PSF Citizen Science Dataset - Secchi depths, Chlorophyll, and Nutrients

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Executive summary

This report contains a preliminary analysis of oceanographic parameters of biological interest in the Strait of Georgia, based on measurements from 2015 and 2016 made by the CitSci citizen science sampling program.

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1 Introduction

The goal of the Salish Sea Marine Survival Project is to understand the decline of salmon in the Strait of Georgia. This project, funded by the Pacific Salmon Foundation (PSF), relies on "citizen scientists" (CitSci) to routinely measure a number of oceanographic parameters related to food availability for salmon. Volunteers with the CitSci program make measurements at about 75 stations mostly in the Strait of Georgia, up to 20 times a year from February through to October. Sampling was carried out in 2015, 2016, and is currently being carried out in 2017.

Data collected in the CitSci program includes high-vertical-resolution profiling using conductivity/temperature/depth (CTD) probes lowered to a depth of 150 m at every station. Also mounted on the CTD instruments are additional sensors to measure profiles of phytoplankton chlorophyll using a fluorescence-based technique, and concentrations of dissolved oxygen. Water clarity is quantified by measurements of the Secchi depth using a lowered Secchi disk. At some stations water sampling at depths of 2 and 20 m is carried out; these samples are later chemically analyzed in a laboratory to determine concentrations of dissolved inorganic macronutrients. A small number of water samples are also collected and directly filtered for phytoplankton; samples of phytoplankton are also preserved for examination and identification using a microscope.

In this report, I describe a preliminary analysis of CitSci data of biological interest obtained in 2015 and 2016. These data include water clarity and chlorphyll concentration in 2015 and 2016, and nutrient concentrations in 2015. Temperature, salinity, and dissolved oxygen measurements are described elsewhere.

2 Data Sources

2.1 Sampling plan

PSF CitSci sampling is divided into 9 'patrols' (Figure 1). A patrol is organized around a volunteer with a boat and is based out of a particular port at the edge of the Salish Sea. Each patrol samples a number of stations at pre-defined locations in their patrol area. The sampling scheme for a patrol includes 5 to 13 stations at which CTD/O_2/Fl profiling and Secchi depth measurements take place. At a subset of 3 to 5 of those stations (called "full" stations) water sampling for nutrients is carried out.

PSF plans about 20 sampling dates each year, located at peaks and minimums of the fortnightly tidal cycle, starting in February and ending in October. Their sampling protocol suggests collecting data within two days of the recommended date so that the measurements from different patrols can be combined into "instantaneous snapshots" of the oceanographic conditions in the Salish Sea. The general pattern is that sampling occurs for about three consecutive weeks with the fourth week off (usually avoiding weekends and holidays). In practice, spacing is greater at the beginning and end of the sampling period due to logistical and weather problems.

In 2015, patrols were based in Lund (LD or LND), Powell River (PR or PRV), Irvine/Sechelt (IS or IRS), Baynes Sound (BS or BSD), Nanaimo/Qualicum (NQ or NQU), Campbell River (CR or CRV), Steveston (SV or SVN), Victoria (VC or VIC), and Cowichan Bay (CB or CWB) (Figure 1). PSF also helped a First Nations group collect data in Ladysmith (LS). However, the actual sampling pattern (Figure 2) contains many deviations from the original plan. In 2015, the Lund and Powell River crew completed all sampling days while the Campbell River patrol often missed some stations. The routes for Irvine/Sechelt, Baynes Sound, Nanaimo/Qualicum, and Victoria were not finalized until March so the first sampling date for these patrols occupied stations that were different from those of the rest of the year. The Steveston patrol started in late May.

In 2016, the Victoria patrol was replaced by the Galiano patrol (GAL), and the stations in the Steveston patrol (actually based in False Creek) were changed significantly as the original route was too long to sample in a single day (Figure 3). Sampling did not begin until mid-March (Figure 4), but was more consistent overall, with the exception of Cowichan Bay sampling which has many gaps. Ladysmith sampling also occurred, but far less frequently (and perhaps on a different schedule) than sampling in the other patrols.

2.2 Chlorophyll fluorescence

Phytoplankton are microscopic photosynthetic organisms that are the food source for larger plankton which in turn act as food for fish. The chlorophyll cells that carry out photosynthesis can be made to fluoresce, and their concentration in the water column can be related to the magnitude of the fluorescent response to a steady light source of a particular wavelength.

Estimates of phytoplankton biomass using in-situ fluorescence profiling of chlorophyll are subject to some uncertainty because the measured response depends on both the particular species being measured, which will change over the season as phytoplankton community structure evolves to adapt to different conditions, and can also change over a day due to light- and time-dependent changes in the physiological response of particular organisms. However, this technique is generally considered to provide results accurate to within a factor of two.

Here the amount of phytoplankton was estimated from CitSci chlorophyll fluorescence profiles obtained from the Ocean Networks Canada data archive. Raw fluorescence profiles were processed using standard CTD algorithms. Fluorescence profiles are usually non-zero at depth because an instrument blank is not well quantified by vendor calibrations, and so this blank was determined by examination of in-situ data at depths well below the near-surface region where phytoplankton have enough light to grow. A blank was found for each different physical unit (i.e. by sensor serial number). Fluorescence profiles also vary with depth in ways that change over time, and so instead of plotting actual profiles I first carried out a depth-integration of these profiles. Thus measurements of chlorophyll mass per unit volume are converted to areal estimates of chlorophyll (with units of mass per unit area).

2.3 Secchi depth

Water clarity affects the distance light penetrates into the upper ocean waters, setting the depth range in which photosynthetic organisms can grow. This clarity depends on the amount of both biologically produced particulate (i.e. phytoplankton themselves, through self-shading) and of terrestrial particulate (river silt) within the water column. The Secchi depth quantifies this clarity. Typically phytoplankton can grow at depths of less than about 3 ± 1 times the Secchi depth.

Roughly speaking, the Secchi depth is the depth at which a white disk (the "Secchi disk", named after its inventor), hanging below an observer looking down into the water from a ship, can no longer be seen by that observer. Although Secchi depth measurements are relatively crude, since they are also affected by ambient light, time of day, and surface wave conditions, as well as the eyesight of the observer, they are simple to carry out and do provide an indication of the degree to which the surface ocean contains fine particles.

Secchi disk data was obtained from the Strait of Georgia data center, and was used without further editing.

2.4 Nutrients

Nutrients are inorganic compounds that, along with carbon, are assimilated into phytoplankton during their growth (i.e., during primary production). Macronutrients are those that are required in greatest amounts. These macronutrients include nitrate (NO_3^-, for technical reasons usually measured in the form of nitrate+nitrite), phosphate (PO_4^{3-}) and silicate (often denoted SiO_2, but generally appearing in the form of $Si(OH)_4$ in seawater).

The uptake of macronutrients by phytoplankton in the ocean occurs in ratios that are roughly constant (named "Redfield ratios" after the scientist who discovered this). Nutrient concentrations in the surface ocean can therefore be used to infer the capacity for phytoplankton growth and the factors which may limit that growth.

Nutrient analysis metadata was collated from written logsheets and bottle labels and transcribed by the laboratory analyst. I examined this initial dataset found a number of anomalies (covering approximately 10% of the 896 samples). These inconsistencies included apparent transpositions in the stated depth of samples at a particular station (concentrations at 2 m were high whereas those at 20 m were low, contrary to expectations in the Strait), and/or errors in the location of samples (by comparison with the time/location information available from the CTD dataset), as well as in the ratio between different nutrient concentrations at the same location. These ratios are generally expected to be "Redfield-like".

After checking with the analyst, many of these anomalies were traced to various recording or mathematical errors; others I corrected using my judgement based on experience with previous field measurements in the Strait. The final dataset still contains some values which seem problematic in comparison with the general trends, but which cannot be ruled out.

3 Results

3.1 Secchi depths and Chlorophyll

Secchi depths range from a maximum of 20 m to a minimum of less than 1 m, whereas chlorophyll amounts range from a maximum of 1.5 g chl m^{-2} to a minimum of about zero (Fig. 5). The largest values of Secchi depth (clearest water) occur in the northern Strait in late winter or early spring (February-April), and the smallest values occur in the southern Strait, probably within the plume of the Fraser River, in mid-summer. The range of variation from summer to winter is also larger in the northern Strait than it is in the southern Strait. Chlorophyll concentrations are highest for brief periods in spring (March-May), are at medium (but variable) amounts in summer, and show indications of being low in winter (winter sampling would be useful in setting baseline values). Chlorophyll variations in the northern and southern Strait have different patterns; variability is higher in the northern Strait.

In 2015, ferry-based measurements in the Southern Strait suggest that a very intense spring bloom occurred between March 6 and March 16th, followed by a "crash". This can also be seen in the (more sparse) chlorophyll estimates we have here (Fig. 5a). No southern Strait Secchi measurements exist at this time, but in the northern Strait Secchi depths of around 15m in late February are replaced by depths of about 4 m in early March (coincident with the bloom in the southern Strait, Figs. 5b and 6). Secchi depths then return to about 15 m in late March, decrease to a few meters in early April and return to 15 m in late April, then gradually decrease to about 7 m in July, remaining reasonably small until the end of sampling in October. This spring pattern is not seen in the Cowichan Bay or Victoria stations, although it is seen in the Johnstone Strait stations off Campbell River.

In 2016, ferry measurements in the southern Strait indicate a relatively weak bloom beginning around the 19th of March, without a noticeable crash following the bloom. Our more sparse chlorophyll estimates show a mid-Strait bloom peaking at the beginning of April, with a much more intense bloom occurring over the whole Strait in mid-May (Fig. 5c). Again, Secchi depths in the northern Strait generally decrease from about 15 m to about 5 m at the time of this larger bloom (Figs. 5 and 7). At some but not all stations, depths again increase slightly, before returning to depths of about 5 m in July and remaining there for the rest of the summer. In mid-October Secchi depths increase (and chlorophyll levels decrease), presumably marking a return to winter conditions. This pattern is not seen in the Cownichan Bay stations (as in 2015), but it is also not seen in the Galiano or Steveston stations either.

Note that in both years there often are significant changes in the magnitude of the Secchi depth (or the concentration of chlorophyll) from survey to survey. This is an indication that the sampling pattern, which has a temporal resolution not previously achieved in the Strait, is still too widely spaced in time to fully resolve changes in phytoplankton biomass over time. This is particularly true in the spring bloom, where phytoplankton concentrations can change by orders of magnitude over a period of days.

3.2 Nutrients

Nitrate concentrations at 20 m are relatively constant for all stations, and also over time, although a slight tendency towards lower values can be seen in summer (Fig. 8a). Surface values are high in February, and then for many stations drop to low values in mid-March before returning to high values in early April (again consistent with an early March spring bloom, followed by a crash), and then drop again to low values in mid-April. Low surface values remain at most stations until mid-August, and even into October for some stations. This is especially true for nitrate.

Phosphate and silicate concentrations follow the same general pattern (Fig. 8b and c). Surface values are are lowest (and close to zero) in April and May, but then, unlikely nitrate concentration, their levels near the surface increase slightly and are greater than zero for the remainder of the summer. The general nature of phytoplankton community structure in the Strait is throught be diatom-dominated in spring, but more dominated by flagellates. This is consistent with silicate concentrations near the surface approaching zero in the early part of the season, but showing greater concentrations later.

The Cowichan Bay surface samples have a different pattern. In this area, the year begins with very high silicate concentrations near the surface (around 100 μM), but quite low nitrate and phosphate concentrations (these stations are indicated with dashed lines in Fig. 8a-c). The silicate anomaly decreases over time, becoming indistinguishable from the measurements at other stations in June. This patrol area is within the Gulf Islands, somewhat separated from the Strait of Georgia, and surface values there are likely heavily influenced by the outflow from the Cowichan River. The Cowichan river has a relatively high discharge during the winter (November through March), driven by rainfalls, but by June the discharge drops to about 10% or less of winter values.

In general, nitrate concentrations at 20 m are between 10 and 30 μM (Fig. 8d). Shallow values can be zero, or as high as deep values. Nitrate and phosphate co-vary with a relationship that is approximately the same as the Redfield ratio of 16:1 (i.e. they are changing in a manner consistent with our knowledge of phytoplankton composition), but the general grouping of values in a scatterplot lies below a line with a 16:1 slope extending from the origin. That is, there is a nitrate deficit relative to phosphate governing primary production. Thus even when nitrate values drop to zero, phosphate (especially later in the summer) is non-zero.

A similar pattern is seen for the co-variation of nitrate with silicate (Fig. 8b). In this case the general trend in the scatter is not inconsistent with uptake in a ratio about 16:15, but there is again a significant deficit of nitrate relative to silicate. In addition, a number of shallow (2 m) points can be seen with high silicate ($> 50\ \mu$M) and low nitrate ($< 10\ \mu$M), quite different from the grouping containing the rest of the data. These anomalous measurements are associated with the Cowichan Bay stations, and (again) suggest that ocean waters in that area are heavily affected by the river.

In order to see whether there are spatial patterns to these seasonal changes in nutrients, we plot these values by distance along the Strait (Fig. 9). For simplicity we plot the data at each station over time, with its value on the x-axis given by position along the Strait. We also attempt to fit a smoothed surface to this data.

Nitrate values for both shallow and deep samples are always relatively high near Victoria, although they drop slightly between June and September. These samples are in the surface outflow region of Juna de Fuca Strait, and are a mixture between high-nutrient Pacific waters which inflow at depth and the nutrient-depleted surface waters exiting the Strait; these two water masses mix in the Haro Strait region. A similar pattern is also seen in Johnstone Strait north of Campbell River. Again, nutrient levels are high all year, but are slightly lower in summer.

Within the Strait surface values are low everywhere through the summer. Values at 20 m remain high through the summer, although lower than winter values. Summer values are lowest in the Southern Strait, probably under the Fraser river plume in May.

As expected from the previous analysis, a corresponding presentation of the phosphate data is very similar (Fig. 10). Again, lowest values at 20 m appear under the Fraser plume in May. Surface values are always high off Vancouver and in Johnstone Strait. One difference is that surface values within the Strait in June and later are greater than zero.

4 Summary

In broad strokes, this preliminary analysis suggests that northern and southern Strait areas are very similar in their general characteristics:

- The historical pattern of low phytoplankton and high nutrients in winter, followed by a spring bloom during which nitrate (at least) is exhausted, followed by a summer in which nutrient levels are low but not necessarily zero, continues in 2015 and (probably) 2016.
- The timing and magnitude of the spring bloom may vary regionally; however more frequent

sampling during the March-May period is needed to fully resolve this. There are significant year-to-year changes.
- Summer waters are less clear than winter waters, with Secchi depths varying by a factor of about 3 between the two seasons.

However, analysis of this dataset also highlights some important regional patterns:

- The northern Strait is more variable than the southern Strait, with higher peaks and lower dips in water clarity and phytoplankton production time series, especially in the spring.
- Conditions within Johnstone Strait (even off Campbell river), within the Gulf Islands, and off Victoria, are quite different than those within the Strait of Georgia itself.
- Water is generally more clear in the northern Strait, presumably because there is no source of terrestrial particulate in the northern Strait comparable to the Fraser River source in the southern Strait.
- Ocean waters near any of the rivers that flow into the Strait may be greately affected by the nutrient load in the river (the region of influence of the river can be estimated by measurements of salinity). Nutrient loads vary seasonally in the Fraser, and perhaps this is also true of these other rivers (some measurements in the river would help resolve this).

Further analysis may result in an even more fine-grained regional description.

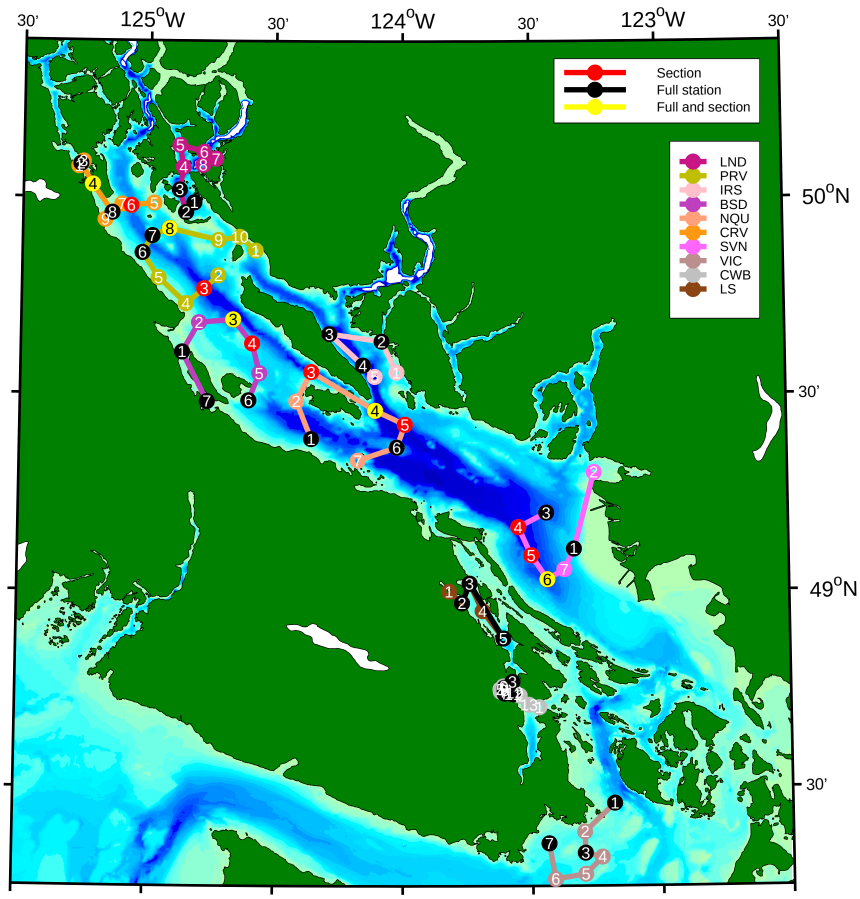

Figure 1: 2015 Station map. Cowichan Bay (CWB) has the most stations with 13 and Ladysmith (LS) and Irvine/Sechelt (IRS) have the fewest stations with 5. Most patrols have 3 full stations where, in addition to CTD profiling and Secchi measurements, water sampling also occurs.

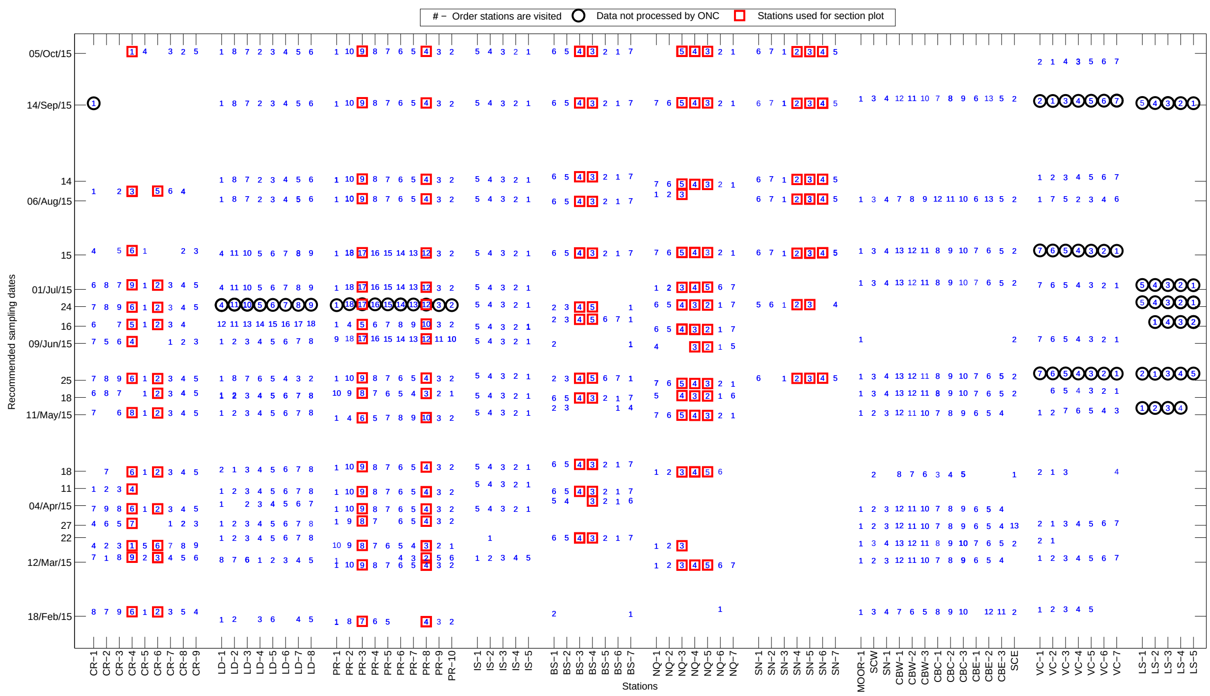

Figure 2: Sampling plan actually carried out in 2015. Numbers are the order in which stations in a patrol were visited on that day. In June and July, Lund and Powell River patrols were combined into a single patrol. At present, partially processed CTD data is available from Ocean Networks Canada for all stations except those marked as unprocessed (this should be fixed eventually). Section plot stations lie along the axis of the Strait.

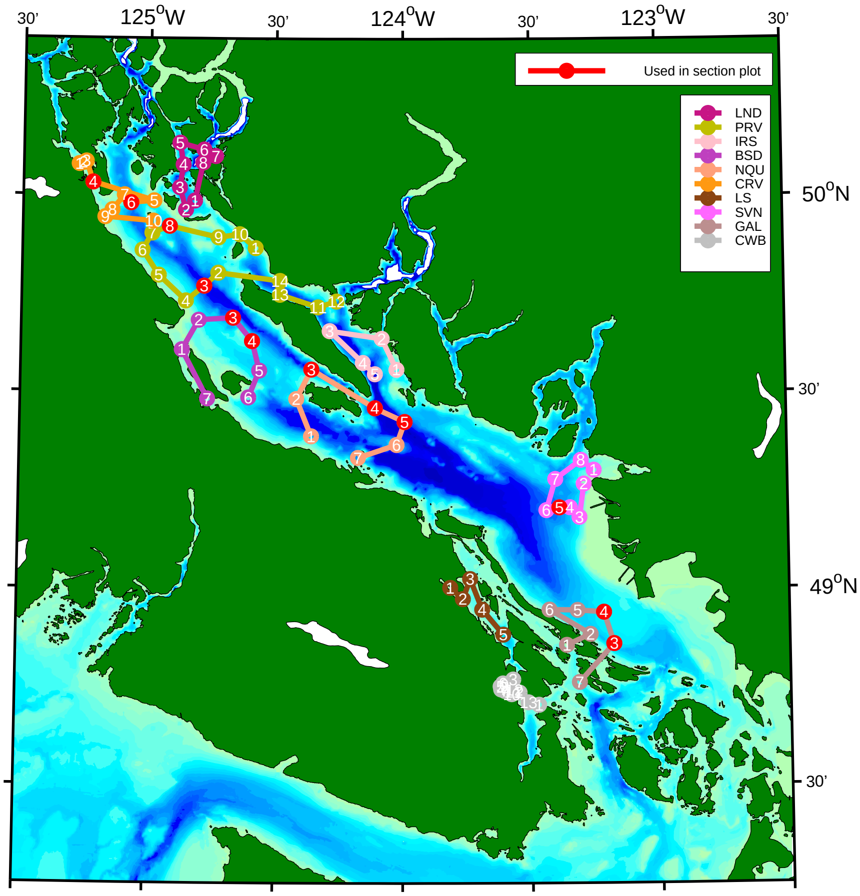

Figure 3: 2016 station map. Major changes from 2015 are that the Victoria patrol was dropped and replaced by a Galiano patrol, and stations in the Steveston patrol were changed.

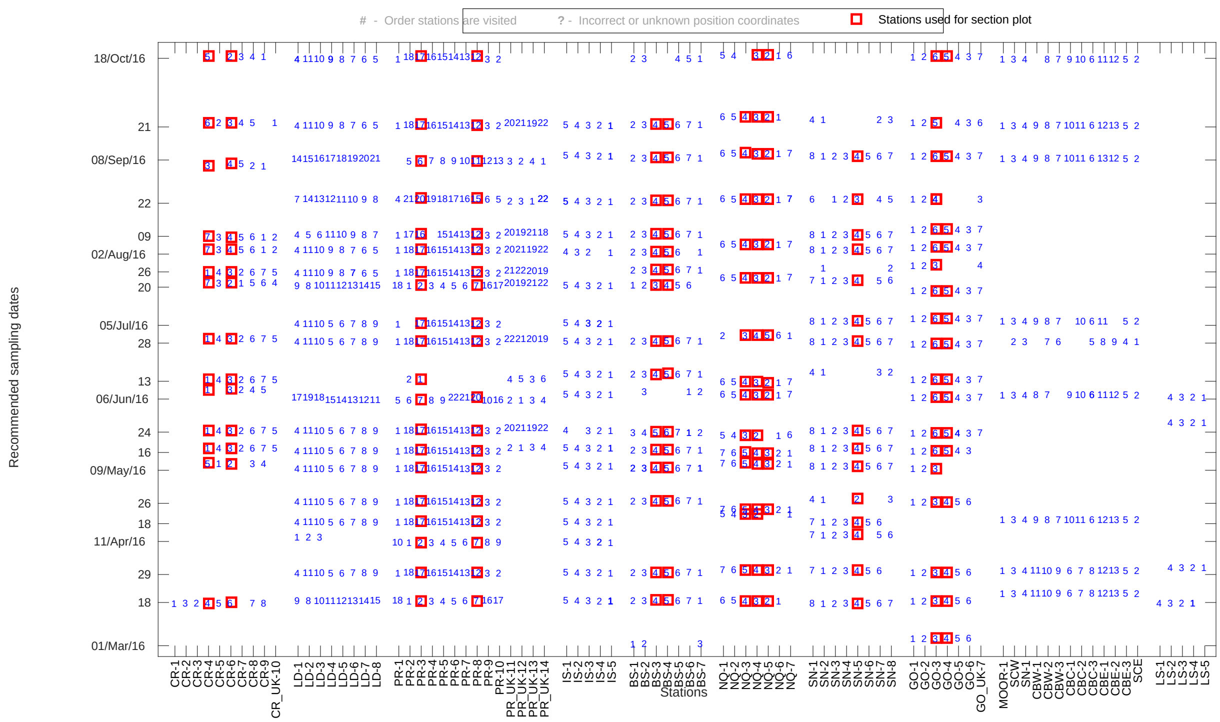

Figure 4: Sampling plan actually carried out in 2016. There are 4 unknown stations in Powell River and one unknown station in Campbell River and Galiano patrols that were surveyed starting May 16. Question marks indicate stations with unknown latitudes/longitudes.

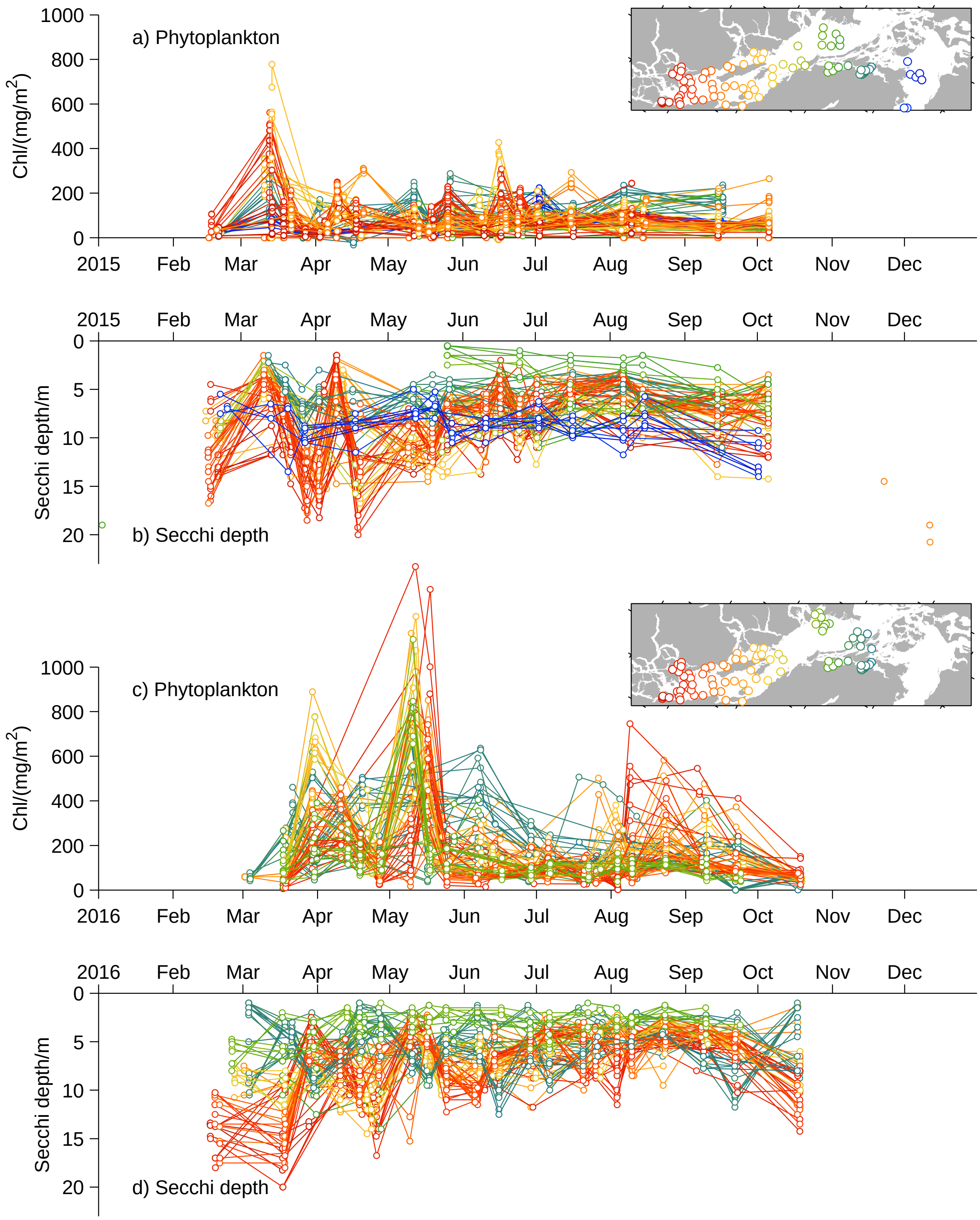

Figure 5: a) Chlorophyll and b) Secchi depths in 2015. c) Chlorophyll and d) Secchi depths in 2016. Each curve in a panel shows data at a particular station; the station locations are shown in matching colours in the inset map for chlorophyll concentration. Red curves are for stations in the northern Strait, blue curves for stations in the southern Strait.

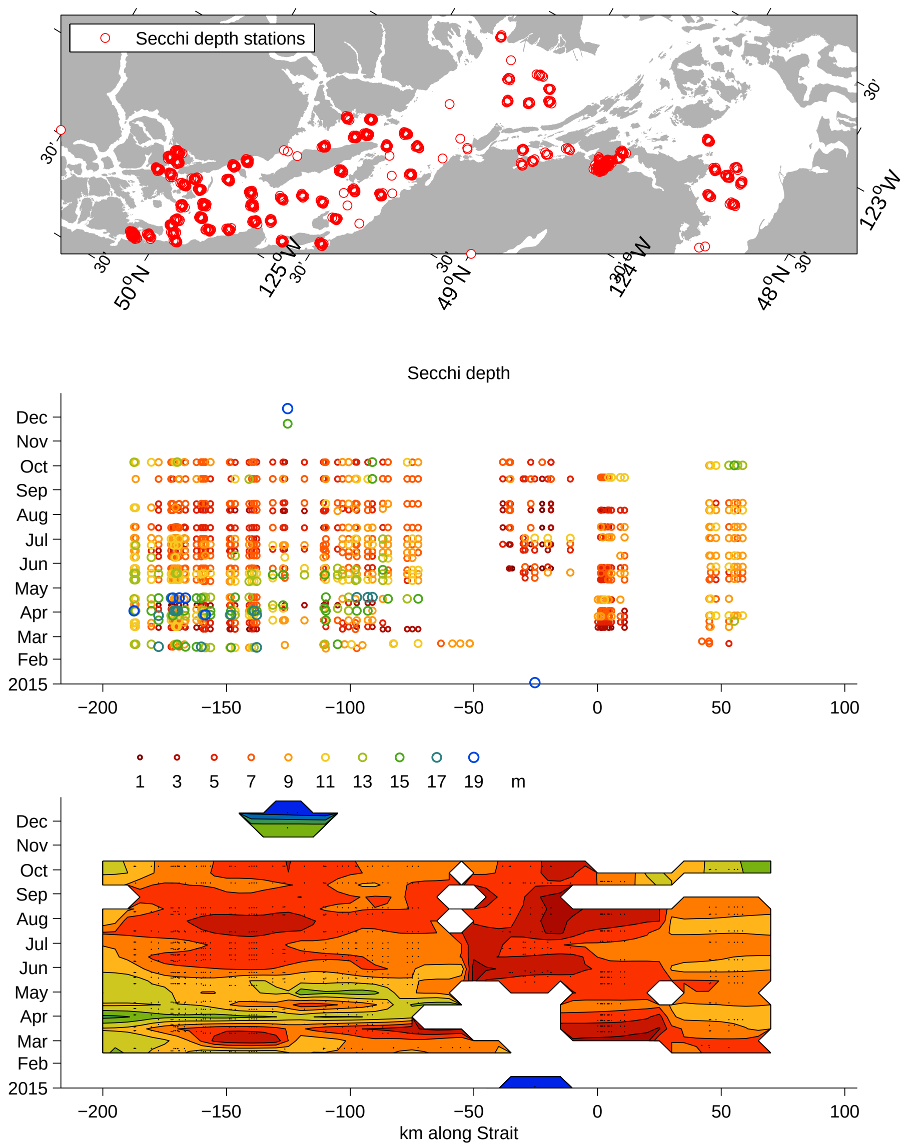

Figure 6: Secchi depths in 2015. Stations are shown in the top panel, their data appears vertically below them in the lower two panels. Actual data is shown in middle panel. A smoothed surface contoured through the scattered data to show trends is shown in the lower panel.

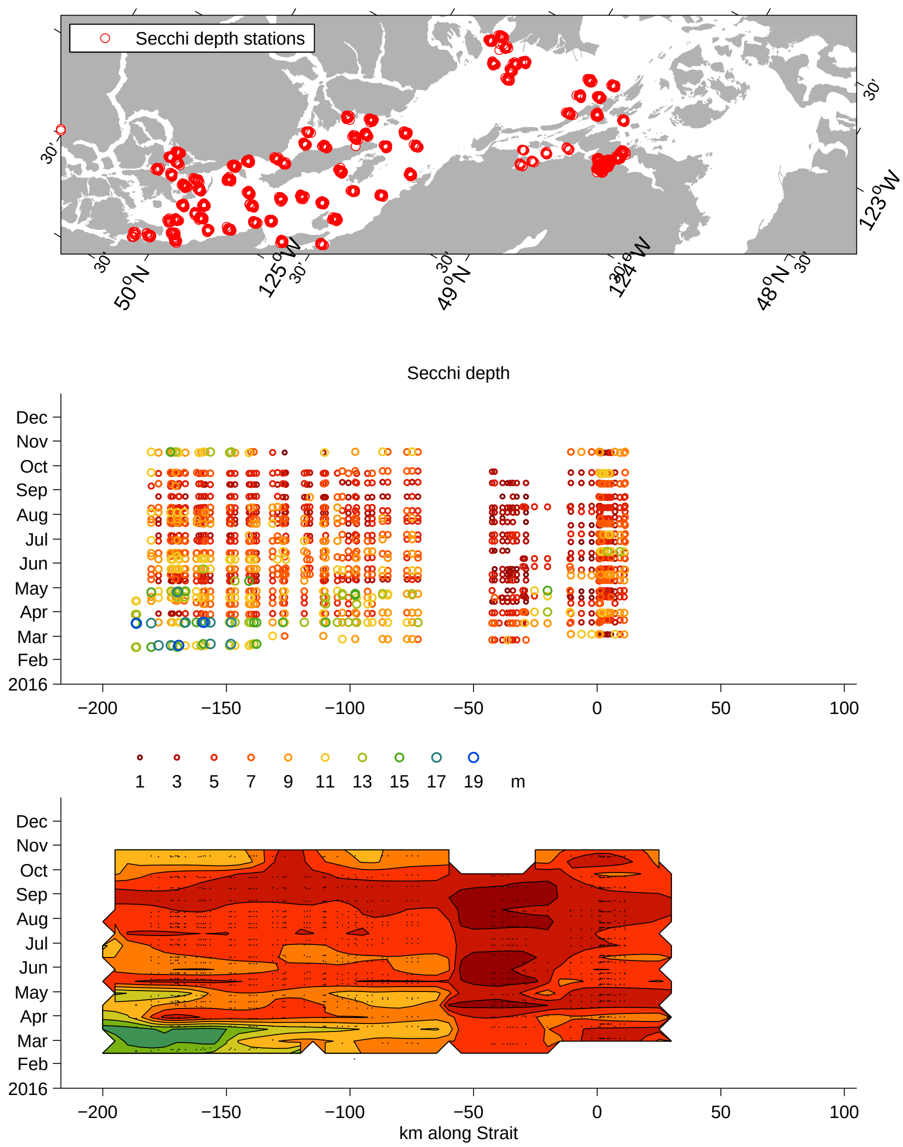

Figure 7: Secchi depths in 2016, presented as in the previous figure.

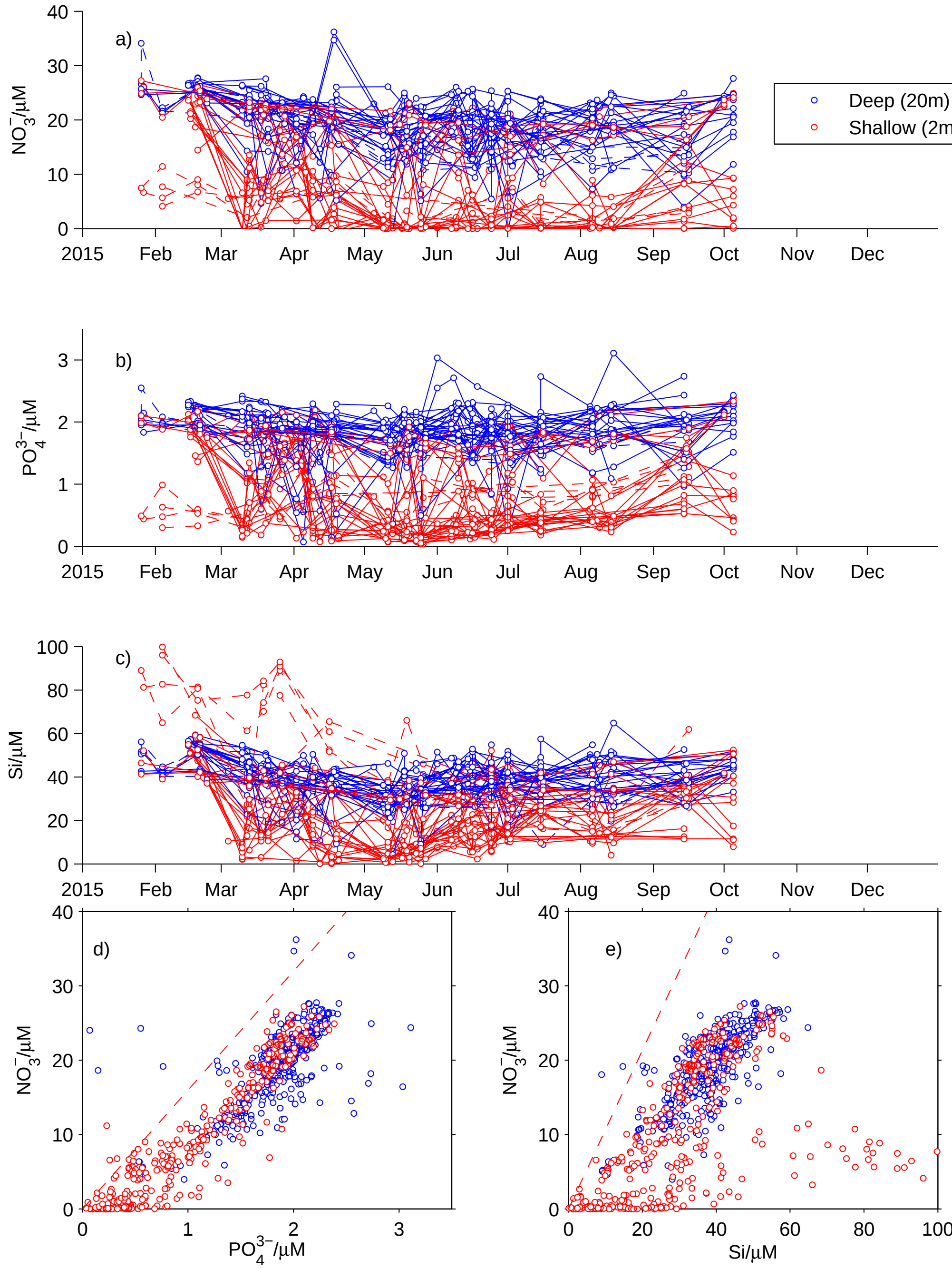

Figure 8: A summary of nutrient measurements. a) Scatter plot of nitrate vs phosphate values for all locations. Shallow (2 m) samples are in red, deep (20 m) samples are in blue. Dashed line shows 16:1 Redfield ratio. b) Scatter plot of nitrate vs. silicate values for all locations. Dashed line shows 16:15 extended Redfield ratio. c) Time series of nitrate. Markers joined by lines are all from a particular station. Dashed lines are used for Cowichan Bay stations. d) Same for phosphate. e) Same for silicate.

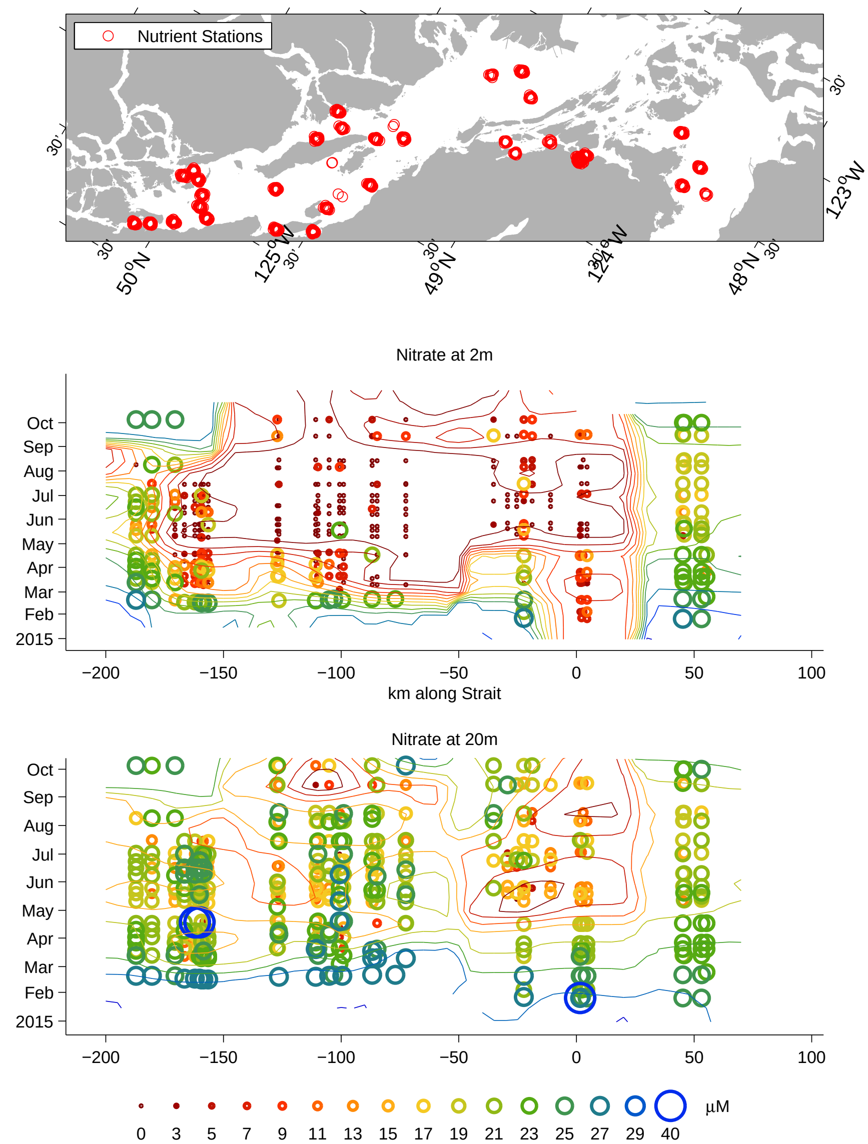

Figure 9: Spatial variation of nitrate. Stations are shown in the top panel, their data appears vertically below them in the lower two panels. A smoothed surface is contoured through the scattered data at 2 m (middle panel) and 20 m (lower panel) to illustrate general trends.

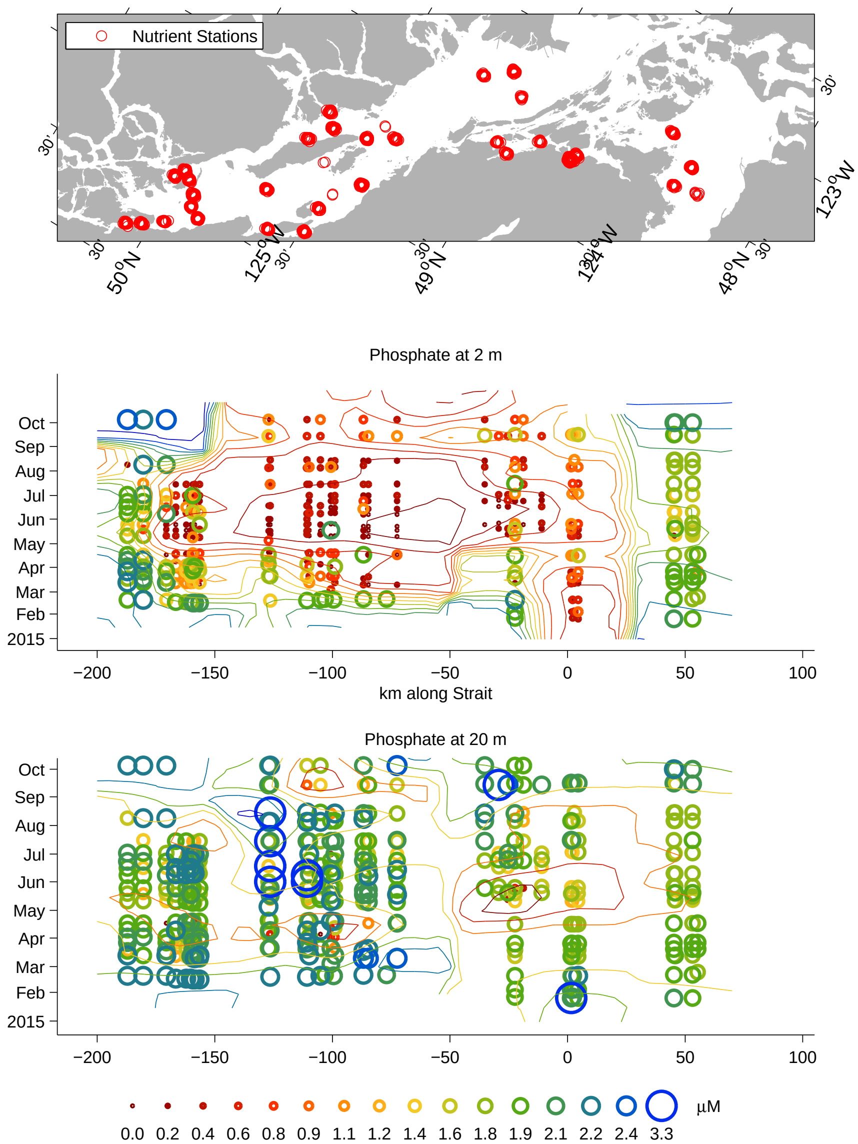

Figure 10: Spatial variation of phosphate. Stations are shown in the top panel, their data appears vertically below them in the lower two panels. A smoothed surface is contoured through the scattered data at 2 m (middle panel) and 20 m (lower panel) to illustrate general trends.