STRATOGEM—The Strait of Georgia Ecosystem Project

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Abstract

Strait of Georgia is a highly productive, semi-enclosed, marine ecosystem that has undergone considerable changes in recent years. Surrounding populations and their sewage have increased, as have commercial (e.g. fishing and shipping) and recreational usages (e.g. boating and sport-fishing). There have also been significant changes in the marine ecosystem of the Strait of Georgia. STRATOGEM (www.stratogem.ubc.ca) is an attempt to understand the links between the lowest levels of biological productivity in this Strait and the physical dynamics of the system. By tying together a 3-year monitoring program of monthly multi-parameter full water column sampling over the southern Strait with a continuous monitoring program of surface properties from ferries and computer models of the circulation and biological dynamics, we hope to come up with some idea about what is going on.

Introduction

The Strait of Georgia (SoG hereafter), on the eastern side of Vancouver Island, Canada, forms a large inland sea (Figure 1). It is about 200km long by 30km wide, with a maximum depth of about 400m. Communication with the open ocean around the northern end of Vancouver Island is through a series of long and narrow passages, believed to have only a minor influence on the complete system. At its southern end the SoG communicates with the ocean through a complex network of channels, the largest of which is Haro Strait, around and between the Gulf and San Juan Islands, and then through the long, wide, and relatively straight Juan de Fuca Strait (hereafter JdF). Sill depths in this southern outlet are around 100m in depth. The SoG is thus a deep bowl separated by shallow sills from surrounding waters. The physical characteristics of the SoG are dominated by the summer inflow of fresh water, primarily from the freshet of the Fraser River. Fraser river flow varies by a factor of 10 between winter and summer, with maximum flow rates of about 10,000 m^3/s forming about half the total fresh inflow (Thomson, 1981; Pawlowicz, 2002). There is considerable interannual variation.

The freshwater inflow spreads out over the top of the SoG forming a highly stratified surface layer less (often much less) than 10m thick. Near the outlet of the Fraser the fresh water forms a plume which is muddy brown in colour in the summer, and in which surface salinities can drop to as low as 5 PSU. Wintertime surface salinities, and surface salinities away from the immediate plume region are usually in the highs 20s. Salinity of the deeper water is usually around 31. The fresh surface water eventually exits the system through JdF. The outflowing layer there is rather thicker and more saline, and so one infers an inflow of saline ocean water beneath to form the classical two-layer circulation of an estuary. Salinity differences in JdF are much less than in SoG, a result of tidal mixing that occurs in the vicinity of the sills near Haro Strait (Pawlowicz and Farmer, 1998).

The primary source of nutrients in this system is this deep estuarine inflow, which traverses the continental shelf within the deep Juan de Fuca canyon, having its source in the nutrient rich deep Pacific waters rather than coastal waters offshore. Observed nitrate concentrations within JdF are always high, ranging from 25-30 μM and are high in surface waters at the eastern end of JdF year-round. Although about 7000 tonnes N/day enters the system via the estuarine inflow in summer, the tidal mixing moves about 90% of this upwards into the outflowing surface layer and only about 10% of this inflow (around 700 tonnes N/day) actually makes its way into the deep SoG

(Mackas and Harrison, 1997; Pawlowicz, 2002). Other nutrient inflows are smaller but less well known. The Fraser River supplies around 50 tonnes N/day in the summer but it appears that the nutrient concentrations in the summertime Fraser are rather low (< 5 um). Sewage inputs are of a similar magnitude. Deep SoG waters are always high in nutrients, although surface waters are low from April to September. Primary production is believed to be limited by nitrates in summer and by light in winter. Previous work (see Harrison et al. 1983) suggests that in winter nanoflagellates are dominant, but in spring the increased light favours a succession of diatom blooms (*Thalassiosira spp*. Followed by *Chaetocerus spp*.). The spring bloom is believed to require the stability of a stratified water column and hence is to some extent controlled by the beginning of the freshet (Yin et al. 1996). Summer blooms of various diatoms and dinoflagellates occur, and it is thought that such blooms are controlled by the availability of nitrates through physical mixing processes that are driven by strong winds, etc.

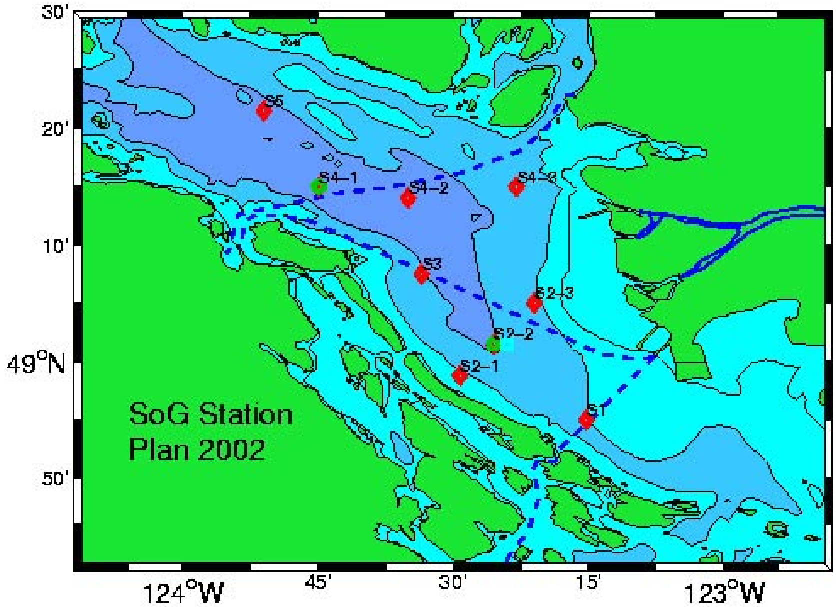

Figure 1: Southern Strait of Georgia showing CTD station plan and ferry routes.

STRATOGEM

Both the biological and physical characteristics of the SoG are relatively well-studied as oceanographers have been working here for over 50 years. However, there is as yet no quantitative understanding of the coupled biological and physical system. STRATOGEM is a program designed to resolve the coupling (for more information, see www.stratogem.ubc.ca). The program began in April 2002 and in spirit is guided by the question "what controls productivity in the SoG?" Clearly such an understanding is of regional interest but in addition the SoG may be an ideal testbed for studying such processes in general. This is because its enclosed nature allows in- and outflow budgets of heat, fresh water, and nutrients to be estimated relatively easily compared with the open coast. In addition, unlike more restricted estuaries for which this is also true the SoG is large and deep enough to be considered "ocean-like." It is therefore possible that a relatively simple physical modeling effort may provide sufficient accuracy to allow for quantitative understanding of biological processes. Finally, the coastal nature of this region makes the logistics of fieldwork much simpler, and as we shall discuss below there are ways in which near-continuous monitoring can be carried out relatively cheaply.

In the rest of this paper we shall outline our scientific strategy and discuss some preliminary results. Clearly a model of some sort will be required to provide a synthesis of the results but it cannot be run in isolation. Field data is needed and two major sampling programs as well as a reanalysis of historical data are being carried out in addition to the modeling effort.

Baseline Surveys

The primary dataset will provide a baseline of physical and biological data. By carrying out monthly cruises over three years we will observe not only the seasonal cycle but also gain knowledge of the interannual variability, which may be important in assessing climatological response. Each cruise consists of 9 hydrographic stations covering the southern and central SoG (Figure 1). At each station complete water column profiles of temperature, salinity, dissolved oxygen, chlorophyll fluorescence, and light transmission at 660 nm are measured. In addition, water bottle samples for nutrients (nitrates, phosphates, and silicic acid) are taken at 4 standard depths (0, 5, 10, and 30m), as well as size-fractionated chlorophyll. Zooplankton abundance is monitored using an Optical Plankton Counter (OPC), which is co-lowered with the CTD. At station S4-1, which has been used as the site of previous monitoring efforts over the years, a full water column profile of nutrients as well as a vertical plankton net tow is also obtained. Station locations were chosen to satisfy a number of criteria. They are spread out in order to best quantify the spatial variability. They are located both within and as far away as possible from the Fraser plume. The drawback of this approach is that it is difficult to use them to, e.g. estimate geostrophic transport, as station density in individual sections is somewhat low. In addition, stations are placed

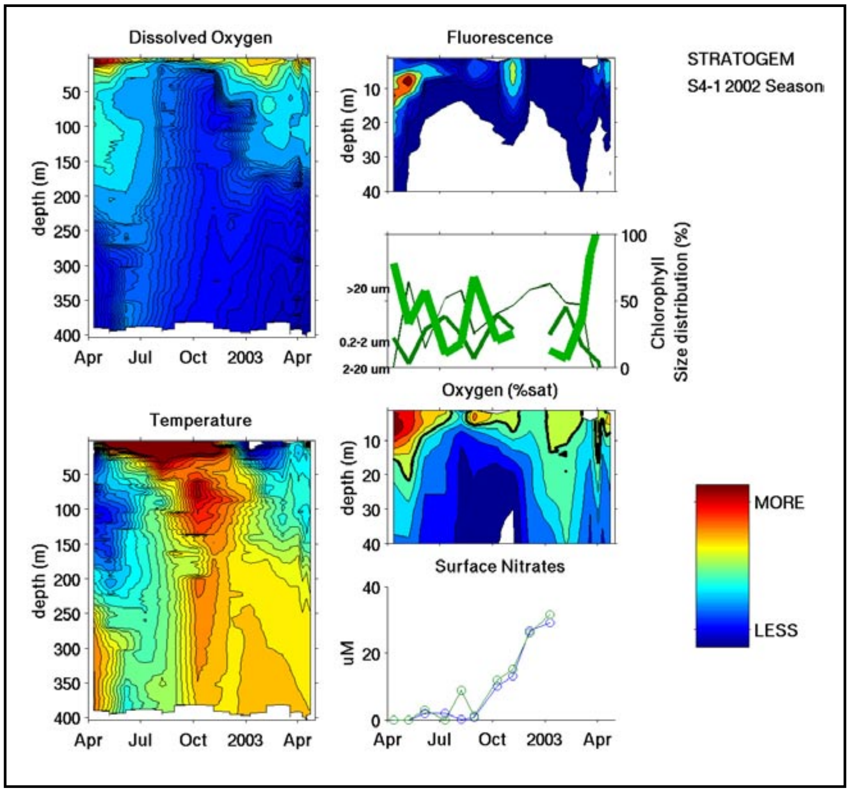

Figure 2: Summary of monthly CTD data at station S4-1. Dissolved Oxygen values range from 2 to 10 ml/l, and the temperature scale is from 7.5-10C (although surface summer temperatures are in excess of 18C). The solid dark line represents 100% oxygen saturation; note that surface waters are generally near 100% saturation except during the spring bloom when 150% supersaturation is observed.

close to major ferry routes to complement the second dataset, described next. Finally, the number of stations, covering a track of about 180km, is the maximum that can be obtained in a one-day cruise using the platform available (the Coast Guard hovercraft SIYAY).

Figure 2 summarizes the results of the first year of sampling by presenting time series at a northern location (Station S4-1). Deep temperatures vary seasonally, lagging the variation in surface temperatures by several months. This rather long lag arises more from the long residence time of deeper waters rather than from the advection time of water parcels from the surface SoG into the tidally mixed southern channels and then back into the deep SoG, which is only several weeks at most. Deep dissolved oxygen values show that the cold winter inflow is highly oxygenated. In contrast, the late summer and fall deep warming is not accompanied by an increase in DO. Instead, oxygen values continue dropping to about 2.5 ml/l until next June. Note that the intermediate waters in spring 2003 have different characteristics than those seen in spring 2002, possibly arising from the relatively mild winter. Near surface oxygen levels are often highly supersaturated, presumably because of biological activity, with a maximum value of nearly 10 m/l in April. At first glance the biological activity (as seen in fluorescence measurements) varies smoothly and appears to be well sampled, but a closer examination of the size fraction data shows that biological activity is really uncorrelated from cruise to cruise, consistent with an aliasing of the short time scales involved. Surface nitrates are generally low in the summer, although measured value are only partially limiting at many times. Note that a small bloom sampled in November (after an extended period of sunny weather) is not accompanied by nutrient exhaustion. Surface phosphates and silicic acid values (not shown) are apparently present in abundance.

Ferry Monitoring Program

The monthly sampling plan appears to be sufficient to capture the variations in deep water properties, and can be used to form a general picture of near-surface properties, but the time scales of biological activity (of order weeks rather than months) implies that there may be little coherence from survey to survey. Hovercraft surveys are being carried out at weekly intervals during spring bloom periods but these intensive sampling periods occur only once a year or so. In order

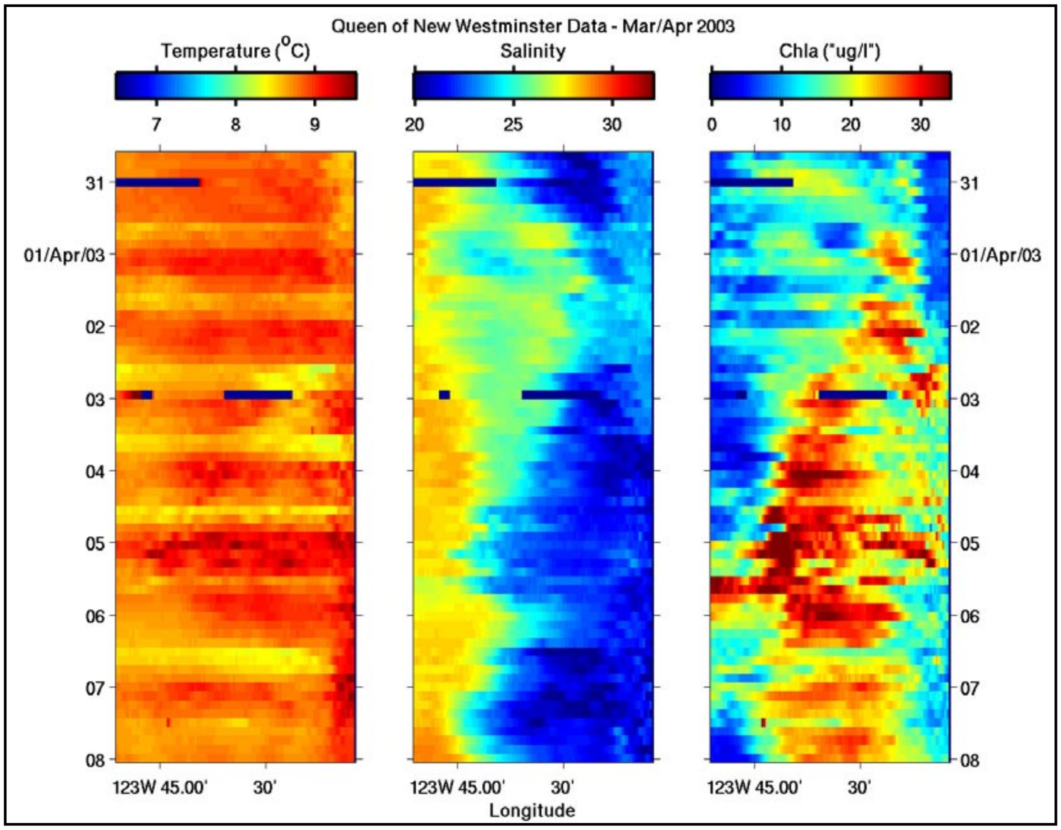

Figure 3. Along-track data on the northern route during onset of the spring bloom. Each line in the panel represents an E/W transect across the SoG, with later transects appearing lower.

to routinely monitor the behavior at shorter time scales instruments have been installed on several ferries in the BC Ferry system that each cross this region many times a day. Three routes are currently instrumented (Figure 1): the southern route is managed by J. Gower (Institute of Ocean Sciences), and we have instrumented the central and northern routes. Each installation consists of a sensor and logging package mounted in the ship's engine room, with water supplied from the main engine cooling system that takes in water from a depth of about 3m. Water temperature, salinity, and chlorophyll fluorescence is measured every few seconds, and the results (as well as ship's position determined using a GPS receiver) are synchronously logged to a stand-alone logging system. In June 2003 we plan to install a nitrate analyzer (the ISUS) that relies on identifying the levels of nitrate present through their absorption spectrum in the ultraviolet. Logged data is collected every few weeks during routine maintenance visits. In addition, a number of 'ferry transects" have been carried out in which water samples are taken every few minutes during the crossing, allowing us to measure other parameters from time to time. This summer we plan to carry out some combined hovercraft/ferry transects in order to quantify the possible biases in the ferry dataset. Temperature values in particular are likely to be biased by warming as they enter the engine room.

Figure 3 shows results through early April along the northern transect as the spring bloom begins. Temperatures vary along the whole track from day to day (reflecting day to day changes in the air-sea-heat flux). The salinity data clearly shows the way in which the Fraser outflow plume tends to hug the eastern coast north of its mouth, although the presence of isolated fresh patches (e.g. near April 1) away from the eastern side suggest that the plume edge may be complex with eddy-like features spinning off. The fluorescence data, which is plotted in terms of nominal chlorophyll levels, shows that phytoplankton location is well-correlated with the gradients at the edge of the plume, with overall levels doubling in less than a week. The existence of a ``productivity band'' near the northern edge of the plume appears to be consistent with the CTD data from monthly surveys.

Historical Data Reanalysis

As mentioned above, the SoG has been studied for some 50 years and a great deal of data of disparate kinds and quality exists. However, much of this data is not archived, or even gathered in a systematic way. Of most immediate use is a collection of CTD profiles taken at the Nanoose Torpedo Test Range (just north of S4-1 and west of S5) since the late 1960s. Stations are available at roughly weekly intervals, although the data quality is uncertain. In addition, work has been carried out by various researchers over the years around the time of the spring bloom and the timing of this bloom is known in certain years (Bornhold 2000). Analysis over the past year shows that, contrary to current theories, the spring bloom appear to peak some weeks before the beginning of the freshet. In fact the highly turbid freshet attenuates surface light so quickly that summer productivity within the plume is rather low.

Numerical Modeling

In recent years a great deal of work has been done in attempting to combine both physical and biological processes within the context of numerical models. In general the problems of doing so are still daunting – getting a satisfactory recreation of physical characteristics is often a difficult task in itself, and correctly understanding the way in which the parameterizations used to, e.g., model turbulent diffusion can affect small-scale biological processes is still uncertain. However, the contained nature of the SoG suggests that a rather simplified physical model may by sufficient, as long as fluxes into and out of the SoG are correctly parameterized. Previous work (Pawlowicz and Farmer, 1998; Pawlowicz, 2002) suggests that the estuarine nature of the system may allow for a simple formulation for these fluxes. The model under development has previously been used to study physical and biological coupling in the subarctic Pacific (Jeffries 2002).

Summary

We believe that the SoG may be an ideal laboratory for studying coupled biological and physical processes. The STRATOGEM program (www.stratogem.ubc.ca) is a multi-year program, now beginning its second year, designed to measure the important physical and biological parameters that may be crucial in determining productivity. In addition to the work described here, we welcome the opportunity to collaborate with others and all data is being provided online to interested parties.

Acknowledgements

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