Distribution and Cycling of Suspended Particles Inferred from Transmissivity in the Strait of Georgia, Haro Strait and Juan de Fuca Strait

Sophia C. Johannessen*, Diane Masson and Robie W. Macdonald

Institute of Ocean Sciences
9860 W. Saanich Rd.
P. O. Box 6000, Sidney BC V8L 4B2

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ABSTRACT *Transmissometer profiles collected during quarterly cruises in 2000–03 indicate that most suspended particles in the Strait of Georgia and Juan de Fuca Strait are confined to the top and bottom of the water column. In Haro Strait, however, the particles are mixed throughout the water column by strong tidal currents, producing an estuarine turbidity maximum. The distribution and cycling of particles provide important aquatic controls for contaminant transport, photochemical reactions and photosynthesis. Particle-associated contaminants that enter Haro Strait may remain in suspension and enter the food web at all water depths. In the autumn and sometimes in the summer, the rate of photochemical transformation of dissolved organic matter is probably higher in Juan de Fuca Strait than in the Strait of Georgia or Haro Strait, because the surface water in Juan de Fuca Strait is less turbid.*

RESUMÉ *[Traduit par la rédaction] Les profils de transmissiomètre recueillis durant les croisières faites de 2000 à 2003 indiquent que la majorité des particules en suspension dans le détroit de Georgie et le détroit de Juan de Fuca se retrouvent près du sommet et près du fond de la colonne d'eau. Dans le détroit Haro, cependant, les particules sont mélangées dans toute la colonne d'eau par les forts courants de marée, ce qui engendre un maximum de turbidité estuarienne. La distribution et la mise en circuit des particules sont des facteurs aquatiques importants dans le transport des contaminants, les réactions photochimiques et la photosynthèse. Les contaminants présents dans les particules qui entrent dans le détroit Haro peuvent demeurer en suspension et s'introduire dans la chaîne alimentaire à toutes les profondeurs. En automne et parfois en été, le taux de transformation photochimique de la matière organique dissoute est probablement plus élevé dans le détroit de Juan de Fuca que dans les détroits de Georgie et Haro, parce que la tranche d'eau supérieure dans le détroit de Juan de Fuca est moins turbide.*

1 Introduction

Suspended and sinking particles play important roles in coastal ecosystems and in the cycling and transport of a wide range of elements and compounds. By sinking, particles transport organic carbon from the euphotic zone to the bottom sediments, participating in the biological sequestration of atmospheric carbon dioxide. Particles also provide substrates for micro-organisms, strongly influence aquatic light climate by scattering and absorbing solar radiation, and distribute and bury contaminants. The Strait of Georgia (Fig. 1a) receives a large influx of terrigenous particles of which about 80% (19×10^9 kg y^{-1}, Thomas and Bendell-Young, 1999) comes from the Fraser River. About a third of the particles carried by the Fraser River are deposited on the delta (e.g., Johannessen et al., 2003a); the remainder move out into the Strait, most noticeably in the turbid surface plume that can extend across the Strait of Georgia during the early summer freshet. Sediment cores (e.g., Johannessen et al., 2003a) and seismic stratigraphy (Hart et al., 1998) indicate that sediment accumulation rates are highest in the central Strait, near the Fraser River mouth, and that particles move generally northward along the bottom. The influence of the Fraser River is apparent in the grain-size distribution and elemental composition of bottom sediments as far north as Texada Island (Barrie et al., 2005; Syvitski and Macdonald, 1982). Particle interception traps, deployed for two years at three sites, support the interpretation of a northward movement of particles along the bottom of the Strait of Georgia and demonstrate that direct, local settling is only a relatively minor particle transport mechanism in much of the Strait (Johannessen et al., 2005). However, sediment traps are spatially limited, and the sediment core and seismic data allow only a crude inference of particle pathways in the water column. Even less information

*Corresponding author's email: johannessen@pac.dfo-mpo.gc.ca

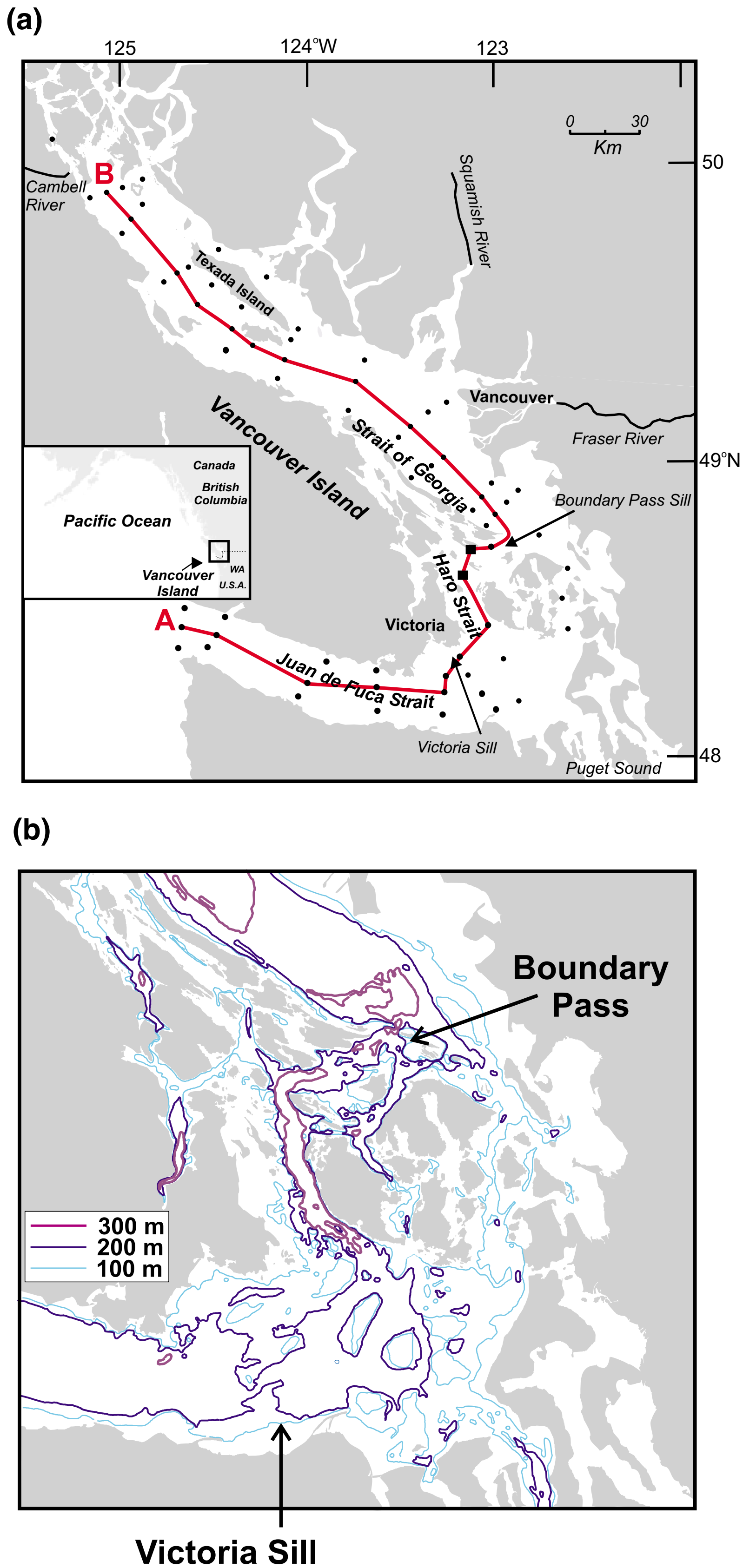

Fig. 1 (a) The study area. Transmissometer profile stations are marked as dots or solid squares. The solid squares represent the stations used in the statistical analysis of the effect of current speed on the clarity of the water in Haro Strait (Fig. 4). The red line, section AB, represents the transect shown in Fig. 3. (b) Bathymetry of Haro Strait.

of any kind is available about particle fluxes through Juan de Fuca and Haro Straits (Fig. 1a), which connect the Strait of Georgia to the Pacific Ocean, and to Puget Sound across the Canadian-American border to the south. To infer the paths taken by particles through the Strait of Georgia and Haro and Juan de Fuca Straits, a description of the distribution of suspended particles in the water column is needed.

Here we present a dense set of transmissometer profiles that provides a sequence of 'synoptic' views of suspended particle distributions in the greater Strait of Georgia including Haro and Juan de Fuca Straits. We then infer from these suspended particle distributions and other oceanographic observations the important particle pathways, thus providing a coherent basis upon which to plan detailed work on the cycling of non-conservative material in this coastal system.

a *Transmissometer Profiles*

Transmissometers have been used to determine concentrations of suspended particles (e.g., Baker, 1984) and particulate organic carbon (Bishop, 1999), to define the extent of hydrothermal vent plumes (Thomson et al., 1992; Baker and Hammond, 1992), and to define boundaries between oceanographic regions (Gardner et al., 1990).

Transmissometers measure the percentage transmission of light over a defined path length. Low transmissivity (alternatively expressed as high beam attenuation coefficient) indicates high light attenuation and a high concentration of particles, because particles scatter light out of the direct path to the receiver. Interpreting transmissometer data can be complicated, however, because particle size, shape and composition affect scattering (e.g., Baker, 1984; Moody et al., 1987; Wells and Kim, 1991; Jago and Bull, 2000). In addition, the bow wake caused by the descent of the rosette, which transmissometers are usually attached to, may disturb the bottom nepheloid layer and create attenuation artefacts near the bottom of the cast. Phytoplankton also affect light attenuation, and, although phytoplankton fluorescence measured at the same time as attenuation allows some correction, physical particle sampling is ultimately required to calibrate transmissometer data to absolute particle concentration.

For the profiles presented here, a time-varying calibration based on filtered samples was not conducted, so the data cannot be calibrated to absolute particle concentration. Nevertheless, these profiles provide the first synoptic view of relative clarity of the water in the Strait of Georgia, and demonstrate spatial and seasonal patterns in particle concentration that could not otherwise have been measured. They also allow for a preliminary assessment of light penetration through the water column and of the consequent distribution of photochemical reactions.

2 Data collection

Transmissometer profiles were collected at 76 stations (Fig. 1a) during 16 quarterly cruises from 2000 to 2003 aboard the CCGS *Vector* (Masson, this issue). The cruises encompassed the Strait of Georgia, Juan de Fuca Strait and Haro Strait. In this paper the Haro Strait – Boundary Passage system and the part of Juan de Fuca Strait east of Victoria Sill (Fig. 1b) will be referred to as 'Haro Strait,' for simplicity. The Sea Tech transmissometer was attached to the bottom of the frame of the sampling rosette, beside the conductivity-temperature-depth instrument (CTD). The rosette was lowered at about 1 m s^{-1} through most of the water column and 0.5 m s^{-1} for the last ~15 m, stopping 1 – 5 m from the bottom. It measured the percentage transmission of a beam of 660 nm light over a 25-cm path length. The 25-cm transmissivity was converted to the beam attenuation coefficient, c (m^{-1}), according to the equation

$$c = \frac{1}{r}\ln\left(\frac{Tr}{100\%}\right),$$

where r is the path length in metres and Tr is the percentage transmission over that pathlength (Baker, 1984). The transmissometer windows were generally cleaned before each cast. Chlorophyll a fluorescence was measured with a Seapoint fluorometer mounted on the rosette frame (excitation wavelength 470 nm, emission 685 nm). For both the transmissometer and the fluorometer, only data from the downward cast were used, and the deepest data, from casts during which the rosette had hit the bottom, were removed.

3 Results and discussion

a *Strait of Georgia*

In the Strait of Georgia the beam attenuation coefficient was typically high at the surface, in association with low salinity water, low at intermediate depths, and high again in the bottom 5 – 30 m (e.g., Fig. 2). This pattern was particularly pronounced in the spring and summer (Fig. 3), when the Fraser River water and sediment discharge are at their peak (Kostaschuk et al., 1989) and the surface water was visibly murky and yellow near the river mouth. The profile section in Fig. 3b shows the Fraser plume clearly as a surface lens of freshwater associated with high attenuation in the uppermost 15 m. The estuarine circulation that moves surface water and some of the associated particles out of the Strait of Georgia through Juan de Fuca Strait is particularly pronounced during the summer freshet of the Fraser River.

Intrusions from Haro Strait, which contain a significant amount of Strait of Georgia surface water reinjected below the surface (Masson and Cummins, 2004), result in an increase in turbidity at mid-depths (100–200 m). This results in interleaving of water masses with high and low particle concentrations in the southern Strait.

High turbidity in the surface water of the northern Strait of Georgia in the summer, associated, as in the southern and central Strait, with low salinity, seemed to be disconnected from the Fraser plume (Figs 3 and 4). This turbid, fresh surface water was consistent with a local source of particles via runoff. The largest river that drains directly into the northern Strait, the Campbell River, was probably not the source, however, because it is a rain-fed river whose maximum discharge

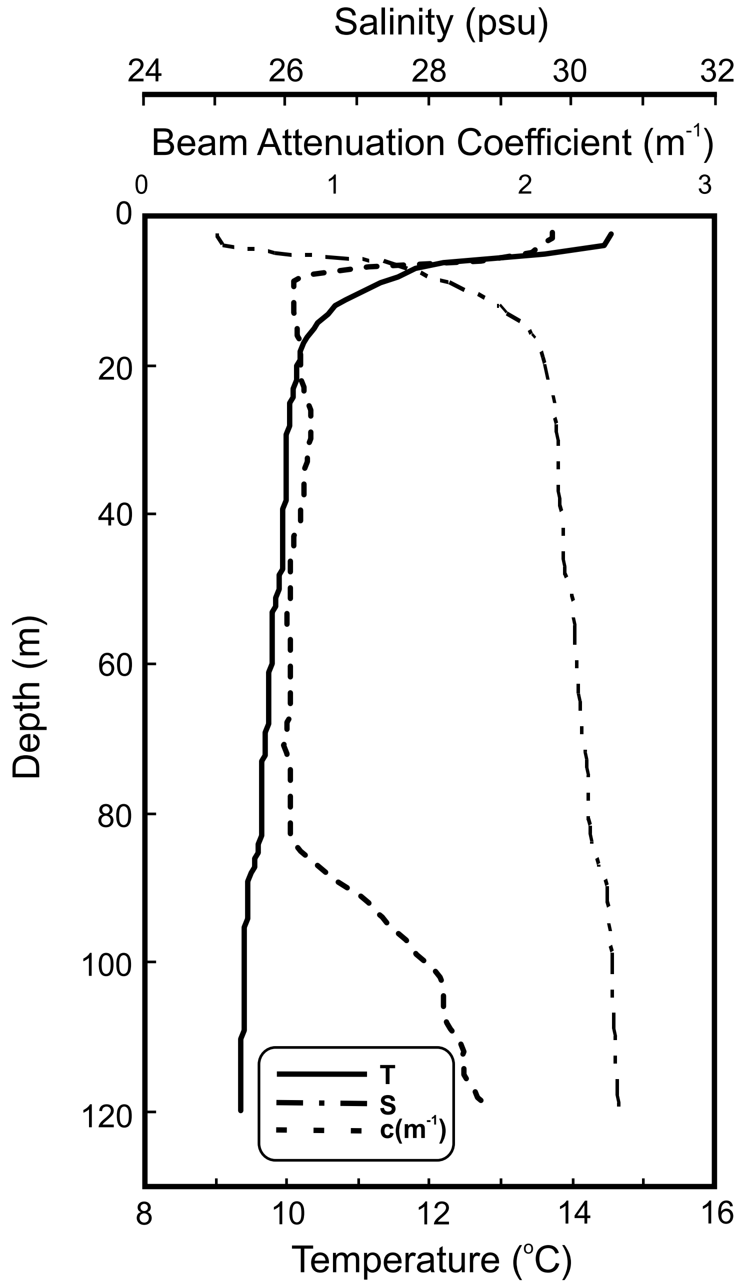

Fig. 2 Example profiles of temperature, salinity and beam attenuation coefficient, collected at the station nearest the mouth of the south arm of the Fraser River, in July 2002.

is in December (Environment Canada, 2003, unpublished manuscript), and it contains a large headwater lake that traps particles supplied by drainage from Vancouver Island interior mountains (e.g., Pedersen and Losher, 1988). The particles are more likely to have come from glacially fed rivers that drain into inlets connected to the northern Strait.

The bottom nepheloid layer extended throughout the Strait of Georgia, but was thickest in the southern Strait, from Haro Strait northward to Texada Island (Figs 1 and 3), where the deep estuarine return flow tends to carry particles northward. It extended farthest north, and was thickest, in summer and autumn, in marked contrast to the extremely clear mid-depth water in the Strait of Georgia at that time. Its winter extent varied among years, while in spring it was generally confined to the southernmost part of the Strait of Georgia. The nepheloid layer of the northern Strait, which was isolated from that of the central Strait by the shallow area near Texada Island, likely developed independently, as a result of occasional resuspension in that area. A similar pattern of high particle concentration at the top and bottom of the water column, with clearer water in between, has been observed in Puget Sound, from which Baker (1984) inferred the isolation of mid-depth

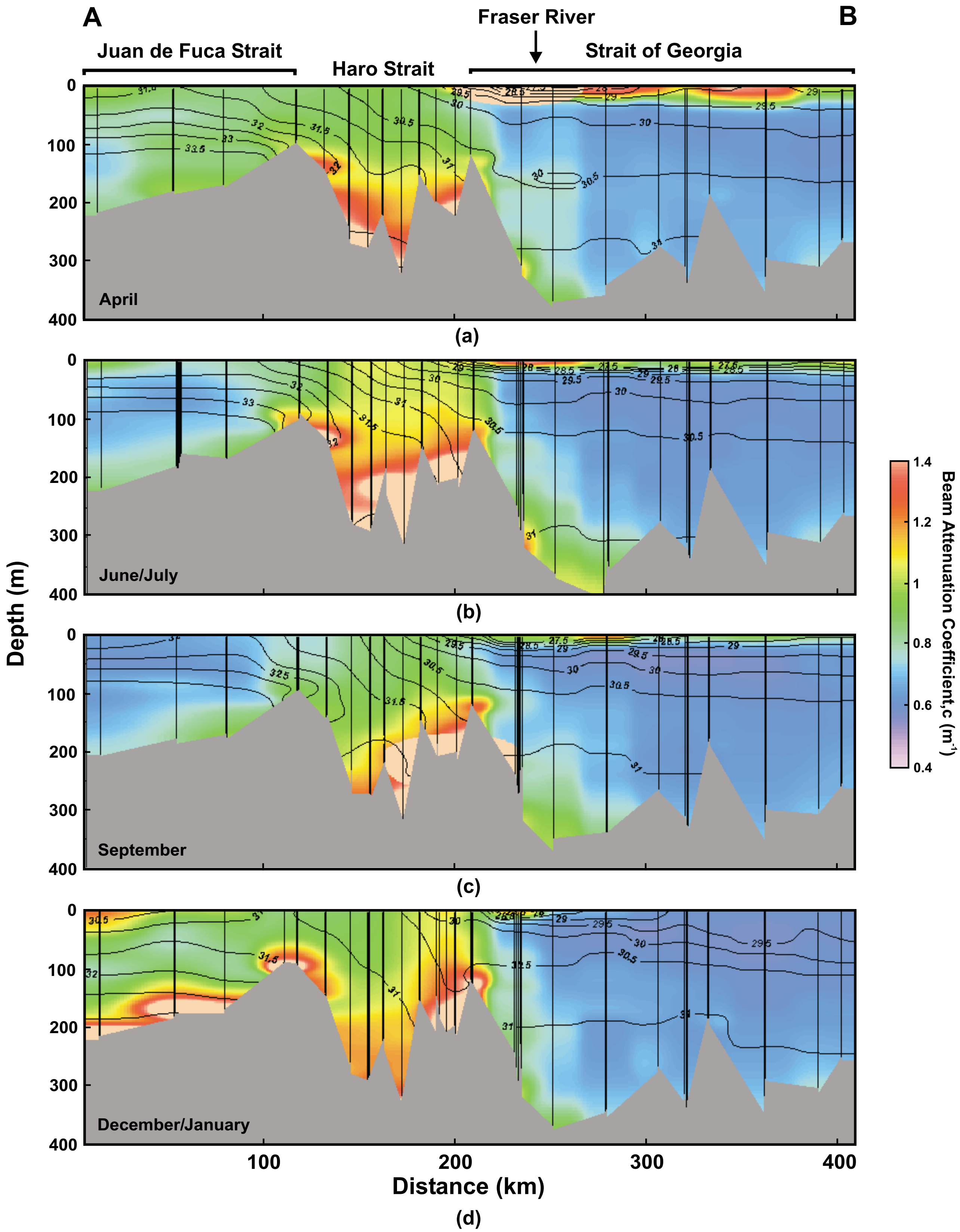

Fig. 3 Seasonal average beam attenuation coefficient profile sections along transect AB, shown in Fig. 1a, with salinity contours overlain, for (a) April, (b) June/July, (c) September and (d) December/ January (2000–03). The x-axis values represent distance from the mouth of Juan de Fuca Strait. The black, vertical lines show the station locations. The bathymetry is not exactly the same in all the panels, because is was plotted based on the bottom depth of each cast. Plots made in Ocean Data View (Schlitzer, 2003).

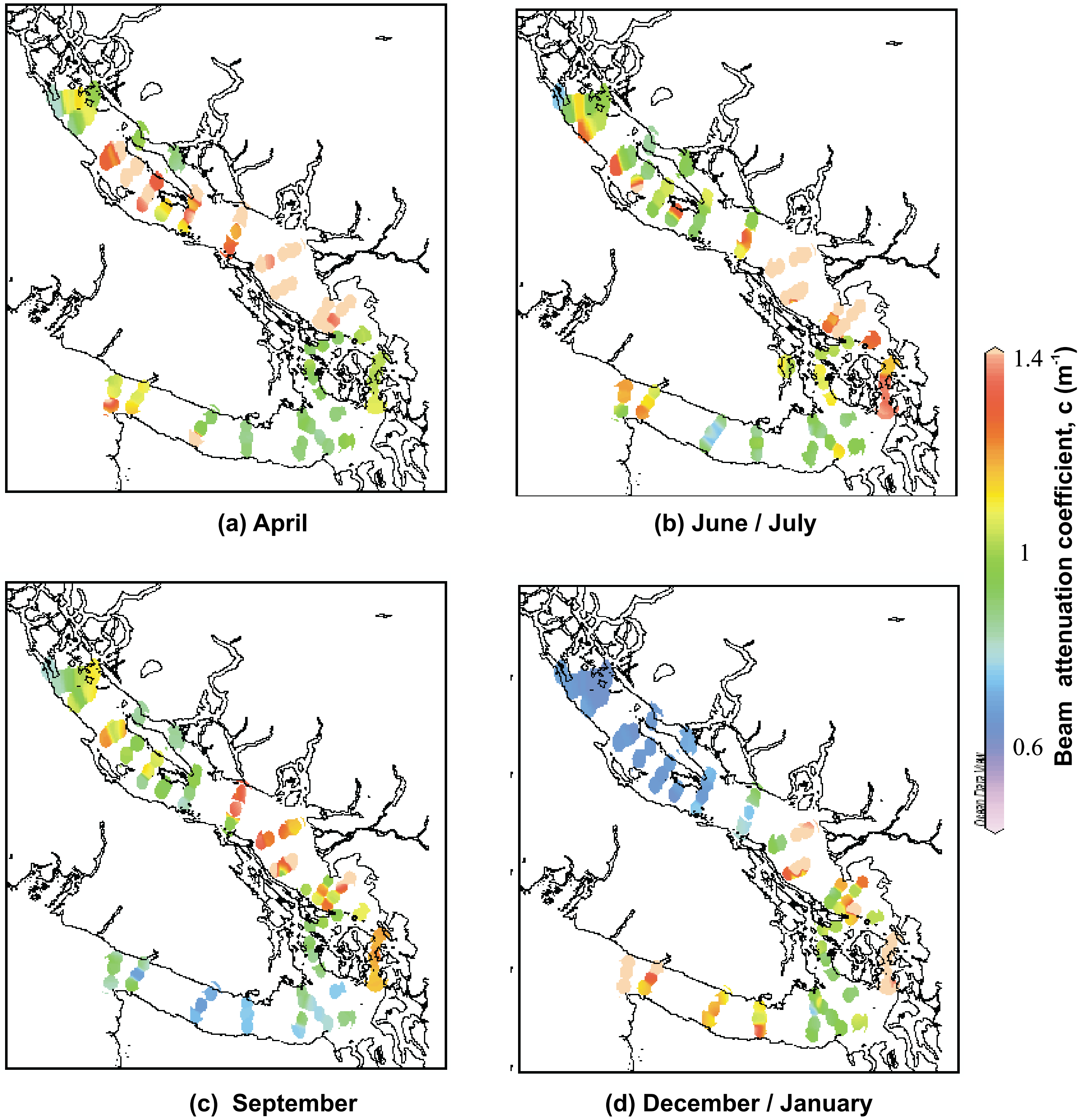

Fig. 4 Seasonal average beam attenuation coefficient at the surface, for (a) April, (b) June/July, (c) September and (d) December/January. Plots made in Ocean Data View (Schlitzer, 2003).

water from sources of particles: fine particles tend to remain in the surface layer, while larger aggregates sink quickly to the bottom.

In the winter, the surface water was clear throughout the Strait (Fig. 4), because the predominant sources of particles, river discharge and primary production, were low.

b *Haro Strait region*

Attenuation was high year-round throughout the water column in Haro Strait, Boundary Pass and the part of Juan de Fuca Strait to the east of Victoria Sill (here discussed together as Haro Strait). Tidal currents in Haro Strait are up to five times as fast as those in the Strait of Georgia (LeBlond, 1983). These strong currents mix the water column and reduce stratification (Thomson, 1994; Masson and Cummins, 2004). Strong turbulence associated with super-critical flow has been observed in this area (Pawlowicz, 2001; Farmer et al., 2002), and undoubtedly contributes to particle resuspension in this area, creating an estuarine-like turbidity maximum. The intensity of the tidally induced mixing varies with the spring-neap cycle (e.g., Griffin and LeBlond, 1990; Masson and Cummins, 2000). The spring-neap control on the mixing and on the breakdown of the salinity structure in Haro Strait and the Strait of Georgia has also been demonstrated in numerical models (Li et al., 1999; Masson and Cummins, 2004). The particle concentration appears to be similarly controlled. Particles are mixed both up from the bottom and down from the surface, with turbidity in Haro Strait strongly related to current speed. The mean beam attenuation coefficient of the water column increases with the intensity of tidally induced mixing (Fig. 5). The high particle load associated with Haro Strait, as shown by perennial high attenuation especially near the bottom (Fig. 3), must be sustained by a local source of particles, such as erosion of glacial deposits by the strong and turbulent currents, as well as seasonal entrainment of particles from the Fraser River plume through downward mixing.

There are sharp fronts in the attenuation coefficient at both ends of Haro Strait (Fig. 3), suggesting that suspension cannot be maintained once particles leave the high energy zone. Particles sink or are consumed by foraging organisms. The attenuation frontal zone at the northern end of Haro Strait may not be quite as sharp as it appears in Fig. 3, since it could fall anywhere between the two nearest sampling stations, but certainly there is a large change in the vertical distribution of attenuation between those two sites. High concentrations of suspended particles at mid-depths are mainly confined to Haro Strait. However, particles may re-enter the Strait of Georgia at mid-depths, as discussed earlier, or may escape along the bottom into the Strait of Georgia or Juan de Fuca Strait. The bottom nepheloid layer is thick on the sides of the sills bounding Haro Strait, which might indicate resuspension of sediments in situ by currents that are strong enough to lift them off the bottom but not turbulent enough to mix them into the upper water column. Alternatively, the high attenuation might identify turbid plumes flowing out of Haro Strait and down the sills. Periodic deep-water renewal events are associated with changes in salinity and temperature of the bottom water that amount to a density difference from ambient of less than 1 σ_T unit (Masson, 2002). This difference would be equivalent to a suspended load of <1 mg L^{-1} of particles. Since we have not calibrated our attenuation measurements locally to particle concentration, we do not know unequivocally the local particle concentration. However, Baker's (1984) calibration to particle concentration for different size fractions, converts the >1.4 m^{-1} attenuation observed near the bottom of Haro Strait to a particle concentration of at least 5 – 50 mg L^{-1}, depending on particle size. Clearly, suspended particles have the potential to affect the momentum of inflowing, deep water plumes. The loss of particles through settling may also contribute to the mixing of the deep intrusions within the deep basin, because, as particle loads are dropped from the plume, the intruding water becomes more buoyant, possibly to the point of instability at the original depth of entry into the basin.

The dominant direction of sediment movement at the bottom of the southern Strait of Georgia is northward (Johannessen et al., 2005; Hart et al., 1998), which is consistent with movement down the Boundary Pass sill and into the Strait of Georgia, either continuously, as a result of advection by the deep estuarine inflow, or periodically, due to turbidity currents. In Puget Sound periodic flushing has been observed to cause up-estuary movement of particles along the bottom (Baker et al., 1983).

c *Juan de Fuca Strait*

There is little modern deposition of sediments in Juan de Fuca Strait (Hewitt and Mosher, 2001). The bottom is composed predominantly of sand, gravel and glacial-marine silty clay, with areas of exposed bedrock (Hewitt and Mosher, 2001). Fine particles (and any associated contaminants) must be carried away and deposited elsewhere (Macdonald and Crecelius, 1994). Active transport is reflected in the high attenuation at the bottom of Juan de Fuca Strait. The deep water attenuation coefficient exhibits a seasonal modulation, with the highest concentration of particles occurring in winter (December/January). This may indicate winter wave-induced resuspension of particles off the shallow banks (e.g., Hewitt and Mosher, 2001), or possibly a seasonal shift in the upstream source of particles. Because the mean estuarine flow direction at depth in Juan de Fuca Strait is landwards, the upstream source must be the shelf. A plausible mechanism to produce a seasonal signal in the particle source would then be the seasonal shift in coastal currents which, in winter, trend to the north-west, bringing water from the Washington Shelf and Columbia River northwards, in contrast to summer when the Columbia River is diverted southward (Macdonald and Pedersen, 1991). If the suspended particles near the bottom of Juan de Fuca Strait in winter signal the import of resuspended particles from the outer shelf to the south (Washington Coast/Columbia River), then the net flow landward along the bottom of Juan de Fuca Strait would provide the means to move these sediments subsequently into Haro Strait and the Strait of Georgia.

The surface water is most turbid in the winter throughout Juan de Fuca Strait, and very clear in late summer/early autumn (Fig. 4c) in contrast to the turbid surface water observed in the Strait of Georgia at that time. The high attenuation in surface water at the mouth of Juan de Fuca Strait in the winter is probably sustained by the seasonal flow of turbid surface water northward along the coast of Washington State, south of the study area (see Landry and Hickey, 1989). This is also supported by changes in water properties (e.g., salinity, temperature, nutrient concentration) at the mouth of Juan de Fuca Strait (Masson, this issue). Cloud and fog cover allow only sporadic satellite glimpses of this region during winter, but several images between December and January in 1995, 1997, 1999 and 2000 show high turbidity along the Washington coast extending northward into the mouth of Juan de Fuca Strait and beyond. The image from January 2001 (Fig. 6) reveals this transport as a stream of suspended particles in a narrow coastal band extending northward from rivers in Washington State and impinging on the region of high surface attenuation (Fig. 4c). This image also confirms the transmissometer finding of clear surface water throughout

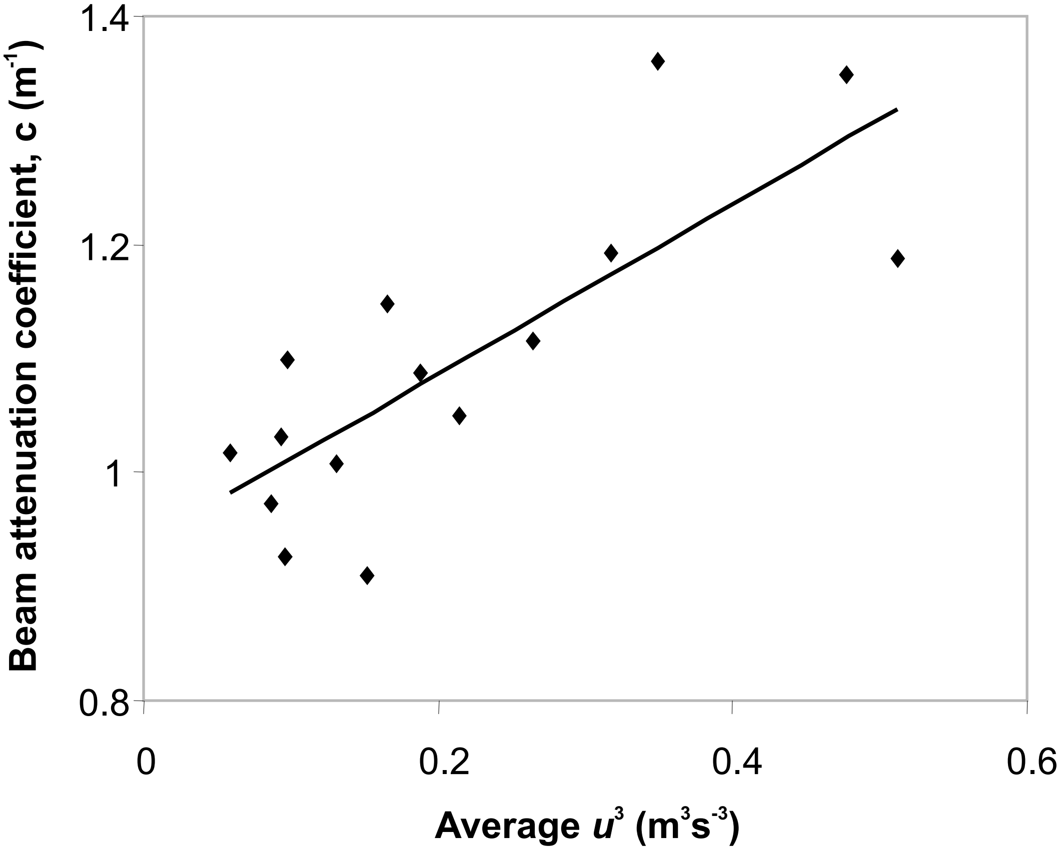

Fig. 5 Average water column beam attenuation coefficient at two Haro Strait stations (Fig. 1a) versus the cube of the tidal speed, u^3, over the day prior to and the day of the cast, during all cruises for which data were available (all but April 2001). The solid diamonds represent data, the line a linear regression on the data ($r^2 = 0.6$; $n = 15$). Tidal currents were computed with a three-dimensional, barotropic, finite element tidal model, including eight tidal constituents (Foreman et al., 1995).

the rest of Juan de Fuca Strait in the winter and of turbidity in Haro Strait and the southernmost part of the Strait of Georgia.

d *Effect of Phytoplankton Blooms on Transmissivity*

Phytoplankton blooms affect transmissivity. Gardner et al. (1990) found that transmissivity decreased from 0.51 – 0.17% m^{-1} during a two-week phytoplankton bloom in the North Atlantic, apparently because of the increased concentration of biogenic particles. In the southern Strait of Georgia, during the Fraser River freshet, there is such a high load of inorganic particles from the river that phytoplankton blooms may have little opportunity to influence the measured beam attenuation coefficient significantly. However, in April (Figs 3 and 4), before the freshet, there is a large patch of strongly attenuating water at the surface, in association with high fluorescence (fluorescence data not shown) that may represent the spring bloom. Farther from the river mouth, during the summer, blooms may also have affected the attenuation. For example, in September, west of Texada Island and at the mouth of Juan de Fuca Strait, high turbidity which was not associated with fresh water occurred in patches where the chlorophyll fluorescence was high. Bottle casts and microscopic particle identification are needed throughout the Strait to assess the contribution of phytoplankton to the pool of particles at different depths and locations in these waters.

e *Contaminant Cycling*

Particle-reactive contaminants, including heavy metals such as lead and mercury, nonylphenol ethoxylates, polyaromatic hydrocarbons, and radionuclides, are sequestered in the bottom sediments of the Strait of Georgia, largely in, or near, the prograding delta (Macdonald et al., 1991; Macdonald and Crecelius, 1994; Shang et al., 1999; Yunker et al., 1999). The rate of resuspension of contaminated bottom sediments is not known.

Haro Strait is an area of intense particle mixing, and may be crucial to the distribution of contaminants and to their entry into the food web. Particles may enter Haro Strait by downward mixing of the Fraser River plume, by resuspension and advection of settled particles from Puget Sound or Juan de Fuca Strait or by erosion of poorly consolidated material from islands and banks within this region. Some fines may reenter the Strait of Georgia at mid-depths, as suggested in the earlier section about the Strait of Georgia. Others may be exchanged among Haro Strait, the Strait of Georgia and Juan de Fuca Strait near the bottom.

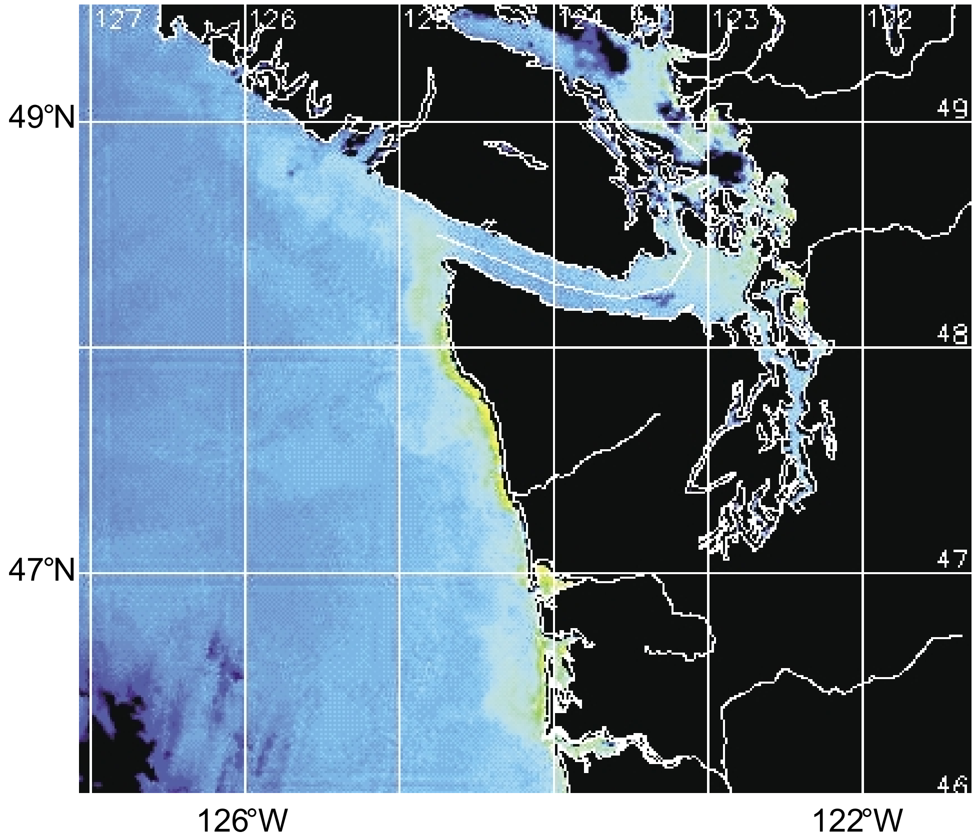

Fig. 6 Normalized water-leaving radiance at 555 nm (reflection from suspended particles) on 26 January 2001, from Advanced Very High Resolution Radiometer (AVHRR), aboard a National Oceanic and Atmospheric Administration (NOAA) weather satellite. Green represents areas of relatively high particle concentration. Image courtesy of Dr. J. Gower, Institute of Ocean Sciences, Sidney, B.C., January 2005. Similar images are posted at http://www-sci.pac.dfo-mpo.gc.ca/osap.

The transmissometer data show that at all times of the year, there is a high concentration of particles suspended in the water column of Haro Strait. And, given that Haro Strait is an important passage for inflow and outflow, the resuspended particles provide a continuous opportunity to scavenge and concentrate contaminants. Based on observations in the North Sea, Bale and Morris (1997) concluded that resuspended particles had a higher concentration of organic carbon than did the bulk bottom sediments. Higher organic carbon suggests stronger partitioning of contaminants like PCBs and PAHs onto the particles and a stronger thermodynamic forcing of such contaminants during metabolism (cf. Macdonald et al., 2002). The high organic content of the particles also potentially increases the attractiveness of the suspended particle reservoir as a food source for zooplankton and filter feeders. In addition to the many sources of contaminants within the Strait of Georgia, which have been documented in several reviews (Waldichuk, 1983; Harrison et al., 1994; Macdonald and Crecelius, 1994; West et al., 1994), contaminants from Puget Sound to the south and from the city of Victoria, which discharges effluent into the deep water of Juan de Fuca Strait near the Victoria Sill, may enter the food chain in Haro Strait, due to the strong tidal mixing of water and particles. The hypothesis that Haro Strait sustains a particle-contaminant reflux sink could and should be tested using a suite of contaminant tracers, large volume collections of suspended particles, and selected species from the food chain.

f *Light, Photochemistry and Photosynthesis*

The transmissometer profiles can be used to infer the penetration of light through the water column. For example, the very turbid surface layer near the Fraser River mouth during the summer must act as a cap that blocks light from entering the clear mid-depth water. Although the instrument measures attenuation only at 660 nm, particle scattering increases with decreasing wavelength (Gordon et al., 1988), so the shorter wavelength radiation relevant to phytoplankton (chlorophyll a absorbance peak at ~440 nm (Kirk, 1983)) and to photochemical reactions (generally most efficient in the ultraviolet (UV) range (Miller, 1998)) must be attenuated even more rapidly than 660 nm light. The differences in the attenuation profiles among the basins and among seasons thus have implications for the rate and distribution of photochemical reactions and primary production.

Coloured dissolved organic matter (CDOM) is the precursor substance for many photochemical reactions, including the production of dissolved inorganic carbon, free radicals, and nutrients (Miller, 1998). It is the main absorber of UV radiation in the ocean in the absence of particles. Where particles are present, however, they may scatter or absorb a significant portion of the UV radiation. For example, in the turbid Delaware Bay CDOM only absorbs about 25% of the incident UV, while in clear coastal waters and the open ocean it absorbs close to 100% (Johannessen et al., 2003b). The surface water of Juan de Fuca Strait is clearest in September and is sometimes clear in June/July (Figs 3 and 4), though it is very turbid in the winter. As a result, photochemical reactions may take place to great depths in the water column of Juan de Fuca Strait in the summer.

Of course, if the CDOM is concentrated at the surface, then that is where most of the reactions will take place. There are currently no CDOM absorption data available for the study area and only a few, unpublished optical profiles. The data presented here indicate that such measurements would yield interesting results, particularly as a comparison among basins.

Regardless of the depth distribution of the CDOM, however, it is likely that during the summer and autumn, when there is the most radiation available for photochemical reactions, those reactions will take place more rapidly in Juan de Fuca Strait than in the Strait of Georgia, where the surface turbidity is high in the summer, or in Haro Strait, where it is high year-round. In the Strait of Georgia, the surface water is clearest in December/January (Figs 3 and 4), which would allow deep penetration of UV and other radiation, but there is much less radiation available in the winter than in the summer, so the total water column rate of photochemical reactions in the winter is probably relatively low. In contrast to those reactions that require CDOM, photochemical reactions that occur on the surfaces of particles may occur more rapidly in areas of high turbidity.

Phytoplankton productivity is controlled by the availability of both light and nutrients. In the Strait of Georgia, turbid plumes from the Fraser and Squamish rivers limit productivity by reducing the penetration of light into the water column, although productivity is high at the edges of the Fraser River plume, due the high nutrient concentration (Harrison et al., 1983). A high surface concentration of CDOM, which would be transparent to the transmissometer because CDOM does not absorb measurably at 660 nm, would also reduce the potential for primary production by absorbing some of the short wavelength radiation used by phytoplankton. The surface waters of the Strait of Georgia are relatively turbid throughout the summer, possibly limiting productivity somewhat, even in the northern Strait far from the Fraser River. In contrast, Juan de Fuca Strait could be highly productive in the summer: the concentration of nutrients is high throughout the water column, especially in summer (Mackas and Harrison, 1997), and the surface water is clear.

4 Conclusions

Together the transmissometer profiles presented here provide a reasonable proxy for the distribution of suspended particles on a small vertical scale (data binned to 1-m resolution), with comprehensive areal coverage. These data reveal previously unknown features of the particle distributions in the three straits, including top-to-bottom water column mixing of particles and spring-neap control of suspended particle concentration in Haro Strait, and a source of particles at the surface of the northern Strait of Georgia. The particle resuspension and mixing observed in Haro Strait identify this region as an important particle-water interaction site, which allows continuous scavenging of contaminants by particles and a means by which such particles may readily enter the food web at all water depths. Photosynthesis is probably limited to shallower depths in the Strait of Georgia than in Juan de Fuca Strait, because of the dense surface cap of particles in the former. Similarly, photochemical reactions based on CDOM probably occur at a higher rate in Juan de Fuca Strait.

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