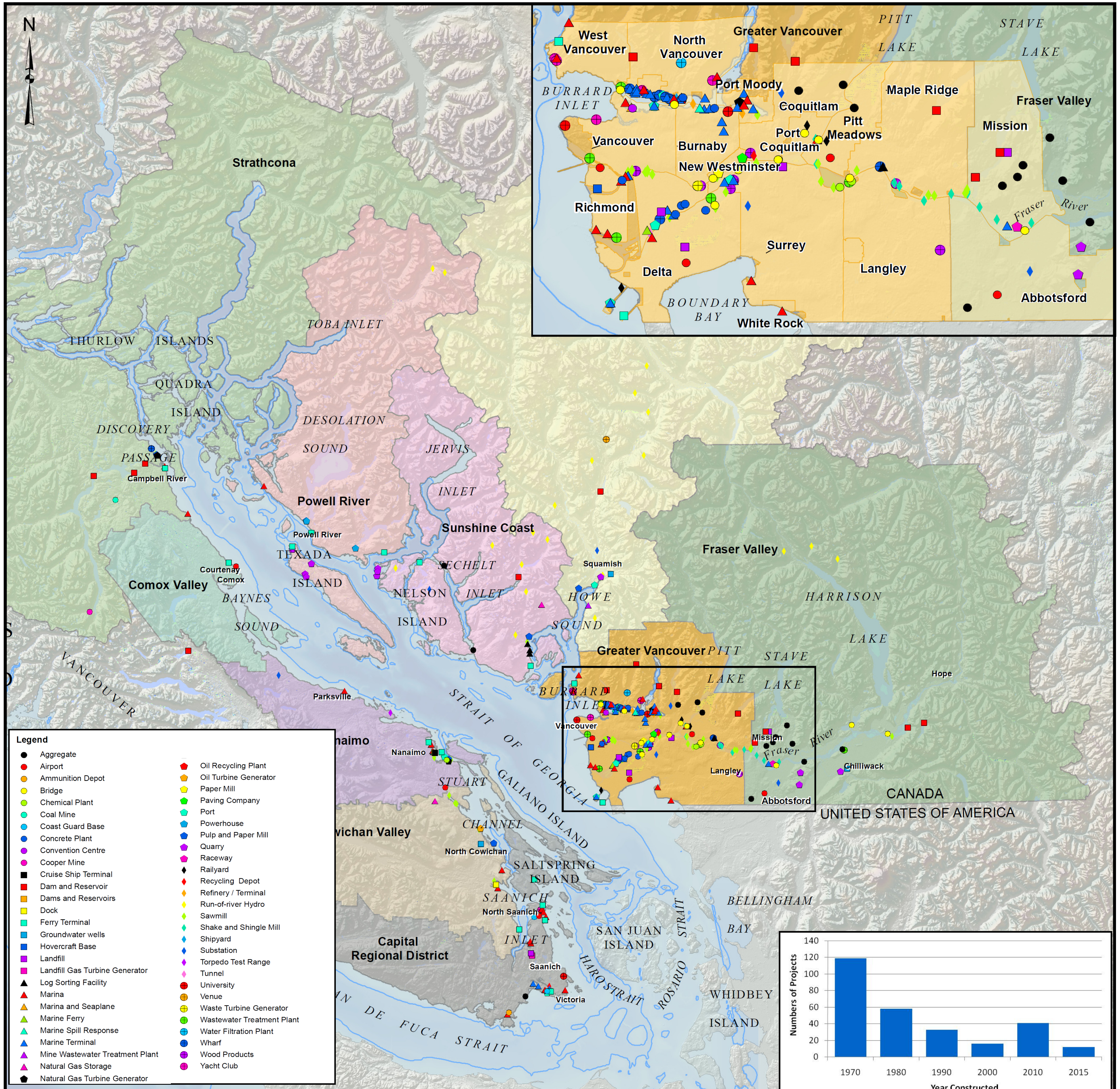


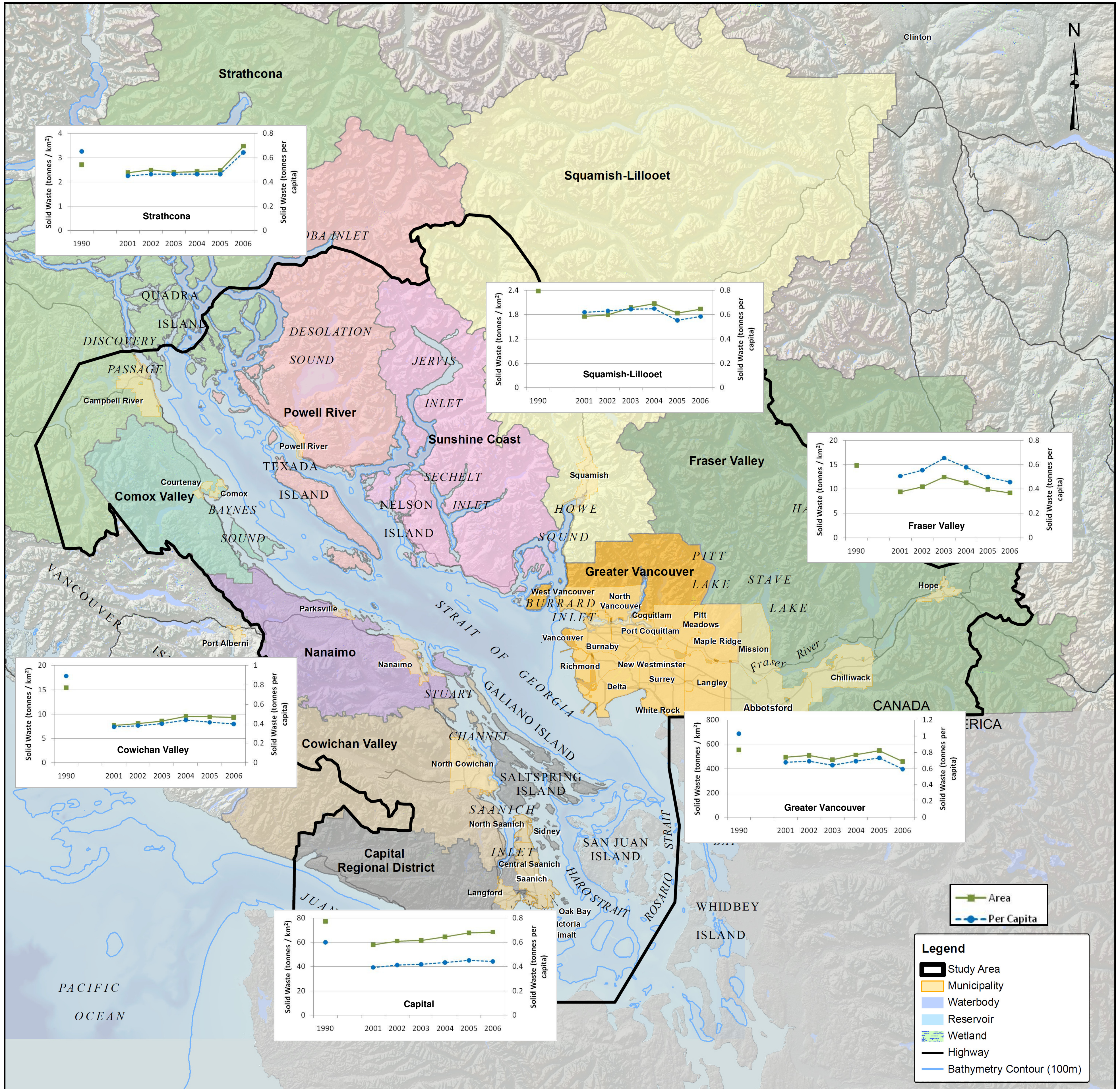
Map 8: Industrial and Public Projects, Sites and Infrastructure in the Lower Fraser River and Strait of Georgia

The distribution, type and extent of large industrial projects, sites and infrastructure can potentially affect Fraser sockeye salmon through direct loss or removal of habitats and indirect effects through increased erosion, sediment, nutrients and contaminant discharge and changes in water quality.

More than 300 large industrial sites and infrastructure projects were constructed and operated in the lower Fraser River and Strait of Georgia during the past century. Approximately 70 projects were constructed and began operations from 1990 to 2010. Twelve major projects are currently proposed, including Terminal 2, Delta Port in Richmond.

The number and distribution of large infrastructure and industrial projects constructed and operated prior to 1980 are included in this report. Large projects were identified as those industrial or public infrastructure / project / development sites which were considered to have potential interaction through geographic overlap, magnitude and duration of effects with sockeye aquatic habitats (this report see Table 1 and Section 3). The potential interactions of large projects on loss or degradation of sockeye salmon habitats was qualified over the study period from 1990 to 2010, but included industrial and infrastructure sites in operation. For example, these include pulp and papers mills constructed and operated from the early 1900's to present (Squamish, Port Mellon, Elk Falls, Powell River, Nanaimo and Crofton) and regional district wastewater treatment plants and operated since the 1960's (Iona, Lulu, Annacis Islands, Lions Gate and NW Langley).

Source: BC Stats Major Projects Inventory 2004-2010.
BC Environmental Assessment Office Project Information Centre 1995-2010.
Canadian Environmental Assessment Agency CEAA Registry 2000-2010.
Online and Wikimapia map based searches for large industrial projects.



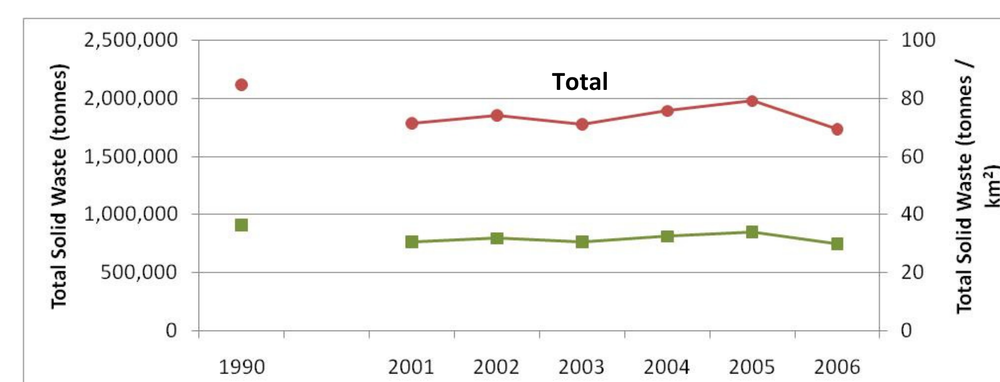
Map 9-A: Solid Waste in the Lower Fraser River and Strait of Georgia

The local and regional volume of residential and industrial solid waste disposed at landfills is associated with local household and industrial resource use and potential interactions with sockeye habitats through reduced water quality due to discharge of contaminants and nutrients.

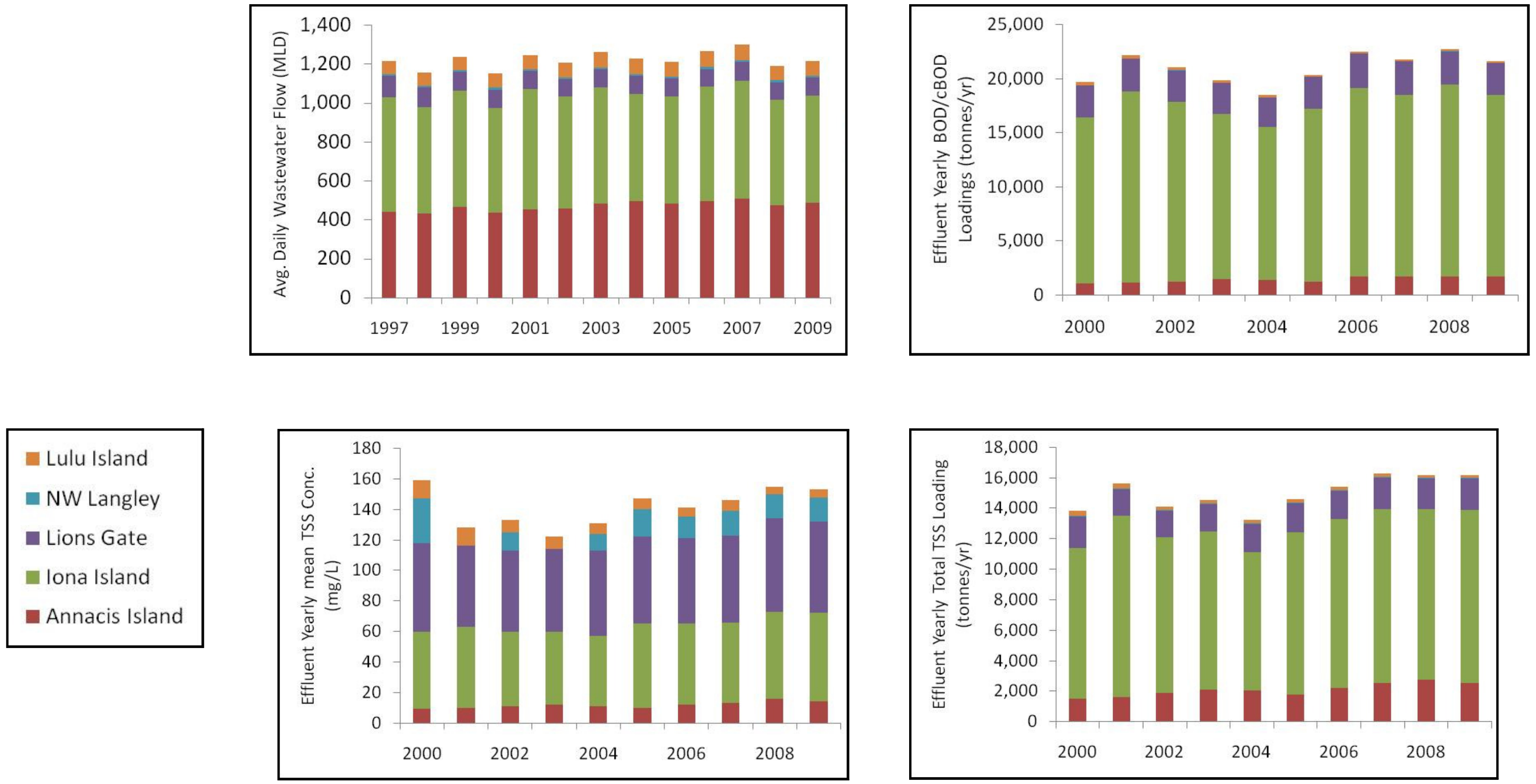
The lower Fraser River and Strait of Georgia are home to greater than 3.5 million residents and over 300 large industrial and infrastructure sites. Across the study area and in all regions, solid waste per capita and per area (km^2) has shown a slight decrease between 1990 and 2001-2006. Over the past 2 decades, household, industry and municipalities have developed and refined waste management, disposal and recycling programs. In all regions reporting across the Lower Fraser and Strait of Georgia, total tonnage of solid waste disposed of at landfills has declined over from 1990 to 2000, and remained stable over the past decade. Although these have been several landfills closed in within the lower mainland in the past 20 years, a large proportion of Metro Vancouver municipal and industrial solid waste is hauled outside the region to Cache Creek. Another large proportion continues to be transported to the Vancouver landfill in Delta.

Source: B.C. Municipal Solid Waste Tracking Report (2006), MOE, Victoria; MOE (2006b).

Six regional districts out of 10 within our study area had available solid waste data which were included in these results. Less populated regional districts do not routinely monitor or have available data time series for solid waste disposal including: Nanaimo, Comox Valley, Powell River, and Sunshine Coast. Data from these regional districts were not included in the results presented.



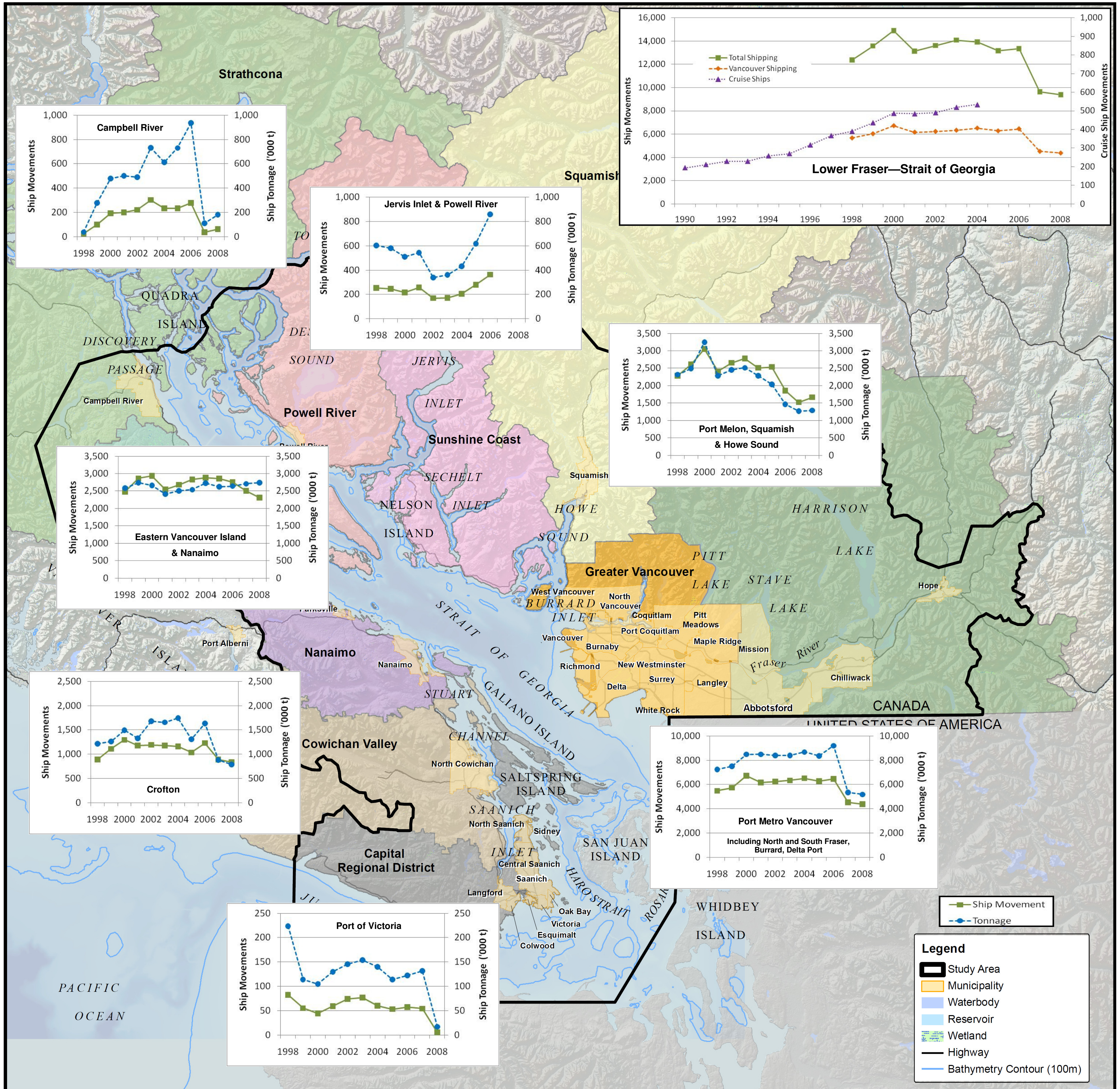
Map 9-B: Liquid Waste from Wastewater Treatment Plants in the Lower Fraser River



Liquid wastewater discharge and effluent water quality is measured in the lower Fraser River and estuary by Metro Vancouver Regional District as part their ongoing management and monitoring of Greater Vancouver wastewater treatment plants (WWTP). Metro Vancouver WWTP effluent volumes, biological oxygen demand (BOD) and total suspended solids (TSS) are associated with potential interactions on water quality and potential risk of degradation to sockeye habitats in the Lower Fraser River and estuary. Given the capacity for treatment of wastewater and population size serviced by the five WWTPs, these plants are considered potential factors indicating general trends in wastewater discharge across the study area. The five plants also represent treat wastewater discharge from areas with the greatest density and population size for urban centres across the Strait of Georgia. These urban centres are adjacent to many key sockeye habitats in the Lower Fraser relative to other regional districts and municipalities in the study area. Information on wastewater discharge from the other 9 regional districts not available in time for this study. However, treatment of wastewater across the Georgia Basin population showed an increase of 40% in secondary from primary treatment during the 1989 to 1999 time period (MOE 2006a).

Total wastewater daily flow shows a consistent average flow across all years of record. The highest effluent daily volume, BOD and TSS discharged was observed at Iona Island on the north arm of the Fraser River, followed by Annacis Island on the main channel of the Fraser River and Lions Gate in Burrard Inlet. Annacis Island and Iona Island have the greatest capacity for treatment of wastewater servicing a population of over 1.5 million Vancouver residents. Iona Islandand Lions Gate have been upgraded numerous times, but were originally constructed in the early 1960's. The other 3 large WWTP in the Lower Fraser River were constructed in mid and late 1970's and Annacis Island was upgraded in the mid 1990's.

Source: Metro Vancouver Wastewater Treatment, http://www.metrovancouver.org/services/wastewater/treatment/Pages/treatmentplants.aspx



Map 10: Marine Vessel Traffic and Cargo Tonnage in the Lower Fraser River and Strait of Georgia

Marine vessel traffic is associated with potential effects such as noise and ballast water and hull fouling for introduction of non indigenous species, and contaminants from spills or vessel discharge. Port vessel movements (into and out-of port) and traffic cargo tonnage across the lower Fraser River, and Strait of Georgia can be used as an indicator of potential effect or change on Fraser sockeye salmon habitats.

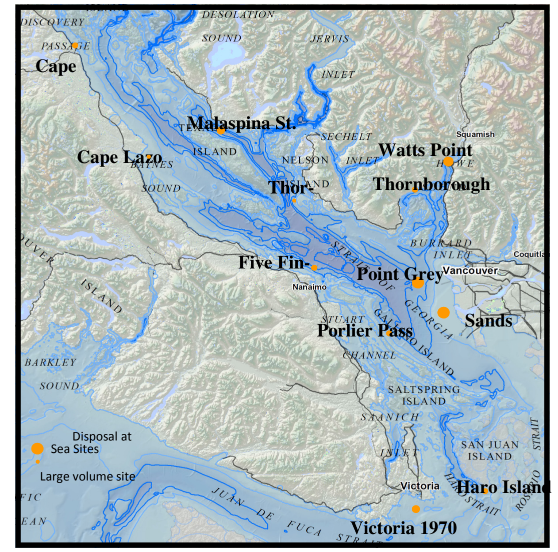
The potential impact of marine traffic on sockeye habitats depends in part on the vessel type, destination port and time of year. The highest proportion of vessel movements originated from passenger ferries, followed by tug and barge traffic and cruise ships (Vancouver) (MOE 2006a). Cruise ships travel predominately during the summer season. Dry and bulk tankers and cargo (containers) vessels had the highest proportion of tonnage with consistent vessel traffic across all seasons.

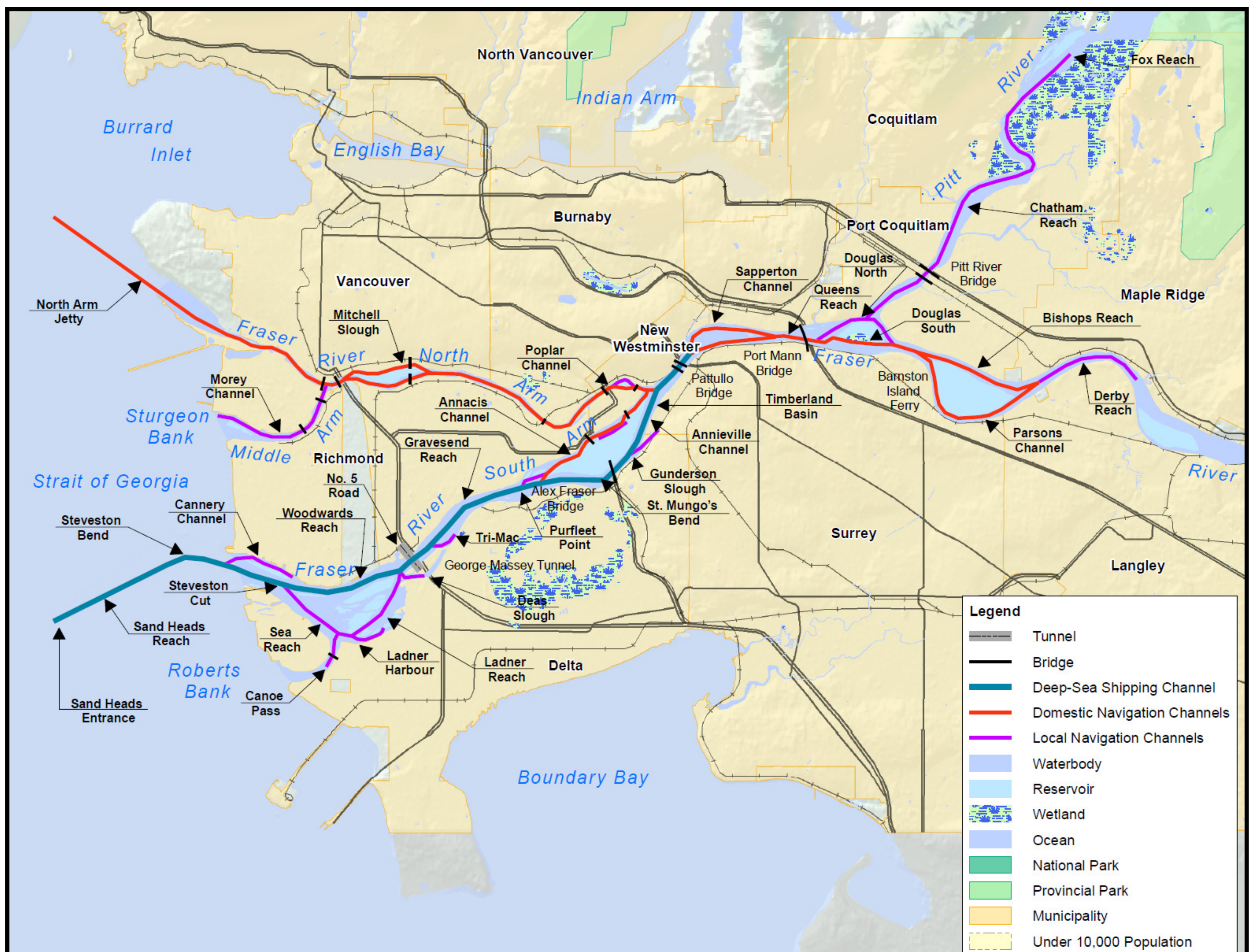
Port vessel traffic across the Strait of Georgia remained generally stable during the past decade with some decline in ship movement and tonnage in recent years associated with slower economic conditions. Vessel traffic showed an increase in Jervis Inlet and Powell River, but represented a small proportion of total vessel movement and tonnage in the area. Cruise ship traffic has been projected to continue to rise over the next decade. Ferry traffic has remained stable throughout the past two decades. Pollution incident reports for marine vessels on the west coast has remained stable between 1999 and 2004, but are considered to under represent the frequency of small spills (MOE 2006a).

Sources: Statistics Canada (2008): Shipping in Canada (1998-2008), published from 2000-2010, Statistics Canada, Ottawa. Website: http://www.statcan.gc.ca/bsolc/olc-cel/olc-cel?catno=54-205-X&chropg=1&lang=eng Data is derived from a series of publications (1998-2008) which present an overview of domestic and international shipping activities at Canadian ports. Data was collected for ports within our study area from table labeled “Domestic shipping – Number of movements, vessel capacity and tonnage transported by province or territory and port – BC”.

Map 11-A: Navigation Channels, Channel Characteristics, Dredging and Disposal at Sea in the Lower Fraser River and Strait of Georgia

Lower Fraser River Dredge Location	Year									
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
North Arm Tidal (North Arm Jetty, Morey Channel)	-	-	-	-	-	-	-	-	-	-
North Arm Meso-tidal (Mitchell Slough, Poplar Channel)	-	-	-	-	-	-	-	-	-	-
Sand Heads Reach	√	√	√	√	√	√	√	√	√	√
South Arm Tidal (Steveston Bend, Steveston Cut, Sea Reach, Woodwards Reach, Ladner Reach)	-	-	√	√	√	√	√	√	√	√
South Arm Meso-tidal (Gravesand Reach, Purfleet Point Reach, St. Mungo's Bend, Annieville Channel,	√	√	√	√	√	√	√	√	√	√
Annacis Channel	-	-	-	-	-	-	-	-	-	-
Sapperton Channel	-	-	-	-	-	-	-	-	√	-
Lower Pitt River (Douglas North, Chatham Reach, Fox Reach)	-	-	-	-	-	-	-	-	-	-
Barnston (Douglas North, Douglas South, Bishops Reach, Parsons Channel, Derby Reach)	-	-	√	-	-	-	-	-	√	√





The extent of dredging in the lower Fraser River and disposal at sea of dredged materials is associated with potential interactions on Fraser sockeye salmon including direct loss or removal of habitats and indirect degradation of habitats through increased erosion, sediment, nutrients and introduction of contaminants accumulated in sediments.

Annual dredging is undertaken in 9 reaches in lower the Fraser River below Mission, to maintain navigation channels in the Fraser River South Arm to provide access for container and cargo vessel traffic and to accommodate upstream access for some of these larger vessels (FREMP 2006). Sands Head, South Arm tidal, and South Arm meso-tidal channels have been routinely dredged over at least the past three decades. Two-thirds of the dredge sand (1-2 x 10^6 m^3 / year) is sold annually and the remaining one-third is disposed at Sands Head or Point Grey disposal at sea sites. Since 1998, dredging has been managed by Port Metro Vancouver rather than the Canadian federal government. Dredging activities are currently restricted by Fisheries and Oceans Canada to periods between January 1st to March 1st, and depending on the timing of the Fraser River freshet, from June 15th to December 31st.

Dredging in the lower Fraser River below Mission, has removed more material than has inflowed into the lower reaches over the past 3 decades (1:1 ratio of dredged to material inflow) (see Figure 2). Dredging has resulted in the navigation channel bed level being reduced by 3 m over a 30 year dredging period. The volume of dredged material removed from the river has declined annually since the early 1990's, ranging in volume from 2 to 3 million cubic metres. Dredging is also conducted annually in gravel reaches of the Fraser River between Hope and Mission to maintain flood protection and reduce freshet water levels in the Fraser Valley (NHC 2009, Church 2010).

Source: Data derived from results published by Fraser River Estuary Management Program. http://www.pep.bc.ca/floods/fraser_sediment_prog.html. Data also derived from results published in NHC 2006, 2008, 2009, Church 2010. Mapping derived from Port Metro Vancouver navigational channel maps and Environment Canada Fact Sheet—Disposal at Sea in British Columbia.

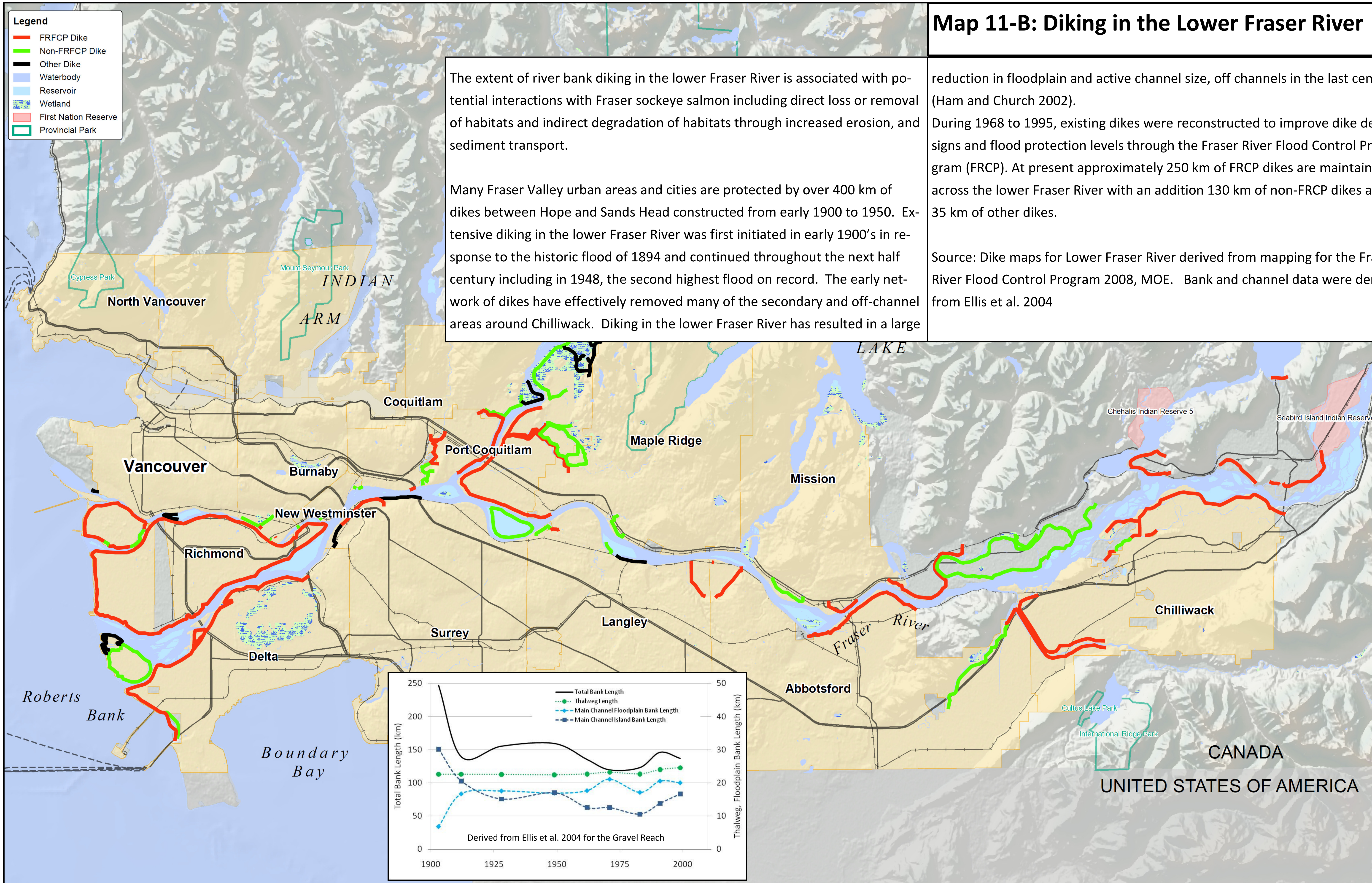
Map 11-B: Diking in the Lower Fraser River

The extent of river bank diking in the lower Fraser River is associated with potential interactions with Fraser sockeye salmon including direct loss or removal of habitats and indirect degradation of habitats through increased erosion, and sediment transport.

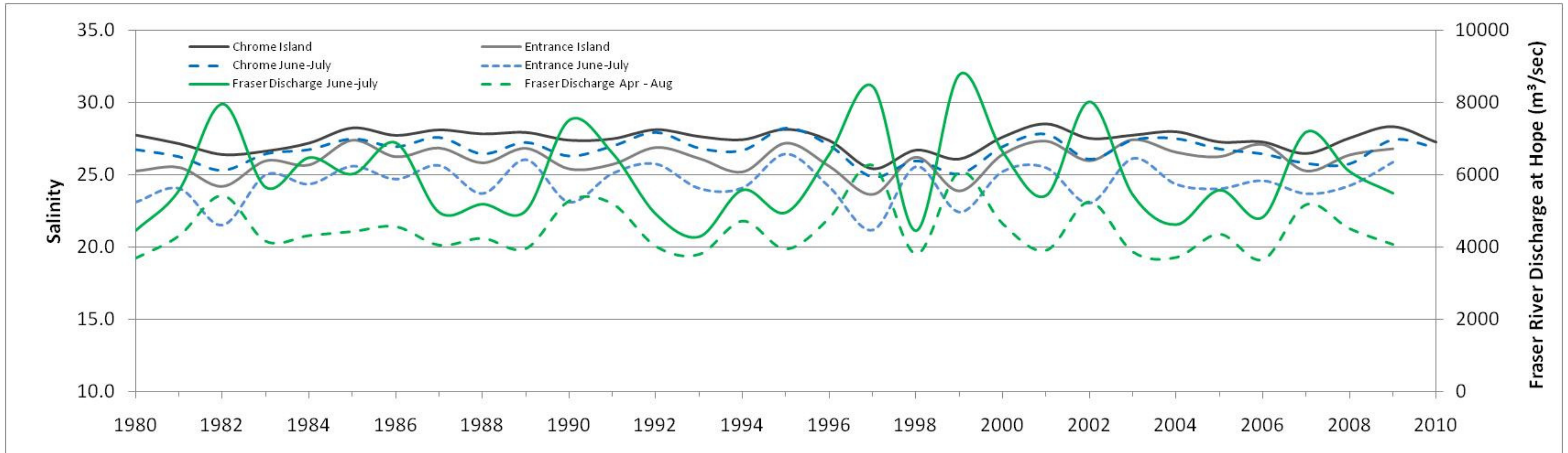
Many Fraser Valley urban areas and cities are protected by over 400 km of dikes between Hope and Sands Head constructed from early 1900 to 1950. Extensive diking in the lower Fraser River was first initiated in early 1900's in response to the historic flood of 1894 and continued throughout the next half century including in 1948, the second highest flood on record. The early network of dikes have effectively removed many of the secondary and off-channel areas around Chilliwack. Diking in the lower Fraser River has resulted in a large reduction in floodplain and active channel size, off channels in the last century (Ham and Church 2002).

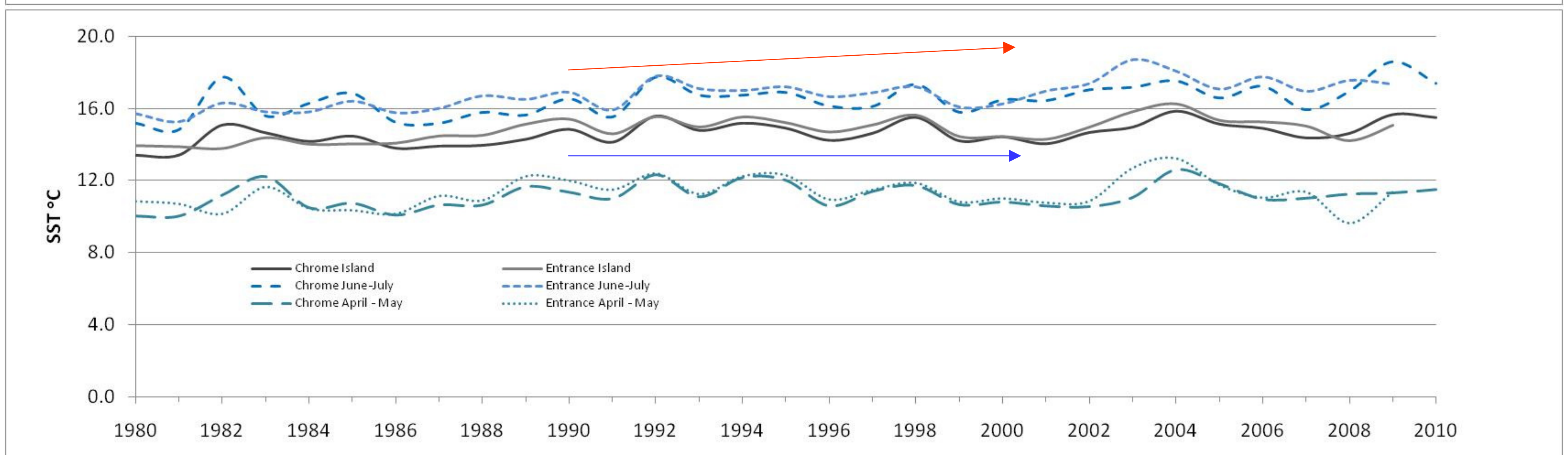
During 1968 to 1995, existing dikes were reconstructed to improve dike designs and flood protection levels through the Fraser River Flood Control Program (FRCP). At present approximately 250 km of FRCP dikes are maintained across the lower Fraser River with an addition 130 km of non-FRCP dikes and 35 km of other dikes.

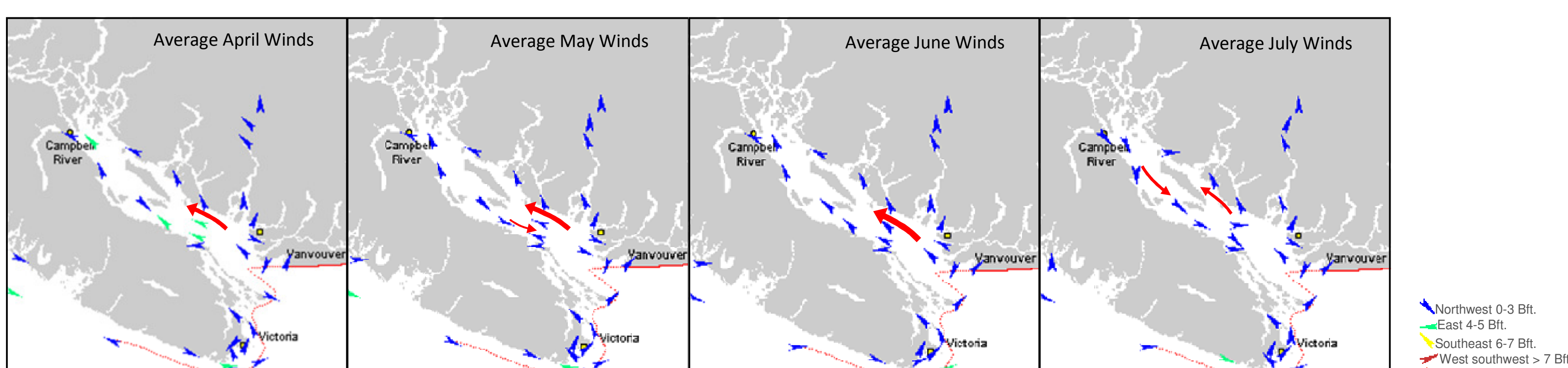
Source: Dike maps for Lower Fraser River derived from mapping for the Fraser River Flood Control Program 2008, MOE. Bank and channel data were derived from Ellis et al. 2004



Map 12-A: Water Properties in the Strait of Georgia



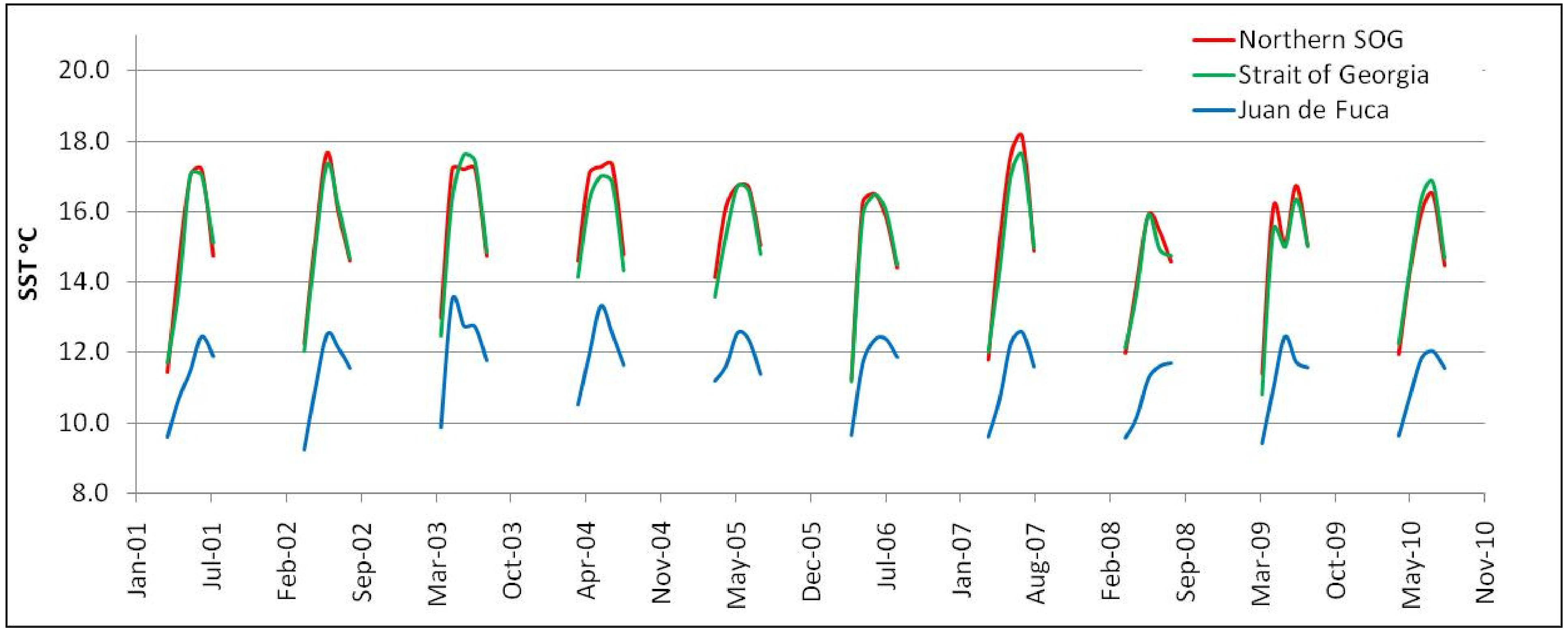


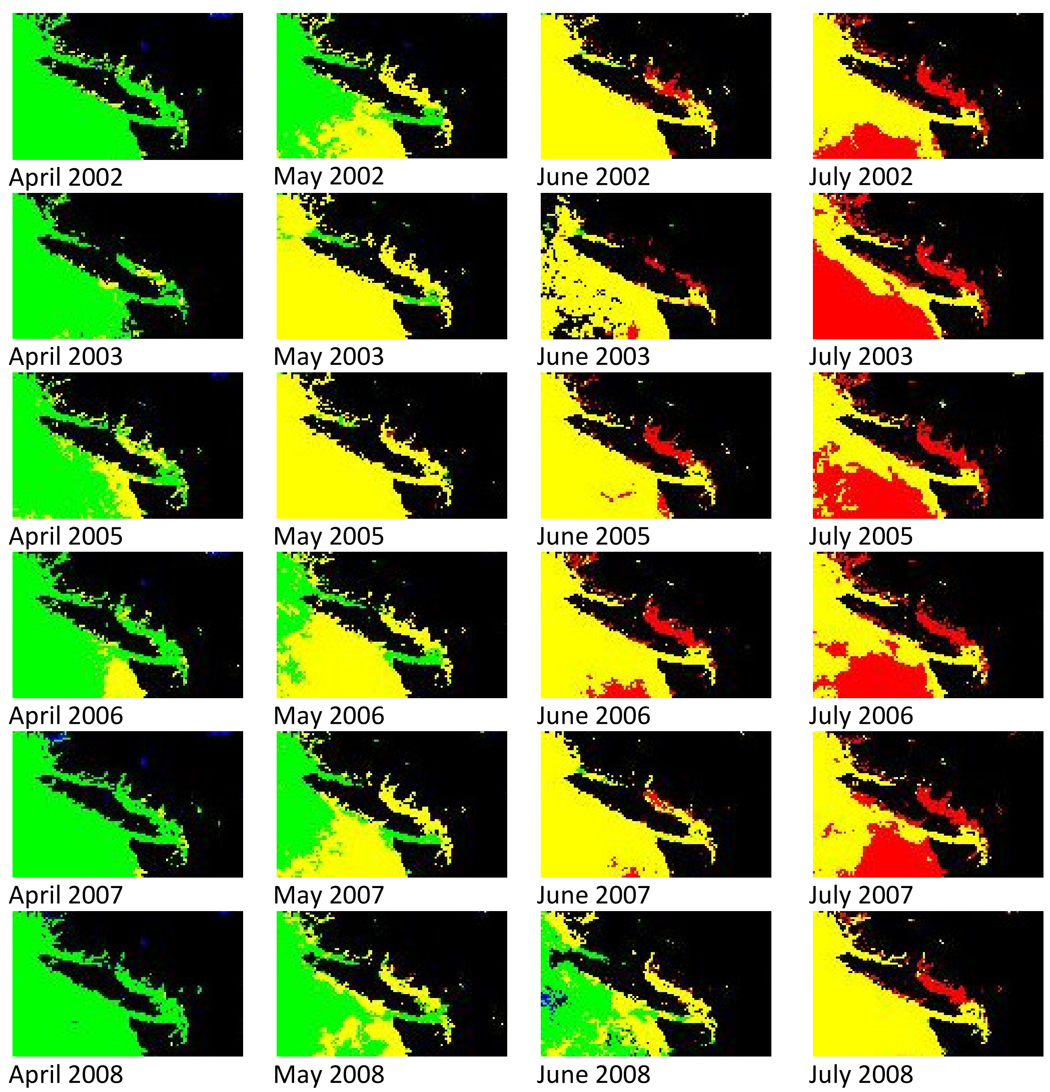


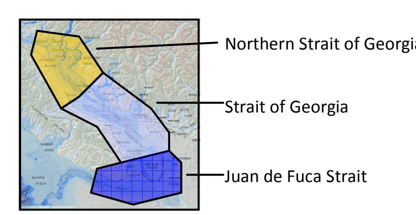
The physical changes observed represent a large spatial scale that overlaps extensively with Fraser sockeye habitat use. Changes in the physical water properties in the strait are linked to biological production which have combined implications on the distribution, growth and survival of sockeye.

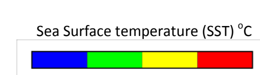
Based on these integration of these water properties, including seasonal patterns of temperature, mixing and currents driven in part by freshwater discharge and winds, determines the spatial distribution and physical habitat use of juvenile sockeye from June through August and adult sockeye from May to June.

The physical properties of marine water in the Strait of Georgia, including sea surface temperature (SST), sea surface salinity salinity (SSS) and nutrient properties and distribution, are determined through a combination of the Strait's physical bathymetry and dimensions (semi-enclosed sea), and energy from tidal mixing, currents, prevailing winds and freshwater input from the Fraser River. The strait is comprised of two shallow sills at the south (Victoria Sill, Boundary Pass) and north (Discovery Passage) ends (Map 1) which restrict water exchange and ocean upwelling from the Pacific Ocean through both the Juan de Fuca Strait and Johnston Strait (Waldichuk 1957, Davenne and Masson 2001). Water properties and circulation in the Strait of Georgia are primarily determined by the seasonality of freshwater discharge from the Fraser River, variation and strength of prevailing winds and strong tidal mixing and currents influence by climate and Pacific ocean conditions (Davenne and Masson 2001, Masson 2002). The variation in SSS associated with inverse association with Fraser discharge. This relationship dampens as freshwater input from the Fraser is diluted in northern portions of the Strait of Georgia. SST generally shows an independent pattern to Fraser River discharge and is controlled in part by climate patterns and regimes, level and intensity of stratification in the Strait, ocean upwelling, and prevailing winds.









Map 12-B: Water Properties in the Strait of Georgia

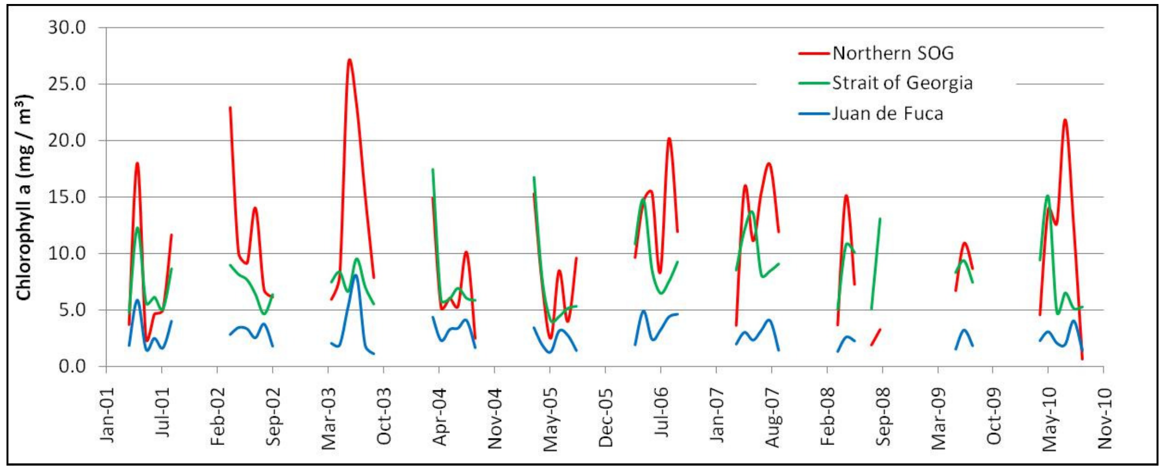
Long-term time series of monthly temperature anomalies from Entrance Island lighthouse (Figure 3) relative to the long term average, suggest that the period from the late 1980's to present experienced warmer conditions than those during the antecedent period from 1940. Similarly patterns of daily temperature from Chrome (northern strait) and Entrance Island lighthouses show a general trend in increased SST from 1980 to present (Map 12-A).

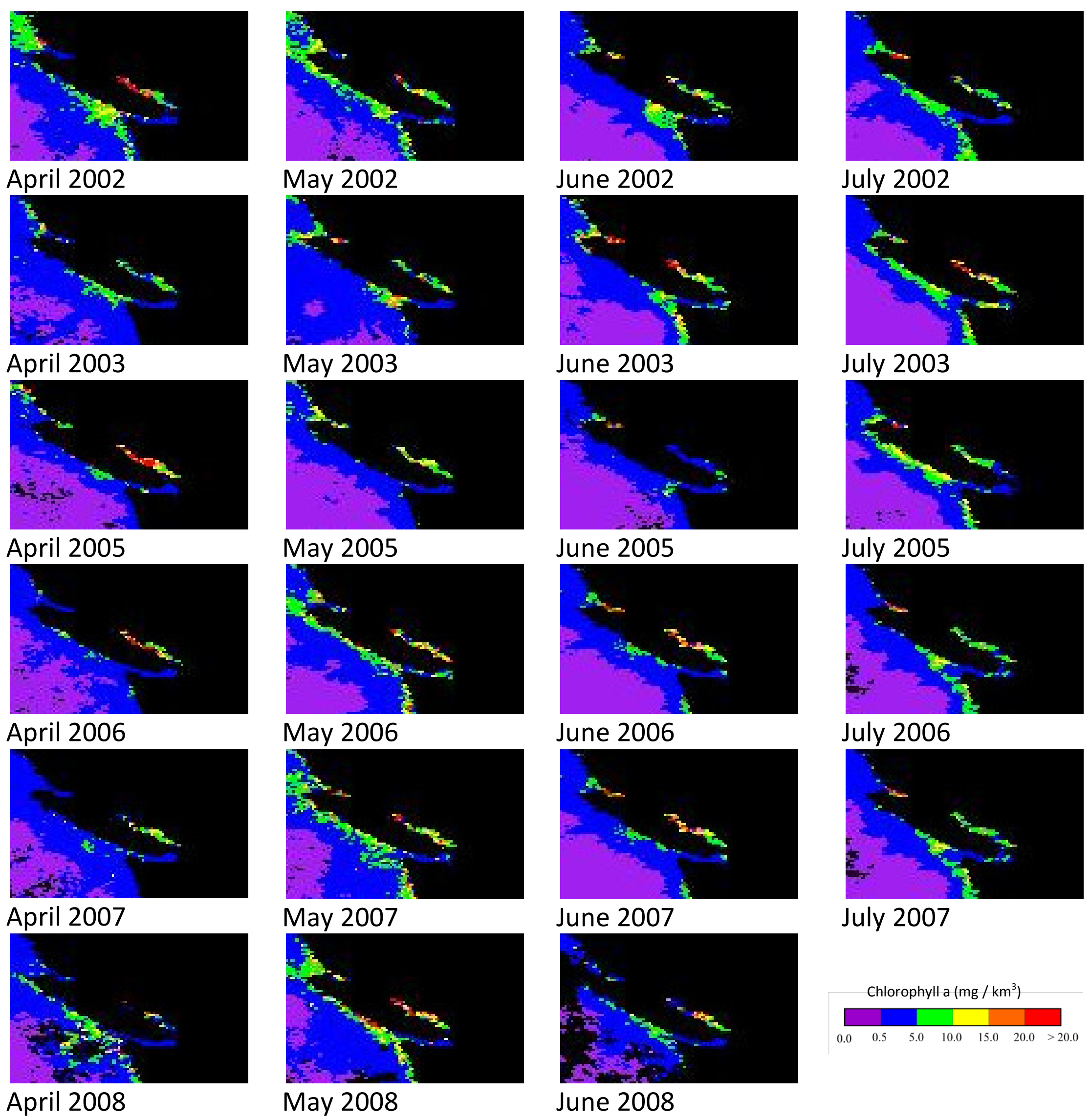
A time series of sea surface temperature (SST) and chlorophyll *a* (Map 12-C) was obtained and analyzed from the Ocean Web site (http://oceancolor.gsfc.nasa.gov/) using MODIS satellite imagery. Each satellite image and file was integrated in a georeferenced layer stack the facilitate the statistic extraction over the time series for each month (April to Aug) 2001-2010 for three areas of interest including Southern Strait of Georgia, Northern Strait of Georgia and Juan de Fuca Strait.

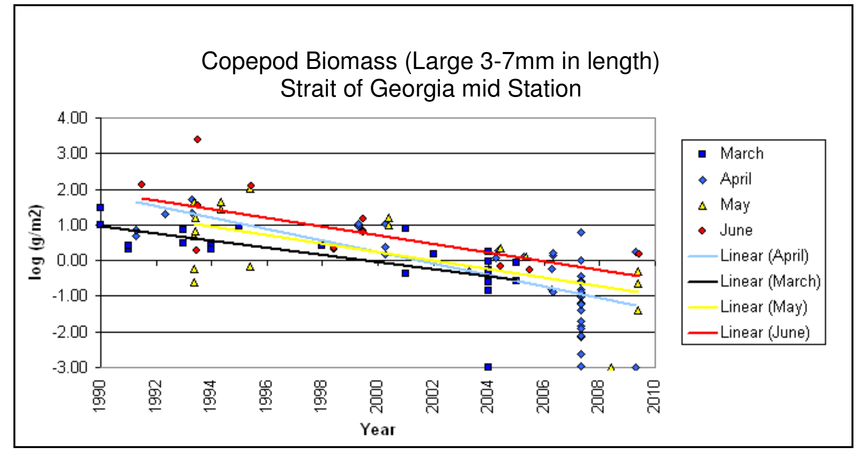
The seasonal warming and cooling pattern was observed in the central and northern Strait of Georgia and Juan de Fuca Strait areas. SST in Juan de Fuca Strait was cooler at all time periods than the SST observed in the Strait of Georgia. The warmest seasonal temperatures were observed in August of each year with the warmest growing season during the 2001 to 2010 period occurring in 2007, and the coolest period occurring in 2008.

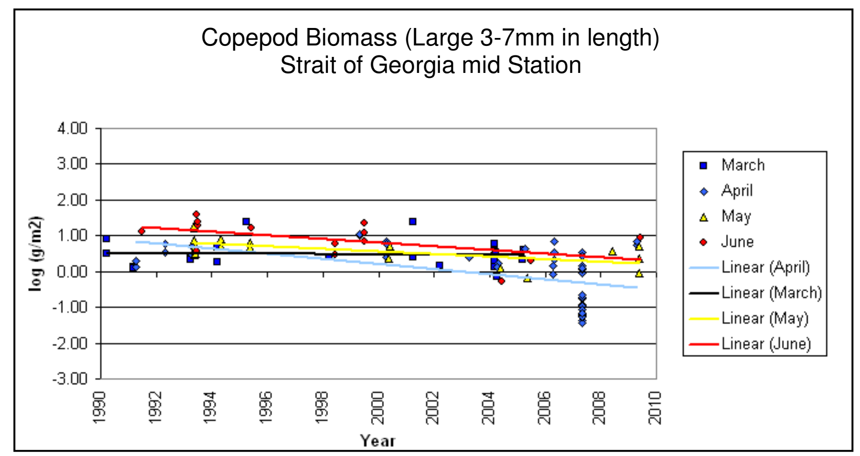
Juvenile sockeye take advantage of the seasonality of surface currents for a northward migration through the strait, and the onset of seasonal increased spring planktonic prey abundance (Mackas et al. 2007, Haro-Garay and Soberanis 2008, Trudel et al. 2008, 2010, El-Sabaawi et al. 2010). Adult sockeye use two alternative migration routes through the Strait of Georgia including a southern route through Juan De Fuca Strait with holding areas above the southern Gulf Islands and Fraser plume and estuary, and a second northern diversion route through Johnstone Strait and Discovery Passage along an western route in the Strait of Georgia to holding areas in the Fraser plume and estuary. Migration routes and timing for adult sockeye are determined in part by outflow water properties (SST, SSS) and conditions from the Strait through Queen Charlotte Sound and Juan de Fuca Strait.

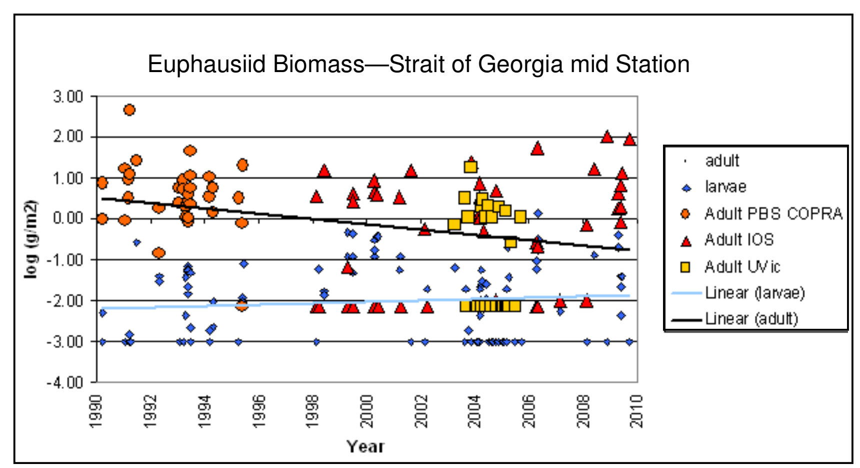
Map 12-C: Biological Properties in the Strait of Georgia











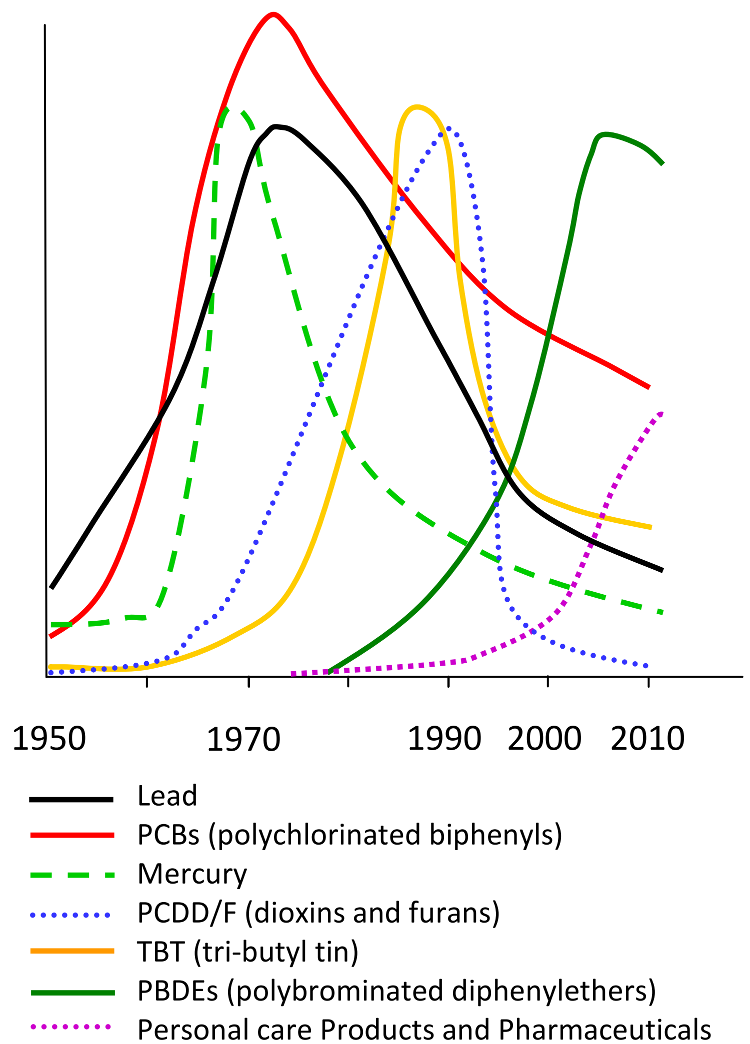
PBS — Pacific Biological Station (DFO)
IOS—Institute of Ocean Sciences (DFO)
COPRA—Cooperative Plankton Research Monitoring Program
UVIC—University of Victoria

Source: Data obtained from D. Mackas and M. Galbraith, IOS, DFO, Sydney, BC (Mackas and Galbraith pers. comm. 2010)

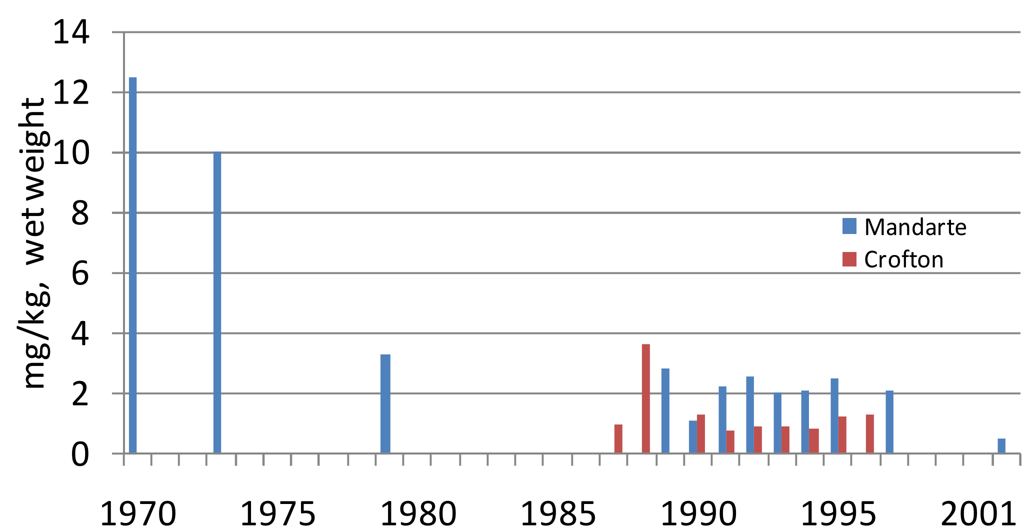
Relative of other factors examined in our review, changes and variation in the biophysical conditions associated with cool or warm years (Map 4, 12-A, B, Figure 3) can be widespread and extend over large areas of sockeye habitats and periods of habitat use for both juvenile and adult life histories. In some seasons or years, changes in biophysical conditions and resulting sockeye preferred food availability, as demonstrated by patterns of abundance in copepods and euphausiids, can be expected to have profound positive or negative effects on sockeye growth and production. The physical water properties in the Strait will have direct influence and impact on changes and variation to higher trophic levels including phyto and zooplankton, larval invertebrates and fish as food for sockeye, other plankton feeding competitors and piscivorous predators.

Data from Mackas and Galbraith (pers. comm. 2010) showed downward trends from 1990 to the present for spring season (log) biomass of large copepods (3-7 mm length), medium copepods (1-3 mm), and adult euphausiids in the Strait. Although 2007 data were obtained with different sampling methods, they suggest that 2007 zooplankton abundance represented near low levels across already lower abundance during the past decade.

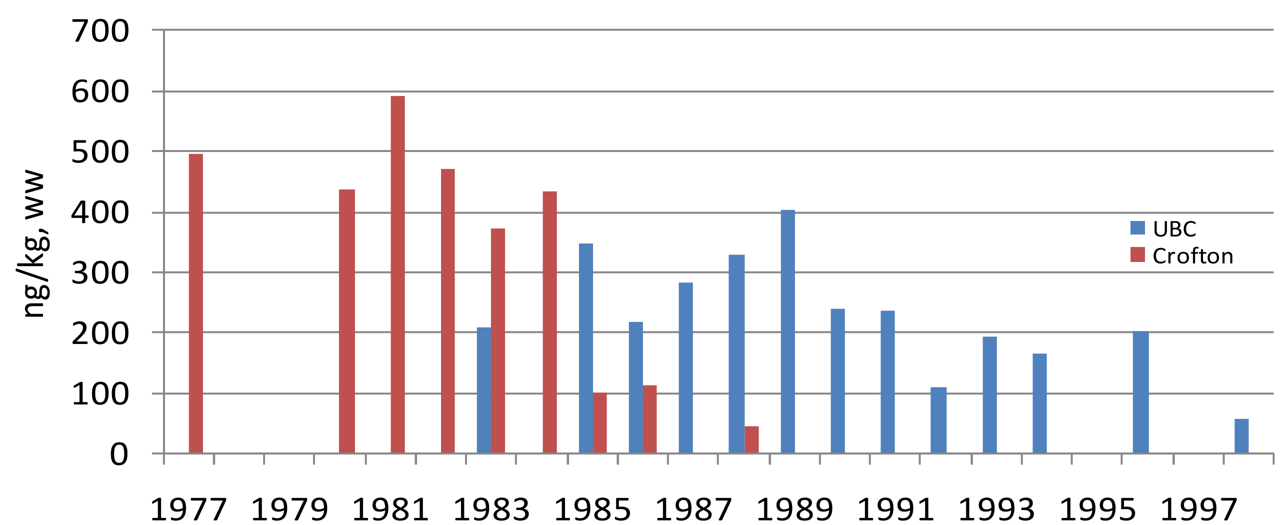
Sub optimal sockeye habitat conditions in warmer years can lead to slower growth through changes in the availability of, or reduced preferred sockeye food abundance (Mackas et al. 2007), altered migration routes (Blackbourn 1987, Peterman et al. 1994), higher levels of predation (Beamish and Neville 2001) and pathogen and parasite exposure and directly impact sockeye survival. Cooler years in the Strait of Georgia are expected to comprise habitats with higher abundance and availability of preferred (larger sized, higher energy content) sockeye prey and lower levels of competitors and predators. Juvenile sockeye will experience greater sensitivity to changes in the biophysical habitats characteristics relative to adult sockeye, due to higher proportionate use of northern strait habitats and migration routes (Groot and Cooke 1987), small size (i.e. Beamish and Mahnken 2001) and altered swimming speeds (both juvenile — Peterman et al. 1994, and adults — i.e., Thomson et al. 1992) which can limit foraging opportunities (Beacham 1986, Preikshot et al. 2010) and enhance vulnerability to predators (i.e., Gregory and Levings 1998, Beamish and Neville 2001, Beamish and Mahnken 2001, Beamish et al. 2010, Irvine et al. 2010, Trudel et al. 2010).



Redrawn from Johannessen et al. 2008, and Johannessen and Macdonald 2009



Concentration of total-PCBs in double-crested cormorant eggs collected from the two long-term monitoring colonies located in the Strait of Georgia (Source: Harris et al. 2005).



Concentrations of PCBs, PCDDs, and PCDFs in heron eggs are displayed as toxic equivalent concentrations (TEQs) collected from the two long-term monitoring colonies in the Strait of Georgia (Source: Elliott et al. 2001)

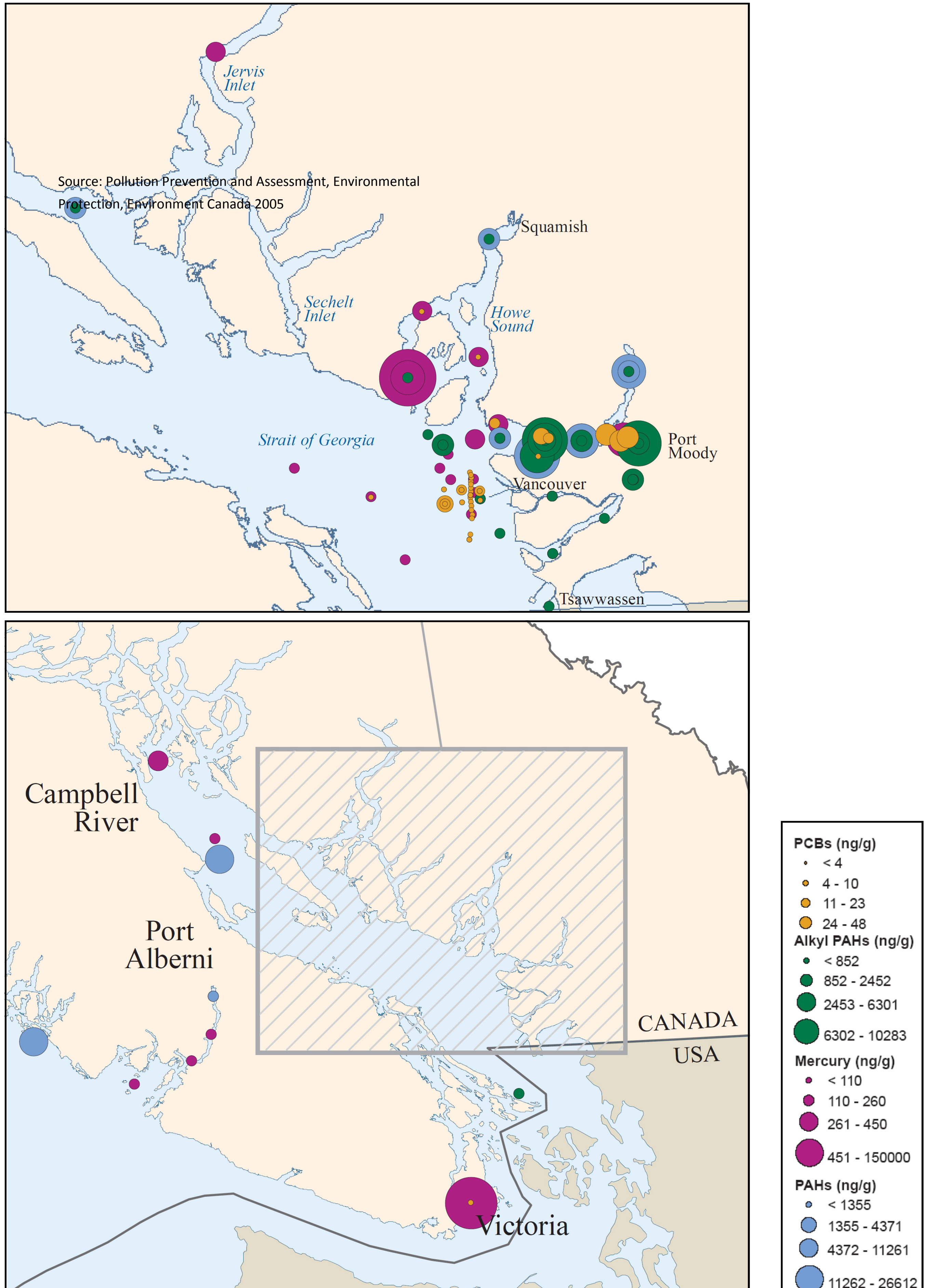
Map 13-A: Contaminants in the Strait of Georgia

Contaminants enter and are distributed in the Strait of Georgia through local industry and municipal discharges and long range transport from the Fraser River and ocean mixing. Urban and industrial activities in the Strait have resulted in a history of contaminants (metals, organic pollutants and other chemicals) observed in the marine sediment core records. These contaminants show a general decreasing trend over time in many organisms including marine birds, presumably as a result of decreases associated with discharge effluent regulation, improved treatment, remediation of contaminated sites, and other initiatives. In contrast, there appears to be an increase in polybrominated diphenylethers (PBDEs) associated with increased use over the past decade or two and an apparent increase in contaminants associated with personal care and pharmaceutical products. The production and use of PBDEs has been banned in Canada and several other countries, but they are still present in fabrics (curtains, furniture, carpeting) and electronics.

Great blue herons (*Ardea herodias*), double-crested cormorants (*Phalacrocorax auritus albociliatus*), and pelagic cormorants (*P. pelagicus resplendens*) can be used as indicators of the health of the Strait of Georgia marine environment because they primarily feed on small forage fish whose contaminant levels can reflect local conditions. In addition, populations of herons and cormorants along the coast of BC are resident year-round and do not migrate outside the region and can provide an indication of the level of contaminant exposure to local sources of contaminants. Temporal patterns in environmental contamination can be evaluated by measuring contaminant concentrations in heron and cormorant eggs. Since great blue herons and cormorants predominantly feed on small fish, changes in the amount of contaminants entering the marine food chain are rapidly reflected in contaminant levels in their prey, and subsequently in their eggs. Observation from long term records maintained by Environment Canada indicate:

- Concentrations of PCBs and DDE (and other dominant OCPs) in great blue heron and double-crested cormorant eggs collected from the Strait have declined and stabilized since the late 1970s(Harris et el. 2003, 2005, Elliot et al. 2005);
- Concentrations of TEQs (from PCDDs and PCDFs in particular) in great blue heron eggs collected from the Strait of Georgia have declined since the 1990s.

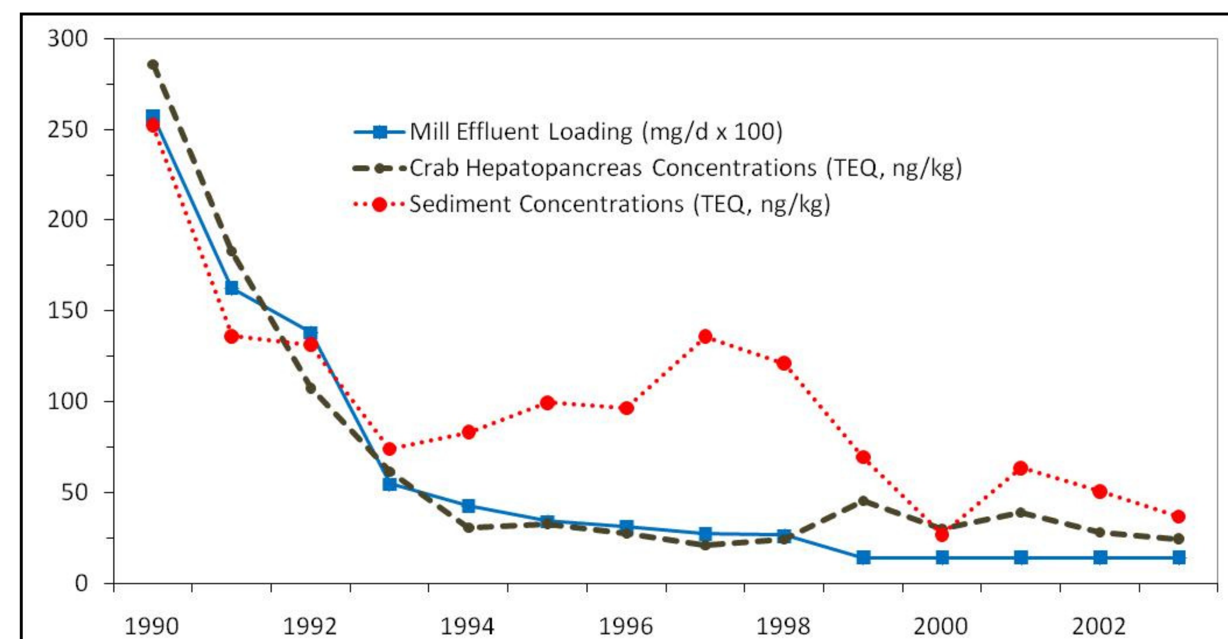
Map 13-B: Water Quality in the Lower Fraser River and Strait of Georgia



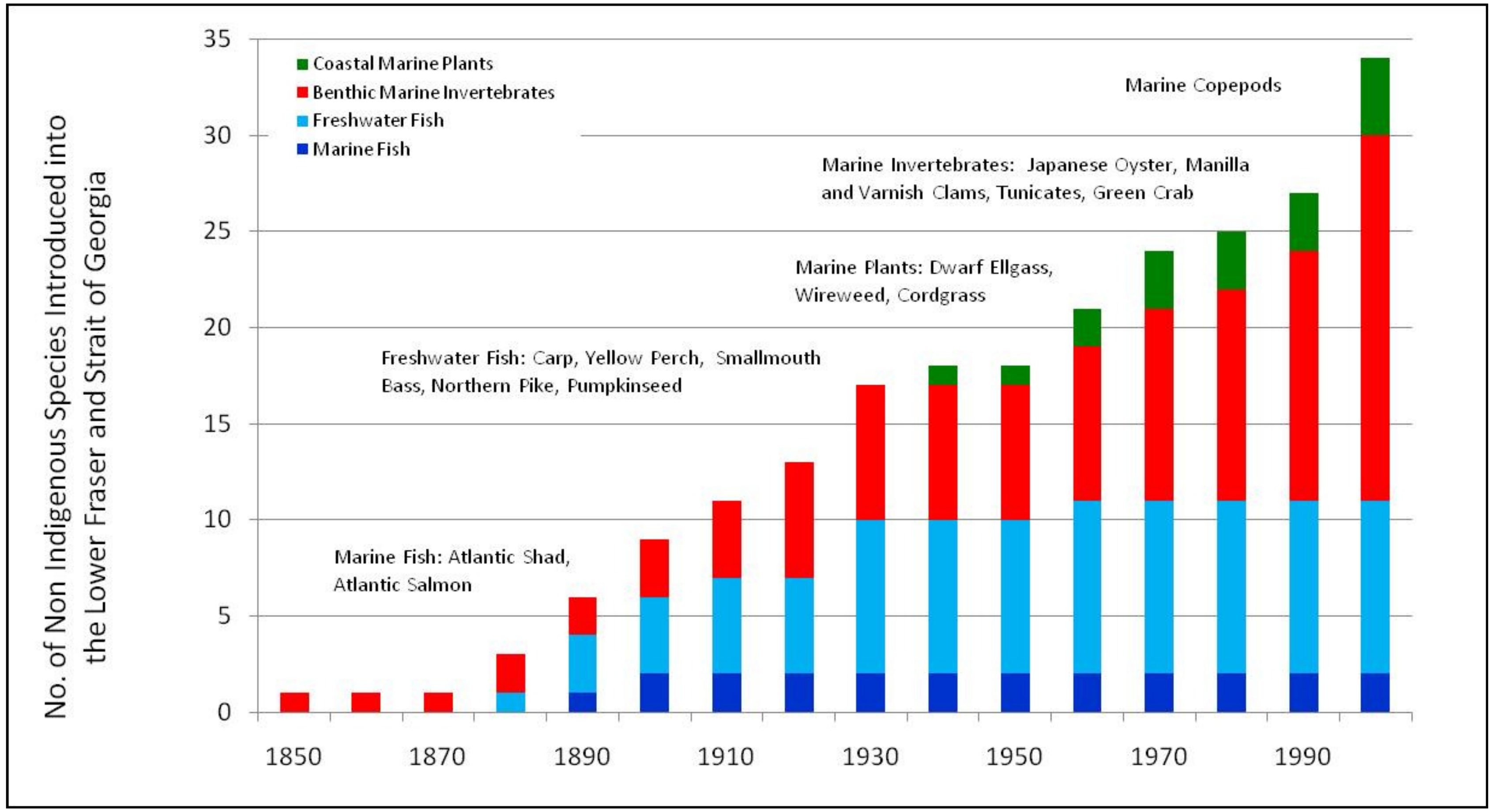
Six pulp and paper mills have operated on the shores of the Strait of Georgia during the period from 1990 to 2010; Squamish (Woodfibre) and Elk Falls closed in 2006 and 2010 respectively.

During the 1970s and 80s, these six mills were major sources of nutrients and contamination of the Strait's coastal marine environment because they discharged large volumes of process effluents that contained pulp and bleaching chemicals including dioxins and furans (MOE 2006c). Stronger regulation and process improvement were implemented in the 1980's and have resulted in more than 100-fold reductions in loads of dioxins and furans in mill effluent. These reductions resulted in almost simultaneous reductions in levels of these compounds in crabs. Contaminant concentrations have shown a decline in sediments and accumulation in marine species monitored including crabs and birds (herons and cormorants—Map 13-A).

Source: MOE 2006c: British Columbia Coast and Marine Environment Project 2006: Industrial Contaminants. Ministry of the Environment, Vancouver.



Map 14: Non Indigenous Species in the Lower Fraser River and Strait of Georgia



Non Indigenous Species Introduction Pathways	
Aquaculture (Accidental)	13
Aquaculture (Introduced)	5
Natural Dispersal	5
Hull Fouling	4
Ballast Water Exchange	2
Recreational (Introduced)	4

Data sources: Gillespie et al. 2006. Sanderson et al. 2009, Tovey et al. 2008, Bradford et al. 2008a,b.

The largest proportion of known introductions of NIS species in the Strait of Georgia and lower Fraser River has occurred in the marine inter and subtidal benthos during the past two decades. With the exception of intertidal benthos, the number of NIS species in freshwater and marine environments have remained stable from 1990 to 2010.

Source: Data derived from published results including—Sanderson et al. 2009, Gillespie 2007, Gillespie et al. 2006, MOE 2006d, Richoux et al. 2006, Levings et al. 2002, Macdonald et al. 2000, Waldichuk et al. 1994.

The introduction, distribution, growth and survival of non indigenous species (NIS) in the Strait of Georgia and lower Fraser River is associated with potential effects on Fraser sockeye salmon including loss and degradation of habitats, increased competition and predation. Non indigenous species are considered one of the major environmental threats to many listed species at risk and natural ecosystem structure and function.

The Strait of Georgia and the lower Fraser River, support a large number of non indigenous species (NIS), greater than twice the number found elsewhere on the Canada's West Coast (Gillespie 2007). The Strait of Georgia's relatively large number of NIS is a function of the combined effects of its long history of human habitation, concentrated aquaculture (e.g., shellfish and finfish), international shipping (associated with transport through hull fouling and ballast water), local estuarine circulation patterns and seasonal refuge habitats, diversity of colonizable habitats, and proximity to populations of NIS in more southern waters like Puget Sound. The number of invasive species in the strait have increased 40-fold since the 1880s (Gillespie 2007, Levings et al. 2002, Macdonald et al. 2000, Richoux et al. 2006, and Waldichuk et al. 1994). Gillespie (2007) estimates that as of 2007, six plant species and 29 invertebrate species had become established in intertidal habitats in the strait . In addition, another 9 fish species have been introduced into freshwater in the Lower Fraser River and an additional 2 species into the Strait of Georgia. Non indigenous smallmouth bass (*Micropterus salmoides*) and yellow perch (*Perca flavescens*) are active freshwater predators and have the potential to directly effect sockeye salmon survival during early life history growth in nursery habitats in Pitt, Harrison and Cultus Lakes (c.f. Ricker 1933, Bradford et al. 2008a, b, Tovey et al. 2008).

It has been estimated that over 117 non indigenous species (terrestrial and aquatic) have established populations in the Strait of Georgia and lower Fraser or along its shoreline and banks. There is uncertainty about when most of these species arrived or their modes of introduction, however it is suspected that many arrived accidentally or were introduced through aquaculture and smaller numbers through hull fouling and ballast water. For example. some species of the dinoflagellates may have been introduced from vessel ballast water and influence secondary plankton production and sockeye food supply.