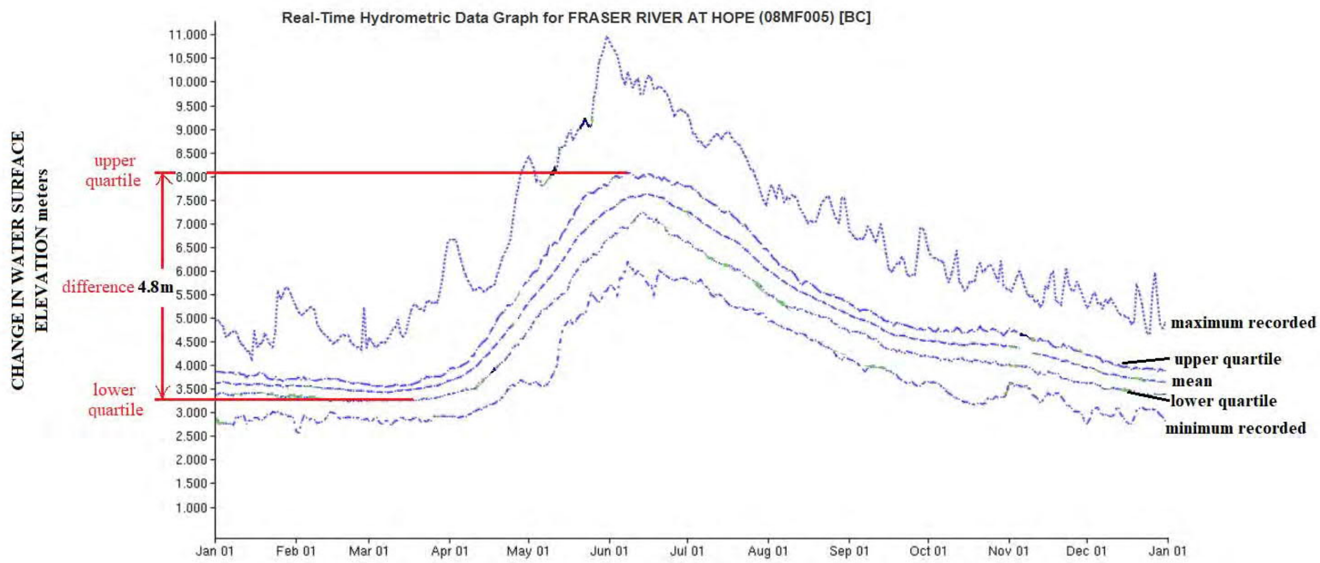

Figure 2. Yearly hydrograph lower Fraser River water-surface elevation changes, including upper and lower quartiles, for flows at Hope, British Columbia over the period of record since 1912 (Rosenau and Angelo, 2007).

Islands within the gravel reach are formed when accumulations of deposited gravel form bars that attain a height that allows for further deposition and accumulation of finer sediment (Figure 3) arising from floodwaters mobilizing them from upstream sources (Hickin, 1984). Over time, when sediment accumulations are sufficient, pioneer-vegetation species such as black cottonwood (*Populus trichocarpa*) and willows (*Salix* spp.) take root further encouraging the trapping of sediments and protecting the bar from erosion, resulting in the continued growth of the island (McLennen, 1993).

Future island formation in the lower Fraser River will likely be limited due to reductions in sediment deposition on bar areas and increases in erosion to existing features as a result of increased flow depths and velocities associated with channelization within the gravel reach. Channelization of the gravel reach is described as flow confinement and the loss of connectivity of the main channel to side channels, back channels, and floodplains as a result of practices such as diking, damming (of the heads of side channels) and bank hardening (Ham and Church, 2002). Confined channels can prolong inundation of mid-channel islands by not having connectivity to other floodplain areas to dissipate floodwaters. In addition, prolonged flooding of newly formed islands can result in a reduction in the establishment of vegetation, loss of seed bank, or conditions that do not favor seed germination (Boniface, 1985). Confined channels in the reach have also resulted in a loss of islands formed by bank avulsion, where-by channel migration into the floodplain isolates a land mass such as how Strawberry Island was formed (Ostercamp, 1996).

Further impeding island formation large woody debris recruitment, known to have an anchoring effect leading to gravel bar formation (Hickin, 1984), has been reduced due to the debris trap near Hope, B.C. The debris trap captures 25,000 to 100,000 m^3 of wood, per annum and prevents it from being mobilized into the gravel reach and to locations further downstream (Thonon, 2006).

Mature islands such as Herrling, Carey, and Strawberry are much more physically and biologically diverse than those that are newly-formed and lack the network of secondary and tertiary channels, dense vegetation, and slightly higher elevations. Compared to younger islands, these older macro-features, specifically mature, dense vegetation communities are associated with reduced overland flow velocities (Tabacchi et al., 2000). Reduced flows result in improved protection and greater food sources (invertebrates and insects) for vegetation growth, fish and other aquatic species. These attributes make mature mid-channel islands diverse and productive habitats, and particularly during freshet (Ham and Church, 2002).

A key aspect of the proper ecological functioning of these islands is the vegetation which can be natural or planted. For Strawberry, Carey and Herrling islands, most of the vegetation has been plantation trees destined for pulp production (Rosenau and Angelo, 2009). The removal of vegetation from these floodplain islands can lead to large-scale changes to their geomorphology and increased erosion rates (Vincent et al., 2009).

Figure 3. Deposited fine sediments and terraces created by erosive forces of receding water levels at Fraser River Ecological Reserve. Photo: Bill and Bev Ramey, 2008.

1.2. Floodplain fish habitat

Mid-channel islands and other un-diked floodplain areas in the lower Fraser River are now known to be important and, for some species and populations, critical off-channel habitat for many fish, and riparian plant and animal species. Much of our understanding of fish use on lower Fraser River floodplains has been undertaken by the British Columbia Institute of Technology Fish, Wildlife and Recreation Program assessments of off-channel habitats at Hope, British Columbia (Frake et al., 2009; Bailey et al., 2010; Morrison et al., 2011; Dubowits et al., 2012, Huard et al., 2013; Aleksich et al., 2014; Born et al., 2015; Atkinson et al., 2017; Bondartchouk et al., 2018). Of interest includes habitats for the threatened White Sturgeon (*Acipenser transmontanus*) and interior Fraser watershed Chinook Salmon populations, two ecologically and anthropogenically important species. Chinook Salmon are a key food item for the Southern Resident Killer Whales (*Orcinus orca*) which reside in the lower Georgia Strait; both Chinook Salmon (some Fraser River populations) and SRKW are at risk (Wasser et al., 2017; COSEWIC, 2019). River-rearing juvenile Sockeye are also thought to extensively use the floodplain areas downstream of the Harrison River during the freshet period and shortly after emergence (Rosenau and Angelo, 2007).

These kinds of habitats are known by fisheries scientists to be extensively used by salmonids, in some instances. For example, Takata et al. (2017) showed that floodplains are highly productive rearing environments for juvenile Chinook Salmon in California's Sacramento-San Joaquin Delta and that increasing duration and frequency of connectivity to these habitats would be beneficial for fish production. Sommer et al. (2001) showed improved growth of juvenile Chinook Salmon using off-channel floodplain habitat in the Sacramento River Valley compared to main channel habitat for rearing. The growth of floodplain-reared Chinook Salmon in the Cosumnes River strongly outperform those who reared in the main channel (Figure 4) (Jeffres et al., 2008). Juvenile fish benefit from the inundation-flows associated with floodplain habitat in a variety of ways. Floodplain vegetation (e.g., cottonwood complexes on these mid-channel islands) and irregular topography (Figure 5), increase the surface area covered by flows and dampen flow velocities. At high water, when flows are at their strongest, these floodplain areas provide refuge for juvenile fish (Winemiller, 2005).

Many other fish species, around the world and including the lower Fraser River, depend on the floodplain and the freshet pulse inundation not only for growth but also for reproduction. For example, Coutant (2004) outlines the importance of inundated vegetated areas for White Sturgeon in the post-hatch free swimming larval stage. This is probably important for White Sturgeon in the lower Fraser River (particularly for Herrling and Carey islands where spawning occurs in the adjacent secondary channels) but has yet to be properly identified for this stream.

Figure 4. Comparison of Cosumnes River, California, juvenile Chinook Salmon reared in intertidal river habitat (left) vs those reared in floodplain vegetation (right), after 54 days (Jeffres et al., 2008).

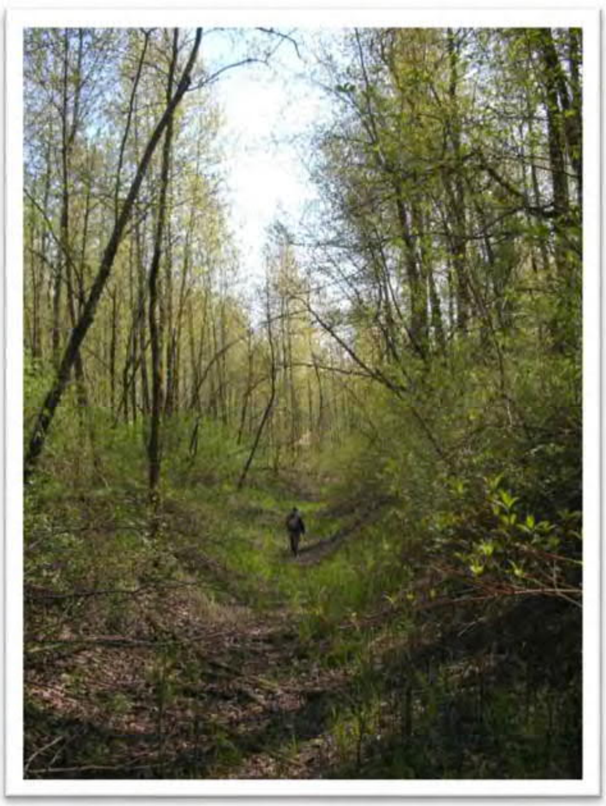

Figure 5. Characteristic mid-channel island tertiary channel that would be inundated during freshet annually and provide a highly productive rearing environment in the lower Fraser River. Located at the Fraser River Ecological Reserve. Photo: Bev Ramey, 2011.

1.2.1. Lower Fraser River Hydrology

The hydrology of the lower Fraser is characterized by precipitation as well as snowmelt from both local and interior headwater areas. Flows at Hope and Mission, British Columbia, peak in spring due to melting snow (Benke and Cushing, 2005). Discharge in the lower Fraser River at Hope, British Columbia has peak flows that are dominated by spring snowmelt (Figures 2, 6). Rapid snowmelt can also be attributed to rain-on-snow events further increasing the rate of discharge in the lower Fraser River (Jeong and Sushama, 2018). The increasing flows of the Fraser River provide the volumes and adequate river depths required by some adult salmon to swim upstream and access their natal watersheds (Brown, 2002). In addition, high flows in large temperate rivers provide fish with access to floodplain habitat and are the driving force behind the flood pulse concept (FPC), a paradigm that describes how ecosystems in streams with large-seasonal flooding events often rely on these regular and predictable inundations (Gorski et al., 2011).

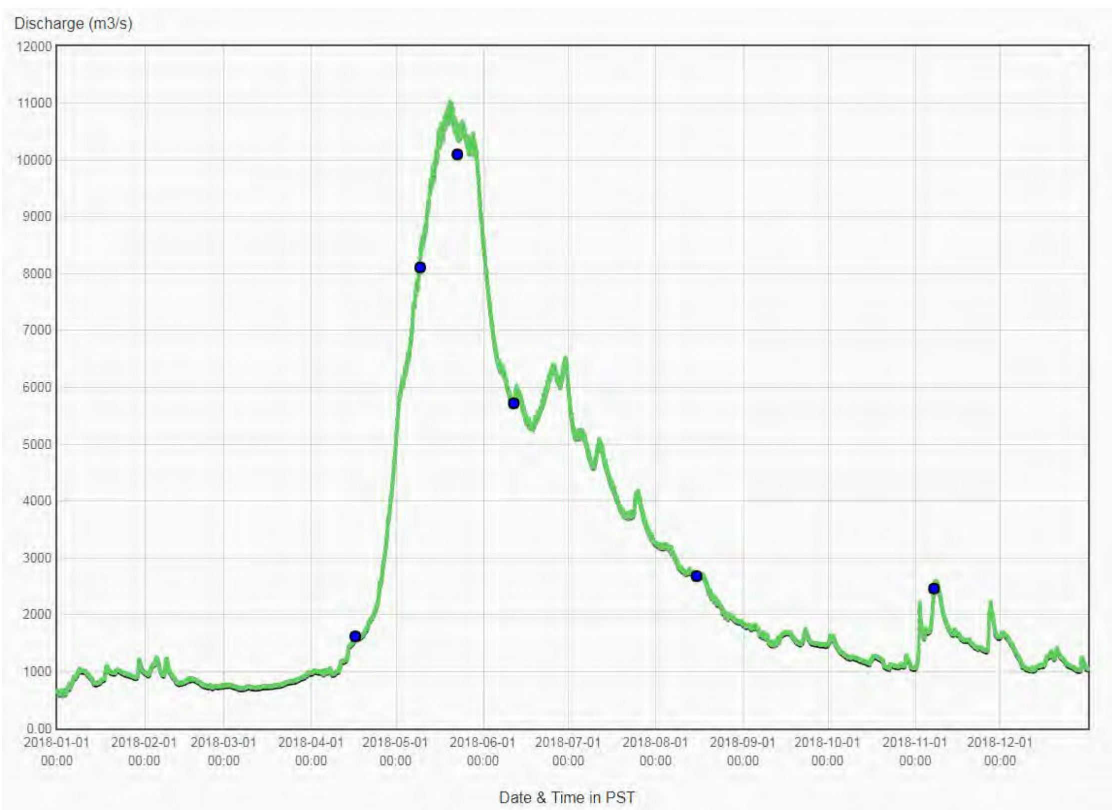

Figure 6. Government of Canada Real-time Hydrometric Data of 2018 Fraser River discharges at Hope, B.C. Note highest water occurs at freshet in late May early June.

1.2.2. The Flood Pulse Concept

The link between the main river channel and off-channel habitat in the lower Fraser River is provided by increased spring flows associated with freshet snowmelt and precipitation (Brown, 2002). This stream behaviour and the accompanying biological response has been described as the flood pulse concept (FPC). The flood-pulse concept (FPC) states that seasonal fluctuations in water levels in large rivers such as the Fraser River contribute to an ecologically functional river-floodplain system and provides improved juvenile growth rates, production, and survival for fish species that rely on the laterally moving littoral zone (Gutreuter et al., 1999; Sommer et al., 2001; Takata et al., 2017). Junk et al. (1989) further elaborate stating that the FPC is “the principal driving force responsible for the existence, productivity, and interactions of the major biota in river-floodplain systems”. Flood pulses (Figure 7) not only provide connectivity of the main river channel to the floodplain but they also redistribute sediment, nutrients, and carbon resulting in enrichment of these ecosystems (*Oncorhynchus tshawytscha*) (Bayley, 1995; Noe, 2013) and transfer of floodplain organic material into the aquatic food web (Sommer et al., 2001; Winemiller, 2004).

In lowland floodplain systems such as the lower Fraser River, this transfer is responsible for primary and secondary production in floodplain habitats, driving the food web associated with this ecosystem. Arscott et al. (2005) outline the importance of off-channel areas to the diversity and structure of macroinvertebrate communities in lowland floodplains. Fraser River mid-channel islands such as Herrling, Carey, and Strawberry are un-diked and still experience the inundations associated with this pulse. As much of the gravel reach has now been disconnected from the mainstem Fraser River to control flooding in outlying areas and protect infrastructure, farms, and communities, it is crucial that these remaining, rare and important connected ecosystem attributes are preserved. For the lower Fraser River, much of the remaining floodplain is comprised of these large island complexes.

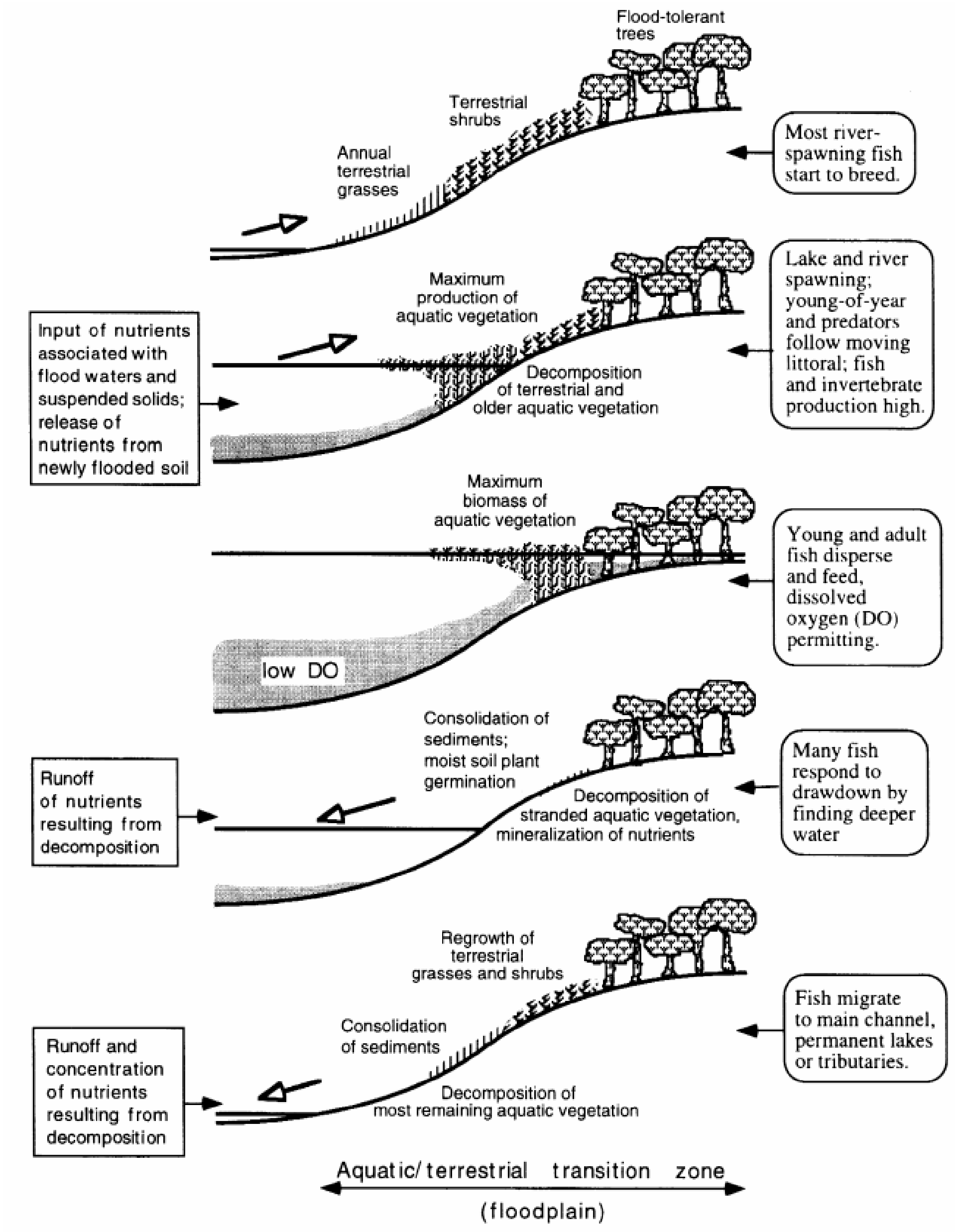

Figure 7. Flood pulse concept explained at aquatic/terrestrial transition zone (Bayley, 1995)

1.3. Channel Habitat

1.3.1. Main, Side, and Tertiary Channels

Although the quality and abundance of overbank floodplain rearing habitat is one key to improving juvenile salmon rearing success, the importance of channels themselves cannot be ignored. The main channel, side channels, and tertiary channels of the lower Fraser River, within the gravel reach, are located adjacent to and, in some cases, intersecting these mid-channel islands. These morphological structures are crucial to many species of fish (Table 1) that inhabit the river to carry out their life stages. This includes spawning, rearing, and migration to-and-from floodplain habitats as well as other rearing environments, including natal streams.

The main channel of the Fraser River gravel reach is characterized by lateral aggradation and deposition within the stream-bed and dominated by sand, gravels, and overbank fines (Ham, 1996). Secondary channels, such as side channels on the lee side of large islands, help regulate flood flows in the main channel and are the interface between the main channel and the floodplain (Ellis et al., 2004). Tertiary channels that cross large islands such as Herrling, Carey, and Strawberry islands have been shown to be very important locations for fish rearing (Rosenau and Angelo, 2007).

Table 1. Fish species that occur in the gravel reach. * = non-native; R=rare; L=at risk (Rosenau and Angelo 2007).

Salmon, trout, char and whitefish	**Minnows (Family Cyprinidae)**
(Families Salmonidae, Coregonidae)	Northern Pikeminnow *Ptychocheilus oregonensis*
Coho salmon *Oncorhynchus kisutch*	Peamouth chub Mylocheilus caurinus
Sockeye salmon *Oncorhynchus nerka*	Leopard dace *Rhinichthys falcatus*
Chinook salmon *Oncorhynchus tshawytscha*	Longnose dace *Rhinichthys cataractae*
Chum salmon *Oncorhynchus keta*	Redside shiner *Richardsonius balteatus*
Pink salmon *Oncorhynchus gorbuscha*	Brassy minnow *Hybognathus hankinsoni L*
Steelhead trout *Oncorhynchus mykiss*	Common carp *Cyprinus carpio**
Cutthroat trout *Oncorhynchus clarkii L*	
Bull char *Salvelinus confluentus L*	
Mountain whitefish *Prosopium williamsoni*	**Suckers (Family Catostomidae)**
Sticklebacks (Family Gasterosteidae)	
Threespine stickleback *Gasterosteus aculeatus*	Mountain sucker *Catostomus platyrhynchus L*
	Largescale sucker *Catostomus macrocheilus*
	Bridgelip sucker *Catostomus columbianus R*
Sculpins (Family Cottidae)	**Sturgeon (Family Acipenseridae)**
Prickly Sculpin *Cottus asper*	White sturgeon *Acipenser transmontanus L*
Coastrange Sculpin *Cottus aleuticus*	Green sturgeon *Acipenser medirostris R L*
Lampreys (Family Petromyzontidae)	**Sunfish (Family Centrarchidae)**
Pacific lamprey *Lampetra tridentatus*	Black crappie *Pomoxis nigromaculatus * R*
River lamprey *Lampetra ayresii*	
Herrings (Family Clupeidae)	**Smelts (Family Osmeridae)**
American shad *Alosa sapidissima **	Eulachon *Thaleichthys pacificus L*
	Longfin smelt *Spirinchus thaleichthys R*
Catfish (Family Ictaluridae)	
Brown bullhead *Ameiurus nebulous **	

1.3.2. Riparian Areas

Another key component of aquatic ecosystems is the edge habitat along the water, known as the riparian area. Riparian habitats are defined as: 1. pertaining to anything connected with or immediately adjacent to the banks of a stream, 2. vegetation growing near a watercourse, lake, or spring, and often dependent on its roots reaching the water table (Bunnell and Dupuis, 1993; Poulin, 1993). Vegetated riparian areas located along the banks of channels have been found to regulate water temperatures, control bank erosion and runoff, as well as provide inputs of woody debris, biomass, macroinvertebrates, including providing habitat for both aquatic (incl. fishes and non-fish organisms) and terrestrial species (Hickin, 1984; Millar, 2000). Vincent (2009) and Millar (2000) outline the potential for erosion in riparian areas and stream banks when the dominant vegetation is removed. Not only is erosion reduced by the integrity of the roots of these vegetation communities that hold onto the soils, but erosion is also controlled by the reduction of shear stress (attenuated flow velocities) associated with the drag on plant biomass, specifically woody stems (Hickin, 1984).

For streams the size of the Heart of the Fraser, riparian areas are much larger than those for small streams yet our scientific knowledge of them is limited (McLennan, 1993). The riparian areas associated with large rivers such as the Fraser River contribute to fish habitat via the changing water levels described in “Flood Pulse Concept” section of this report (1.2.2). Bayley (1995) describes how the floodplain and this pulse are the drivers behind nutrient cycling and increased laterally-moving littoral area which provides highly productive fish habitat and invertebrate production (Figure 7).

The vegetation communities associated with Fraser River riparian areas, which are seasonally inundated and contribute to floodplain fish habitat, are adapted to a range of flows and discharge velocities. Duration of inundation will vary across the islands (dependant on the magnitude of the freshet and the structure of the island and the type of plants on it) and therefore vegetation communities will reflect the tolerance by species to this duration. It is important to note that vegetation species succession will occur as the islands develop. Initially, newly formed islands will be dominated by Black Cottonwood and Willow as well as some pioneer herb and grass species. As the islands mature and the substrate changes from gravel to sands and silts, other plant species begin to grow in the understory of maturing Black Cottonwood forests (Table 2) (Boniface, 1985).

Table 2. Native (dominant) species surveyed at mid-channel islands by vegetation class as islands undergo vegetation succession (adapted from Boniface,1985).

Vegetation Class	*Surveyed Species (native)
1 = Bare alluvium 2 = Young pioneer stand 3 = Intermediate aged pioneer stand	Black cottonwood (*Populus trichocarpa*) Willow (*Salix* sp.) Vasey's rush (*Juncus vaseyi*) Rice cutgrass (*Leersia oryzoides*) Common bentgrass (*Agrostis tenuis*) Canada goldenrod (*Solidago canadensis*) Tansy (*Tancetum vulgare*) Common horsetail (*Equisetum arvense*) Rough horsetail (*Equisetum hymale*) Thistle (*Cirsium* sp.)
4 = Mature cottonwood 5 = Mixed cottonwood cedar 6 = Cedar	Black cottonwood (*Populus trichocarpa*) Willow (*Salix* sp.) Red alder (*Alnus rubra*) Western redcedar (*Thuja plicata*) Western hemlock (*Tsuga heterophylla*) Salmonberry (*Rubus spectabilis*) Red-osier dogwood (*Cornus stolonifera*) Vine maple (*Acer circinatum*) Common horsetail (*Equisetum arvense*) Rough horsetail (*Equisetum hymale*) Canada goldenrod (*Solidago canadensis*)

*Plant diversity was dependent on sediment texture for surveyed vegetation class sites:
gravel (1), sand-gravel (2), sand (3), and silt (4) ranging from lowest (1) to highest (4) plant diversity.

1.4. Fish Species and Life History within the Heart of the Fraser

There are approximately 30 native and introduced fish species known to occur in the gravel reach of the Fraser River (Table 1). I do not intend to diminish the importance of non-salmonid species to this ecosystem; however, this study focusses on salmon and sturgeon due to their diminished numbers, anthropogenic and economic significance, and keystone importance to the ecosystems in which they occur (Lane et al., 1995; Beechie et al., 2006; Rosenau and Angelo, 2007; Fisheries and Oceans Canada, 2012). They also have a significant traditional and subsistence relationship to First Nation communities. Another salmonid species, the Sockeye Salmon, contributes significantly to British Columbia's economy and was reportedly worth $9.2 million (value of the 818,000 sockeye caught) in 2012 (Fisheries and Oceans Canada, 2012). Sockeye Salmon rear in the floodplain of the lower Fraser River downstream of the Harrison River Rapids; a rare form of this species (for the Fraser River) (Atkinson et al., 2017; Freshwater et al., 2018). Other salmonid species that are found using the lower Fraser River include Steelhead Trout (*O. mykiss*) and Cutthroat Trout (*O. clarkii clarkii*). Additionally, White Sturgeon, in the lower Fraser River is the basis of a catch and release fishery that accounts for an additional $9 million in revenue, on average, annually (Fisheries and Oceans Canada, 2012).

Non-game/commercial native species of ecological interest found in the gravel reach of the lower Fraser River comprise members of the taxonomic groups including suckers (Catostomidae), minnows (Cyprinidae), and sculpins (Cottidae). These fishes rely on both main and off-channel habitats including those provided by vegetated mid-channel islands during freshet. The life-history of these species includes many uses of the habitats on or around these large islands including for spawning, rearing, and foraging (Table 3). They also are assumed to be a food source for some of the salmons and White Sturgeon that also inhabit this reach (Table 3) (Frake et al., 2009; Bayley et al., 2010; Morrison et al., 2011; Dubowits et al., 2012, Huard et al., 2013; Aleksich et al., 2014; Born et al., 2015; Atkinson et al., 2017; Bondartchouk et al., 2018).

White Sturgeon, all Pacific salmon, and many other species of fish rely on the unique habitat provided by the gravel reach in the Heart of the lower Fraser River. Fish have evolved to use habitats temporally and spatially to avoid competition among species but also to take advantage of the timing of flows, temperatures, and connectivity needed to carry out their life processes. All species of Pacific salmon are known to migrate through the gravel reach of the Fraser River; adults migrate upstream to their natal spawning grounds and juveniles migrate downstream to the ocean. Pink salmon (*Oncorhynchus gorbuscha*) spawn in the main channel of the reach between Agassiz and Sumas River in mid-September of odd numbered years and are populations are estimated to have reached over 10 million fish in recent years (Fisheries and Oceans Canada, 2012). Chum salmon (*Oncorhynchus keta*) and coastal cutthroat trout spawn in side channels in the gravel reach (Holtby and Ciruna, 2007). White sturgeon spawn in both the main and side channels and are known to forage on salmon carcasses and eggs within in the gravel reach (Perrin et al., 2003; Rosenau and Angelo, 2007; COSEWIC, 2013)

Juvenile Pink Salmon, Steelhead Trout, and Cutthroat Trout are not known to rear in the gravel reach after emergence, but they do migrate through the reach as juveniles. Chum Salmon, some populations of Sockeye Salmon, Coho Salmon, and Chinook Salmon all rear in off-channel sites including ephemeral floodplain habitat within the gravel reach (Rosenau and Angelo, 2007; Frake et al., 2009; Bayley et al., 2010; Morrison et al., 2011; Dubowits et al., 2012, Huard et al., 2013; Aleksich et al., 2014; Born et al., 2015; Atkinson et al., 2017; Bondartchouk et al., 2018). Juvenile White Sturgeon move from the main stem of the heart of the Fraser to more productive side channels during freshet when increased flows allow for connectivity to these sites (Lane et al., 1995; COSEWIC, 2013).

Table 3. Spawning, migration and juvenile residency of some selected fish species found in the gravel reach of the lower Fraser River.

Species	Spawning/adult migration	Juvenile life history
Pink salmon (*Oncorhynchus gorbuscha*)[1]	Main channel between Agassiz and Sumas River Mid-September of odd numbered years.	Migrate out to sea immediately.
Chum salmon (*Oncorhynchus keta*)[1,2]	Fall/winter spawning and incubate in side channels during periods not connected by surface flow to main channel (ground water fed).	Chum fry stay in the gravel reach for up to several weeks in the spring before migrating to sea.
Sockeye salmon (*Oncorhynchus nerka*)[1]	Don't spawn in gravel reach but migrate through the reach to get to spawning areas.	Harrison River Rapids and other populations use the gravel reach for rearing before migration to sea.
Chinook salmon (*Oncorhynchus tshawytscha*)[1,2]	Don't spawn in gravel reach but adults migrate through the reach to get to spawning habitats	Emerge April and May and migrate to/through the gravel reach. Gravel reach "stream type" Chinook rear in freshwater (for approx. 90 days) before migration to sea. Ocean type migrate directly out to sea.
Steelhead (*Oncorhynchus mykiss*)[1,2]	Don’t spawn in gravel reach but migrate and stage through/in the reach to get to spawning habitats.	Juveniles migrate through this reach out to sea
Coastal cutthroat trout (*Oncorhynchus clarkii clarkii*)[1,2]	Sub- adults and adults forage in the reach outside of freshet and adults spawn in side channels.	Little evidence of juvenile rearing in the reach.
White sturgeon (*Acipenser transmontanus*)[1,3]	Spawn in main and side channels	Juveniles move from less productive main stem to rear in large slow-moving side channels during freshet such as the Nicomen and Hatzic sloughs. Free swimming and feeding larval sturgeon may rear in vegetation along and on top of large islands.
Suckers (Catostomidae), minnows (Cyprinidae), sculpins (Cottidae)[1]	Spawn and forage in off-channel habitat including side channels and floodplain during freshet	Juvenile rearing and act as prey/forage for larger fish (Sturgeon, some salmon…)

1) Rosenau and Angelo, 2007
2) Frake et al., 2009; Bayley et al., 2010; Morrison et al., 2011; Dubowits et al., 2012, Huard et al., 2013; Aleksich et al., 2014; Born et al., 2015; Atkinson et al., 2017; Bondartchouk et al., 2018
3) Lane et al., 1995; Coutant, 2004; COSEWIC, 2012

1.5. Other Aquatic Species

Within the Heart of the Fraser the overbank and stream-channel habitats are home to a diverse array of aquatic, riparian and terrestrial organisms that comprise non-fish species. In this ecosystem there are a significant number of species which are at risk including Oregon Spotted Frog (*Rana pretiosa*), Pacific Water Shrew (*Sorex* *bendirii*), and Coastal Giant Salamander (*Dicamptodon tenebrosus*) (B.C. Conservation Data Centre, 2019). Although not located directly in the lower Fraser River main channel, these species occur in adjacent aquatic habitats (Figure 11). Some habitats for these species at risk are only ephemerally connected as a function of the freshet flood pulse. Still others have been completely disconnected from the Fraser River due to diking. Finally, some of these habitats include upland streams that lead to the Heart of the Fraser (Farr, 2007; Environment Canada, 2014; Environment and Climate Change Canada, 2017). In addition, although not an inhabitant of the lower Fraser River, the critically endangered southern resident killer whale (SKRW) population (*Orcinus orca*) relies on the Chinook Salmon and Chum Salmon that, in turn, rely on the Heart of the Fraser for the habitat they require to be successful (Fisheries and Oceans Canada, 2017). Ford et al. (2009) showed a direct correlation between Chinook Salmon abundance and the success of SRKW.

Aquatic vertebrates such as beavers (*Castor canadensis*), muskrats (*Ondatra zibethicus*), harbour seals (*Phoca vitulina richardsi*), and river otters (*Lontra canadensis*) also inhabit the gravel reach of the lower Fraser River. They rely on the diverse food sources, including fish populations and vegetation that occurs in the Heart of the Fraser. Recent research has found that beaver activity can provide conditions favorable to salmon, therefore, can be a helpful tool for maintaining and restoring salmon habitat (Pollock et al., 2012). Confirmation of the occurrence of beavers on mid-channel islands in the lower Fraser River was noted by Liner et al. (1983).

1.6. Terrestrial Vertebrate Species and Birds

The Heart of the Fraser, and specifically mid-channel islands, are home to terrestrial mammals including Deer Mice (*Peromyscus maniculatus*), Coyotes (*Canis latrans*), Black Bears (*Ursus americanus*), and Black-tailed Deer (*Odocoileus hemionus*). Riparian forests associated with these mid-channel islands are also home to Western Toads (*Anaxyrus boreas*), Pacific Chorus Frogs (*Pseudacris regilla*), and Garter Snakes (*Thamnophis elegans*). Seasonally when Fraser River low flows allow for land bridges and passage across side channels, Bobcats (*Lynx rufus*), and Red Fox (*Vulpes vulpes*) are known to temporarily inhabit the islands (Farr, 2007; Pojar et al., 1991).

Bald Eagles (*Haliaeetus leucocephalus)* and Red-tailed Hawks (*Buteo jamaicensis*) take advantage of large cottonwood trees associated with mid-channel islands for nesting adjacent to gravel bars where they feed and loaf (Farr, 2007; BC Parks, 2012; MFLNRO, 2019). Blue Heron (*Ardea herodias*) have been known to frequent seasonally inundated mid-channel island water features used by salmon fry at the Fraser River Ecological Reserve (FRER), a mid-channel island in the gravel reach with similar attributes to the islands in this study (and one of the reference sites for this project). The FRER warden report lists several additional bird species that frequent this ecological reserve including Glaucous-Winged Gulls (*Larus glaucescens*), Thayer's Gulls (*Larus glaucoides thayeri*), Violet-Green Swallows (*Tachycineta thalassina*), Mallards (*Anas platyrhynchos*), Lesser Yellowlegs (*Tringa flavipes*), and Yellow-rumped Warblers (*Setophaga coronate*). Over 60 species of bird have been seen at the FRER or a have been visible from that location (Farr, 2007).

Figure 8. Fraser River Ecological Reserve (mid-channel island reference site) surveyed species (clockwise from top left) Pacific Chorus Frog (Pseudacris regilla), Lesser Yellowlegs (Tringa flavipes), Black Bear (Ursus americanus) tracks, and Western Toad (Anaxyrus boreas); exact location at the FRER unknown Photos: B. Ramey, 2011 from tour of reserve.

Chapter 2. Ecological Restoration Plan

2.1. Developing a plan

In order to develop an ecological restoration plan for impacted floodplain salmon rearing habitat at Herrling, Carey, and Strawberry islands, the spatial extent of this habitat was defined. Herrling, Carey and Strawberry islands, as described in the introduction of this study, are geologically-mature fluvial complexes located in the mid-channel of the lower Fraser River between Hope and Mission, British Columbia. These islands are not diked; therefore, they are part of the floodplain in the gravel reach of the Fraser River and are seasonally inundated. This seasonal inundation provides access for many fish species to off-channel habitat including secondary and tertiary channels as well as at lower lying portions of the island tops.

As part of Tree Farm Licence (TFL) #43, Herrling, Carey, and Strawberry islands were long managed by Kruger Forest Products Ltd. as cottonwood plantations for the production of paper products. Kruger retired the Fraser River portion of the TFL and sold the private land parcels in 2016 (Province of British Columbia, 2016). The islands are part of the Agricultural Land Reserve (ALR) and new owners have cleared large areas of cottonwood forest to prepare the land for crops.

Understanding the importance of cottonwood complexes (Chapter 1), areas that were cleared of vegetation to prepare Herrling, Carey, and Strawberry islands for intensive agriculture (degraded sites) are defined where they overlap mapped floodplain fish habitat. These degraded floodplain fish habitat areas are classified using the Biogeoclimatic Ecosystem Classification System (BEC) (Pojar et al., 1991; McLennan, 1993; Green and Klinka, 1994) in order to clearly define the potential for natural regeneration of these sites or the appropriate species mix for floodplain restoration planting. Reference sites are presented to confirm BEC classification at Herrling, Carey and Strawberry islands as these private lands were not accessible for field assessment. The key to successful restoration of the degraded fish floodplain habitat at these mid-channel islands will be to first carry out pre-restoration site assessments on each island when access is permitted. This will confirm site condition, specifically details about the amount and location of invasive plants and regeneration of native vegetation. The condition of the landscape to define the extent of degraded sites was determined from photographs. This was easily defined from satellite and drone imagery, particularly where the vegetation was completely removed, and soils tilled and cultivated.

2.2. Study Area

2.2.1. Drone Imagery

As Herrling, Carey, and Strawberry islands are privately owned I was not able to physically access the degraded sites for this study. To provide insight into the condition and extent of damage due to land clearing at the islands, drones were used to take pictures and record video during freshet in late May 2018. UAviation Aerial Solutions Ltd. was hired to capture drone imagery of Strawberry Island on May 18, 2018. The drone was launched from public land at the Dewdney Boat launch to the west of Strawberry Island on the west side of Nicomen Slough (Figure 21). UAviation Aerial Solutions Ltd. was also hired to capture imagery of Herrling and Carey islands on May 24, 2018. Drones were launched from the deck of a river fishing boat anchored adjacent to the islands. The boat was supplied by Dean Werk from Great River Fishing Adventures.

2.2.2. Herrling Island

Herrling Island is located approximately 27 km south of Hope along Highway 1 (Hwy 1/Trans-Canada Highway) (Figures 1, 9). Parcels owned by Kruger Forest Products Ltd. on Herrling Island were sold to private interests and most or all of this property is located within the Agricultural Land Reserve (ALR). There is no year-round road access to Herrling Island since freshet flooding makes the side channel impossible to cross over with a vehicle (Figure 9). Because there are no bridges, vehicles currently cross the side-channel over White Sturgeon and salmon spawning gravels when the channel is dry or during very low water. Roads used to access these side-channel crossings are accessible via Herrling Island Road which is at Exit 146 on Hwy 1 (Figure 10). Herrling Island has a network of Forest Tenure roads that were built and used by Kruger to access timber (Figure 9). It appears that several of these roads are being used by the new owners to access areas to clear land for farming. The harvesting of approximately 192 ha of regenerating cottonwood dominated plantations occurred between 2016 and 2017 after the sale to agricultural interests.

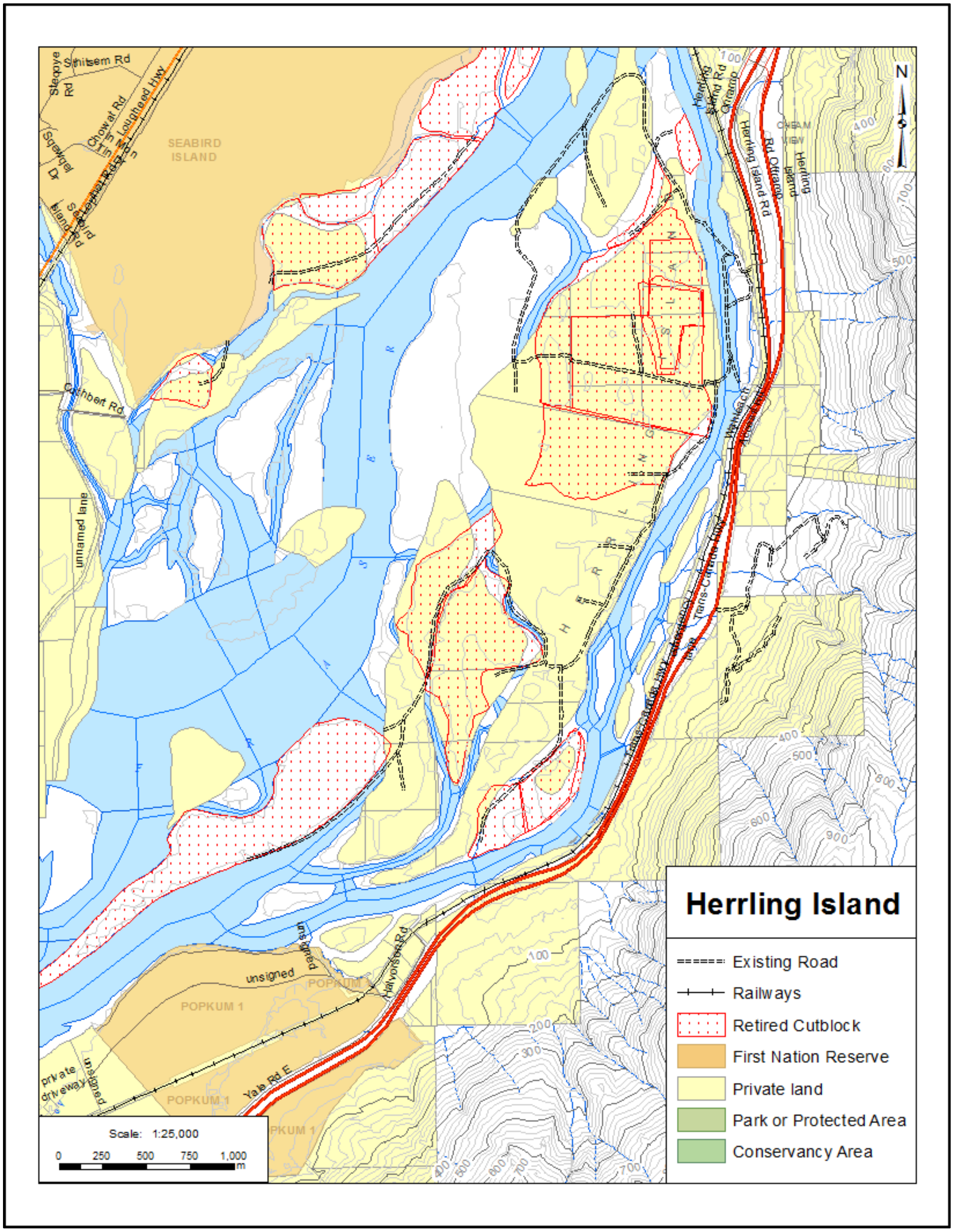

Figure 9. Map of Herrling Island showing private land and previously harvested cutblocks (Map by: L. Bartsch, 2019 using publicly available data from DataBC). Refer to Figure 1 for location in the lower mainland of British Columbia.

Figure 10. Google Satellite Imagery (accessed February 12, 2019) of Herrling Island from August 2016, on the left, and one year later in August 2017, on the right. Using Quantum GIS (QGIS), the cleared portion was digitized to produce a polygon for which the surface area (in acres) was calculated. Approximately 192 ha of cottonwood plantations were harvested.

Several species at risk occur in the vicinity of Herrling Island including occurrences for Mountain Sucker (*Catostomus platyrhynchus*), Green Heron (*Butorides virescens*), Oregon Forestsnail *(Allogona townsendiana)*, Oregon Spotted Frog, Salish Sucker (*Catostomus* sp.), and White Sturgeon (Figure 11). White Sturgeon are known to spawn in the large back channel of this island (Perrin et al. 2003; Rosenau and Angelo, 2007; COSEWIC, 2012). This map only contains known species at risk occurrences reported and included in the BC government database but does not include the more-recently listed species at risk including juveniles of some stocks of Chinook Salmon likely to rear at Herrling Island. Since all species of salmon found in the lower Fraser River use this reach of the river, at one point or another in their life history, and several of these stocks are now at risk, this map will change significantly when the species-at-risk database for which this figure is based on is updated.

Finally, not all fish species in-and-around Herrling Island are either at-risk, or salmonids, or White Sturgeon. The British Columbia government has mapped occurrences of fish in the vicinity of Herrling Island (BC Gov. Habitat Wizard, 2019) (Figure 12) although many more species occur within the Heart of the Fraser (Rosenau and Angelo 2007).

There are several cross-island channels (Figure 10, 11) at Herrling island that constitute off-channel habitat (including flooded island surfaces) during freshet and high-water flows in this reach. The use of off-channel habitats by White Sturgeon, Chinook and other salmon in the lower Fraser River as described in Chapter 1 tells us that these off-channel habitats at Herrling are highly likely to be used as well.

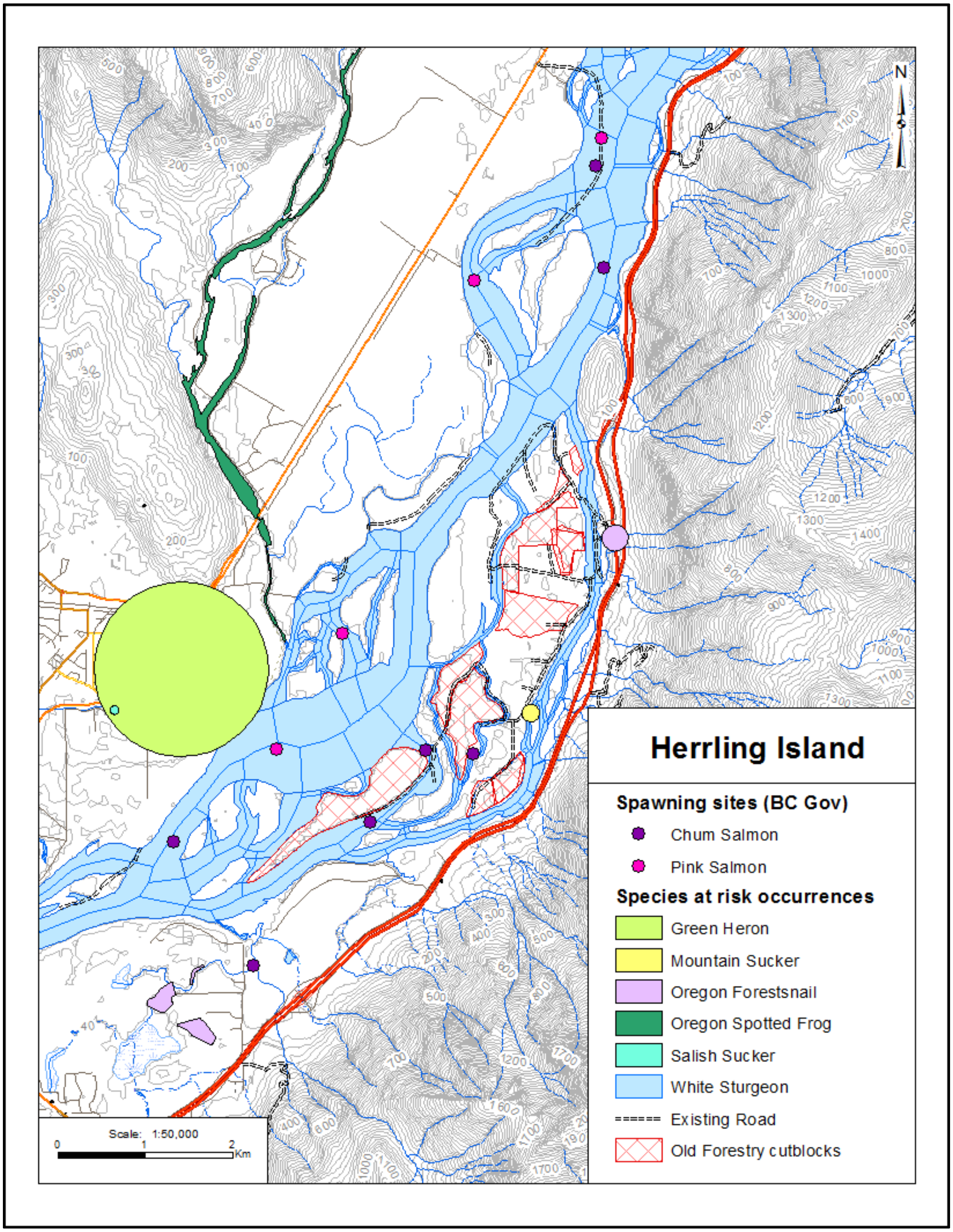

Figure 11. Species at risk occurrences of fish and wildlife and known spawning sites at Herrling Island (Map by: L. Bartsch, 2019 using publicly available data from DataBC).

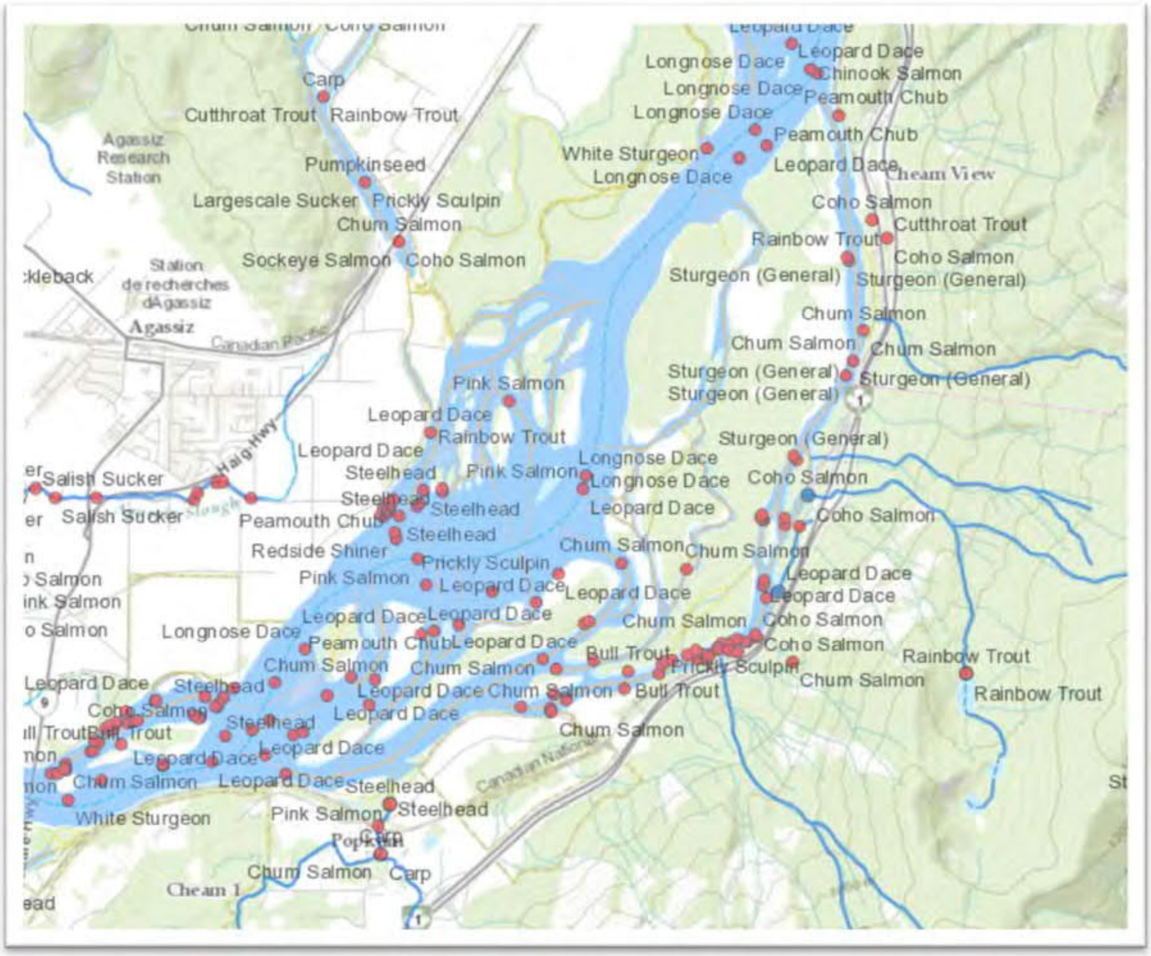

Figure 12. Habitat Wizard map of all fish occurrences in the vicinity of Herrling Island, including both species-at-risk and those not warranted listing (Government of BC Habitat Wizard, 2019).

2.2.3. Carey Island

Carey Island is located 30 km to the southwest of Herrling Island along Highway 1 and 9 km west of Herrling island as the crow flies. Most or all of the private land parcels on Carey Island are located in the ALR. Like Herrling Island, Carey is not accessible by road year-round due inundation of its main secondary channel at freshet and other periods of high water. The island is accessed by crossing Greyell Slough to the south and west at low water via Jespersen and Carey Roads (Figure 13). The parcels were sold by Kruger Forest Products Ltd. to the current owners who have cleared approximately 65 hectares of cottonwood dominated forest, apparently for agricultural purposes (Figure 14).

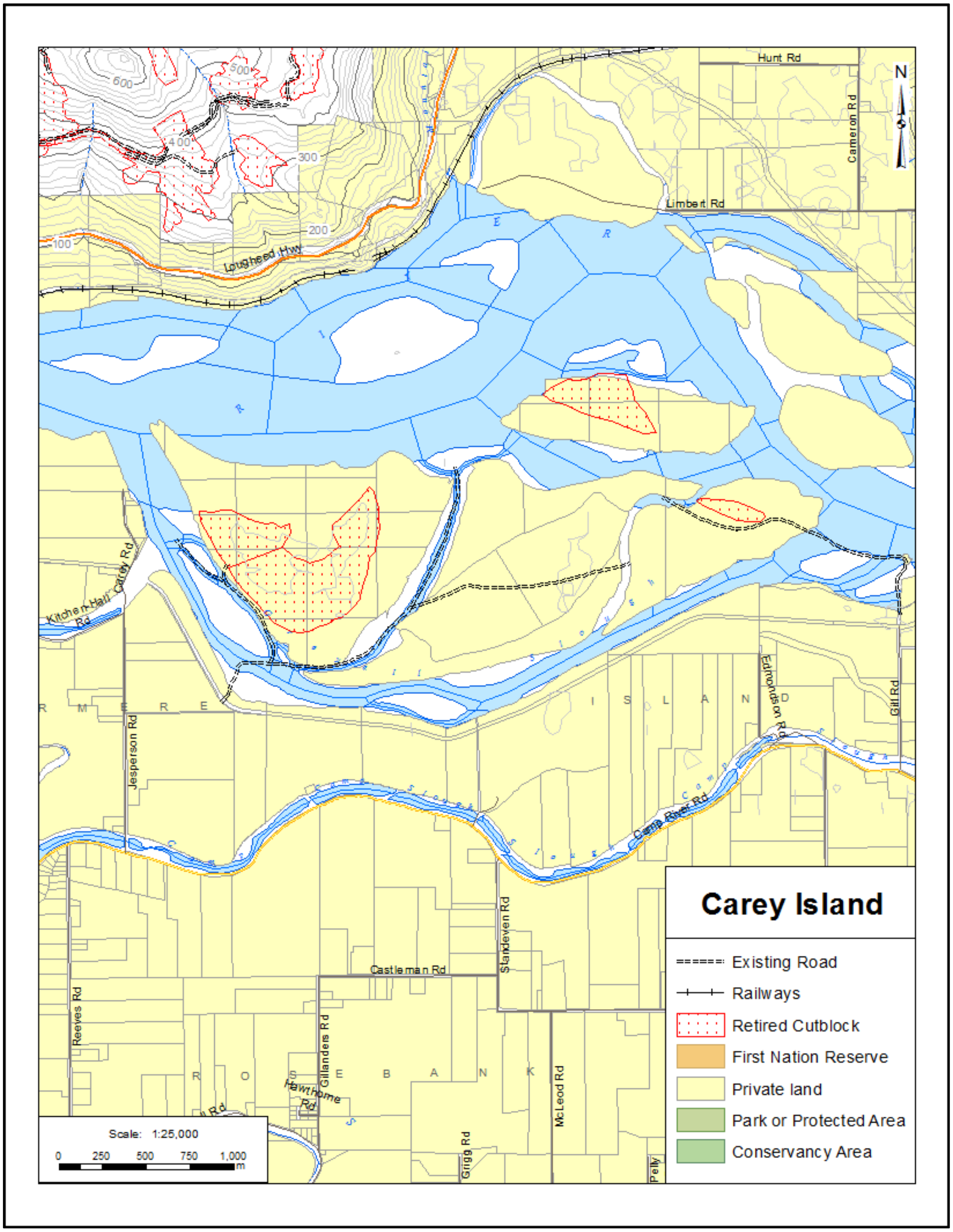

Figure 13. Map of Carey Island showing private land and previously harvested pulpwood forestry cutblocks (Map by: L. Bartsch, 2019 using publicly available data from DataBC).

Figure 14. Google Satellite Imagery (accessed February 12, 2019) of Carey Island from August 2016, on the left, and one year later, in August 2017, on the right. Using Quantum GIS (QGIS), the cleared portion was digitized to produce a polygon for which the surface area (in acres) was calculated. Approximately 65 ha of cottonwood plantations were harvested.

Like Herrling Island, the waters around Carey Island are defined as White Sturgeon habitat and the main secondary channel has been shown to be a location of White Sturgeon spawning (Perrin et al. 2003). Mapping using Habitat Wizard (BC Government, 2019) shows reported and mapped occurrences of various fish species in the vicinity of the island (Figure 15). It is important to note that this figure shows only those fish sightings reported and mapped by the agencies and others; the potential list of species that occur within this area is likely much more exhaustive than those shown on this image (Rosenau and Angelo, 2007).

Figure 15. Habitat Wizard map of all fish occurrences in the vicinity of Carey Island, including both species-at-risk and those not warranted listing (Government of BC Habitat Wizard, 2019).

2.2.4. Strawberry Island

Strawberry Island (Figure 16) is located 14 km east of Mission, British Columbia, along the north side of the Fraser River. There is a private road used to access Strawberry Island from Highway 7 (Lougheed Highway) via Nicomen Island Trunk Road and Thompson Road. The access road from Nicomen Island to Strawberry Island floods during freshet and periods of heavy rain. Strawberry Slough, the northerly-located island-forming channel is connected to the Fraser River by Nicomen Slough to the west. The private land portion of Strawberry Island was sold by Kruger to agricultural interests. Most of the remainder of the island is part of the Bert Brink Wildlife Management Area (WMA).

The portion of Strawberry Island located within this WMA was used as a reference site for this study. The private parcel, approximately 95 hectares of cottonwood plantations was harvested between September 2015 and July 2016 (Figure 17). Drone imagery of the site from late May 2018 during freshet shows much of the island inundated and several piles of debris (not log booms along the edge, within the low-water riparian zone) remaining after harvest (Figure 18).

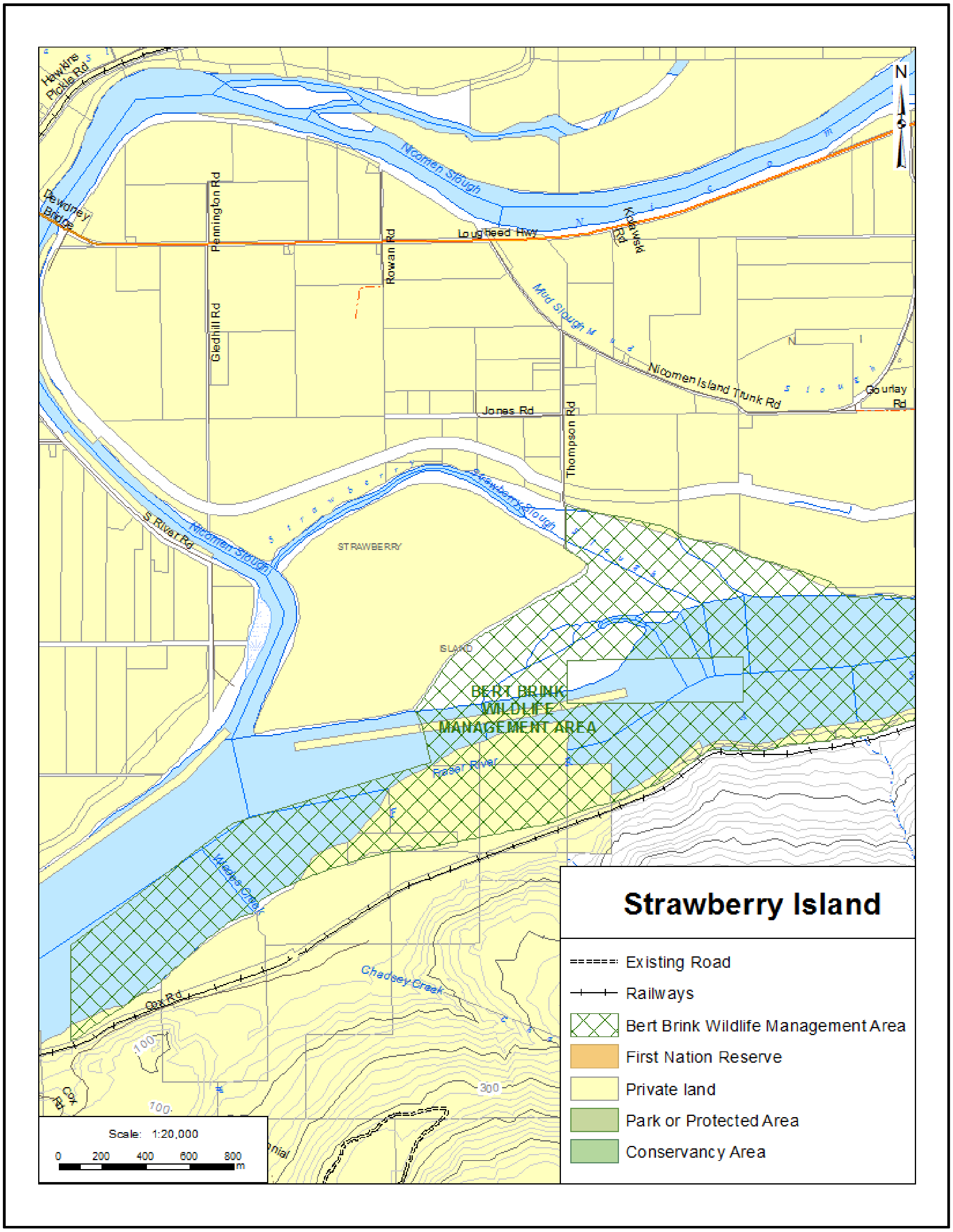

Figure 16. Map of Strawberry Island showing private land and portion covered by Bert Brink Wildlife Management Area (Map by: L. Bartsch, 2019 using publicly available data from DataBC).

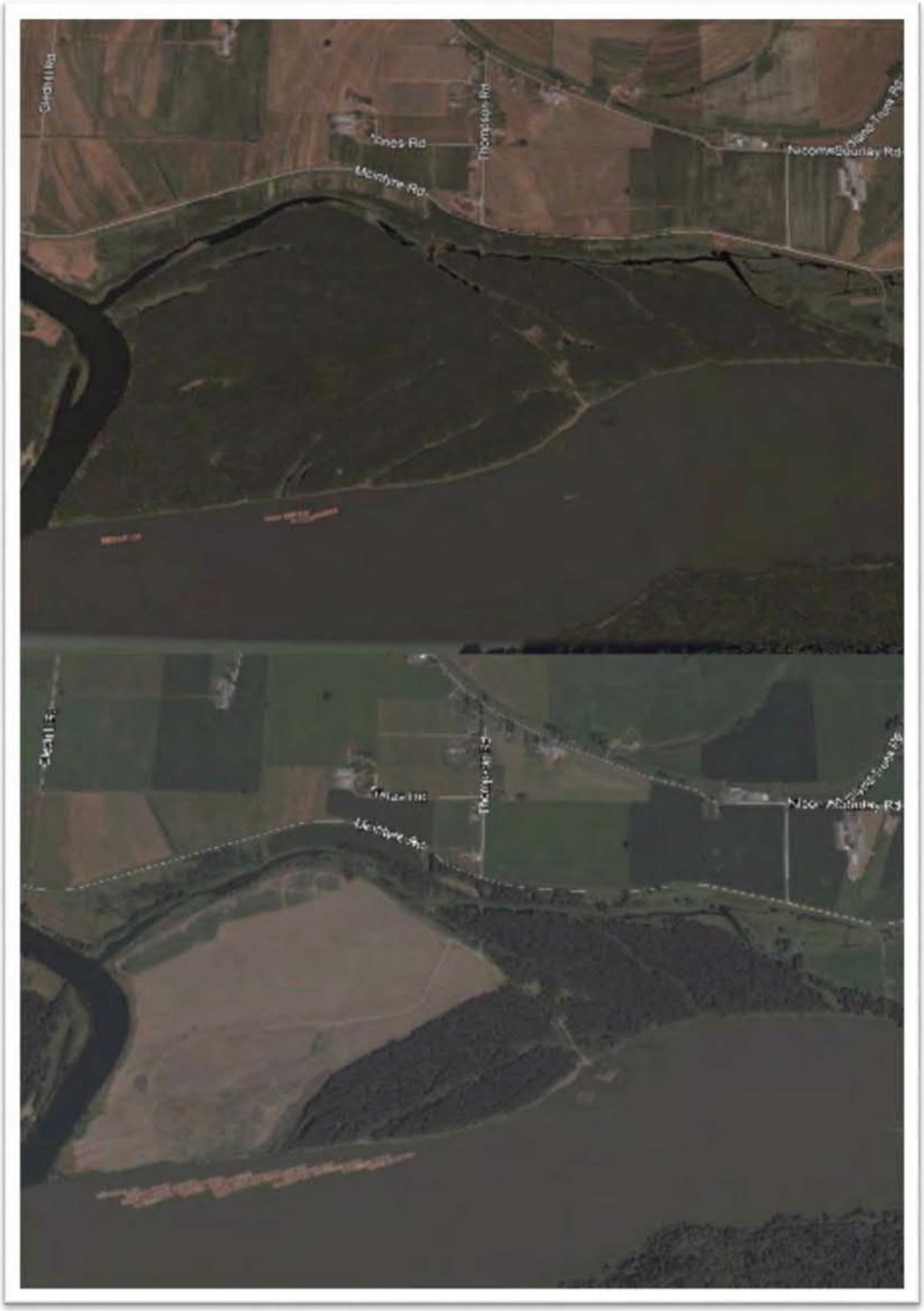

Figure 17. Google Satellite Imagery (accessed February 15, 2019) from September 2015 (top) and July 2016 (bottom) showing the harvest of cottonwood forest at Strawberry Island. Using Quantum GIS (QGIS), the cleared portion was digitized to produce a polygon for which the surface area (in acres) was calculated. Approximately 95 ha of cottonwood plantations were harvested.

Figure 18. May 2018 drone image of Strawberry Island facing northeast from the southwest corner of the island at the edge of the Fraser River (right side of photo) (UAviation, 2018). Note the large volume of piled wood waste along the western bank of the inundated Strawberry Island, adjacent to the log booms anchored in Nicomen Slough.

:

Habitat Wizard (BC Government data) has mapped fish occurrences known to occur around Strawberry Island (Figure 19). Not shown on this map and not recorded in the occurrence database are the juvenile White Sturgeon that use Nicomen Slough as freshet habitat (Lane et al. 1995). Nicomen Slough is located directly adjacent to Strawberry Island and Strawberry slough is connected to Nicomen Slough, therefore, it is likely that these features are key to the productivity of White Sturgeon rearing habitat for this location (Lane et al. 1995).

Figure 19. Habitat Wizard map of all fish occurrences in the vicinity of Strawberry Island, including both species-at-risk and those not warranted listing (Government of BC Habitat Wizard, 2019).

2.2.5. Reference Sites

As the privately-owned lands on Herrling, Carey and Strawberry islands, were not accessible for this study, nearby natural reference or proxy sites were used to ground-truth the presumptive ecological classifications on the islands. This was predominantly based on island elevation class which is defined using the Biogeoclimatic Ecosystem Classification (BEC) system for Coastal Western Hemlock dry maritime (CWHdm) BEC zone and subzone for floodplain sites (Pojar et al., 1991). These floodplain sites are classified as low, middle and high bench and differentiated by elevation which results in varying frequencies and duration of flooding and, therefore, differences in plant communities and site type (forest, wetland, shrub complex) (Pojar et al., 1991; McLennan, 1993; Green and Klinka, 1994) (Figure 20). These bench sites are used to classify what the naturally occurring vegetation types would be at Herrling, Carey and Strawberry islands for restoration prescriptions. Reference Site #1 is the Bert Brink Wildlife Management Area (BBWMA) and Reference Site #2 is the Fraser River Ecological Reserve (FRER) (Figure 1).

Bert Brink Wildlife Management Area at Strawberry Island

Bert Brink Wildlife Management Area (BBWMA) was designated in 2009 to conserve Fraser River floodplain to support resident and migratory wildlife. This Wildlife Management Area (WMA) partially overlaps Strawberry Island and is directly adjacent to the private land portion which had its vegetation removed for agricultural purposes (Figure 16). WMAs in British Columbia are designated by the acting Minister of Forests, Lands, Natural Resource Operations, and Resource Development (FLNRORD) under Section 4 of the *Wildlife Act* with the consent from provincial cabinet (MFLNRO, 2019). WMAs are intended first to benefit fish and wildlife species and their habitats but can also be used for other land uses that are compatible with the conservation and management of species and habitats. For example, at BBWMA, a portion of the WMA is being leased to a farmer for cattle grazing (MFLNRO, 2019).

Bert Brink WMA, where it overlaps Strawberry Island, has been defined as Reference Site #1 for this project. It was chosen as a reference site to confirm ecological classification and reference condition of the adjacent cleared portion of Strawberry Island as well as for Carey and Herrling islands that were also cottonwood forests. Where forests occur in the WMA, there are mature and almost entirely made up of Black Cottonwood (Figures 17, 20). It is possible that these forests could have been plantations, however, information on the history of the stand was not available. Like the islands assessed in this study, Bert Brink WMA provides habitat for many species at risk including the Marbled Murrelet (*Brachyramphus marmoratus*) (Ryder et al. 2012), Great Blue Heron (*Ardea herodias*), Peregrine Falcon (*Falco peregrinus*), White Sturgeon, and all species of Pacific Salmon. The mature cottonwood forest at the WMA was once an active heron colony that may re-establish itself over time according to the MFLNRO website (MFLNRO, 2019).

Assessments were conducted at Bert Brink WMA on January 12, 2019 and March 19, 2019 to collect site information for cottonwood stands, wetland and slough riparian areas, and lower-lying areas dominated by grasses, sedges, and Horsetail (*Equisetum spp.*). Information collected at plots included vegetation species and percent cover as well as signs of animal use or human disturbance. Plots (lettered from A to E) (Figure 21) were located along a straight transect to ensure all mapped polygons were represented in the survey. Mapped polygons define BEC CWHdm floodplain sites (low, middle, and high bench) obtained from digitizing the Fraser Valley Watershed Atlas (FVRD, 2015). Intermediate viewpoints were located as needed in the field when an interesting or identifying feature was found such as at the confluence of two water features, a heavily browsed shrub, and transitional areas between wetlands and bench sites (Figure 21). Appendix A includes pictures from these plots and viewpoints entitled “Strawberry Island Ecological Classification site pictures”.

Figure 20. Images from Viewpoint #1 located at the eastern limit of Bert Brink WHA at Strawberry Island along the shore of the Fraser River (Figure 21), picture on the left is facing west showing mature cottonwood forest along the whole shoreline of Strawberry Island within Bert Brink WMA. Picture on the right facing north from Viewpoint #1 shows mature cottonwood surrounding a man-made clearing and bank erosion
Photos: L. Bartsch, 2019.

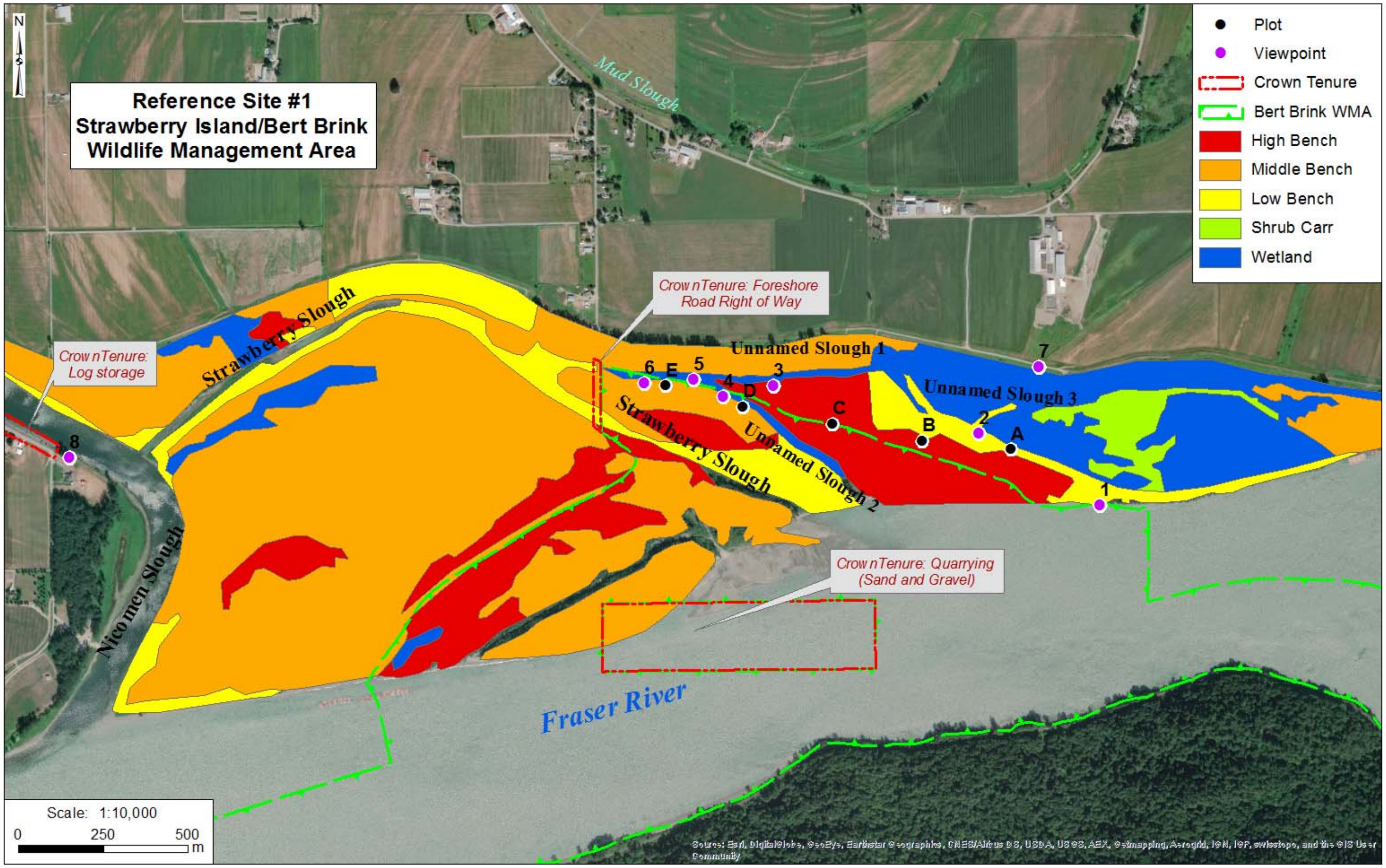

Figure 21. Field map of Reference Site #1 at the Bert Brink Wildlife Management Area portion of Strawberry Island showing Plots (red and letter names) and Viewpoints (yellow and numbered). Map developed by: L. Bartsch, (2019). Imagery source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Fraser River Ecological Reserve

The 177 ha Fraser River Ecological Reserve (FRER) was established on February 24, 1977 as BC Ecological Reserve #76 to “conserve unaltered and uncommitted lower Fraser River floodplain islands” (BC Parks, 2012) (Figure 1). The purpose of this ecological reserve was changed more recently to one of preserving a mid-channel island cluster as an unaltered example of the physical processes (erosion and accretion), vegetation succession, wildlife, and habitat that occur there (BC Parks, 2012). BC Parks published description of this island (2012) indicates that the complex is made up of two islands with naturally vegetated and mature cottonwoods, and three upstream islands with younger stands in earlier stages of succession. The older islands are bisected by a deep river slough that runs year-round and several freshet-inundated swales that transect the islands. Swales are seasonally wetted and are an example of the seasonal fish habitat connected to the main river channel by the freshet flood pulse. Herons frequent the pools formed in swales of the FRER that almost certainly support juvenile rearing salmon (chinook/chum) as well as other species of fishes and aquatic organisms (BC Parks, 2012).

There is a predominance of low bench sites at the FRER, specifically at the less developed upstream areas of the island complex and a mix of high, middle and low bench sites at the downstream end (Figure 22). This map is consistent with the BC Parks description of the reserve in terms of vegetation succession.

Recent reports show increasing amounts of Himalayan blackberry at FRER (Farr 1997; BC Parks 2012); however, the island complex is largely physically unaltered by humans and is a reasonable representative of natural succession of floodplain cottonwood stands and mid-channel island formation based on the BC Parks detailed site assessment (BC Parks, 2012), the warden report describing the FRER as undisturbed natural cottonwood forests (Farr, 1997), and a beaver/bio-survey stating the same (Liner et al., 1983). The survey and report by Liner et al. (1983) defined four vegetation plots all located at low bench sites at the FRER in 1983 (Figure 22).

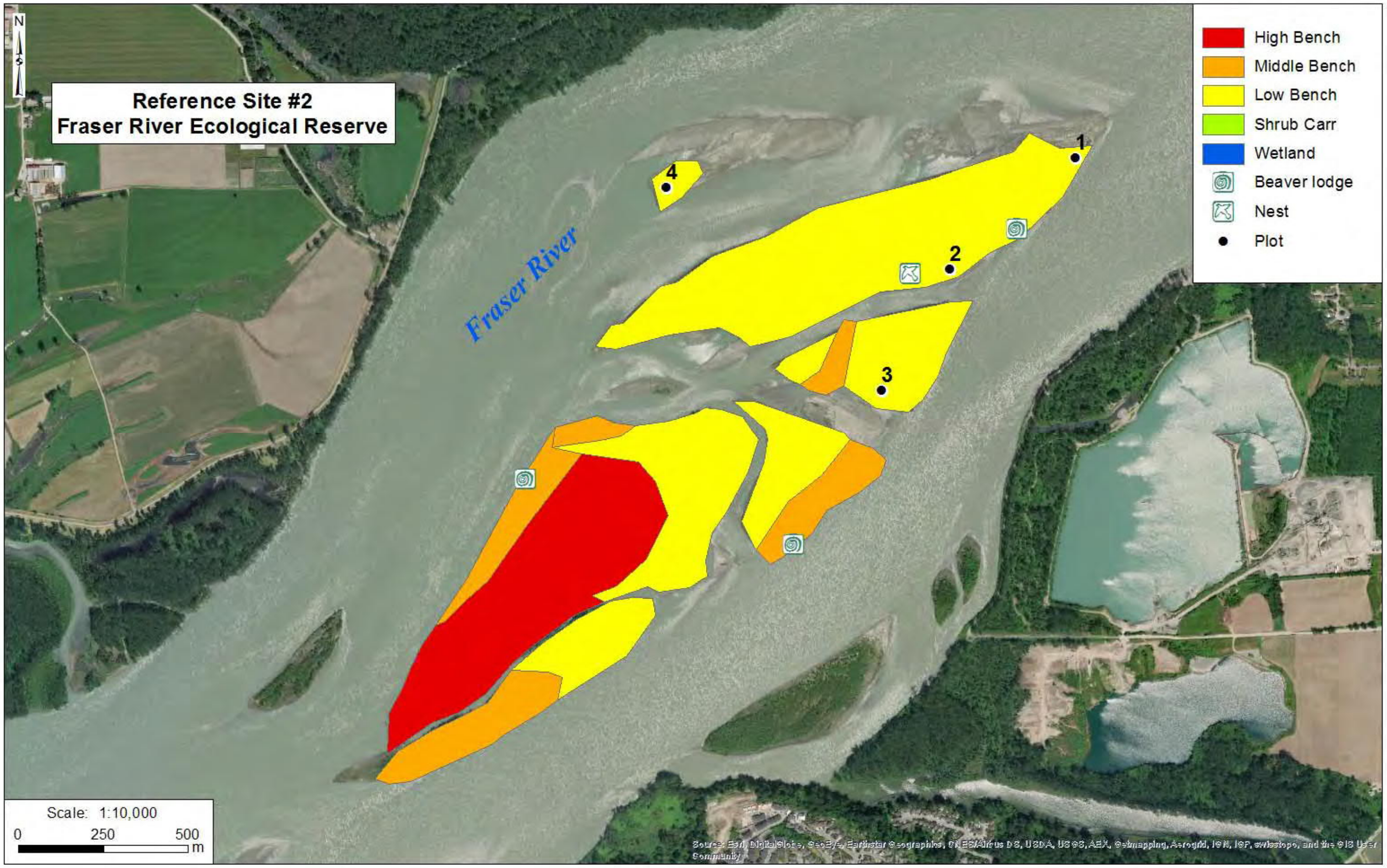

Figure 22. Fraser River Ecological Reserve (located between Abbotsoford and Chilliwack, British Columbia) showing 1983 beaver ecology and biosurvey (Liner et al., 1983). Plots were grouped in the younger cottonwood stands in the low bench areas. Findings are representative of those from Reference site #1 (Strawberry Island at Bert Brink WHA) (Figure 21) (Map by: L. Bartsch, 2019; Imagery source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community).

2.3. Methods

2.3.1. Off-channel Fish Habitat Mapping

To identify floodplain fish habitat over a range of flows at Herrling, Carey, and Strawberry islands, a two-dimensional hydraulic model of the lower Fraser River, between Hope and Mission, British Columbia, was used for this study. The basic assumption of this work was that any landscape that was inundated and connected to the mainstem of the river could be used by fish (See Flood Pulse Concept Section 1.2.2). The extent of inundation changes over time with changes in Fraser River discharges (m3/s), peak flows occur at freshet in late spring while moderate to low flows are the norm for the remainder of the year. Hydraulic modelling was undertaken define freshet water levels in 2018.

As it was available for use free of charge and I was able to find training resources and tutorial online, I used the United States Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) two-dimensional modelling software (US Army Corps of Engineers, 2019) to run a hydraulic model for the lower Fraser River between Hope and Mission, British Columbia to define freshet water elevations (extent of fish habitat) at Strawberry, Carey and Herrling islands. The extent of fish habitat or freshet water elevations was compared to drone imagery captured in late May 2018 to ensure model results were accurate. A spatial overlay of defined fish habitat with maps of disturbed habitat (cleared for agriculture) was used to determine area (ha) of the islands requiring restoration.

Hydrometric data for the lower Fraser River including discharges (m^3/s) at Hope (inflow) and Mission (outflow) British Columbia, as well as water elevations at Harrison River inflow were used to run the model (Figure 23). Hydrometric data were obtained from the Government of Canada's real-time hydrometric data resource online and Fraser Basin Council (FBC) provided the Digital Elevation Model (DEM) of the lower Fraser River between Hope, B.C. and Mission, British Columbia.

HEC-RAS software was used to convert the DEM into a terrain in .hdf format which is used for this stand-alone two-dimensional (2D) flow modelling. A flow area (model extent) was then defined that coincided with dike locations and higher ground to limit the flow outside of this area and to mimic the flood control in the gravel reach. An in-flow point was defined at Hope, British Columbia, where hydrometric data are collected to define discharge entering the system at this point. An end point was defined at Mission, British Columbia, downstream of Strawberry Island where outflow discharges are applied. Water levels collected at Harrison Mills were used to keep flow elevations consistent as discharge data is not collected for Harrison River inflow (Figure 23).

The HEC-RAS 2D model was run using default Manning n roughness co-efficient values that reflect all sources of flow resistance in the channel determined during the calculation of the flow area mesh/geometry from the terrain model. These default values were used as they represent a reasonable or average flow resistance value for large rivers (Brunner, 2016). I was not able to find specific roughness co-efficient values for the gravel reach, therefore, chose the default as recommended in the software manual. The 2D model was run for the full range of 2018 discharges (Figure 6) which ranged from 588m^3/s (January 2, 2018) to 11,100m^3/s (May 20, 2018). Screen shots of model set up using HEC-RAS are located in Appendix A “Hydraulic Model”. Spatial extent of freshet flows was exported from HEC-RAS to ArcMap and saved as a shapefile. The shapefile was clipped to only include Herrling, Carey and Strawberry islands. Stitched drone imagery (using Agisoft Photoscan) was draped over the flooded extent and used to confirm model results.

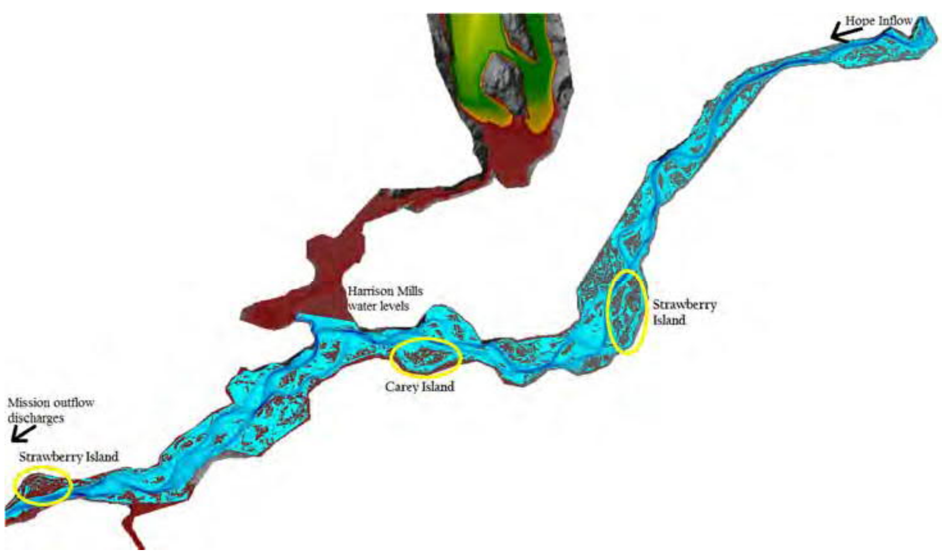

Figure 23. HEC-RAS model layout showing Hope, British Columbia inflow, Harrison Mills water level constant, and Mission, British Columbia outflow sink. The model was run using hydrometric data for all three points from Government of Canada real-time data for 2018.

2.3.2. Ecological Classification of Off-channel Fish Habitat

As the privately-owned lands on Herrling, Carey and Strawberry islands, were not accessible for this study, nearby natural reference or proxy sites (Figure 1) were used to ground-truth the presumptive ecological classifications on the islands. Ecological classifications were predominantly based on island elevation class which is defined using the Biogeoclimatic Ecosystem Classification (BEC) system for Coastal Western Hemlock dry maritime (CWHdm) BEC zone and subzone for floodplain sites. These floodplain sites are classified as low, middle and high bench and differentiated by elevation which results in varying frequencies and duration of flooding and, therefore, differences in plant communities and site type (forest, wetland, shrub complex) (Pojar et al., 1991; McLennan, 1993; Green and Klinka, 1994) (Figure 21, 22). Bench sites and Vegetation Resources Inventory (VRI) data were used to classify the naturally occurring vegetation type at Herrling, Carey and Strawberry islands for restoration prescriptions.

To determine if in-office identification of vegetation communities using BEC was accurate, existing plant species data from surveys at the Fraser River Ecological Reserved were compiled. In addition, at Bert Brink WMA, information collected at 10x10m plots included vegetation species and percent cover as well as signs of animal use or human disturbance. Plots (lettered from A to E) (Figure 21) were located along a straight transect to ensure all mapped polygons were represented in the survey. Mapped polygons define BEC CWHdm floodplain sites (low, middle, and high bench) obtained from digitizing the Fraser Valley Watershed Atlas (FVRD, 2015).

Vegetation Resources Inventory data (VRI) is a photo-based vegetation inventory funded by the British Columbia government to help the Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) track and manage resources for economic and environmental sustainability goals (MFLNRO, 2013). Vegetation Resource Inventory data was used in conjunction with the BEC bench site classifications to confirm dominant tree species as well as height classes, age classes, and site index values for the forests that were cleared at Herrling, Carey, and Strawberry islands (Figure 25, 26, 27). To interpret VRI data, map labels associated with the VRI layer required the use of a key or legend (Figure 24).

Example of a Vegetation Label:

○12
123/L
Fd(Hw)
211-20
he,sl
GL78

LINE DESCRIPTION
1 Silviculture symbol and Opening Number
2 Polygon Number and multi-layer stand indicator (L)
3 Species Composition
ex: the most important layer is described as Fd (Dougls Fir) and Hw (Western Hemlock).
4 Age, Height, Crown Closure Class Code - seporator Site Index / estimated SI
ex: stand is age class 2 (21-40 yrs), height class 1 (0.1-10.4m), crown closure class 1 (6-15%), SI 20m
5 Vegetated Density Class (or Non-Forest/Productive Descriptor)
ex: a herb polygon with no distinction between forbs and graminoids, shrubs less that 2m.
6 Disturbance History & year - ex: Logged in 1978

Figure 24. Vegetation Resource Inventory map label interpretation key (Province of British Columbia, 2016). Complete document: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stewardship/forest-analysis-inventory/data-management/standards/vegetation_map_legends.pdf

Survey data was collected at Bert Brink Wildlife Management Area for ground-truthing of BEC and VRI derived site classification (Table 4). All data is included in Appendix A "Bert Brink WMA plot data".

Table 4. Field data collection format for Bert Brink Wildlife Management Area ground truthing of mapped Biogeoclimatic Ecosystem Classification of Coastal Western Hemlock dry maritime bench sites.

Plot or viewpoint	Wetland or forest	Tree species	Shrub species	Other plants
A	Wetland	Black cottonwood at perimeter of wetland outside of plot	Red-osier dogwood (2%)	Reed canary grass (98%)

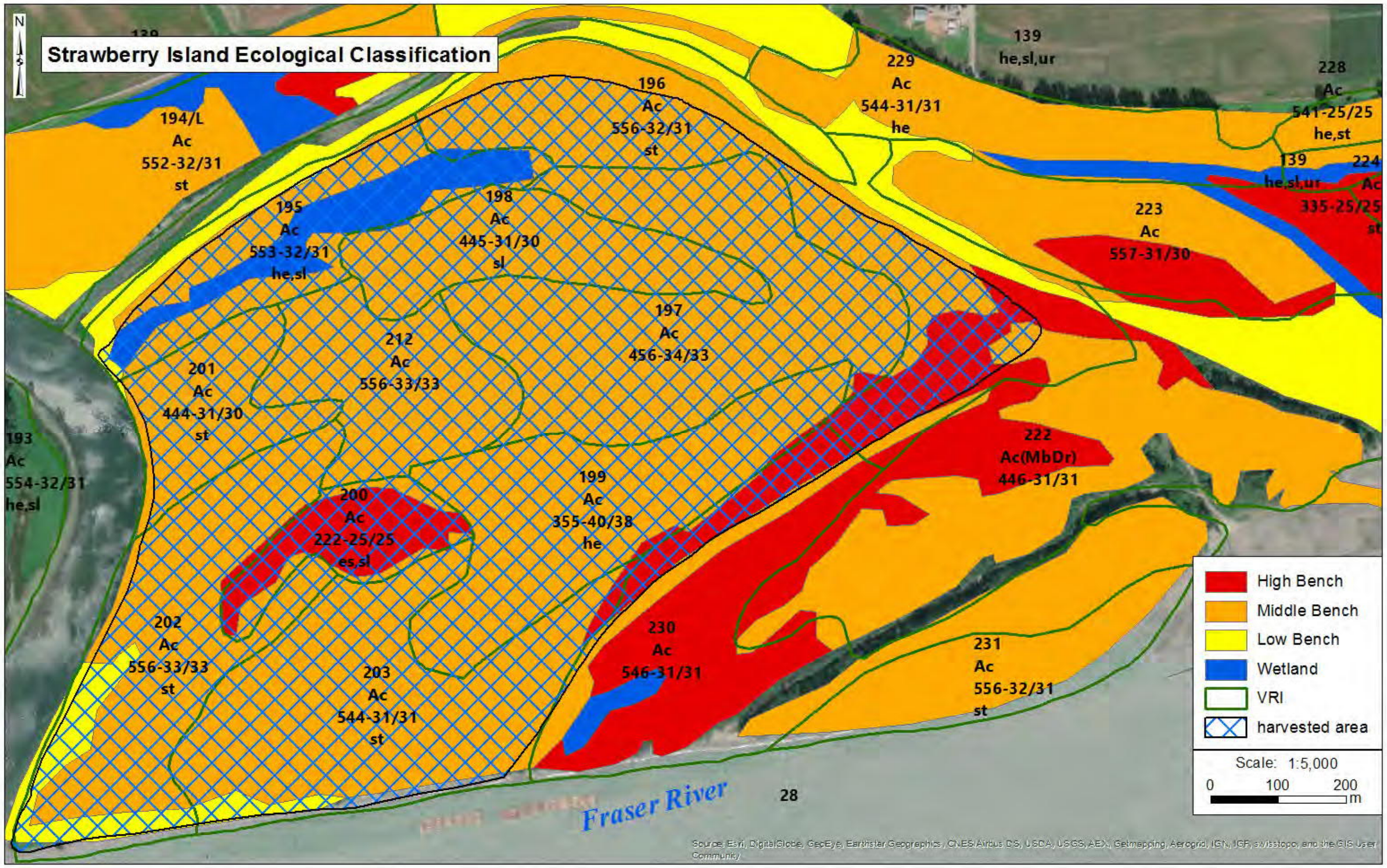

Figure 25. Strawberry Island Vegetation Resources Inventory (VRI) data showing dominant trees species, age and height classes, site index and overlay with Biogeoclimatic Ecosystem Classification (BEC) Coastal Western Hemlock dry maritime (CWHdm) floodplain bench sites. (Map by: L. Bartsch, 2019; Imagery source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community).

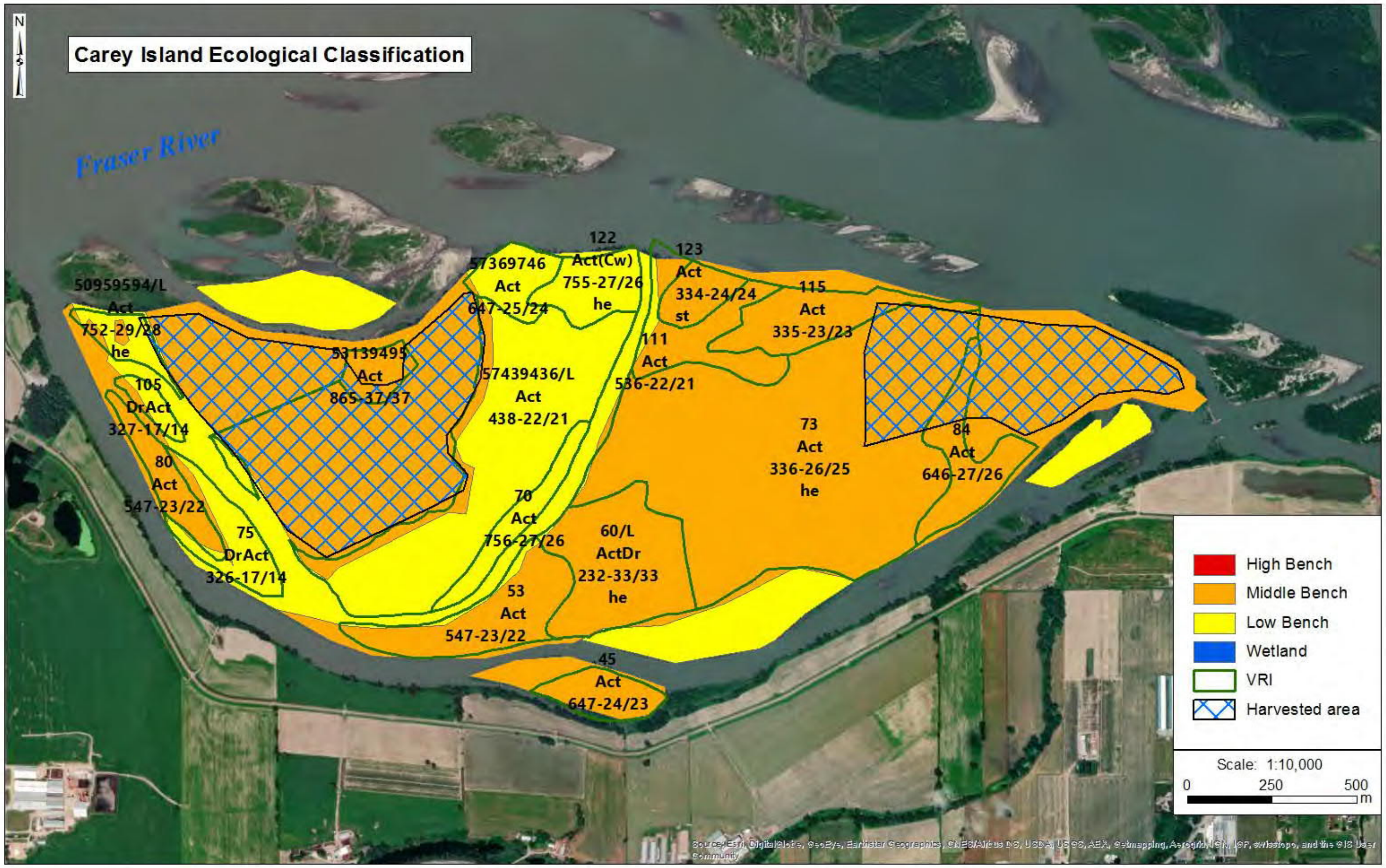

Figure 26. Carey Island Vegetation Resources Inventory (VRI) data showing dominant trees species, age and height classes, site index and overlay with Biogeoclimatic Ecosystem Classification (BEC) Coastal Western Hemlock dry maritime (CWHdm) floodplain bench sites. (Map by: L. Bartsch, 2019; Imagery source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community).

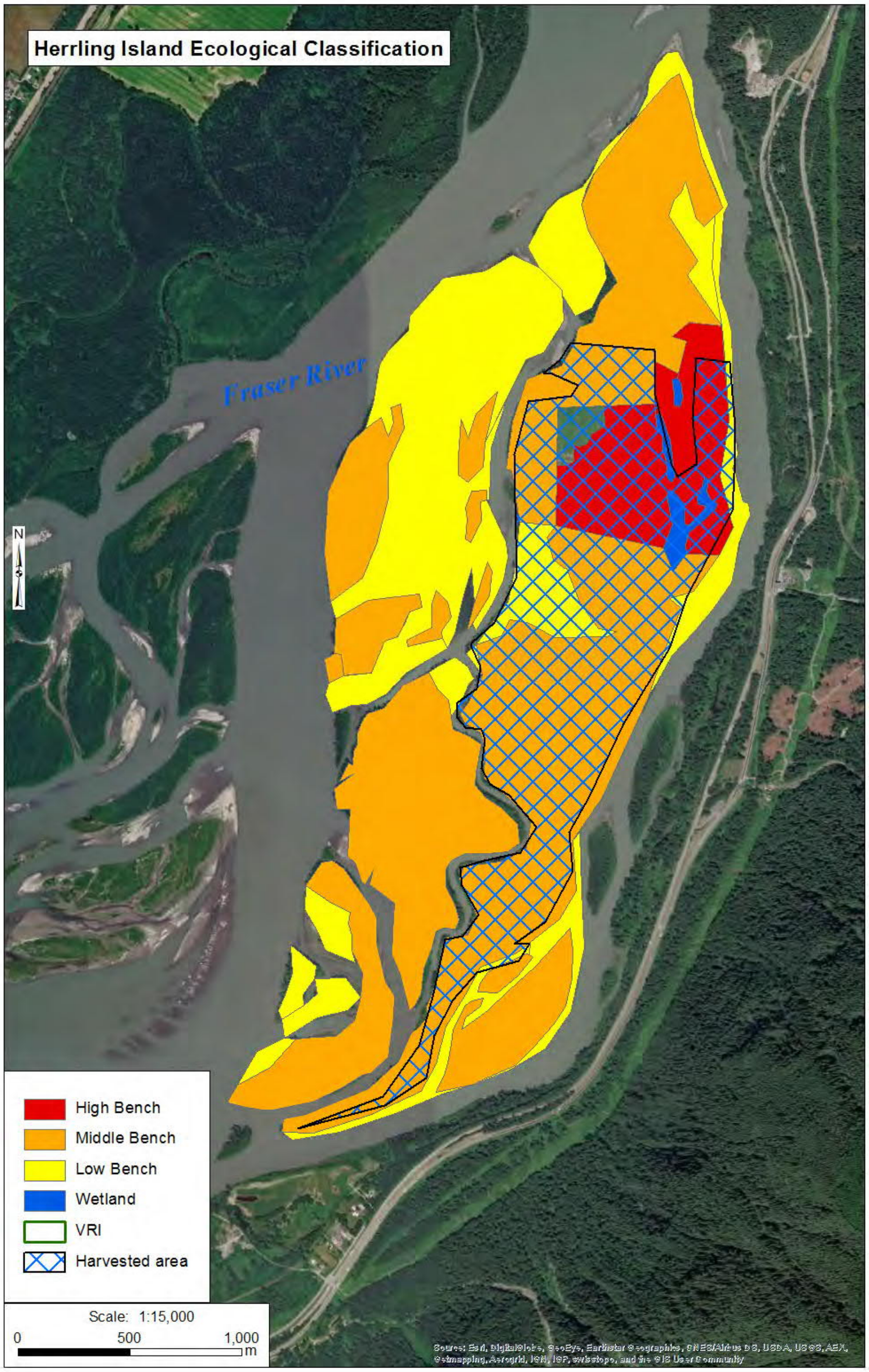

Figure 27. Herrling Island Vegetation Resources Inventory (VRI) data showing dominant trees species, age and height classes, site index and overlay with Biogeoclimatic Ecosystem Classification (BEC) Coastal Western Hemlock dry maritime (CWHdm) floodplain bench sites. (Map by: L. Bartsch, 2019; Imagery source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community).

2.4. Results

2.4.1. Off-channel Fish Habitat Mapping

The extent of floodplain fish habitat was derived (using methods as described in Section 2.3.1) and mapped (Figure 28, 39, 30). The portion of the harvested area at each island that was inundated at freshet in 2018 has been calculated (Table 5). The HEC-RAS model resulted in slightly larger flood extents than were evident in the 2018 drone imagery for the islands, therefore, the flood extents were clipped to more closely match the imagery and to ensure the amount of fish habitat was not exaggerated.

Table 5. Area (ha) of harvested, inundated, and habitat buffer for Herrling, Carey, and Strawberry islands. Inundated area defines extent of floodplain fish habitat at each island. The 30 m habitat buffer was added to the outer edges of the inundated areas to protect the fish habitat at times when flows may be higher, to provide shade and therefore control temperatures of the shallow water habitat, and to contribute nutrients and forage for fish.

Island	Harvested area (ha)	Inundated area (ha)	Habitat buffer (ha)	Percent of harvest within fish habitat
Herrling	191.8	68.9	49.6	36%
Carey	65.4	18.7	25.5	29%
Strawberry	95.4	54.5	19.7	57%

A 30 m buffer was applied on defined inundated areas (floodplain fish habitat) to provide for vegetated areas that can contribute to shading and regulating temperatures of the shallow water associated with this habitat. In addition, vegetated buffers protect the soil from erosion if freshet flows are higher than those modelled. The width of the buffer was chosen based on Riparian Areas Regulation (RAR) requirements for stream offsets (Government of British Columbia, 2016).

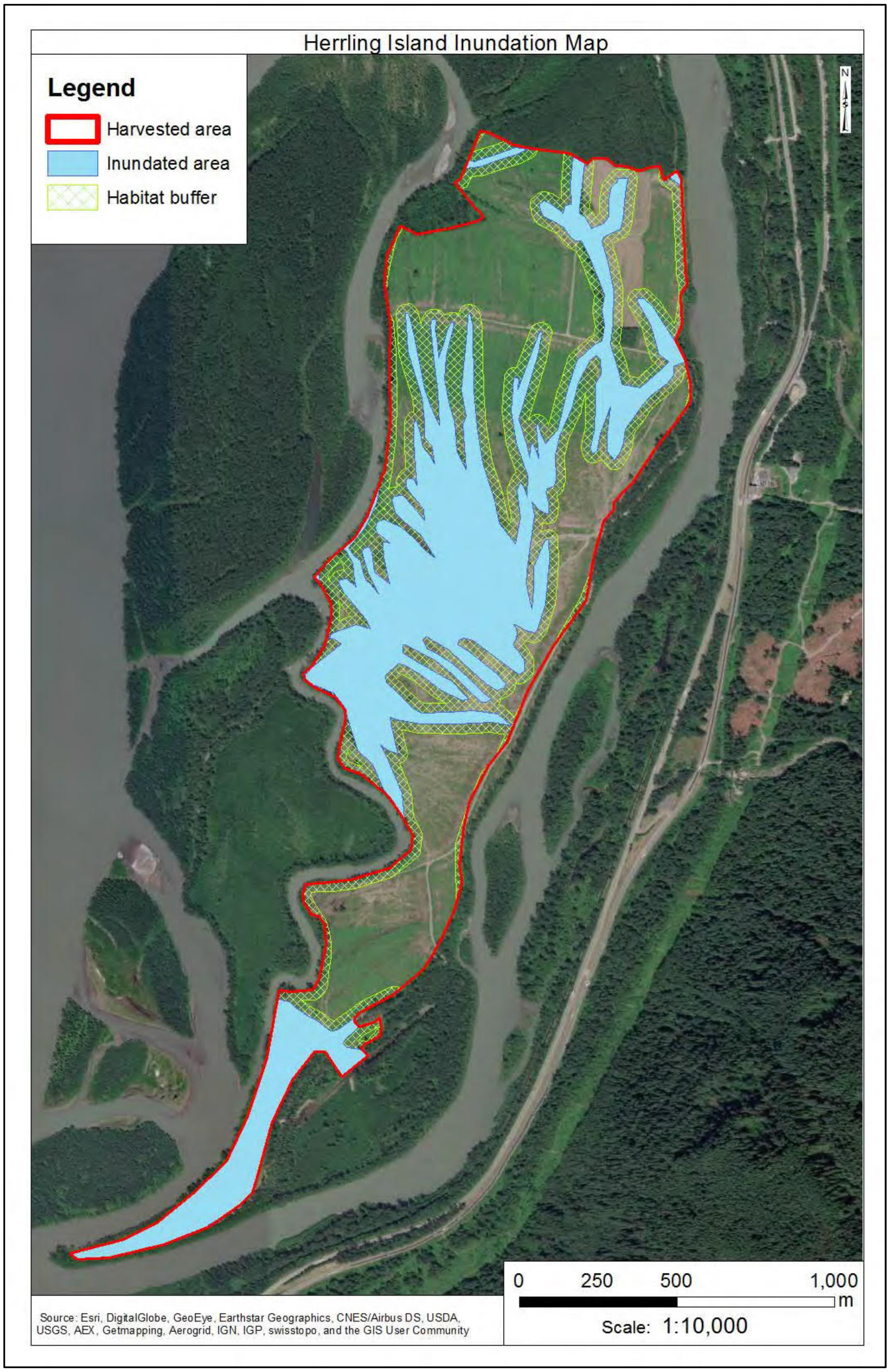

Figure 28. Herrling Island inundation map showing the extent of floodplain fish habitat (inundated area) and the 30m habitat buffer added as defined in Riparian Area Regulations. (Map by: L. Bartsch, 2019; Imagery source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community).

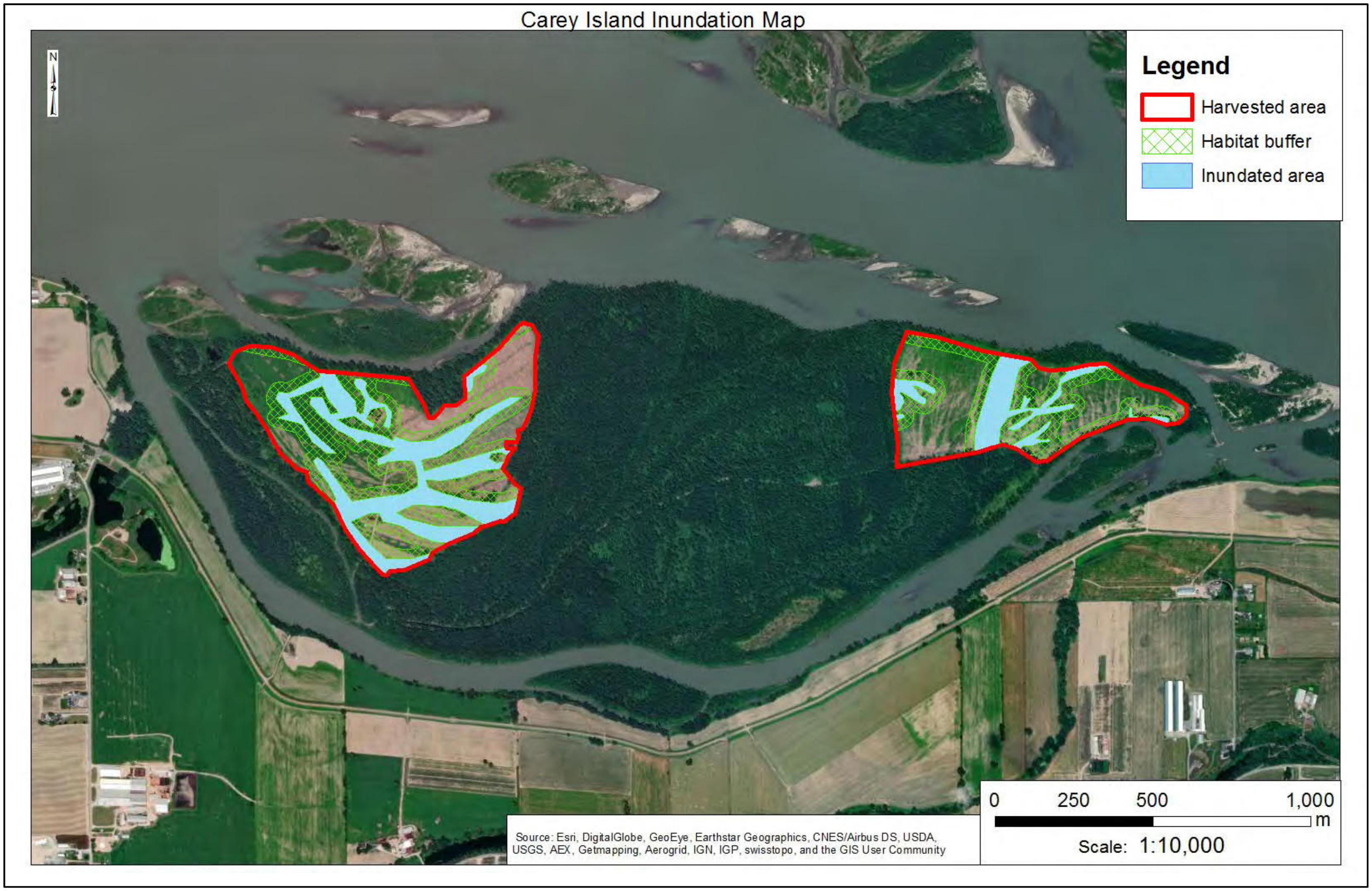

Figure 29. Carey Island inundation map showing the extent of floodplain fish habitat (inundated area) and the 30m habitat buffer added as defined in Riparian Area Regulations. (Map by: L. Bartsch, 2019; Imagery source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community).

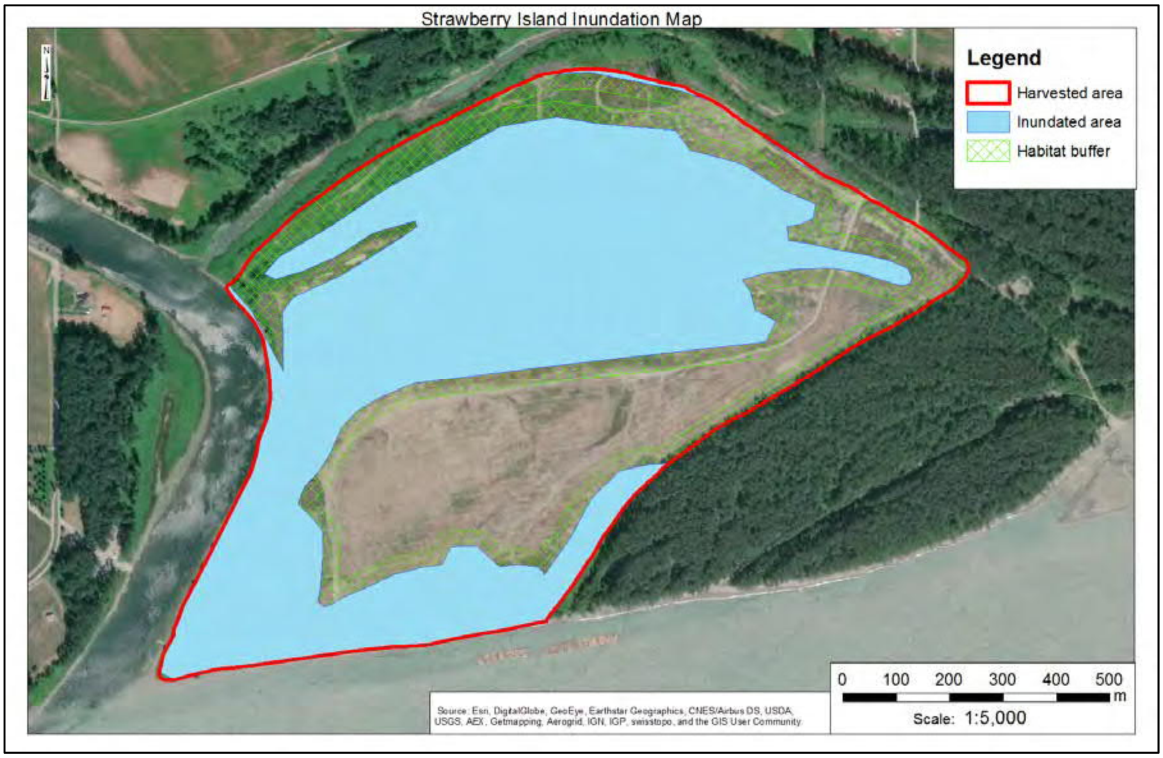

Figure 30. Strawberry Island inundation map showing the extent of floodplain fish habitat (inundated area) and the 30m habitat buffer added as defined in Riparian Area Regulations. (Map by: L. Bartsch, 2019; Imagery source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community).

2.4.2. Ecological Classification of Off-channel Fish Habitat

Biogeoclimatic Ecosystem Classification (BEC) and Vegetation Resource Inventory (VRI) ground-truthing data was summarized for BBWMA potential vegetation community types at low, middle, and high bench floodplain sites within the Coastal Western Hemlock dry maritime (CWHdm) BEC zone and variant (Table 6). When comparing these findings to the bench sites, as defined by the Fraser Valley Watershed Atlas (FVRD, 2015) and Vegetation Resource Inventory (VRI) data (Government of BC VRI, 2019) (Figure 21, 25, 26, 27) we see that low and middle bench locations at reference sites, if not comprised of a wetland, are usually open (less dense) Black Cottonwood predominated forest with willow and other shrubs as well as understory grasses, sedges, and horsetail. High bench sites are usually comprised of stands dominated by Black Cottonwood with smaller components of Big Leaf Maple (*Acer* *macrophyllum*) and Western Redcedar (*Thuja plicata*), Western Hemlock (*Pseudotsuga menzesii)* Depending on the maturity of the stand, the vegetation community will vary (Table 2; Table 6), however, a mature high bench site understory tends to include Salmonberry, Red-Osier Dogwood, and Thimbleberry where adequate light exists, usually at the forest edge (McLennan, 1992). Fraser River Ecological Reserve (Reference Site #2) plant species data (Liner et al., 1983; Farr, 2007; BC Parks, 2012) is consistent findings at Reference Site #1.

Table 6. Summary of findings at Bert Brink Wildlife Management Area at Strawberry Island to confirm mapped classifications of CWHdm floodplain bench sites (L. Bartsch, 2019).

Plot	BEC classification	Type	Description	Photo(s)
A	CWHdm Low Bench	Wetland	Edge of Reed canary grass dominated wetland	Plot A
B	CWHdm High Bench	Forest	Approximately 45-year-old cottonwood stand with tall shrub understory	Plot B
C	CWHdm High Bench	Forest	Approximately 80-year-old cottonwood stand with tall shrub understory	Plot C
D	CWHdm Middle Bench	Grass, sedge, horsetail open forest	Native grasses, sedges, and horsetail in open forest	Plot D
E	CWHdm Middle Bench	Open forest	Native shrubs and open cottonwood forest	Plot E

2.4.3. Climate Change

Peak flows in the lower Fraser River are driven by snowmelt in late spring and early summer (Benke and Kushing, 2005). It is thought that this snow-dominated system may be transitioning to one predominated by rain or a hybrid pluvial/nival system (Shrestha et al. 2012). Reductions in snow and earlier melt are anticipated to be the norm in the lower Fraser River (Morrison et al., 2002). In addition, with a transition to a more pluvial system and warmer temperatures, peak flows will occur earlier, and flows associated with rain events will be more pronounced and frequent (Shrestha et al. 2012; Morrison et al., 2002). The effects of an earlier freshet, increased temperatures, and seasonal reductions and/or increases in flows can affect growth and survival of Sockeye Salmon. Salmon expend more energy when faced with increased temperatures as well as increased flows (Healey, 2011). More frequent and pronounced peak flows in the gravel reach of the Fraser River can lead to erosion of channel banks as well as floodplain islands (Ham and Church, 2002). Ensuring highly productive, yet sensitive, floodplain fish habitat at mid-channel islands such as Herrling, Carey, and Strawberry are vegetated with native species and functioning as natural ecosystems can help protect them from the potential effects of climate change in the lower Fraser River (Tabacchi et al., 2000; Ham and Church, 2002; Shrestha eta al. 2012).

2.5. Discussion

The over 90% loss of floodplains within the lower Fraser River downstream of Hope, British Columbia is consistent with the global phenomenon of floodplain loss (Tockner et al., 2008). Practices used to disconnect the main river channel from the floodplain such as diking, bank armouring, alteration of the channel and riparian areas at stream crossings and draining of associated wetlands are often used where developed land is being protected including for the protection of farmlands and crops (Levings, 2000).

Herrling, Carey, and Strawberry islands, mid-channel islands located between Hope and Mission, British Columbia in the gravel reach of the lower Fraser River were once part of Tree Farm License (TFL) #43. These mid-channel island complexes have been cleared, or are partially cleared, of vegetation in preparation for agricultural development. As with so many developed parcels in the past along this reach of the Fraser River, it is anticipated that flood protection measures may ensue to ensure farm crops and infrastructure are not affected by annual freshet flows and potentially larger than average peak flows associated with floods. It is imperative that no further floodplain habitat be disconnected from the main channel of the Fraser River and it is becoming increasingly important for us to restore connectivity to back channel spawning and floodplain rearing habitat, so the populations of salmon that the SRKW rely on will have a hope for recovery (Rosenau and Angelo, 2007).

Based on the results of this study (Section 2.4.1), it is evident that the development of these islands has removed large areas (Table 5; Figure 28, 29, 30) of critical floodplain habitat (Appendix A – Selection of drone images) for some stocks of fish, particularly Chinook Salmon. This study presents a restoration plan for these impacted areas.

2.5.1. Pre-restoration Site Assessment

Pre-restoration site assessments of each island will need to be undertaken prior to implementation of the restoration plan. This assessment will be used to confirm site condition in defined floodplain fish habitat areas (Section 2.4.1; Figures 25, 26, 27). Specifically, the assessments will confirm the extent of land clearing has not changed, determine what plant species and densities remain or have regrown including species and locations of invasive plants. The initial survey or assessment will include sampling at plot locations throughout the disturbed areas by randomly locating plots on a grid prior to field work. The intensity of plot coverage at these islands does not need to be very high as there is not much site variation, therefore, 1 plot per 5ha should be sufficient to capture any trends in regrowth (species, density, distribution). Furthermore, soil disturbance within floodplain fish habitat areas such as areas covered by roads, landings, and other cleared and compacted features will be mapped, measured, and prescribed rehabilitation to enable revegetation.

Plot data, as described above, for these site assessments will be collected using georeferenced maps in a mobile app called Avenza (https://www.avenza.com/avenza-maps/) to accurately mark locations of findings (GPS points, lines, and polygons) and attach notes and pictures directly to these features. This information will be used to confirm what has been mapped using remote or office methods (satellite imagery, ecosystem classification mapping (FVRD, 2015), and available government data for roads, Digital Elevation Model, and drone imagery). The findings from these assessments will help guide and confirm the final treatments prescribed in the restoration plan summarized in the next sections of this document.

2.5.2. Legislation and Permitting

The Canada *Fisheries Act* Section 2(1) defines fish habitat as “spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes”. Knowing that several fish species depend on inundated floodplain islands in the gravel reach of the lower Fraser River for rearing, we can state unequivocally that these defined areas are fish habitat. The Act clearly states that the Department of Fisheries and Oceans (DFO) must provide approval if any proposed works might cause Serious Harm to fish or their habitat. Section 35 of the Canada *Fisheries Act* specifically states that "*no person shall carry on any work, undertaking or activity that results in serious harm to fish that are part of a commercial, recreational or Aboriginal fishery, or to fish that support such a fishery*". We know that Chinook Salmon supply both commercial and Aboriginal fisheries and we know the economic importance of White Sturgeon recreational fishery (Fisheries and Oceans Canada, 2012).

The proposed restoration of the lower Fraser gravel reach islands floodplain habitat, as outlined in this report, is intended to improve the floodplain habitat condition for fish over the current situation where it was recently damaged. According to the DFO website, approval is not required for habitat restoration activities if the purpose is to improve or repair habitat such as by riparian planting. Timing windows (MOE, 2006) must be followed when proposing to work in-stream, in this case, we are not proposing to work in-stream, and restoration activities will be undertaken when water levels are lower (outside of highest freshet flows). To transport machinery, people, and supplies back and forth to these islands, crossing of side channels and sloughs will be required. Crossing locations must be assessed prior to use to determine if temporary log matting or other protection measures will be required. As per Fisheries Act and Water Sustainability Act recommendations, Best Management Practices for crossings will be incorporated into the plan.

At the provincial level, under the Water Sustainability Act (WSA), a notification of proposed works in and about a stream must be submitted a minimum of 45 days prior to the work being commenced. Notifications are used when low risk works are proposed, meaning they will have minimal impact (negative) on the environment to work in and around water in British Columbia.

2.5.3. Invasive Plant Removal

Himalayan Blackberry was identified at Herrling and Carey islands by boat (during drone imagery collection), and at Strawberry Island during field assessment of adjacent Bert Brink Wildlife Management Area. As Himalayan Blackberry (HB) is a colonizing invasive and occurs at several locations on these three islands, it should be removed early-on in the restoration phase. Based on reference site attributes, HB occurs predominantly on middle and high bench sites of the three islands. Although the presence of HB doesn't directly impede fish use of floodplain habitat, HB roots do not act as native species roots to protect these floodplain sites from erosion. Floodplain species such as cottonwood and willow have extensive (deeper) root systems better adapted to controlling erosion; HB has shallower roots, but its presence prevents these native species from establishing (Forest Renewal BC, 2002; Invasive Species Council of British Columbia, 2014).

Manual treatment of HB is proposed for this restoration plan. Other groups in the area have already undergone extensive prescriptions of this invasive and are familiar with effective techniques for its removal. For example, the Fraser Valley Invasive Species Society, the King County Noxious Weed Control Program (Washington), and the Invasive Species Council of British Columbia indicate that an effective combination of treatments for large infestations of HB starts with chemical treatment using glyphosate (Round-up©) in the fall followed by manual removal of above and below ground parts once dead (brown). Subsequently, planting of native species is prescribed to shade out regrowth.

Due to the proximity of HB infestations to fish and aquatic animal habitat both year-round and seasonal, chemical treatment is not suitable at most of my study locations. Lyons et al. (2018) identified significant reduction in growth rate of Atlantic salmon (*Salmo salar*) during the parr-smolt phase (at sea) due to five pesticides including glyphosate. They suggest that pesticides in rivers associated with these runs of wild salmon reduce their growth rates and consequently reduce their success at sea. Tierney et al. (2006) showed that even exposures to low concentrations of pesticides, including glyphosate, can impair olfactory neurons which enable fish (Coho Salmon) to migrate to their natal streams. The Fisheries Act (Section 34(1)) prohibits the introduction of deleterious substances into fish habitat. In addition to potential damage to fish, retreatment is often required when using herbicide and this can cause damage to adjacent native vegetation.

Manual removal of HB must always include either burning of all plant parts or removal from site. HB waste from Strawberry Island can be taken to the District of

Mission Landfill, waste from Herrling and Carey islands can be taken to the Parr Road disposal site in Chilliwack. Alternately, the preferred method would be to burn the waste on site (with approved burning permits). Tractor mounted mowers (long mower boom for areas with sensitive soils) followed by planting of fast-growing willows, cottonwood, and salmonberry to shade out regrowth is prescribed (Chow, 2018).

Monitoring of HB regrowth will be important for my study sites on these islands, along with some manual spot treatments; however, the long-term goal is for native vegetation to overtop the HB and dominate the site. This restoration plan includes a pre-restoration site assessment of the islands to confirm the exact location and amount of HB on site. In addition, this site assessment will be used to identify other invasive species on the islands such as Holly (*Ilex* sp.) and English Ivy (*Hedera helix*) and assign treatment methods.

2.5.4. Revegetation

Degraded areas at Herrling, Carey, and Strawberry islands are made up of predominantly middle bench sites (Figures 25, 26, 27) and very small amounts of high bench and low bench sites. The harvested areas (degraded sites) at all three islands were comprised of cottonwood dominated forests, confirmed by both satellite imagery (Figures 10, 14, 17), prior to the harvest of these parcels, as well as, Vegetation Resources Inventory (VRI) data indicating cottonwood (Ac) as the leading species of vegetation at these sites (Figures 25, 26, 27). The Vegetation Resource Inventory (VRI) data (Figures 25, 26, 27) also shows that the cottonwood led stands were of various age classes (Figure 24). This was likely because the stands were managed on a rotation in the TFL and not all were cut and planted at the same time (Boyce, 2010).

The minimum extent recommended for restoration includes all harvested areas that overlap defined off-channel fish habitat (Figures 28, 29, 30). Ideally, a buffer beyond this line will be restored as well to account for variations in water levels year to year as well as ensuring soils at those points are protected from erosion. At the Fraser River Ecological Reserve (Reference Site #2), even the highest elevation areas (high bench) (Figure 22) are periodically flooded as evident by sediment deposits on tree trunks at those locations (BC Parks, 2012). A 30 m buffer was selected as defined in the Riparian

Areas Regulations (RAR). This essentially leaves very small pockets of higher elevation (high bench sites) that are located outside of this defined restoration area. These remaining pockets are not technically defined as floodplain fish habitat based in the model for this study but to access them those areas that are defined as fish habitat will need to be crossed. It is my hope that the entirety of the degraded sites at Herrling, Carey, and Strawberry islands will be restored and protected to reduce the potential for future damage.

Smith (1957) suggested that after logging, cottonwood stands will be replaced by willow and alder naturally. Boniface (1985) indicated that planting must be done to re-establish a predominantly cottonwood forest that would have naturally occurred at the time the island was formed when cottonwood seeds were dispersed by wind and water and soil conditions were ideal to allow for successful germination. It is my view, to protect soils from erosion caused by seasonal inundation and to control HB (Section 2.4.5), it is important not to wait to allow for natural regeneration of cottonwood, especially, if ground conditions and continued tilling may prevent or slow their natural establishment.

The pre-restoration on-site assessments will provide a valuable insight into these island-restoration locations. However, based on both drone and satellite imagery it is evident that these areas were cleared and then prepared down to the bare soil for intensive agriculture (planting of large-scale crops), so the landscape can be described as a *tabula rosa*, or blank slate. Although the soils will contain seed from native plants, the continued tilling since harvesting has kept their growth at bay. Natural regeneration of cottonwood, alder, willow, and salmonberry is reasonable to expect, particularly considering the volume of seeds that the former produces in the spring; however, blackberry will present an issue if native vegetation does not establish quickly enough to shade-out blackberry. Based on satellite imagery, it appears that some regrowth of cottonwood and willow has occurred at the islands, however, subsequent cutting and cultivation may have occurred since then. I recommend first seeing if there is a ground cover of native plants that has already begun to generate by natural means. If inventory and assessments indicate that natural regrowth is not occurring, planting cottonwood and willow, initially, as a method of controlling invasive regrowth is the preferred prescription. Plantings should occur immediately after freshet flows have receded in late spring or early summer to take advantage of moisture and nutrient inputs associated with inundation. In lower-lying areas where grasses, horsetails, and sedges/rushes would naturally occur, and HB does not, sites will be assessed to determine if plantings will be required. If soils are exposed on the lower lying sites that are inundated for longer durations, planting of willow spp. can protect them from erosion, while also providing cover for fish in this floodplain rearing habitat.

Table 6. Plant species occurring at CWHdm floodplain sites (L. Bartsch, 2019 - adapted from Pojar et al. 1991 and field surveys of reference sites).

	English	***Latin***
Trees	Red Alder	*Alnus rubra*
	Paper Birch	*Betula papyrifera*
	Black Cottonwood	*Populus trichocarpa*
	Flowering Dogwood	*Cornus nuttalli*
	Douglas-fir	*Pseudotsuga menziesii*
	Bigleaf Maple	*Acer macrophyllum*
	Western Redcedar	*Thuja plicata*
	Western Hemlock	*Tsuga heterophylla*
Shrubs	Red-osier Dogwood	*Cornus stolonifera*
	Vine Maple	*Acer circinatum*
	Pacific Ninebark	*Physocarpus capitatus*
	Salmonberry	*Rubus spectabilis*
	Devil's Club	*Oplopanax horridus*
	Thimbleberry	*Rubus parviflorus*
	Red Elderberry	*Smbucus racemose*
	Common Snowberry	*Symporicarpos albus*
	Black Twinberry	*Lonicera involucrate*
	Trailing Blackberry	*Rubus ursinus*
	Cascara	*Rhamnus purshiana*
	Mackenzie Willow	*Salix prolixa*
	Pacific Willow	*Saliz lucida* ssp. *Lasiandra*
	Sitka Willow	*Salix sitchenis*
	Soft-leaved Willow	*Salix sessilifolia*
Herbaceous	Horsetail, common	*Equisetum arvense*
	Scouring Rush	*Equisetum hyemale*
	Smooth Scouring-Rush	*Equisetum vaevigatum*
	Pearly Everlasting	*Anaphalis margaritacea*
	One-sided Wintergreen	*Orthilia secunda*
	Sedges	*Carex* spp.
	Grasses	*Poa* spp.
	Sword Fern	*Polystichum minutum*

Understanding how the vegetation communities develop at these floodplain islands over time (Figure 31) will help with natural regeneration and planning appropriate plantings at low, middle, and high bench sites that require restoration. Mid-channel island vegetation succession usually proceeds over time; however, it is sometimes interrupted by erosion caused by high discharges that reshape the wandering channel (McLennan, 1993). Although, vast areas have been cleared at the study islands, native vegetation seed still exist in the seedbank and can also be naturally transported from adjacent areas. Since these parcels were cottonwood plantations in the past on rotation, the plant and animal biodiversity at these sites may be reduced compared to undisturbed sites, therefore, there is potential for seed bank diversity to be low. The cottonwood planted was predominantly a hybrid variety, therefore, the composition of the seed bank is of concern since we hope to restore the site with native Black Cottonwood (*Populus trichocarpa*), and not a hybrid. However, since natural seeds can travel by wind and water to floodplain sites, the potential for seed diversity might be better than expected (Boniface, 1985; McLennan, 1991).

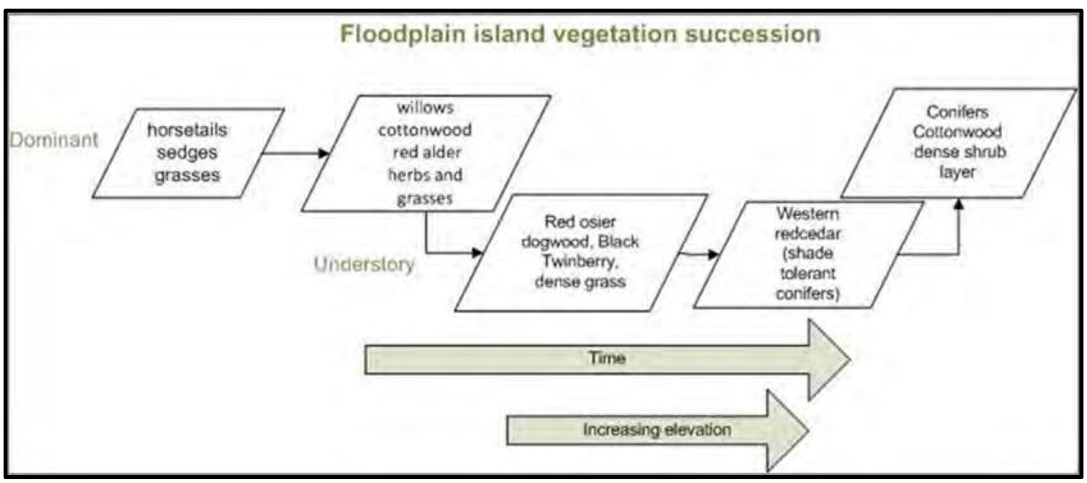

Figure 31. Vegetation succession on floodplain sites at large rivers, Coastal British Columbia (L. Bartsch, 2019). Adapted from McLennan, 1993.

If the pre-restoration site assessment shows that natural regrowth of cottonwood and other species is not occurring, cottonwood and willow whips will be collected from nearby accessible floodplain sites in early spring prior to bud flush, stored (soaked), planted at the restoration sites when water has receded (NRCS, 2009; Hoag, 2007). I was not able to find a nursery that grows Black Cottonwood (*Populus trichocarpa)* in large quantities, therefore, this appears to be the best option for immediate restoration of these sites. The strategy for revegetation at the islands will be to allow for natural revegetation of native species with an initial planting of cottonwood and willow where HB needs to be controlled and where natural regrowth is not already occurring. On high bench sites, the planting of Western Redcedar at the fill planting stage can improve the speed at which diversity is introduced to the stand (compared to natural succession) (Forest Renewal BC, 2002).

2.5.5. Monitoring

After Himalayan blackberry (HB) removal and re-vegetation of the islands, regrowth of HB and performance of native vegetation must be assessed at regular intervals. Although the first real phase of monitoring will occur at pre-restoration site assessments (Section 2.5.1) at harvested sites on Herrling, Carey, and Strawberry islands, to get a clear picture of the starting point for their restoration, a well-developed monitoring plan will be able to guide next steps (adaptive management) based on the findings.

As per this restoration plan, after the pre-restoration site assessment, Himalayan Blackberry (HB) removal and treatment will occur in conjunction with planting to control HB regrowth. In other restoration areas, where natural regeneration has not occurred, plantings to protect exposed/cultivated soils from erosion and control HB encroachment will be the next step. This initial planting of pioneer species (cottonwood, willow spp.) will occur in late spring/early summer (once freshet waters have receded). Plant species regrowth (salmonberry, and other shrubs, horsetails, grasses, and other herbaceous species) and distribution should be assessed as part of an intensive monitoring plan to ensure the revegetation of cleared sites is on track and native species are indeed regenerating naturally from seed bank and dispersal (water and wind). Further planting needs will be determined based on monitoring results.

As with the pre-restoration site assessment, plots will be located randomly on a grid within the restoration area. The intensity for which the restoration area is sampled will be the same as the initial survey (1 plot per 5 ha), however, depending on the outcome of the initial survey, this intensity may be reduced to 1 plot per 10 ha depending on the variability of vegetation. These monitoring surveys are intended to capture information about species, densities, and distribution, but also, if regrowth is not successful in some areas or if there are performance or pest issues in the regenerating stand complex. The objective will be to determine if the vegetation complex is moving towards a diverse community of plants that would naturally occur at the site or if the site will remain less diverse and impeded by invasives. One difficulty that will present itself in association with these surveys is that it will be very difficult to identify native vs hybrid cottonwood unless we mark all planted trees. Although the goal would be to restore the site to its historical condition and obviously that would include native cottonwood, this could be difficult to control.

The first post-treatment survey should occur within the same growing season (Table 8) (late September or October) to monitor regrowth of invasive plants (mainly HB unless others are identified) and general performance of tree and shrub growth. The next assessment should occur one year after the initial treatment after freshet to see how treatments have responded to inundation (damage, erosion). Subsequent monitoring will be dependent on the findings of these initial site visits to determine the frequency of future assessments and specific details to focus on. I anticipate the main issue will be regrowth of HB but am hopeful that it will be kept at bay by fast growing trees and shrubs. Where needed, HB can be re-treated in the summer of Year 1 (Table 8). Based on monitoring outcomes, it may also be identified that some areas will need fill planting or further assessment to determine why regrowth has been hindered. Although the ideal timing for planting will be in the spring (Forest Renewal BC, 2002), fall plantings may be required where fill planting is required on lower lying sites.

Table 7. Initial timing of restoration plan tasks at Herrling, Carey and Strawberry islands. Year 0 represents initial assessment and treatments. Monitoring surveys will guide schedule beyond Year 1 (L. Bartsch, 2019).

<table>
<tr><th rowspan="2">Task</th><th colspan="7">Year 0</th><th colspan="7">Year 1</th><th colspan="4">Year 2</th></tr>
<tr><th>Winter</th><th colspan="2">Spring</th><th colspan="2">Summer</th><th colspan="2">Fall</th><th>Winter</th><th colspan="2">Spring</th><th colspan="2">Summer</th><th colspan="2">Fall</th><th>Winter</th><th>Spring</th><th>Summer</th><th>Fall</th></tr>
<tr><td>Pre-restoration survey</td><td>■</td><td>■</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4" rowspan="5">Subsequent task timing will be based on monitoring survey outcomes</td></tr>
<tr><td>Blackberry treatments</td><td></td><td></td><td>■</td><td>■</td><td>■</td><td>■</td><td></td><td></td><td></td><td></td><td>■</td><td></td><td></td><td></td></tr>
<tr><td>Planting</td><td></td><td></td><td></td><td>■</td><td></td><td></td><td>■</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Monitoring survey</td><td></td><td></td><td></td><td></td><td></td><td></td><td>■</td><td></td><td></td><td></td><td>■</td><td>■</td><td></td><td></td></tr>
<tr><td>Fill planting</td><td></td><td></td><td></td><td></td><td></td><td></td><td>■</td><td></td><td></td><td></td><td>■</td><td></td><td></td><td>■</td></tr>
</table>

2.5.6. Safety

The main concern at Herrling, Carey, and Strawberry islands in terms of safety stems from the issues associated with accessing these sites and how this can affect response times for emergency personnel. It is recommended that an emergency response package be prepared to provide location details to helicopter ambulances in the case of an emergency. These islands all have mobile network coverage.

Strawberry Island is the most accessible (by road) although access is not year-round when water levels are high (Figure 16). Herrling and Carey islands must be accessed by boat at the times we intend to carry out most of the treatments associated with this restoration. Therefore, planning to get equipment to the islands via their respective land bridges at low water in the winter is essential.

Boat operators hired for this project will be responsible for safety training and preparedness for transportation by boat. Machine operators hired to treat HB should be certified/qualified, insured, and registered with WorkSafeBC. Other safety concerns associated with these islands include: Injury due to uneven ground, falls, and environmental factors (cold and heat). In addition, wild animals such as Black Bears could pose a threat. Working in teams of two at a minimum is essential. A detailed Safety Plan must be developed prior to the initial site assessment at the islands and is included in the cost of the pre-restoration survey (Table 10).

2.5.7. Budget

Determining a precise budget for restoration of impacted floodplain fish habitat at Herrling, Carey, and Strawberry islands is difficult, it would be unrealistic to calculate costs based on worst-case-scenario conditions. Worst-case-scenario, as identified by the pre-restoration site assessment would be no natural regrowth of cottonwood and other native trees and plants. That would mean planting cottonwood and willow on 118.5 ha at Herrling Island, 44.2 ha at Carey Island, and 74.2 ha at Strawberry Island, although, it is highly doubtful that natural regrowth will not have occurred to some extent (OSU, 2002). Stand density of mature Black Cottonwood floodplain forests range from 110 to 294 trees per hectare (Braatne et al., 1996). Collection, storage, transportation, and planting of cottonwood and willow whips at the islands is estimated to cost $4000 per hectare depending on the source of the cuttings. However, it is likely that a significant portion of the islands will regrow naturally. Therefore, plantings may be limited to those areas where we are treating HB. To be safe I am estimating that 30% of the restoration for each island will require planting (Table 10) based on satellite imagery showing regrowth after the initial cuts at the islands.

Table 8. Final restoration areas (ha) for Herrling, Carey, and Strawberry islands.

Island	Harvested area (ha)	Inundated area (ha)	Habitat buffer (ha)	Restoration area (ha)
Herrling	191.8	68.9	49.6	**118.5**
Carey	65.4	18.7	25.5	**44.2**
Strawberry	95.4	54.5	19.7	**74.2**

The cost of mechanical brushing blackberry is approximately $3000 per hectare if the use of a boom mower is required to reach areas with sensitive soils. Manual or hand removal of small patches can be done but this method is not realistic for the treatment of large areas and is quite costly (up to $7500 per hectare) (Bennett, 2007). It is likely that HB occurs to some extent throughout the restoration areas (Table 9), however, at Reference Site #1 it was predominantly along the edges of open areas or in less dense stands of cottonwood.

Based on recent satellite imagery (Figures 10, 14, 17), restoration areas have been cleared to the soil with little to no plants remaining, therefore, HB is likely only to occur at the perimeter of the harvested areas. A reasonable estimate for treatment is 20% of the restoration area, however, if time passes between the last cultivation of the sites and pre-restoration site assessment, this number can increase substantially. An estimated cost for HB treatment and plantings will be based on the assumptions as described here (Table 10).

Table 9. Estimated costs for Year 0 and Year 1 of Restoration of Herrling, Carey, and Strawberry island floodplain fish habitat and 30 m habitat buffers assuming significant natural regrowth of cottonwood and willow and 20% regrowth of Himalayan Blackberry post-harvest by private landowners (L. Bartsch, 2019).

Activity	Area (ha)	Cost ($ per ha)	Total Cost ($)
Site Assessment	236.9 ha	$45.00	$10,660.50
Himalayan Blackberry treatment	50 ha	$3000	$150,000
Revegetation* (Cottonwood, willow spp.)	70 ha	$4000	$284,280
Monitoring	236.9 ha	$40.00	$9476.00
Follow-up HB and planting treatments	25 ha	$3500	$87,500
			$541,916.50

*Including collection, storage, transportation, and planting of cottonwood and willow whips. All areas in Table 10 are estimates, final areas will be determined at the pre-restoration site assessment for each island. In addition, areas (ha) will increase if the whole harvested area associated with each island is restored. Costs could change if access issues are encountered due to unseasonably wet conditions. Costs are estimates only, final costs to be determined based on findings from pre-restoration site assessment.

2.5.8. Stakeholder Engagement

First Nations

The lower Fraser River is traditional unceded territory of the Stó:lō Nation, Stó:lō Tribal Council, Sts'ailes, and Yale First Nations. The Stó:lō Nation includes 11 bands whose traditional territories occur in the lower Fraser including the Aitchelitz, Leq'a:mel, Popkum, Skawahlook, Skowkale, Tzeachten, Yakweakwioose, Matsqui, Shxwha:y, Squiala, and Sumas bands. The Stó:lō Tribal Council consists of the Chawathil, Cheam, Kwantlen, Kwaw-kwaw-Apilt, Scowlitz, Seabird Island, Shxw'ow'hamel and Soowahlie First Nations. The traditional territory of the Sts'ailes extends from the areas surrounding Harrison Lake and east of Chehalis Lake down to the Fraser River in the vicinity of Carey Island. Yale First Nation traditional territory extends down to the Fraser River near Herrling Island from areas surrounding Hope, British Columbia.

In British Columbia, First Nation peoples have a strong connection to the Fraser River and the fish habitat required to support salmon which is relied on for economic benefits, traditional practices, and sustenance. The inclusion of First Nation communities in the restoration of lands within their traditional territories would be a positive aspect of these efforts. Traditional knowledge and ecological information about past site conditions could be invaluable for the restoration of highly productive ecosystem lands such as these mid-channel islands. First Nations groups might also be valuable partners for the long-term monitoring needs of these sites due to their strong connection and respect for and proximity to the land as well as traditional and ongoing use. First Nations may consider themselves to, and therefore, have a vested interest in seeing a restoration project such as this be a success.

Private Landowners

Herrling, Carey, and Strawberry islands comprise privately-owned parcels that mostly or all occur within the ALR. Intensive agriculture and, specifically, crops that require fertilizer, pesticides, continued mowing and cultivating, and barriers to freshet flooding, are not conducive to healthy floodplain fish habitat in the gravel reach of the Fraser River.

The Public and Non-Profit Groups

The public has already been involved in this project to some extent through their exposure to the plight of these islands from newspaper articles, petitions, and social media. Non-Profit Groups have had ongoing involvement in bringing awareness to the conversion of Herrling, Carey, and Strawberry islands to cleared and cultivated lands for intensive agriculture. With public support, non-profit groups such as these can aim to raise funds to protect important habitat such as these mid-channel islands.

Fisheries and Recreation

Fisheries and recreational users and outfitters all want fish habitat to be protected so the fish will be available to them in larger numbers. A key part of restoring fish numbers is controlling the catch and working with these groups to understand the importance of protecting the habitat and ensuring populations remain to produce the next generations of the fish they rely on.

The potential to involve interested stakeholders in the restoration of these islands is clear; along with a pre-restoration site assessment of the islands, it is essential to reach out to stakeholders through community outreach events, information sessions, and through social media. Where stakeholders buy-into a project, specifically where involved in the implementation or monitoring after restoration, the potential for success is much greater.

2.6. Conclusion

This study demonstrates the importance of floodplain fish habitat in the lower Fraser River and the increasing rarity of this habitat due to flood control measures in the gravel reach. Based on the HEC-RAS model and 2018 drone imagery of Herrling, Carey, and Strawberry islands, it is evident that recently cleared parcels on these islands overlap with seasonally inundated fish habitat. The Flood Pulse Concept demonstrates how this habitat functions and drives the biodiversity and highly productive nature of large river systems such as the lower Fraser River between Hope and Mission, B.C. where Herrling, Carey, and Strawberry islands occur.

It is imperative that we protect floodplain fish habitat from being disconnected from the main channel of the Fraser River, and we must ensure that these ecosystems are functioning as they are intended to, naturally. Floodplain cottonwood forest complexes at Herrling, Carey, and Strawberry islands, cleared for the development of large crop farming must be regrown to protect soils from erosion, to provide for the natural exchange of nutrients, and to supply healthy floodplain rearing sites for increasingly rare Pacific Salmon, specifically, Chinook. Farming and the associated exposed soils, fertilizing of crops, run-off, and increased risk of soil erosion that accompany it is not a activity that is compatible with one of the most biodiverse river reaches in the world, specifically, where it overlaps crucial juvenile salmon and sturgeon rearing habitat. The harvesting of sites at Herrling, Carey, and Strawberry islands (Figures 28, 29, 30) is contravention of Section 35 of the Canadian *Fisheries Act.* In order to be within the law, these degraded sites should be restored and protected from the threat of future disturbance.

This study and preliminary restoration plan included herein are intended to guide the development of a more comprehensive restoration plan based on thorough pre-restoration site assessments of the degraded sites at Herrling, Carey, and Strawberry islands.

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Appendix A.

Strawberry Island Ecological Classification site pictures

Below figures are from site visit on January 12, 2019 at Strawberry Island (Reference Site #1) (Figure 21)

Reference Site #1 - Plot A: Edge of reed canary grass dominated wetland. Cottonwood only grow on adjacent low bench site. This can be viewed as a lower than low bench site.

Reference Site #1 - Plot B: Vegetation Resources Inventory (VRI) Age Class 3 – high bench open cottonwood stands (approx. 50 years old) with some alder – understory dominated by Himalayan Blackberry, Willow spp., and Salmonberry.

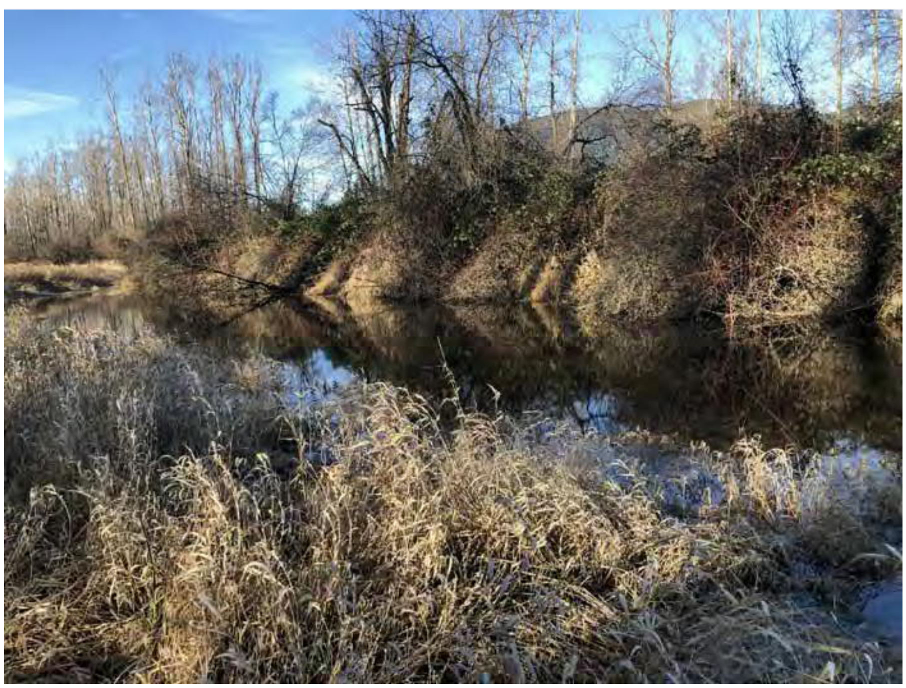
Reference Site #1 - Plot C: Vegetation Resources Inventory (VRI) Age class 5 high bench cottonwood stand (oldest trees approx. 80 years old) – understory dominated by Willow spp., Salmonberry, and Red-osier Dogwood (tall shrub understory).

Reference Site #1 - Plot D: Horsetail and grasses in sparse patchy cottonwood forest on middle bench site.

Reference Site #1 - Plot D: Native grasses in Plot D. Lower lying area between two stands of Cottonwood trees.

Reference Site #1 - Viewpoint 2: Large wetland dominated by Reed Canary grass. Located on lower than low bench site.


Reference Site #1 – Viewpoint 3 – Edge of unnamed slough #1 at high bench cottonwood forest.


Reference Site #1 - Viewpoint 4 – Edge of unnamed slough #2 located between middle and high bench sites.

Reference Site #1 - Viewpoint 5 – Confluence of unnamed sloughs #1 and #2 facing east. Fully connected to the Fraser River via Strawberry Slough to the west and Nicomen Slough

Reference Site #1 – Viewpoint 6 – Representative example of deer browse. Browse on Willow spp. and Red-Osier Dogwood throughout site.

Reference Site #1 – Viewpoint #7 – Unnamed slough #3 looking southwest. Fully connected to the Fraser River via Strawberry Slough and Nicomen Slough to the west.

Reference Site #1 – Viewpoint #8 – Looking east from west side of Nicomen Slough towards Strawberry Island and Slough. Fully connected to the Fraser River.

Bert Brink WMA plot data

Plot	Site class	Tree species	Shrub species	Other plants
A	Wetland edge	Cottonwood (10%) Alder (1%) BG Maple (1%)	Red-osier (2%) Salmonberry (4%)	Reed canary grass (82%)
B	Transition low to high bench	Cottonwood (30%) Alder (3%)	Salmonberry (15%) Blackberry (20%) Willow spp. (15%)	Horsetail (2%) grasses (15%)
C	High bench	Cottonwood (50%) Alder (5%)	Willow (20%) Salmonberry (10%)	Grasses (15%)
D	Middle bench	Cottonwood (40%) Alder (5%)	Blackberry (20%) Willow (20%) Salmonberry (5%)	Grasses, sedges, and horsetails (10%)
E	Middle bench	Cottonwood (60%) Alder (2%) BG Maple (2%) Cedar (1%)	Salmonberry (10%) Willow (10%) Blackberry (10%)	Grasses (5%)

Herrling Island late May 2018 drone image selection

Picture captured by drone from side channel between Herrling Island and Highway 1 facing northwest showing inundated areas within the harvest area.

Picture captured by drone from side channel between Herrling Island and Highway 1 facing west showing inundated areas within the harvest area.

Picture captured from near centre of harvested area facing southeast showing large inundated area connected to tertiary channel that bisects greater Herrling Island.

Carey Island late May 2018 drone image selection

Picture captured from northern edge of westernmost clearing on Carey Island facing southwest showing floodplain fish habitat at flood pulse (freshet).

Picture captured from northern edge of easterrnmost clearing on Carey Island facing southwest showing floodplain fish habitat at flood pulse (freshet).

Strawberry Island late May 2018 drone image selection

Picture captured from western boundary of Strawberry Island along Nicomen Slough. Facing east with Fraser river along top right corner.

Picture captured from north of Strawberry Island with Strawberry Slough below. Facing south-southeast to the Fraser River in the background below large gravel pit on Sumas Mountain.

Hydraulic Model

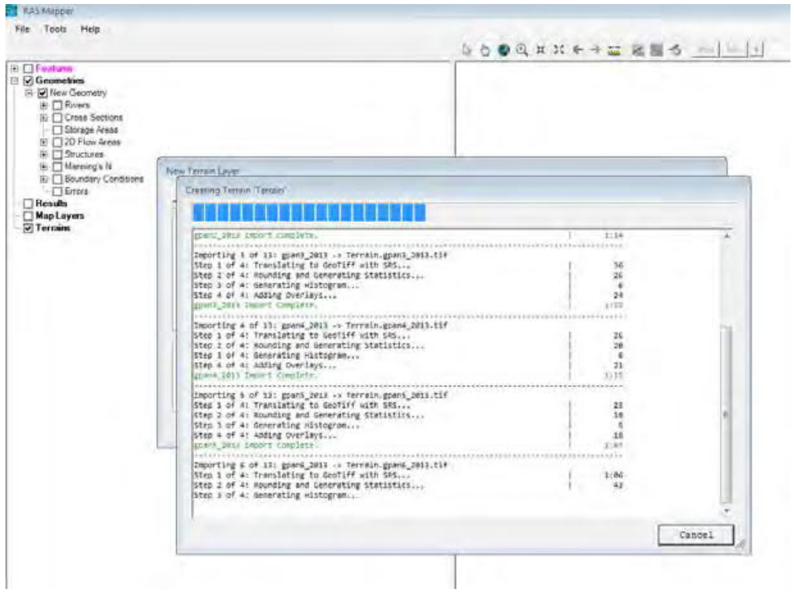


Image above shows conversion of data by processing 13 grids into one Terrain Model exported as a GeoTiff in image below.