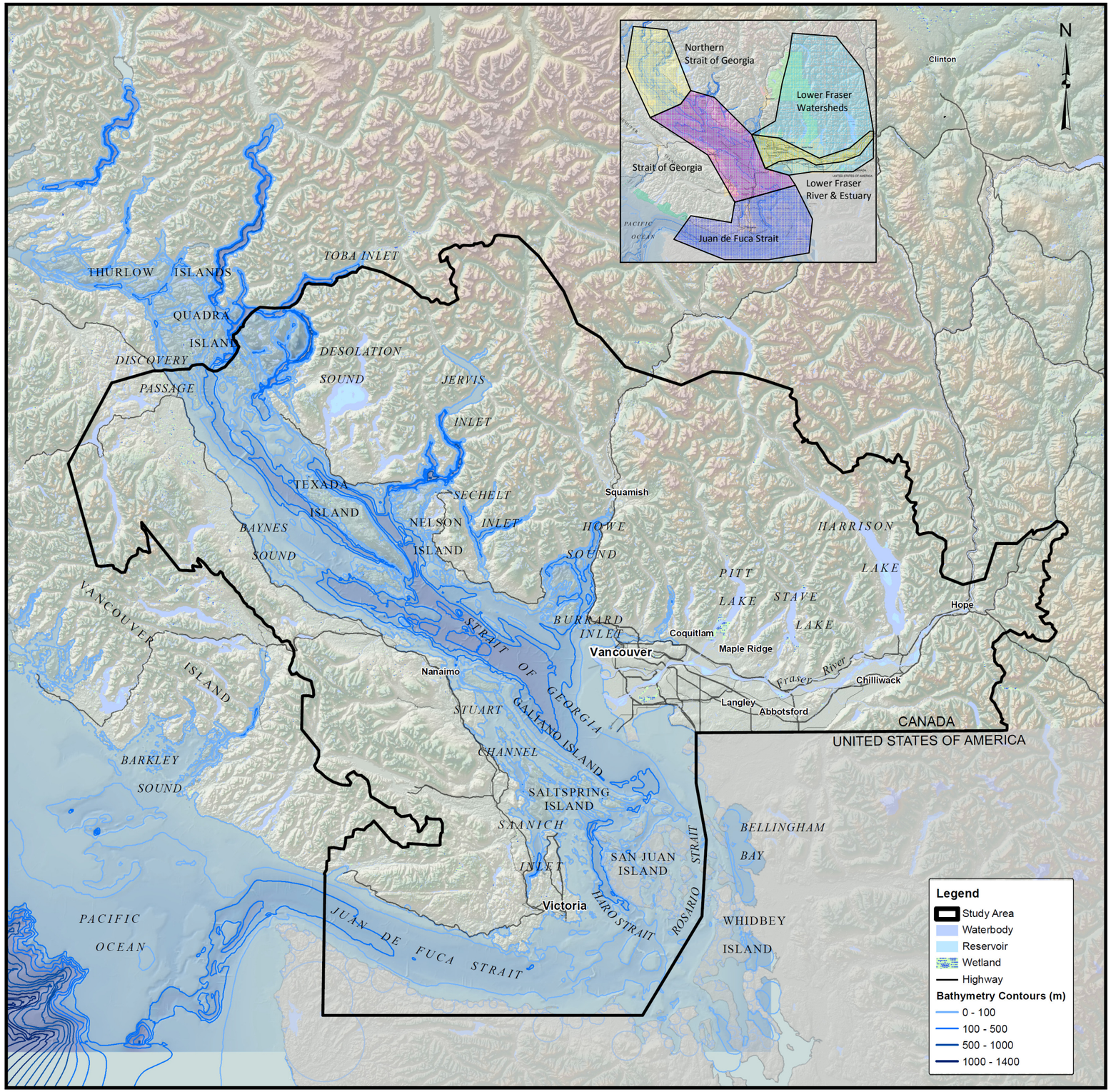
Map 1: Characteristics of the Lower Fraser River and Strait of Georgia Study Area



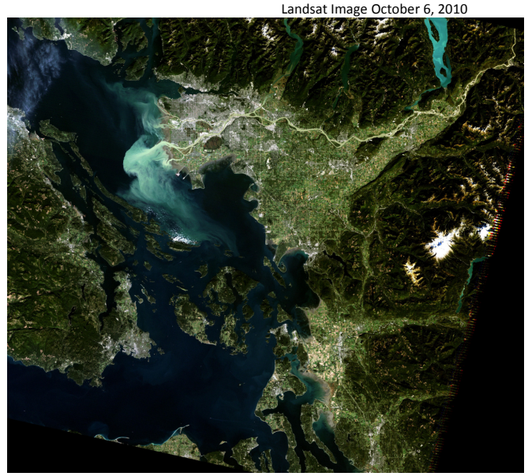
The Lower Fraser River, Fraser River estuary, Strait of Georgia and Juan de Fuca Strait are integral components of a large coastal estuarine ecosystem in south-western British Columbia. The area is used by all Fraser and coastal salmon species across all life history stages.

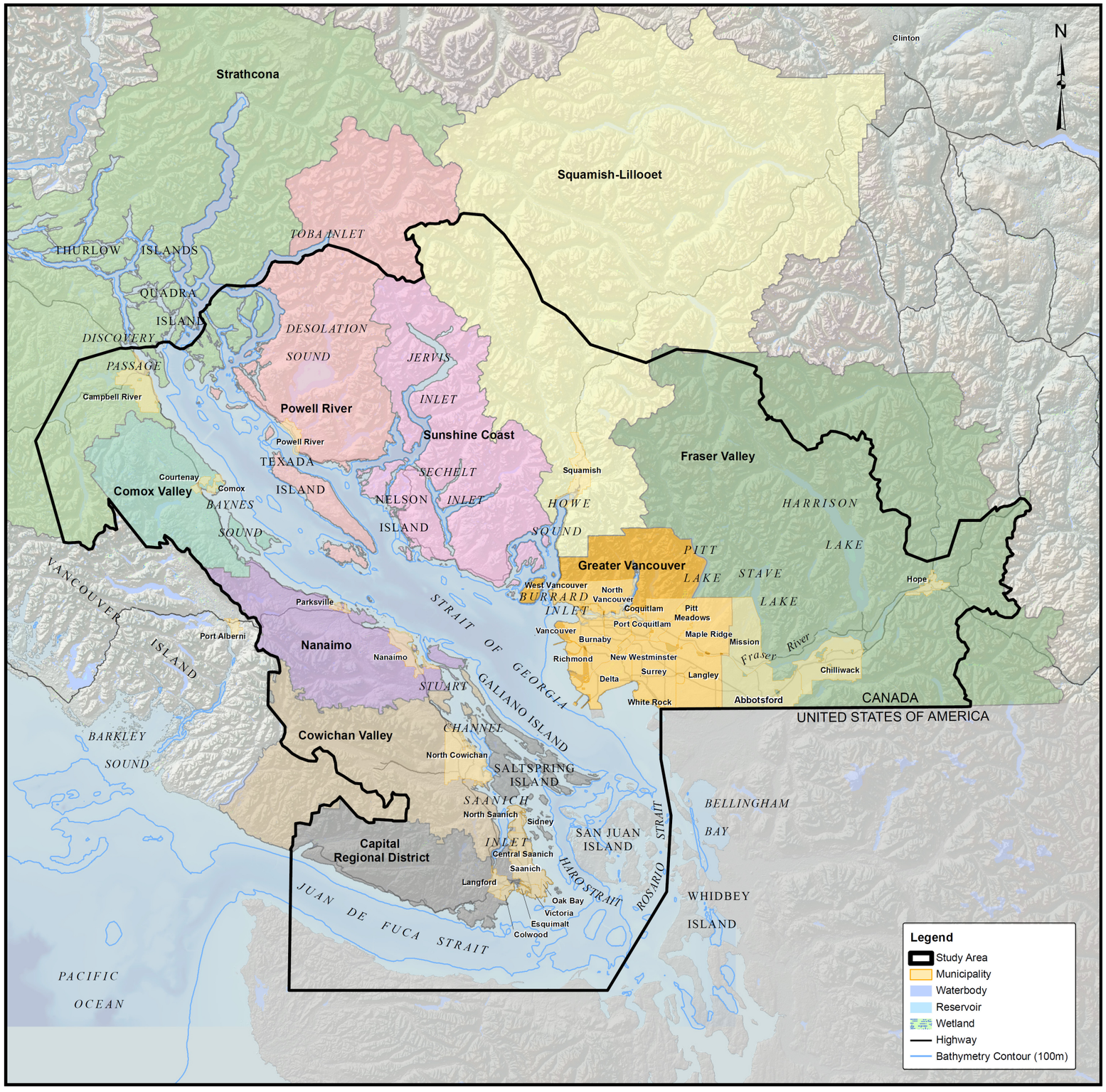
The Strait of Georgia is a semi-enclosed coastal sea over 200 km in length, with depths over 400m in central basin between Vancouver and Nanaimo. The Juan de Fuca Strait is the 100 km long basin and connects Puget Sound and the Strait of Georgia with the Pacific Ocean.

Downstream of Hope, the Fraser River enters the lower valley and a reach of relatively low gradient. The lower Fraser River and its estuary are turbid as a result of accumulation of suspended sediment supplied from a combination of glacial flour and insoluble silts and clays from bedrock and erosion of glacial deposits of fine sediment on river banks, particularly through the middle Fraser upstream of Hope.

The Georgia basin and Lower Fraser study area encompass an area of approximately 49,500 km^2. The lower Fraser River has a length of approximately 165 km from Hope to Sands Head at the outer extent of the Fraser delta (Ellis et al. 2004)

Landsat Image October 6, 2010





Map 2: Regional Districts in Lower Fraser River and Strait of Georgia Study Area

The study area, including the Strait of Georgia and lower Fraser River down-stream of Hope, comprises 10 separate British Columbia Regional Districts and at least 30 moderate to large urban areas and cities.

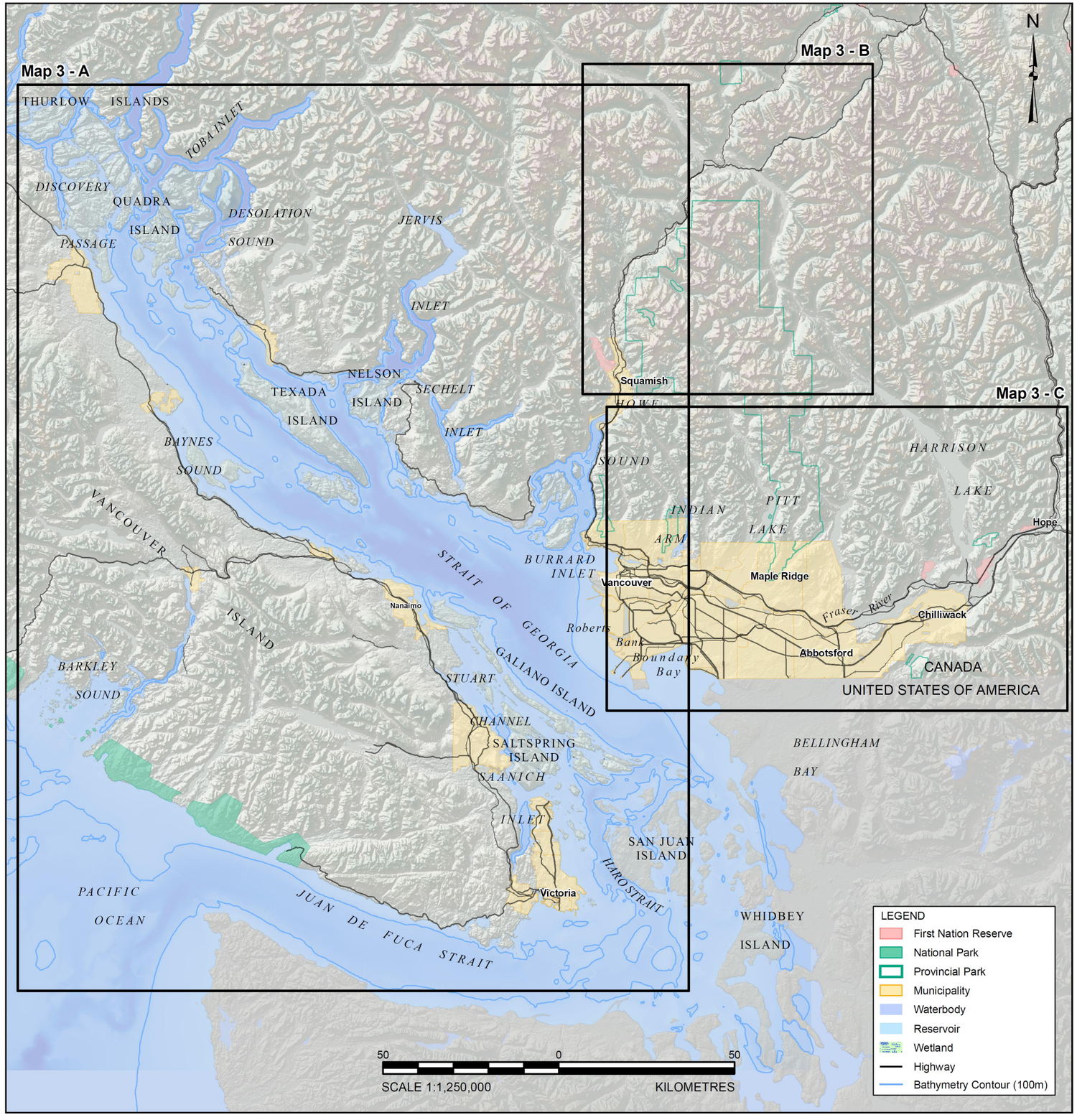
The Regional Districts include:

- Metro (Greater) Vancouver
- Fraser Valley
- Squamish-Lillooet
- Sunshine Coast
- Powell River
- Strathcona
- Comox Valley
- Nanaimo
- Cowichan Valley
- Capital

The larger cities and municipalities in the area include:

- Metro Vancouver (Vancouver, North and West Vancouver, Rich-mond, Surrey, Coquitlam, Port Coquitlam, Delta, White Rock, Port Moody, Pitt Meadows, Maple Ridge),
- Fraser Valley (Langley, Abbotsford, Chilliwack, Hope),
- Greater Victoria,
- Duncan,
- Nanaimo,
- Comox,
- Campbell River,
- Powell River and
- Sechelt.

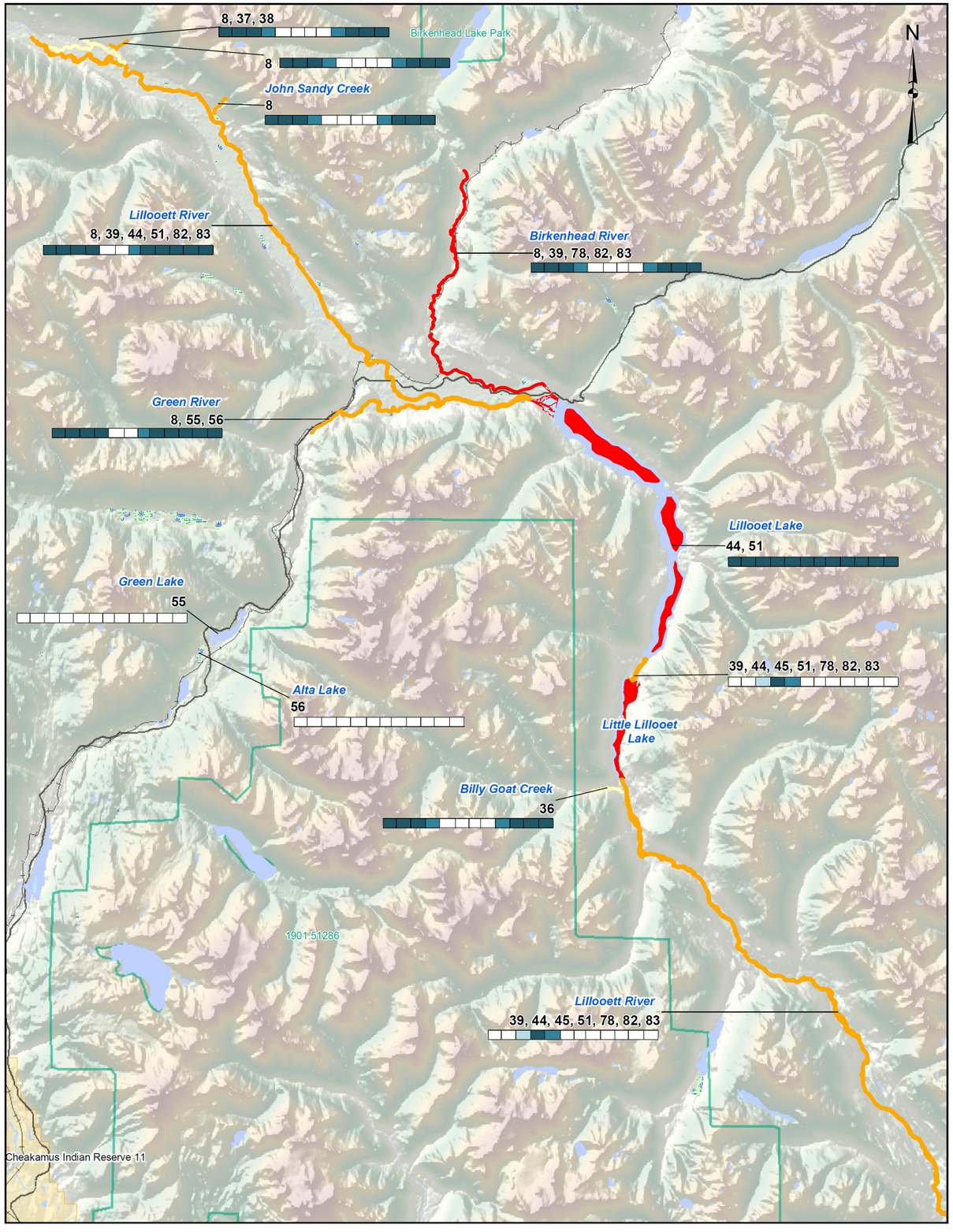
The Greater Vancouver and Fraser Valley areas are the largest urban areas in British Columbia and line the banks of the Lower Fraser River, estuary and Strait of Georgia.



Map 3: Key Map for Adult and Juvenile Fraser Sockeye Habitat Use in the Lower Fraser River and Strait of Georgia

Fraser sockeye salmon distribution and habitat use are presented in the following map series (Map 3-A to 3-D) across the study in Lower Fraser sockeye watersheds, the Lower Fraser River and estuary, and the Strait of Georgia and Juan de Fuca Strait.

The information presented in the maps is based on review of existing literature and data reports and compilation of summary results. The map presented here show Fraser sockeye salmon spawning, rearing and migration habitat use and residence period (timing) and key citations for these observations.



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14	Marshall and Hancock 1985
15	Elvidge 1986
16	DFO 1998
17	DFO [no date]
18	Duval 1975a
19	Duval 1975b
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53	Usher 1986
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55	Whately 1968a
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91	Burgner 1991
92	Labelle 2009
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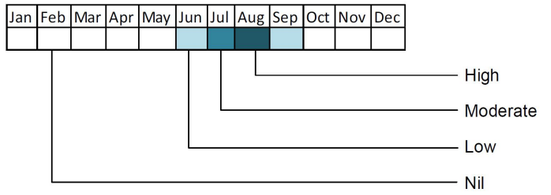
107	St. John et. et. 1992
108	Levings et.al. 2003
109	Brown et.al. 1989
110	Whitehouse and Levings 1989
111	Greer et. al. 1980
112	Levings and Kotyk 1983
113	Levings et.al. 1983

Map 3-A-i: Juvenile Fraser Sockeye Habitat Use in the Lillooet Sub Basin of the Lower Fraser River

A map Juvenile Fraser sockeye salmon habitat use in the Lillooet sub basin of the Harrison watershed was created based on known distribution and residence period in a habitat, derived from existing literature, data reports and available georeferenced spatial information. Citations are provided above each habitat timing (residence) bar graph. Habitats and habitat use were ranked as low, medium (med) or high based on the available literature for specific locations and the documented sensitivity or relative magnitude of habitat use (residence period, sensitivity of life history) by juvenile sockeye; for example a well documented juvenile habitat, known to provide a long term rearing (1 to 2 years) in Harrison Lake (water column greater than 10 m isobaths), was documented as high value habitat. The period of juvenile sockeye residence is provided for each the identified habitat based on use during a specific life history stage (i.e. incubation, fry emergence, rearing, smolt migration) in the Lillooet sub basin. Key habitats in the Lillooet area include juvenile rearing in Lillooet Lake.

LEGEND

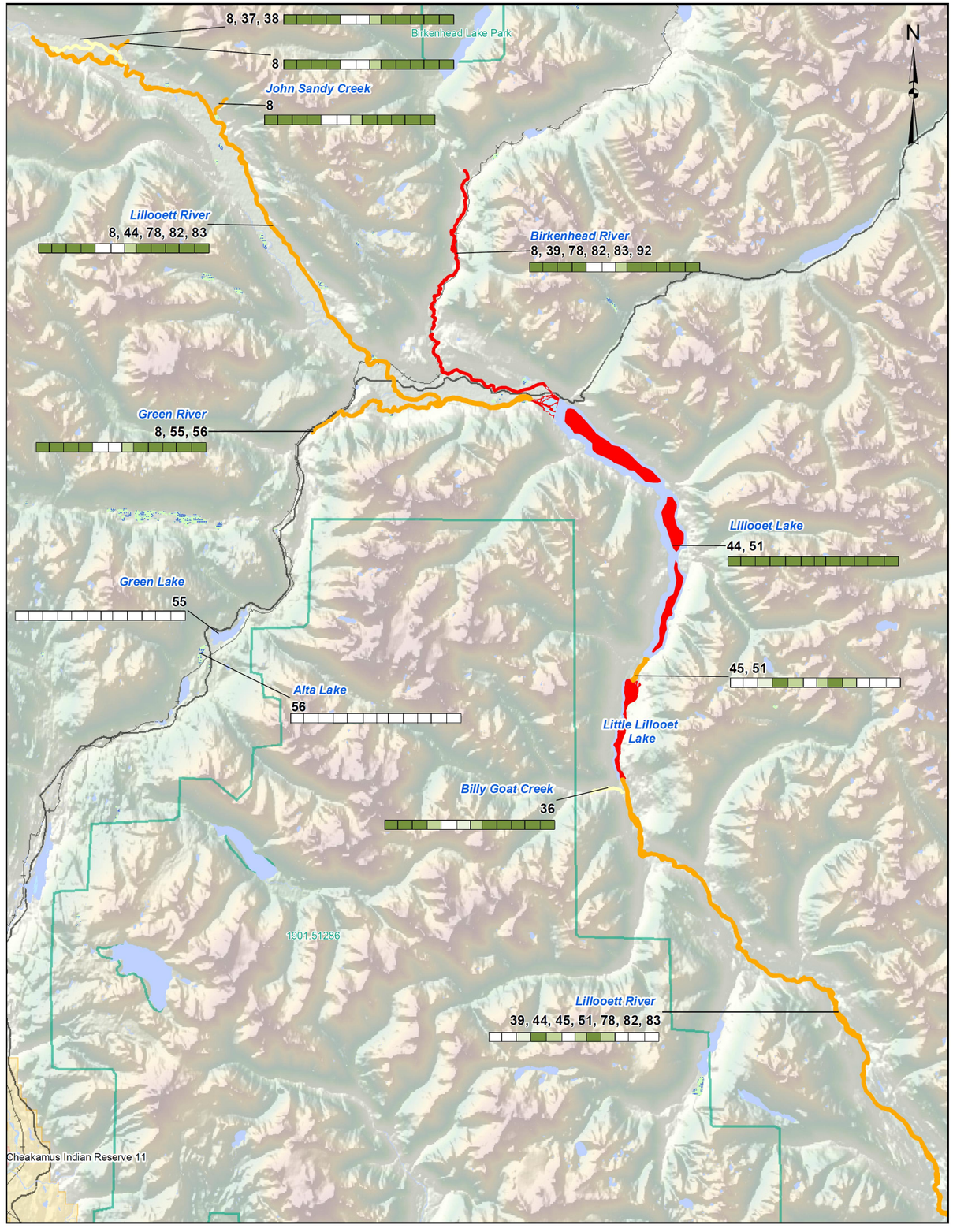
Annual Habitat Use



- Low
- Med
- High
- First Nation Reserve
- National Park
- Provincial Park
- Municipality
- Waterbody
- Reservoir
- Wetland
- Highway
- Bathymetry Contour (100m)

15 0 15

SCALE 1:350,000 KILOMETRES



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37	MELP 1995b
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74	Phillips and Barraclough 1978
75	McKinnell et.al. 1999
76	Cave and Gazey 1994
77	Barraclough and Phillips 1978
78	Schubert and Tadey 1997
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82	Houtman et.al. 2000
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86	Schubert et.al. 2002
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93	Levy 1990
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95	Peterman et.al. 1994
96	Cooke et.al. 2008a
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98	Pascual and Quinn 1991
99	Barraclough 1967a
100	Beamish et.al. 2009
101	Groot et.al. 1985
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108	Levings et.al. 2003
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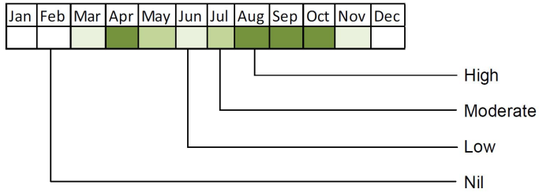
113	Levings et.al. 1983

Map 3-A-ii: Juvenile and Adult Fraser Sockeye Habitat Use in the Lillooet Sub Basin of the Lower Fraser River

A combined map of adult and juvenile Fraser sockeye salmon habitat use in the Lillooet sub basin of the Harrison watershed was created based on known distribution and residence period derived from existing literature, data reports and available georeferenced spatial information. Citations are provided above each habitat timing (residence) bar graph. Habitats and habitat use were ranked as low, medium (med) or high based on the available literature for specific locations and the documented sensitivity or relative magnitude of habitat use (sensitivity of life history, residence period) by adult and juvenile sockeye; for example a well documented high use adult spawning and incubation habitat in Birkenhead River, Lillooet Lake, was documented as high value habitat. The period of sockeye residence is provided for each the identified habitat based on use during a specific life history stage (i.e. incubation, fry emergence, rearing, smolt migration, juvenile and adult migration in marine and freshwater) in the Lillooet sub basin.

LEGEND

Annual Habitat Use

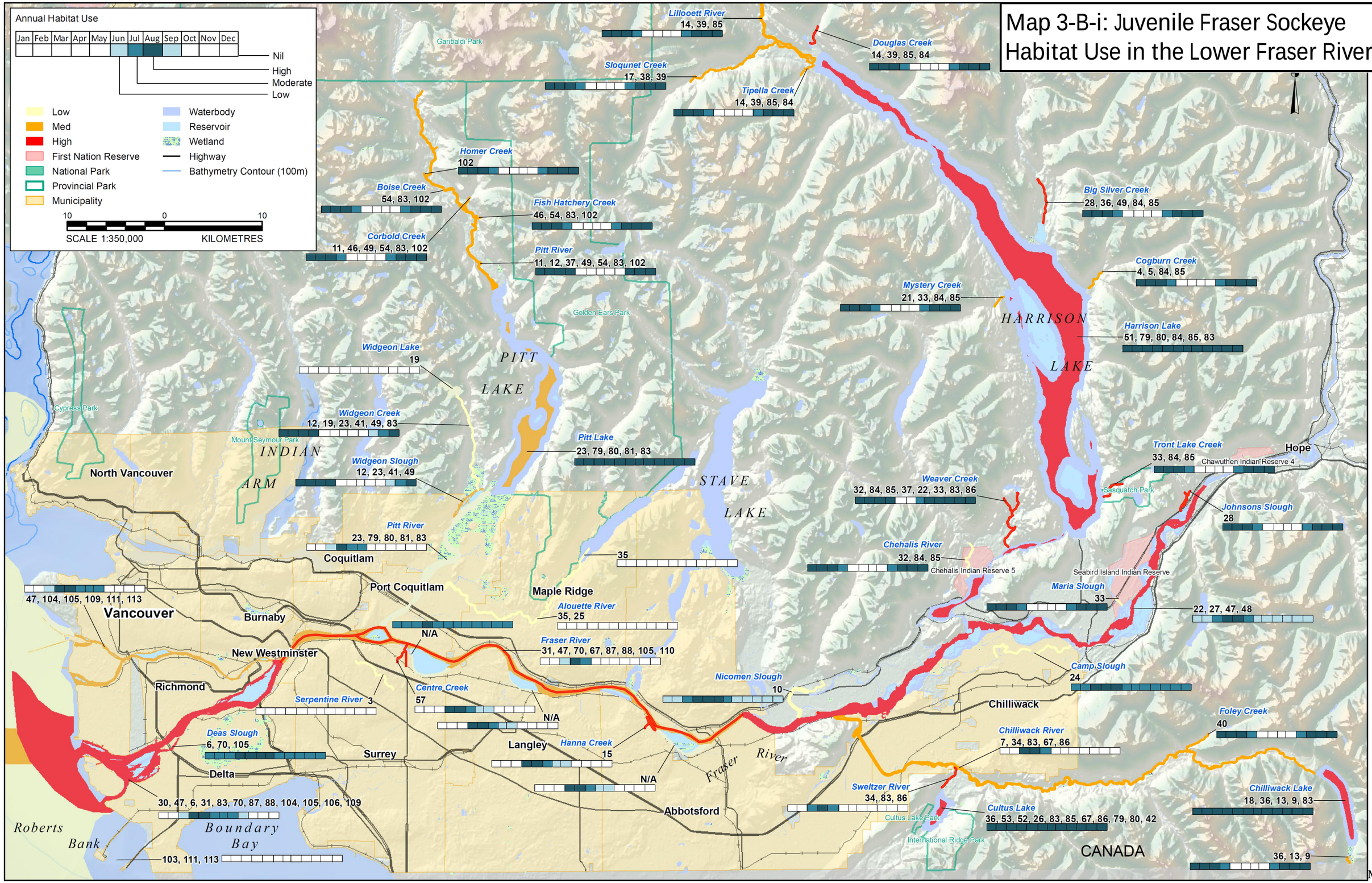


- Low
- Med
- High
- First Nation Reserve
- National Park
- Provincial Park
- Municipality
- Waterbody
- Reservoir
- Wetland
- Highway
- Bathymetry Contour (100m)

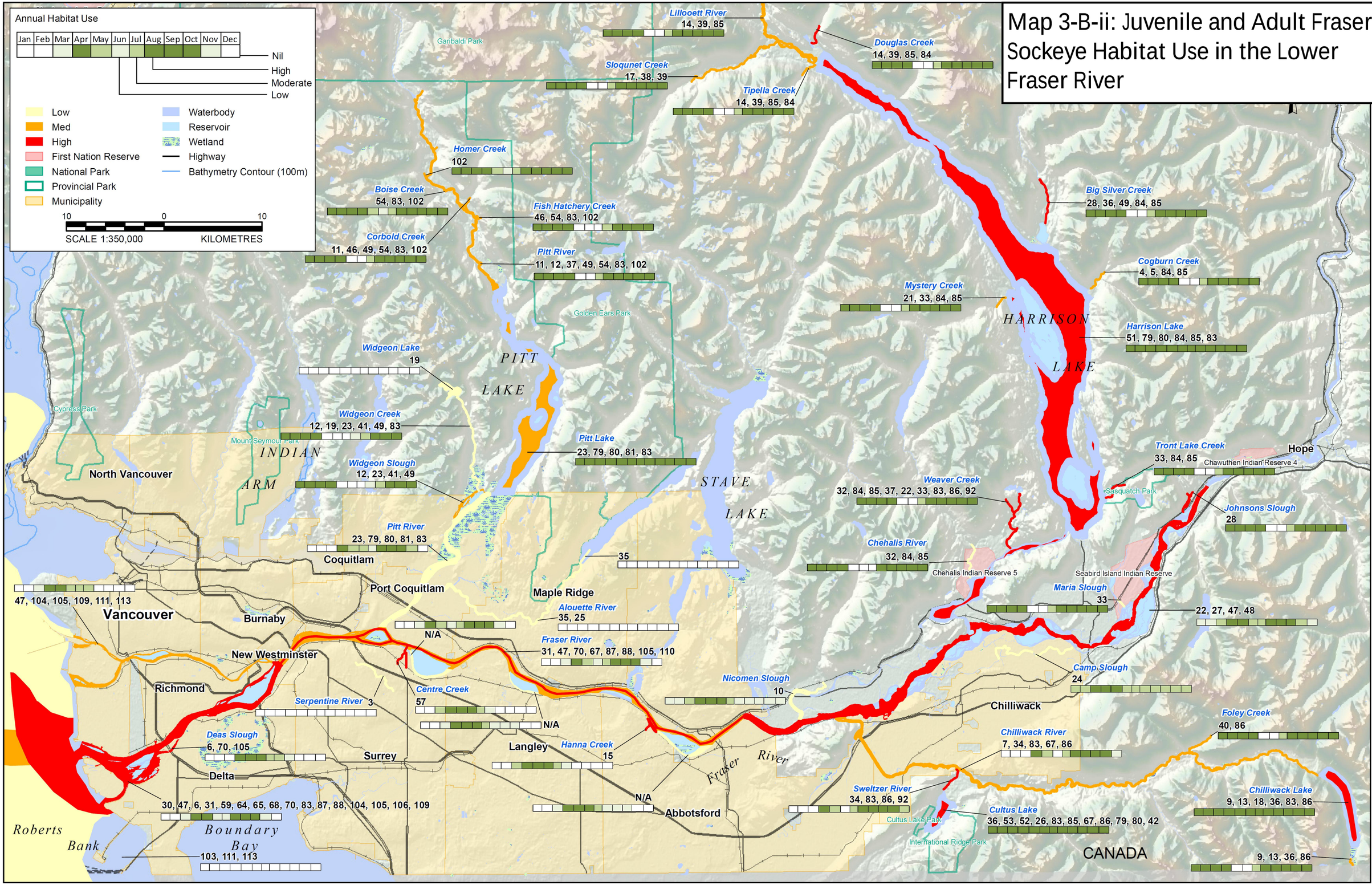
15 0 15

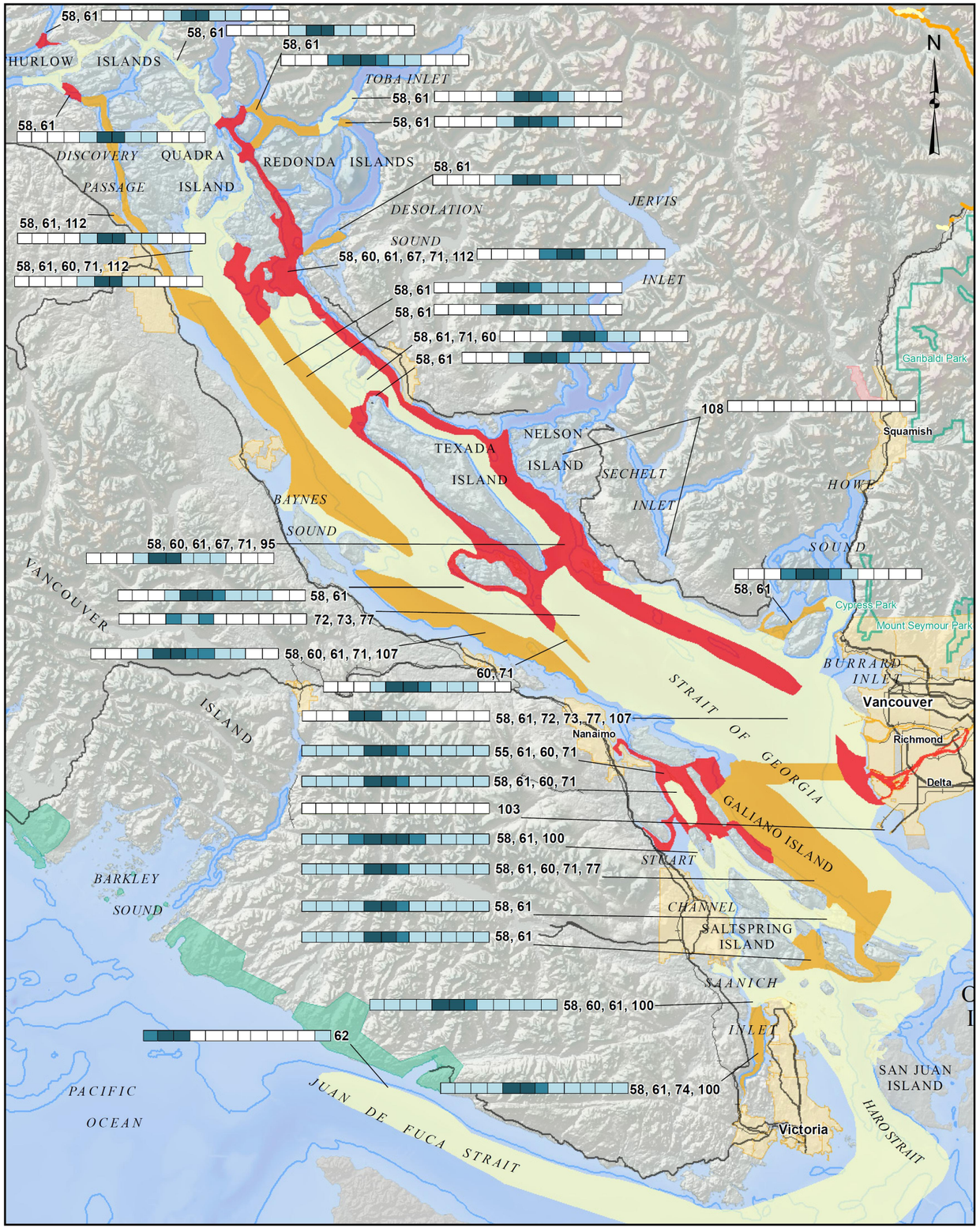
SCALE 1:350,000 KILOMETRES

Map 3-B-i: Juvenile Fraser Sockeye Habitat Use in the Lower Fraser River



Map 3-B-ii: Juvenile and Adult Fraser Sockeye Habitat Use in the Lower Fraser River





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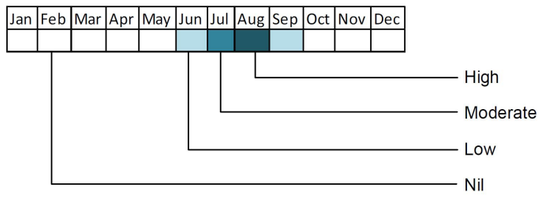
Map 3-C-i: Juvenile Fraser Sockeye Habitat Use in the Lower Fraser River and Strait of Georgia

A map of juvenile Fraser sockeye salmon habitat use in the Fraser River estuary, Strait of Georgia and Juan de Fuca was created based on known distribution and residence period in a habitat, derived from existing literature, site specific catch data reports and available georeferenced spatial information. Citations are provided above each habitat timing (residence) bar graph. Habitats and habitat use were ranked as low, medium (med) or high based on documented catch and relative abundance data in the literature for specific locations and the documented sensitivity or relative magnitude of habitat use (residence period, sensitivity of life history) by juvenile sockeye; for example a aged 1+ post smolt migration (Welch et al. 2009) in the Strait of Georgia using eastern and western migrations routes. The period of juvenile sockeye residence is provided for each identified habitat and migration route. Key habitats in the Strait of Georgia include juvenile migration route on the eastern side of Texada Island at depths 0– 15m, over the 100 m isobath.

LEGEND

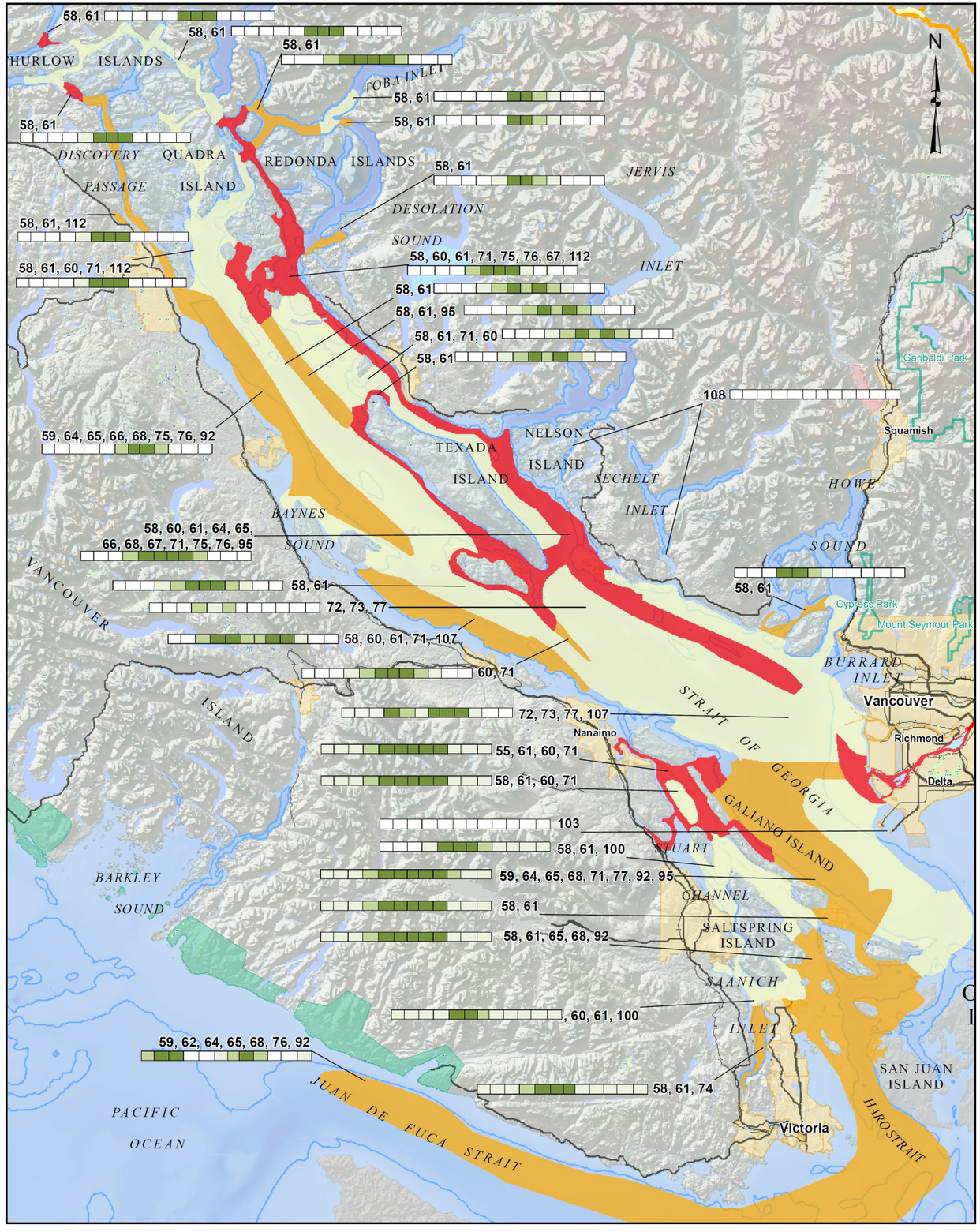
Annual Habitat Use



Low
Med
High
First Nation Reserve
National Park
Provincial Park
Municipality
Waterbody
Reservoir
Wetland
Highway
Bathymetry Contour (100m)

50 0 50

SCALE 1:1,007,260 KILOMETRES



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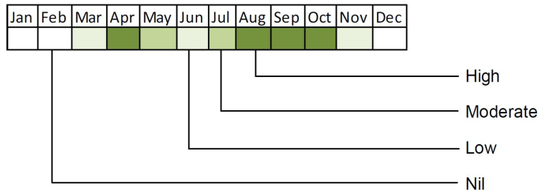
Map 3-C-ii: Juvenile and Adult Fraser Sockeye Habitat Use in the Lower Fraser River and Strait of Georgia

A combined map of adult and juvenile Fraser sockeye salmon habitat use in the Fraser River estuary, Strait of Georgia and Juan de Fuca was created based on known distribution and residence period in a habitat derived from existing literature, site specific catch or monitoring data reports and available georeferenced spatial information. Citations are provided above each habitat timing (residence) bar graph. Habitats and habitat use were ranked as low, medium (med) or high based on documented catch, indices and relative abundance data in the literature for specific locations and the documented sensitivity or relative magnitude of habitat use (residence period, sensitivity of life history) by adult and juvenile sockeye; for example the timing of adult migration (Cooke et al. 2008) in the Strait of Georgia / Lower Fraser using southern and northern diversion migrations routes. The period of adult and juvenile sockeye residence is provided for each identified habitat and migration route. Key habitats in the Strait of Georgia include key migration routes and adult holding areas in the strait and Fraser estuary.

LEGEND

Annual Habitat Use

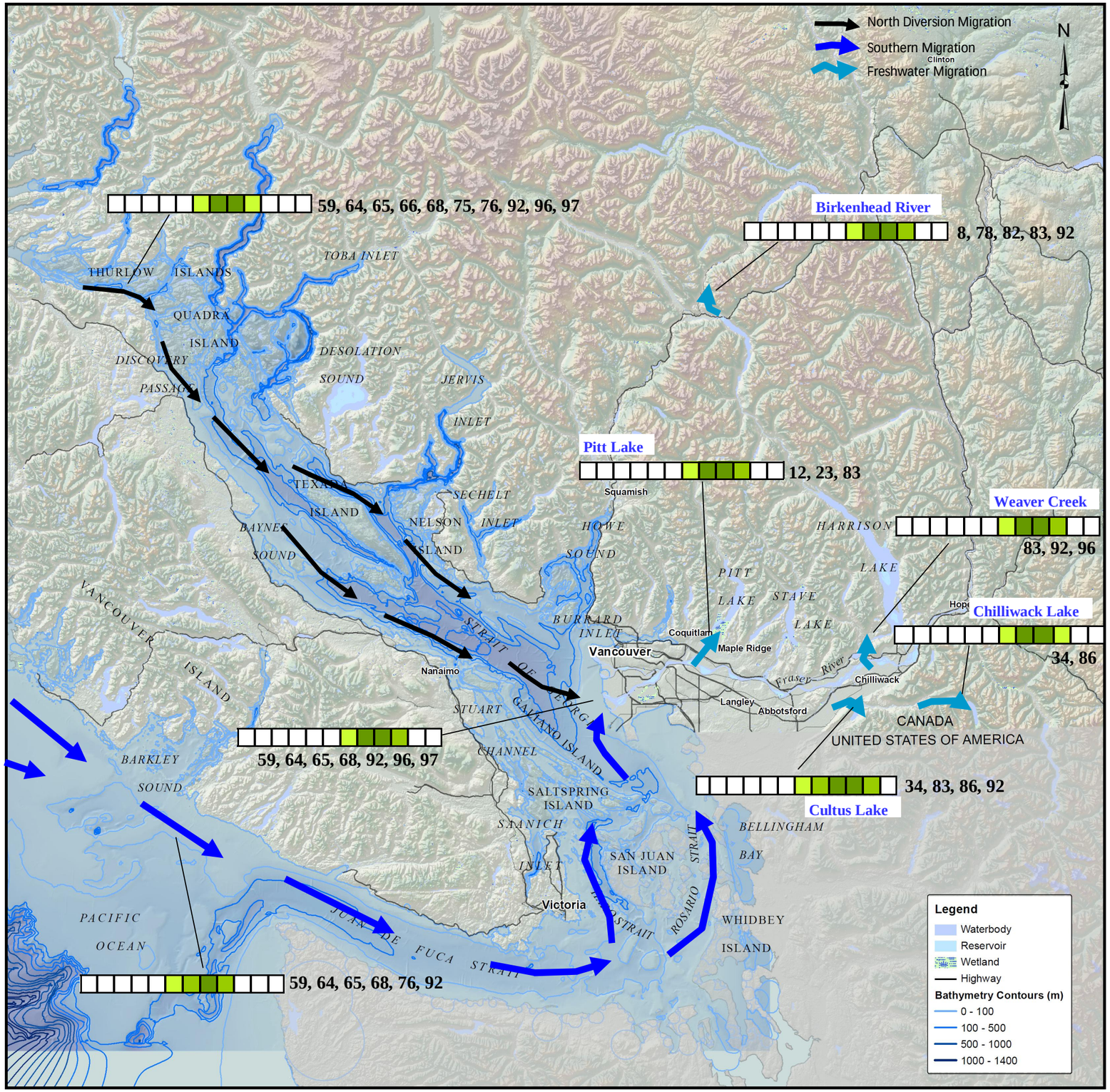


- Low
- Med
- High
- First Nation Reserve
- National Park
- Provincial Park
- Municipality
- Waterbody
- Reservoir
- Wetland
- Highway
- Bathymetry Contour (100m)

50 0 50

SCALE 1:1,000,000 KILOMETRES

Map 3-D: Adult Migration Routes and Habitat Use in the Lower Fraser River and Strait of Georgia

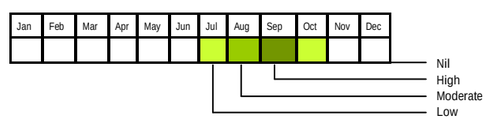


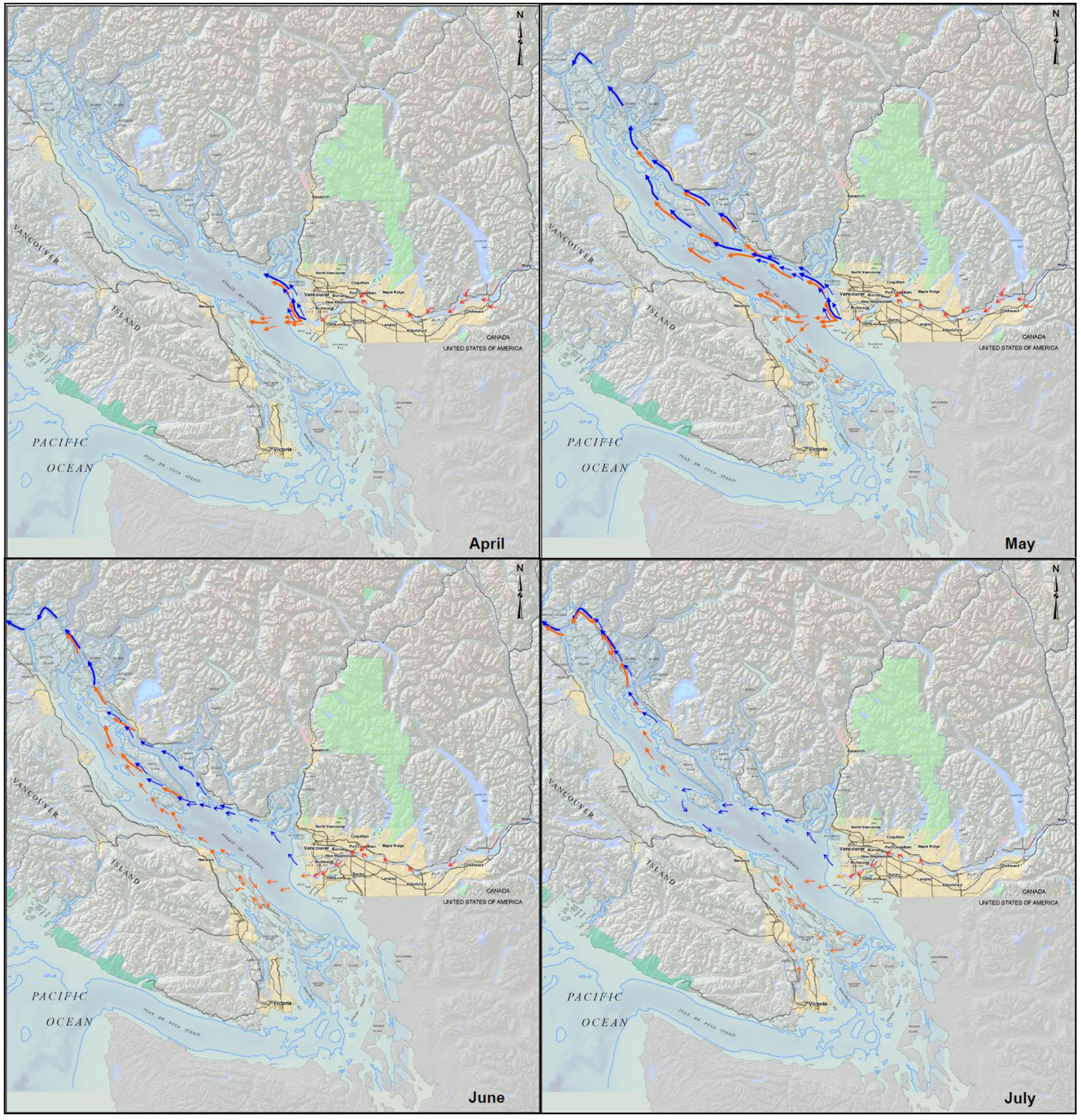
Adult sockeye salmon are distributed throughout the lower Fraser River and Strait of Georgia and use habitats for migration, holding and spawning. Migratory corridors and holding areas extend through the Strait of Georgia, Fraser estuary, Lower Fraser River, and lakes and rivers adjacent to spawning areas. The Strait of Georgia, Juan de Fuca and Lower Fraser River are used by all Fraser sockeye stocks migrating from rearing areas in the North Pacific Ocean to return to freshwater spawning areas. Two main migration routes have been observed through the Strait of Georgia including (a) southern higher use route, and (b) northern diversion route along the western edge of the Strait of Georgia.

Sockeye salmon spawning distribution in the Lower Fraser River, from Hope to Sands Head, extends into 4 watersheds including the Lillooet, Harrison, Chilliwack and Pitt. Key spawning habitats are found in the Lower Harrison at the Weaver Creek spawning channel, in portions of Harrison Lake and its tributaries, and in the upper Harrison watershed in the Lillooet sub basin in the Birkenhead River. Sockeye spawning habitats are also found in the Pitt watershed above Pitt Lake in the lower Pitt River and Widgeon Creek and slough, and in the Chilliwack watershed in tributaries and beaches in Cultus Lake and in the Chilliwack River upstream of Chilliwack Lake.

Adult sockeye salmon distribution and habitat use were derived based on review of existing literature and data reports. The map presented here shows the spatial distribution of adult sockeye habitat use, timing and key citations for these observations.

8	Brown et.al. 1979
23	Henderson et.al. 1991
34	Marshall et.al. 1980
59	Groot and Quinn 1987
64	Gable and Cox-Rogers 1993
65	Crossin et.al. 2007
66	Kolody and Healey 1998
68	Hamilton 1985
75	McKinnell et.al. 1999
76	Cave and Gazey 1994
78	Schubert and Tadey 1997
82	Houtman et.al. 2000
83	Schubert and Houtman 2007
86	Schubert et.al. 2002
92	Labelle 2009
96	Cooke et al. 2008a
97	Cooke et al. 2008b
98	Pascual and Quinn 1991





Map 4-A: Concept Model of Juvenile Sockeye Micro-Habitat Use and Migration in the Lower Fraser River and Strait of Georgia

April to July

Warm Low Productivity Year

Juvenile sockeye habitat use, residence period and migration routes were integrated into a concept model based on existing information and observations to derive a pattern of micro-habitat use and distribution. Key factors were identified which influence juvenile sockeye habitat use including:

- Lower Fraser River—timing and downstream aggregations (pulses) related to magnitude/timing of Fraser River discharge;
- Lower Fraser River—extent and timing of Fraser River freshet related to habitat use of sloughs, off channel areas by Harrison river-type 0+ sockeye;
- Strait of Georgia—eastern /western migration routes and residence period in the strait related to prevailing wind direction outside the Fraser estuary, surface currents related to marine water density (Fraser discharge, winds, tides), sockeye size, abundance and school size (swimming speed and density dependent feeding and predation);
- Strait of Georgia—residence period in northern migration related to warm years and increased spatial heterogeneity and lower abundance of available zooplankton prey and higher than optimal temperatures and altered surface currents;
- Strait of Georgia—residence period in western and southern migration related to size and swimming speed of Harrison river-type 0+ sockeye.

Sources: Barraclough and Phillips 1978, Healey 1978, Groot and Cooke 1987, Peterman et al. 1994, Crittenden 1994, Groot et al. 1989, Burgner 1991, Haegele 1997, DFO 2002, DFO 2003, Sweeting et al. 2008, Beamish et al. 2005, 2008, 2009, Welch et al. 2009, Preikshot et al. 2010)

Large sized 1+ aged smolts (fast swimming); NW wind direction

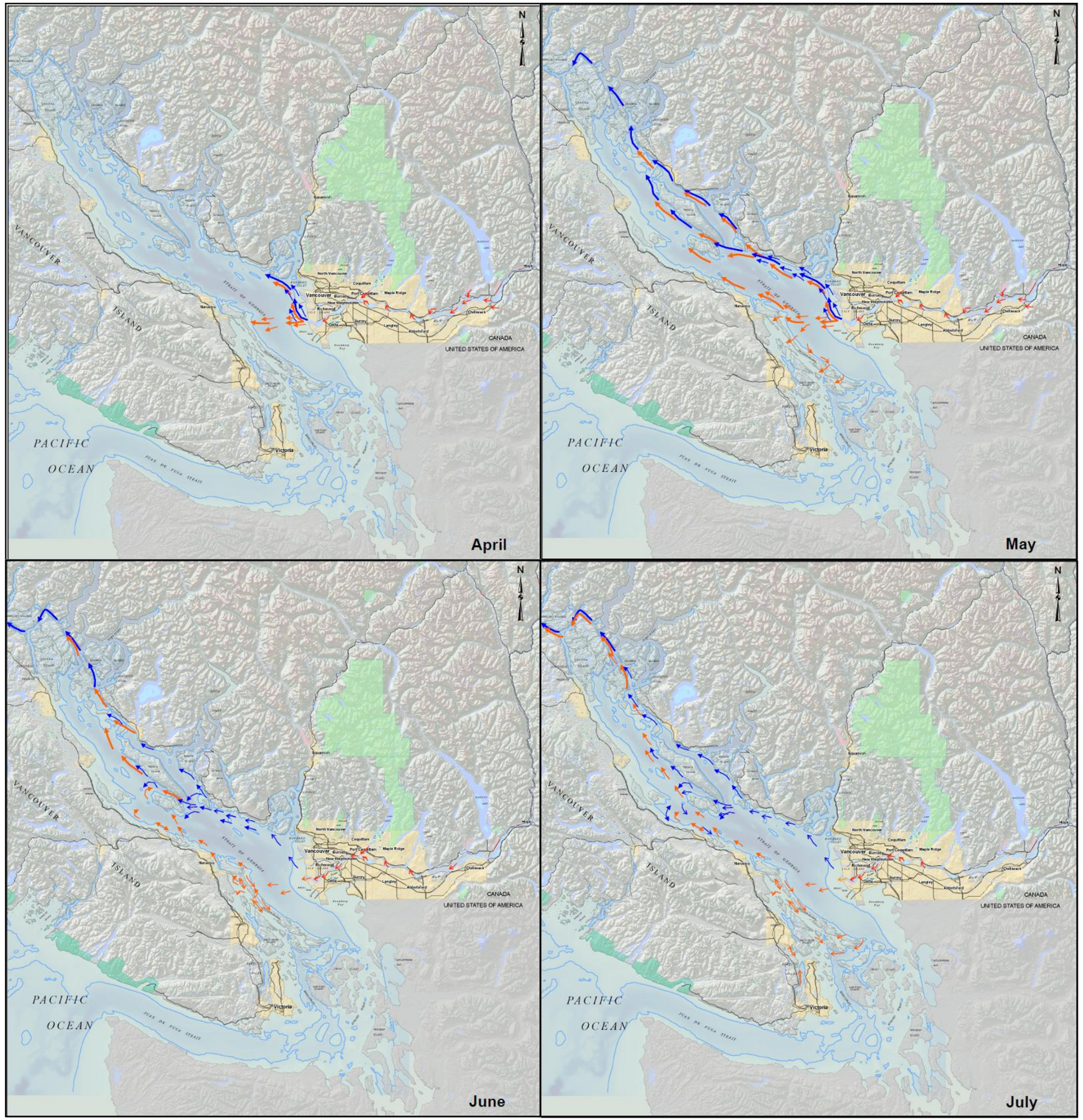
Small sized 1+ aged smolt (slow swimming); NW wind direction

0+ aged fry - Harrison, upper Fraser river-type sockeye (slow swimming); NW wind direction

Large sized 1+ aged smolts (fast swimming); SE wind direction

Small sized 1+ aged smolts (slow swimming); SE wind direction

0+ aged fry - Harrison, upper Fraser river-type sockeye (slow swimming); SE wind direction



Map 4-B: Concept Model of Juvenile Sockeye Micro-Habitat Use and Migration in the Lower Fraser River and Strait of Georgia

April to July

Cool High Productivity Year

Juvenile sockeye habitat use, residence period and migration routes were integrated into a concept model based on existing information and observations to derive a pattern of micro-habitat use and distribution. Key factors were identified which influence juvenile sockeye habitat use including:

- Lower Fraser River—timing and downstream aggregations (pulses) related to magnitude/timing of Fraser River discharge;
- Lower Fraser River—extent and timing of Fraser River freshet related to habitat use of sloughs, off channel areas by Harrison river-type 0+ sockeye;
- Strait of Georgia—eastern /western migration routes and residence period in the strait related to prevailing wind direction outside the Fraser estuary, surface currents related to marine water density (Fraser discharge, winds, tides), sockeye size, abundance and school size (swimming speed and density dependent feeding and predation);
- Strait of Georgia—residence period in northern migration related to cool years and reduced spatial heterogeneity and higher abundance of available zooplankton prey and optimal temperatures and surface currents;
- Strait of Georgia—residence period in western and southern migration related to size and swimming speed of Harrison river-type 0+ sockeye.

Sources: Barraclough and Phillips 1978, Healey 1978, Groot and Cooke 1987, Peterman et al. 1994, Crittenden 1994, Groot et al. 1989, Burgner 1991, Haegele 1997, DF0 2002, DFO 2003, Sweeting et al. 2008, Beamish et al. 2005, 2008, 2009, Welch et al. 2009, Preikshot et al. 2010)

Large sized 1+ aged smolts (fast swimming); NW wind direction

Small sized 1+ aged smolt (slow swimming); NW wind direction

0+ aged fry - Harrison, upper Fraser river-type sockeye (slow swimming); NW wind direction

Large sized 1+ aged smolts (fast swimming); SE wind direction

Small sized 1+ aged smolts (slow swimming); SE wind direction

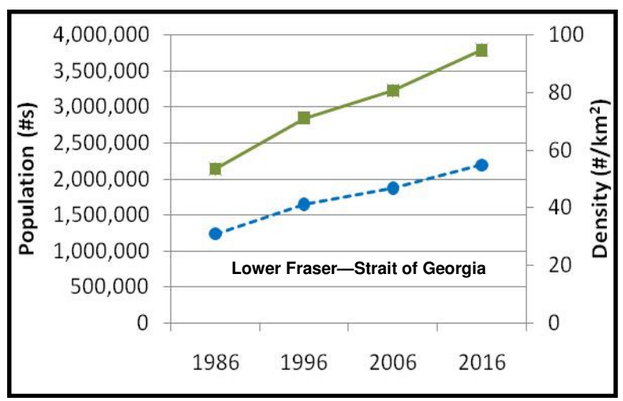
0+ aged fry - Harrison, upper Fraser river-type sockeye (slow swimming); SE wind direction

Map 5-A: Regional District Population Size and Density in the Lower Fraser River and Strait of Georgia

The distribution and population size and density are general indicators of human activities and development associated with potential effects on Fraser sockeye salmon habitats through direct loss or removal of habitats and degradation of habitats through contamination, nutrient and sediment discharge.

The Lower Fraser River and Strait of Georgia are home to more than 3.5 million residents in 10 regional districts and at least 30 large cities and urban centres. Projections from Stats Canada and BC Stats indicate a continued increase in population size and density across all Regional Districts. Population density is highest in the Greater Vancouver area (Metro Vancouver Regional District) with projections rising to approximately 1000 residents per square km by 2016.

Source: Population statistics for Regional Districts and municipalities were derived from national and provincial census data from 1986, 1991, 1996 and 2006, with projections of population size and density to 2010-2016 by BC Stats, BC Ministry of Citizens' Services.

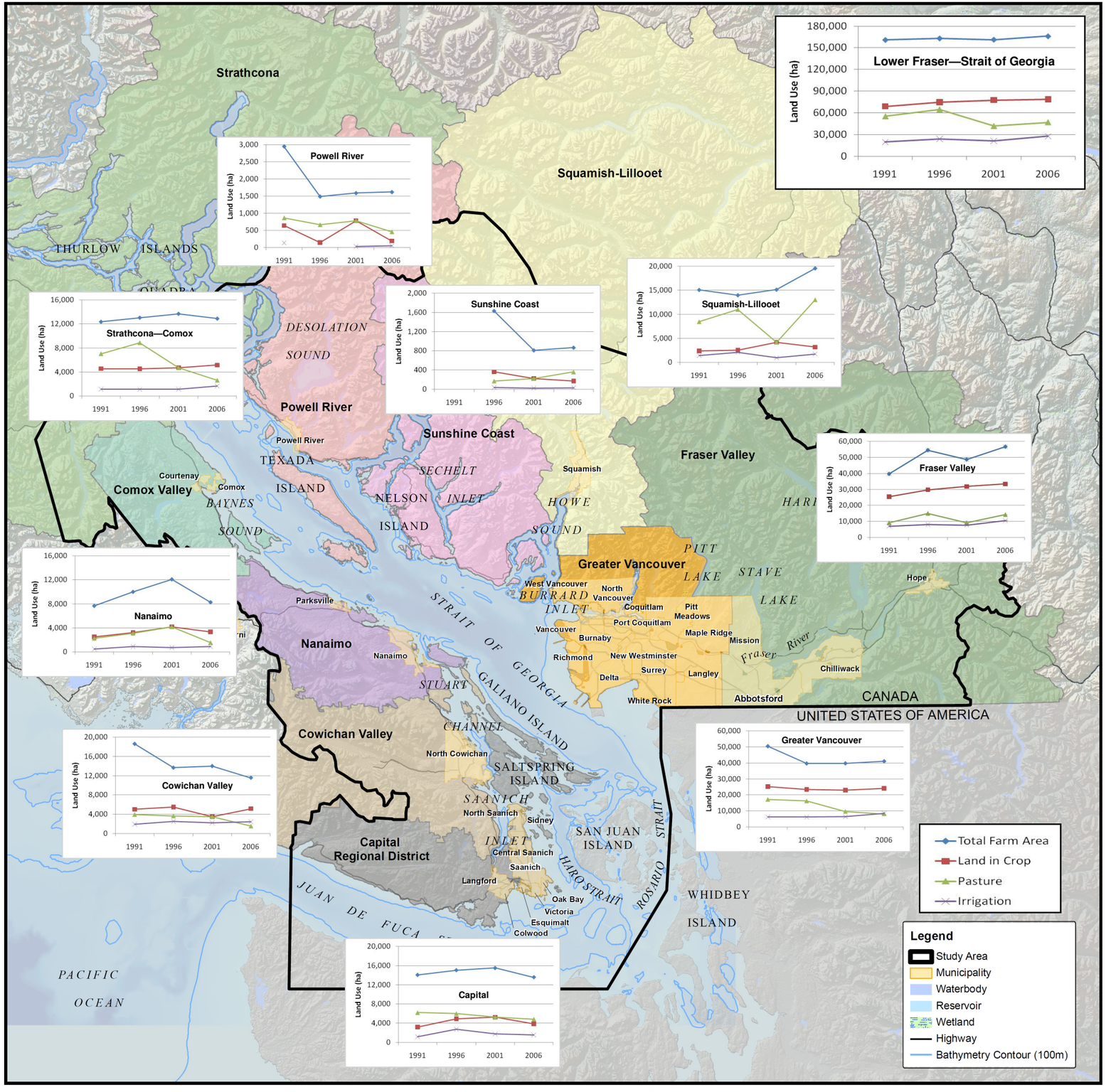


Map 5-B: Municipal Population Size and Density in the Lower Fraser River and Strait of Georgia

Population size and density have increased over the past 25 years more than two fold in many cities around the Strait of Georgia. Cities near to the lower Fraser River, like Surrey, Coquitlam, and Abbotsford, have shown large increases in population size and density over the past 25 years. The highest proportion of the population in the region and study area live around the lower Fraser River and estuary in the lower Mainland area comprising Greater Vancouver municipalities and to a smaller extent Fraser Valley cities. Many of the other smaller communities on the Georgia Basin including Sunshine Coast, Powell River, Strathcona and Vancouver Island communities, have also shown increased population size and density over the past 25 years.

Projections from Stats Canada and BC Stats indicate a continued increase in population size and density in all these communities across the study area. Population density is highest in the City of Vancouver with projections rising to greater than 5000 residents per square km by 2016.

Source: Population statistics for municipalities were derived from national and provincial census data from 1986, 1991, 1996 and 2006, with projections of population size and density to 2010-2016 by BC Stats, BC Ministry of Citizens' Services. Municipal population data for the study area was collected from the 1986-2006 Census Profiles from Statistics Canada, but prepared by BC Stats. In some cases, data was aggregated to reflect changes in municipal delineations or changes in how data was presented from census to census.



Map 6-A: Regional District Agricultural Land Use and Area in the Lower Fraser River and Strait of Georgia

The characteristics of resource and land use provide an indication of potential effects of human activities and development and on Fraser sockeye salmon habitats in the lower Fraser River and Strait of Georgia. Impacts to sockeye salmon from agricultural land use arise from loss or degradation of freshwater habitats used by sockeye salmon for spawning, incubating and rearing; for example enhanced or reduced erosion and sediment transport in key sockeye incubation habitats. Changes in agricultural land use and practices can often have a more direct link than population size and density, to potential changes in the quality and quantity of habitats available for sockeye salmon use.

The lower Fraser River, Fraser Valley and Georgia Basin have a mix of land uses, ranging from the urban and industrial centres of Greater Vancouver and the Fraser Valley through recreation and urban and rural forest lands and farm lands.

Much of the agricultural land around the Georgia Basin and Vancouver and Fraser Valley areas is protected from residential and industrial development by the Agricultural Land Reserve. Agricultural land is often intensively farmed through a combination of crops, pasture, animal production. The Vancouver area and Fraser Valley support greater than half of British Columbia's annual agricultural revenue, but comprise a small proportion of BC's total farm land area.

Total agricultural land area, and the portion of land comprising crops, pastures and irrigated lands has not shown large change over the past 20 years. Areas of the Fraser Valley, and Squamish-Lillooet Regional District have shown a 20 percent increase in agricultural land use.

Source: Agricultural data for the study area was collected from the 1986 to 2006 Agricultural Census data tables. In some cases, data was aggregated to reflect changes in Regional District delineations or changes in how data was presented from census to census.

Map 6-B: Regional District Agricultural Crop Area and Livestock Production in the Lower Fraser River and Strait of Georgia

Total agricultural land area, and the portion of land comprising specific intensively farmed crops and farmed animals (livestock) has shown a 10 percent increase in land use and production over the past 20 years in the Lower Fraser River and Strait of Georgia basin. The Fraser, Cowichan and Comox Valleys have shown an increase in corn producing farm area, while nursery and fruit tree farm area have increased in Vancouver and Victoria. Total farm animal production has increased in the Fraser Valley. Farm animal production and management practices have changed over the past half century and have greatly improved control to limit potential nutrient runoff associated with farm animal waste. Nursery and fruit tree farms often have a lower general impact on aquatic habitats than active and intensive farm practices which require higher levels of tilling and fertilizer use associated with corn, vegetables and field crops.

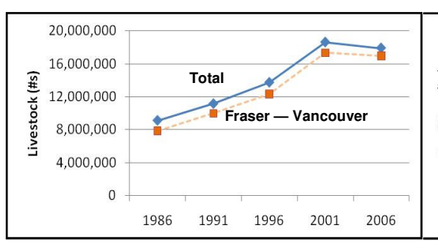
Source: Statistics Canada— Census of Agriculture.

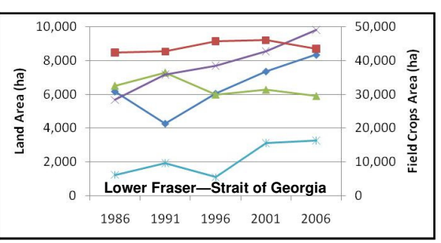
1986 Canadian Census of Agriculture: British Columbia. Ottawa: Ministry of Supply and Service Canada, 1987. Catalogue number 96-112

1991 Agricultural Profile of British Columbia, Part One. Ottawa: Ministry of Industry, Science, and Technology, 1992. Catalogue number 95-393

1996 Agricultural Profile of British Columbia. Ottawa: Ministry of Industry, 1997. Catalogue number 95-181-XPB

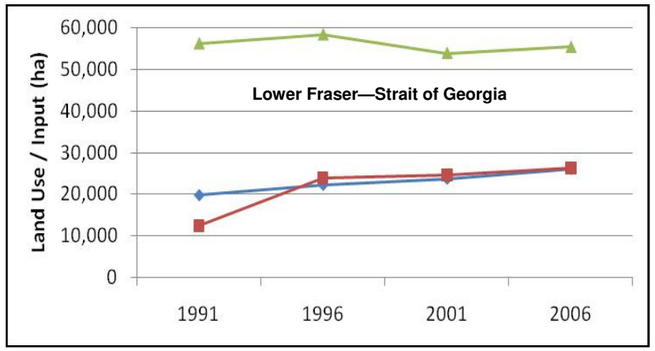
2006 Census of Agriculture, Farm Data and Farm Operator Data, for British Columbia Census Subdivisions, 2006 and 2001 Agricultural Census Data (table). Catalogue no. 95-629-XWE. Ottawa. May 16



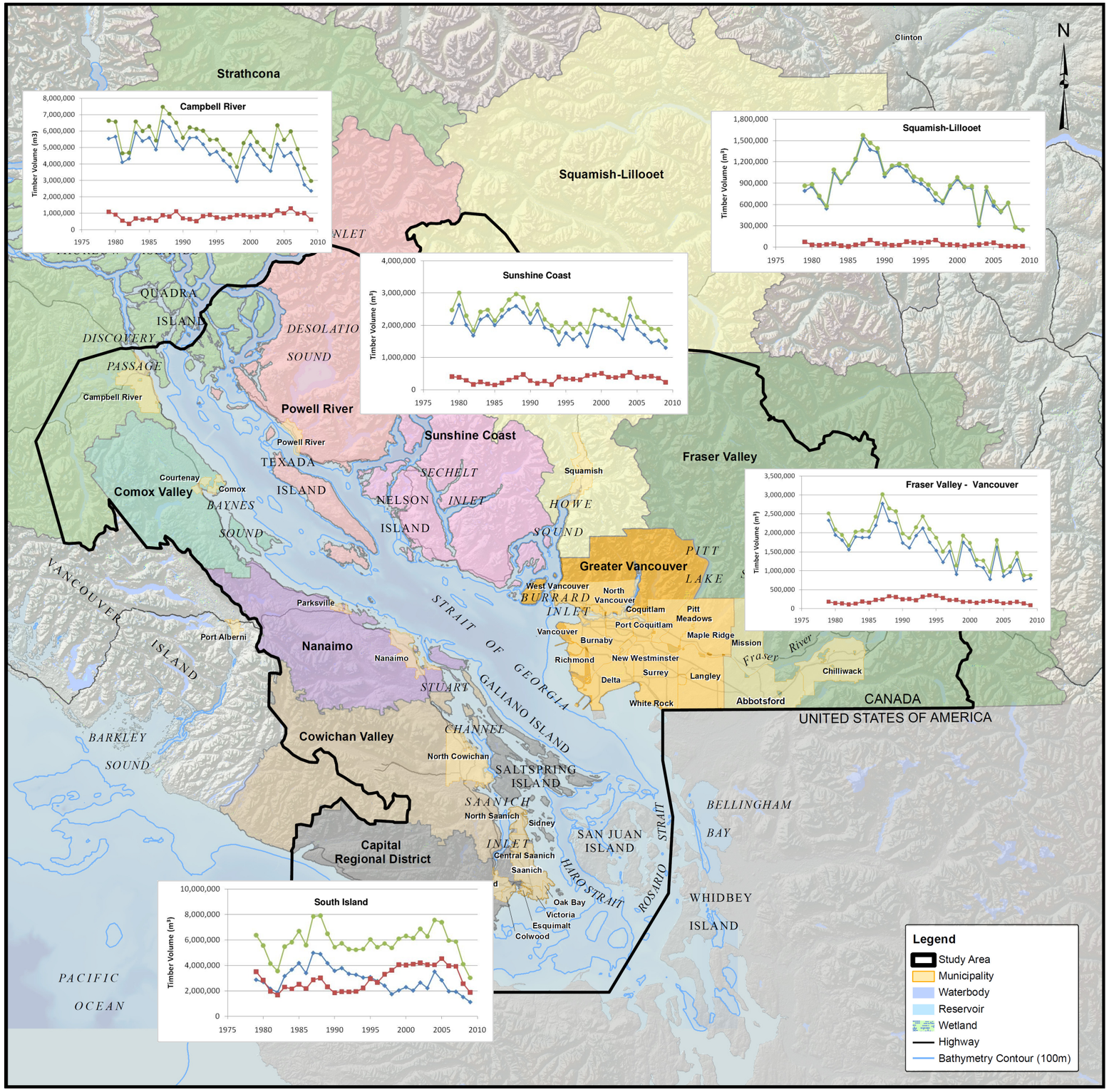


Map 6-C: Regional District Agricultural Land Use Practices and Applications in the Lower Fraser River and Strait of Georgia

Agricultural practices and application of herbicides, pesticides (both insecticides and fungicides) and fertilizers to farm lands and crops has remained consistent or shown a slight decline in use and land area application during the past 2 decades. Herbicide, pesticide and fertilizer use for crops and the associated land and surface runoff, local discharge and transport have been identified in as contaminants in aquatic habitats and a variety of freshwater and marine species in the Lower Fraser River and Strait of Georgia (i.e., Johannessen et al. 2008). Due to regulation and best practices, herbicides, pesticides and fertilizers concentrations in aquatic ecosystems have demonstrated a trend over time associated with early use in the 1950's, concentration increase and subsequent decrease in use to present (see Map 14).



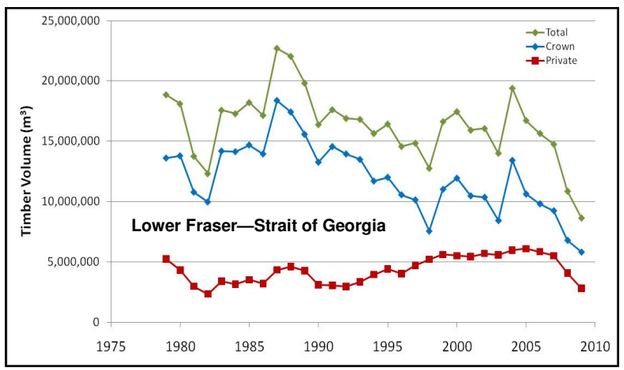
Map 7-A: Forest Timber Volume in the Lower Fraser River and Strait of Georgia

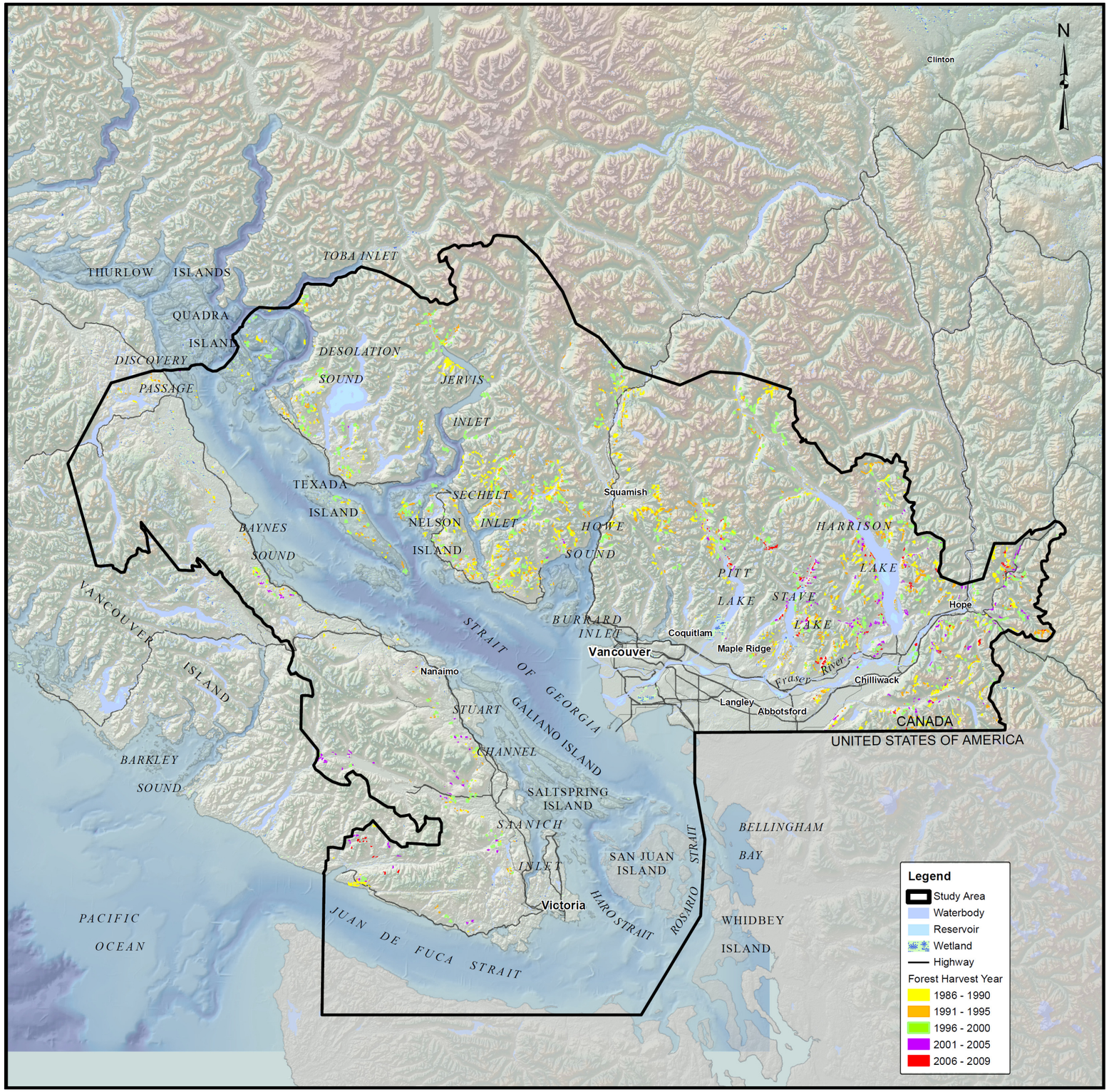


Forest harvesting activities are used as an indicator of human development and land and resource use and inferred potential impacts on Fraser sockeye salmon habitats in the Lower Fraser River and Strait of Georgia. Forest harvesting activities are known to have a negative effect on water quality and quantity and adverse impacts to freshwater and estuarine salmon habitats, and potentially salmon production at various freshwater life history stages (i.e., coho—Holtby and Scrivener 1989; sockeye— MacIsaac 2003).

Forest harvesting is often the major land use activity in coastal British Columbia. Forest harvesting in the Georgia Basin began in the 1800's and had increased until the 1950's. Forest harvesting has shown considerable variation in the amount of harvested timber volume over the past 3 decades across all regions of the Georgia Basin; presumably associated with market driven demand for timber and wood fibre (i.e., recent economic down-term. Over the past 2 decades, forest harvesting across all regions in Lower Fraser and Strait of Georgia area has declined 50% in the amount of harvested timber volume.

Source: Ministry of Forests and Range, Timber Supply Area timber volume statistics 1975 to 2009.





Map 7-B: Distribution of Forest Harvesting in the Lower Fraser River and Strait of Georgia

Forest harvesting was active in the 1980's and early 1990's in sub basins supporting key sockeye spawning habitats in the Harrison (Birkenhead), Pitt (upper Pitt River), and Chilliwack watersheds. The decline in areas harvested in the past two decades is consistent with patterns of declining harvested timber volumes in Map 10 and reflects regulations mandated under the Forest Practices Code to support improved forest harvesting practices on crown and forest lands.

The distribution of pulp and paper mills across the Strait of Georgia and associated water quality issues are presented in Maps 8 and 14-A respectively.

Areas of forest harvest disturbance were mapped based on BC Ministry of Forest and Range Vegetation Resource Inventory data for Crown lands separated into the following time periods: 1986-1990, 1991-1995, 1996-2000, 2000-2005, and after 2005. No information was readily available for private lands on Vancouver Island north of Victoria.

Year	Harvested Crown Land Area (ha)
1986-1990	28011
1991-1995	14649
1996-2000	10946
2001-2005	4151
2006-2009	1964
Total	**59722**