Section II Site Description and Oceanography

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Vancouver Harbour

Vancouver Harbour, here defined as the waters to the east of Point Atkinson (Figs. 1.2-1.4), consists of three or four water bodies, namely Outer Burrard Inlet or English Bay, Inner Burrard Inlet, Port Moody Arm, and Indian Arm, a long fjord (22 km) which leads to the northeast from the main harbour. All of the PICES sampling stations were on the first three water bodies, except for a far field reference station located about 15 km to the north, in another part of the Strait of Georgia (see below). The approximate length of the inlet system is about 30 km with maximum width of approximate 4 km in English Bay. Inner and Outer Burrard Inlets are separated by a narrowing of the harbour, known as First Narrows. Further to the east, Inner Burrard Inlet and Indian Arm/Port Moody are separated by Second Narrows. Each narrows is about 0.5 km wide. Maximum depth ranges from about 45 m in Outer Burrard Inlet to about 10 m in Port Moody Arm.

The harbour is the largest port on the west coast of Canada. For administration purposes, the harbour comes under the jurisdiction of the Vancouver Port Authority, and includes port facilities on Roberts Bank and the Fraser River estuary, which is outside of the area where the PICES workshop was focused. In 1998 there were about 2500 deep sea ship landings in the harbour. About 8 million tons of ballast water was discharged into the harbour in 1999, and 71.2 million tons of cargo (containers and bulk goods) were handled, including 1.07 metric ton equivalent units of containers. Coal and sulfur are stockpiled in large volumes on docks and backup land adjacent to the docks. The shoreline of the harbour has been modified for dock construction, with 42.1 km out of the total shoreline length of 102.7 km converted to riprap revetment or docks. The undisturbed shorelines consist primarily of rock and cobble beaches, rocky shores, and mudflats, with the latter most common in Port Moody Arm.

The following description of the general oceanography of the harbour is adapted from Stockner and Cliff (1979) who relied extensively on Tabata (1971) for their text.

Tides and currents

Tides in Vancouver Harbour are of the mixed diurnal type, with mean range of 3.1 m and maximum of 4.9 m. At both First and Second Narrows, maximum tidal currents can range up to 11 $km \cdot h^{-1}$. These are the areas of greatest tidal mixing in the harbour. In a recent study currents at depth were found to be as high as 1.5 $m \cdot s^{-1}$ (Isachsen and Pond 2000). The average tidal prism for the inlet is approximately 8.4×10^7 m^3 (Davidson 1979 cited in Lewis and Thomas 1986).

Temperature and salinity

Figures 2.1a and b show sections of temperature and salinity through the harbour area obtained during a survey in July 1966. The pattern shown is supported by more recent work (eg Davidson 1979). The positions of the four stations sampled by trawling and the additional sediment sampling stations are also shown. Bottom water temperatures near the locations were about 10-11°C except for the shallow stations in Port Moody Arm (Stations T-38, B-38 and B-41B). Surface temperatures, which might represent conditions on the intertidal zone, ranged from 13-15°C in Outer Burrard Inlet to 16–18°C in Port Moody Arm.

Salinity in outer Burrard Inlet is strongly influenced by discharge from the Fraser River (annual mean discharge 3600 $m^3 \cdot s^{-1}$). During

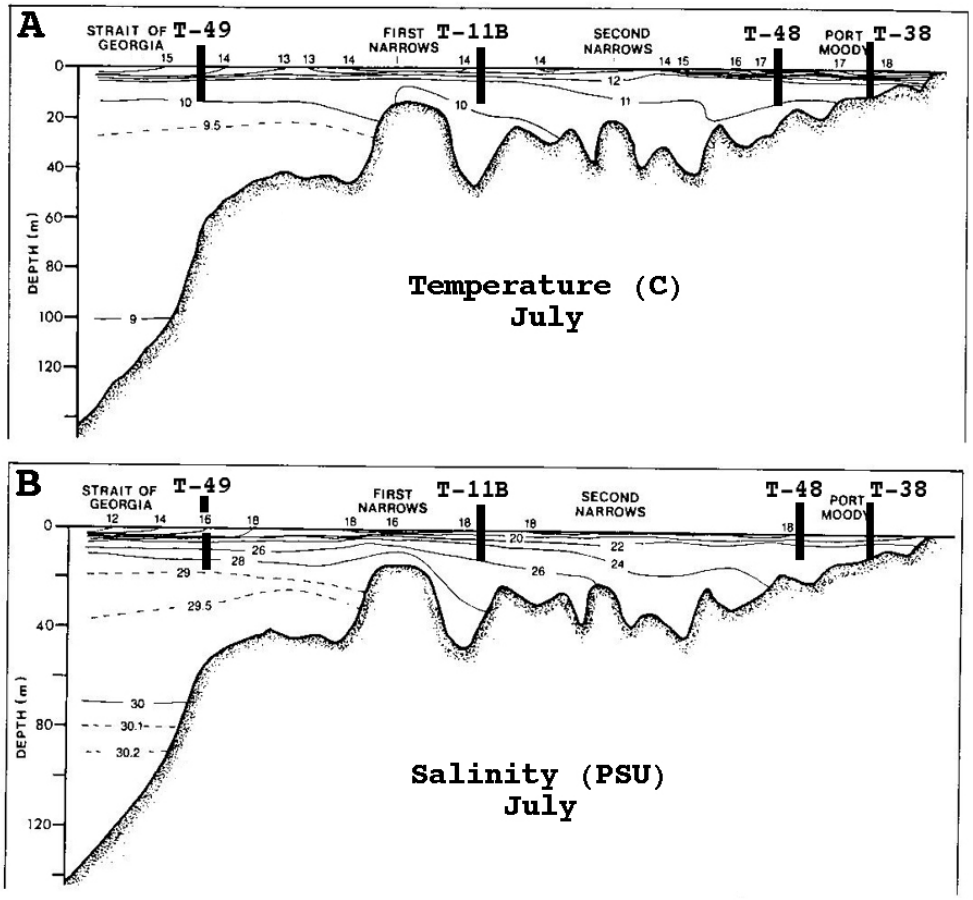

Fig. 2.1 Location of trawl and benthos sites in relation to longitudinal variation in bottom water temperature (A) and salinity (B) in Vancouver Harbour. Oceanographic section data are from Thomson (1981).

high discharge periods, the freshwater plume of the Fraser River occasionally penetrates through First Narrows, into the inner harbour. Other sources of freshwater include the Capilano River (regulated, discharge range 4.5 to 25.0 $m^3 \cdot s^{-1}$) and the Seymour River (regulated 2.8 to 23.3 $m^3 \cdot s^{-1}$) which enters the harbour near the First and Second Narrows, respectively. Bottom salinities in July 1966 decreased from about 29.5 psu in outer Burrard Inlet to between 22.0 and 24.4 psu in Port Moody Arm. Surface salinities ranged from 12 psu in outer Burrard Inlet to 18 – 22 psu in Port Moody Arm.

Dissolved oxygen

In the main harbour Stockner and Cliff (1979) recorded a seasonal dissolved oxygen (DO) range of 5.0 to 10.0 $mg \cdot l^{-1}$, well above the levels that would impair marine organisms. Early investigations of pollution in the harbour (Waldichuk 1965) established that even in shallow Port Moody Arm, at the landward end of the Inlet system, the estuarine circulation enabled a relatively rapid flushing of bottom water so bottom water DO was always > 6.0 $mg \cdot l^{-1}$. Recent investigations connected with dispersal of heated effluent in Port Moody Arm have tended to confirm Waldichuk's findings (Taylor *et al*. 2001).

Nutrients

Data from 1976 (Stockner and Cliff 1979) showed little evidence of eutrophication in Vancouver Harbour when their phytoplankton surveys were

conducted in 1976. Nitrate levels in June were 0.120 $mg \cdot l^{-1}$ in Outer Burrard Inlet, 0.175 $mg \cdot l^{-1}$ and 0.120 $mg \cdot l^{-1}$ in Inner Burrard Inlet and Port Moody Arm, respectively. Since there is less discharge of untreated sewage into the harbour now relative to when their surveys were made, it is likely nutrient levels have not increased.

Sediments

Sediments in Vancouver Harbour range from fine mud in deposition areas such as Port Moody Arm, to coarse cobble and gravel at First and Second Narrows, and on river deltas such as the mouth of Capilano River. However all of the PICES stations were located on mud substrates, as shown in the benthic invertebrate study of Je *et al*. (this report). The sediment transport patterns are relatively well known. McLaren (1994) concluded that the west portion of Inner Burrard Inlet and the north portion of outer Burrard Inlet were essentially characterized by a counter-clockwise circulation with flood-directed sediment transport dominating the south side, and ebb-directed transport dominating the central and northern half. Dredging is needed at First Narrows to maintain the navigational channel, indicating net deposition at that location. In Port Moody Arm, sedimentation rates of about 1 cm y^{-1} have been documented (Pedersen and Waters 1989) and dredging of deep-sea berths is periodically needed in this area.

Thornbrough Channel (Howe Sound)

A far field reference area was chosen in Howe Sound, specifically on the southern end of Thornbrough Channel near Granthams Landing, about 2 km north of the town of Gibsons (population about 4000) (Figs. 1.2-1.4). Both trawling and intertidal collecting were conducted to match sampling in Vancouver Harbour. However, because of bottom conditions, the trawling could not be done at the same depth relative to the Outer Burrard Inlet station (T-49, 45 m) and hence the three trawls were completed at deeper depths, between 55 to 75 m. Thornbrough Channel is connected to the same water masses as Vancouver Harbour via deeper channels leading to the Strait of Georgia. Sediments in the deeper parts of the Channel are sand (see Je *et al*., this report) and beach substrates at Granthams Landing consist of sand and gravel.

Only a few data are available on the physical and chemical oceanography of southern Thornbrough Channel. Although part of Howe Sound, which is considered a true fjord, Thornbrough Channel is well outside the area of the sill in the fjord and thus shows characteristics similar to the adjacent Strait of Georgia.

Temperature, salinity and dissolved oxygen

Waldichuk *et al*. (1968) gave limited data from a station within one km of PICES station T-50. In September 1960, at 50 m depth, temperature was 8.6°C and salinity 29.6 psu. Dissolved oxygen was 6.2 $mg \cdot l^{-1}$.

Sediment transport

McLaren *et al*. (1993) concluded that sediment in southern Thornbrough Channel was moving from south to north and that deposition was occurring in the area of the PICES station. As shown by Je et al. (this report) sediments were sandy at the sampling site (mean grain size 0.25 μm). Some of this sediment may be transported to the area from nearby islands.

Victoria and Mission Point

Three sites in Victoria, Vancouver Island, and one on the eastern side of the Strait of Georgia north of Howe Sound (Mission Point, near Sechelt, Fig. 1.5), were chosen for imposex studies because suitable neogastropod monitoring organisms were absent at the time of sampling from Vancouver Harbour at the PICES stations. Victoria is situated at the south east point of Vancouver Is. (Fig. 1.5) and is exposed to tidal currents from the eastern Strait of Juan de Fuca. The "estuarine" circulation conditions attributable to the influence of the Fraser River discharges on the Strait of Georgia are probably at the limits of their influence at the most northerly Victoria sampling site at Ten Mile Point. All sites have moderately wave-exposed rocks and sand or sandy-mud beaches. Tributyltin contamination arising from large vessel traffic, either locally or

through the Straits of Georgia and Juan de Fuca, is likely to have the most impact at the Breakwater and Clover Point sampling sites; Ten Mile Point is likely to be less affected. Mission Point is similarly located in an area where nearby vessel traffic is minimal.

Sources of Contamination

Vancouver Harbour

Shipping and industrialization began in Vancouver Harbour in the late 19th century. The first major cargo exported from the harbour was wood products from the forest industry. Other industries located around the shoreline after 1900 included petroleum refineries, shipyards, a chlorine plant, seafood processing industries, fuel loading docks, and marinas. Some of these industries are no longer present on the harbour but their footprints or remnant contamination may still be present, as described below.

Burrard Inlet has about 36 permitted discharges to the marine environment, comprised of municipal and industrial effluents. The largest discharge is from Burrard Thermal, a gas-fired electrical generator. The operator of Burrard Thermal has a permit to discharge 1,700,000 m^3/day of cooling water into Port Moody Arm at a temperature of 27ºC. Second in size is the Lion's Gate Waste Water Treatment Plant, the operator of which has a permit to discharge 102,000 m^3/day of primary treated sewage at First Narrows (Burrard Inlet Environmental Action Program, 1997).

Burrard Inlet also receives effluent from 32 unpermitted combined sewer overflows (CSOs), the largest of which is at Clark Drive. The two Clark Drive overflows (49º17.31′N, 123º4.65′W; 49º17.27'N, 123º4.69′W) discharge approximately 143 times per year, with an average annual discharge of 20,800,000 m^3 of mixed stormwater and untreated domestic sewage. Non-point source discharges in Burrard Inlet include those from 29 marinas, 11 ship repair facilities, 7 fueling operations, 29 ship loading facilities (sulfur, metal concentrates, coal, potash, phosphate rock, grain, forest products, chemicals, petroleum) and 38 anchorages. Sediments in Vancouver Harbour are contaminated with a variety of heavy metals and organics, as described by Tkalin et al. (this report) as well as several comprehensive recent reports by Canadian authorities (Boyd *et al*. 1998). The origins of these pollutants are likely a combination of the above point and non-point sources.

Thornbrough Channel

There are no industrial developments in southern Thornbrough Channel but there are residences on the shore. These homes have septic tanks that may contribute contaminants to the groundwater above the intertidal zone. Very large volumes of logs from elsewhere in BC are brought to the north end of Thornbrough Channel where they are dumped into the water, stored, and eventually towed for processing at sawmills in the lower Fraser River and elsewhere. A marina is located in the town of Gibsons. Sewage is treated in a secondary sewage treatment plant with an outfall discharge located at 49°23.13'N, 123°30.78'W. Permitted effluent volume is 1389 m^3/day. A pulp mill located at Port Mellon, about 12 km north of the PICES sample station has a permitted discharge of 106,500 m^3/day of pulp mill effluent, and 44,500 m^3/day of cooling water. The main diffuser outfall from Howe Sound Pulp and Paper at Port Mellon is located at 49º31.19′N, 123º28.50′W. This mill was upgraded to secondary treatment and chlorine substitution in response to amended and new federal Fisheries Act and Canadian Environmental Protection Act regulations enacted in May 1992. The Howe Sound pulp outfall diffuser has 6 ports ranging in depth from 30 m to 115 m below the low water mark. The outfall extends 277 m into the channel from shore into northern Thornbrough Channel where it enters a predominately northward flow. According to McLaren *et al*. (1993), Thornbrough Channel is entirely tidally dominated. As a result, the ebb and flood tidal currents probably disperse contaminants to the north and south of the discharge point.

Fisheries closures

Vancouver Harbour is closed for commercial trawling for fish but portions are open for shrimp trawling, primarily for smooth pink shrimp (*Pandalus borealis eos*). English Bay/Outer

Burrard Inlet has supported a shrimp fishery for over 75 years (Butler 1980). Until several years ago there was large by-catch of a variety of fish species in this fishery, including English sole (*Pleuronectes vetulus*), the target species for the ecophysiological studies in the PICES workshop. By-catch in the shrimp fishery has been reduced by the use of mandatory escape devices or extruders which are now built into the trawl nets. Inner Burrard Inlet was closed to crab fishing in May 1992, due to dioxin/furan contamination of crab hepatopancreas. The contaminant-related closure was lifted in August 1995, however, due to navigational risk, the area between First Narrows and Second Narrows is closed to all crab and shrimp fishing. Commercial and recreational crab fishing is permitted in Outer Burrard Inlet and east of Second Narrows, including Port Moody Arm.

Southern Thornbrough Channel is also closed for commercial trawling for fish but is an area for shrimp trawling. Howe Sound, including south Thornrough Channel, remains closed to commercial crab harvesting because of dioxin and furan contamination of hepatopancreas. Recreational crab harvesting is allowed with a consumption advisory issued to the public on crab hepatopancreas.

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