Report of the Sixth Annual Line P Workshop, Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC, March 7 and 8, 2013

Chaired by **Marie Robert**, Line P program manager, Institute of Ocean Sciences, Fisheries and Oceans Canada (IOS/DFO).

Introduction

Fifty ocean scientists and technicians met in March 2013 to share recent observations along Line P, as well as to present their current research interests and proposed future sampling plans. "Line P" is a 1400-km-long set of ocean stations off Canada's West Coast, monitored for over 50 years by weatherships and research vessels. It began with sampling from weatherships during their transits to and from Ocean Station Papa (OSP) at 50N, 145W, from the 1950s until 1981. Fisheries and Oceans Canada has financed ship time and core scientific programs since 1981. With more international and academic partners joining the program, leading to more diverse studies, it became useful to meet annually to compare insights and plan future programs. At the 1st workshop in February 2008 scientists met to discuss future experiments and techniques. The 2nd workshop in March 2009 focused more on scientific results, as well as on promoting collaborations and optimizing ship time and space. Since then the workshop has been very beneficial every year in allowing scientists to share their observations of conditions along Line P as well as in introducing new partners into the Program.

Marie Robert (IOS/DFO): *Overview of the Line P Program.*

Marie first stated the goals of the Line P Workshop: to promote collaborations between all scientists in order to better understand the Pacific Ocean; to maximise the use of ship time; and finally to discuss some issues that can potentially affect everyone involved in the program. She then described the basics of the Line P Program; what sampling is done at what station, what is the distance/timing between stations, how long each cruise lasts, etc. She also described the paperwork needed and schedule for the next year:

- Requests for security clearances and radioisotope use have to be started at least two months prior to the cruise.
- Please contact **Marie Robert** if you want to participate in a cruise. Do NOT contact the DFO security clearance officer directly.
- The name of a student's supervisor will be sent to the security clearance officer with the intent that the supervisor can help his/her student fill-in the paperwork if there are any questions. Too many unnecessary questions are asked repeatedly to the security clearance officer.
- Try not to send untrained people on a cruise on their own. But if you have to, at least give them as much information about the cruise as possible. Tell them about the cruise report expected of them, and let them know that demands like "dry ice" need to be addressed well before the end of the cruise.

- The milli-Q water maker on board the Tully cannot be used for making large volume of distilled water. If you need large volumes please bring your own milli-Q water and use the system on board only as a back-up.
- There is a very strong possibility that Internet-at-Sea will no longer be available for science personnel on board CCG vessels.

Marie then showed the line-up for berth reservations for the cruises of the next three years and the dates of this fiscal year's cruises:

Cruise 2013-17 will go from 7 June to 25 June 2013.
Cruise 2013-18 will go from 20 August to 6 September 2013.
Cruise 2014-01 will go from 10 February to 24 February 2014.

She concluded her talk with an update about the Line P Website: the Website will move to a new server and will hopefully be ready before the start of the next sailing season. An email will be sent to the Line P general distribution list when the site is publicly available. There will also be a new climatology available to compute Temperature (T), Salinity (S), Sigma-t and Dissolved Oxygen (DO) anomalies. It will include data from 1981 to 2010 for T, S and sigma-t whereas the range of DO data will be from 2001 to 2010.

Doug Yelland (OSD/DFO): *Meteorological sensors on the CCGS John P Tully.*

Doug's presentation was in four main points:

Met sensors

There have been requests for more and better meteorological data during Line P cruises. As there are already several sensors on board the *CCGS John P Tully* for ship use (anemometer, barometer, gyro, etc) it seems sensible to add what we need (PAR, temperature/humidity, others?). Coast Guard technicians have agreed to install the sensors if Science purchases and maintains them. They will also interface the output onto the ship's network for real time use and archiving.
Calibrations will be performed by Science, so having two or more of each sensor is likely the best way to ensure coverage. **Doug**'s preference is to have three, so if one sensor is being calibrated (we go by the calibrator's schedule), one will be in service and there will be a spare on board.
"Donations" from non-DFO participants will be required; solicitations will begin when we have identified the appropriate make and model for the sensors. Likely the easiest mode for this is to have the sensors purchased by the users directly.
Please let **Doug** know if there are other sensor requests (Doug.Yelland@dfo-mpo.gc.ca)

ADCP update

The new transducer has been installed on the *Tully* but isn't commissioned or operational yet. The logging computer died immediately upon completion of the transducer installation. The present plan is for commissioning in late April 2013.
Data from the ADCP in a raw form is visible during the cruise, plotted in several ways (ship track, depth profile, etc), but processed data will likely take some time to be available, if at all. The likely mode of delivery will be a preliminary processing step to show what's available, with distribution of raw data if requested. We have no data processing stream in place yet.

Ship Server/Network changes

Doug will be installing a new Science Server, with great disk capacity and enhanced data archiving software, on board the *CCGS John P Tully*. It's not likely that people will notice the change.

The Coast Guard has experienced a huge over-expenditure on their data usage over the satellite system ("Email at Sea"). They are therefore indicating that Science may be cut off from using the Internet while on board. We really have very little further information. Through informal discussions with Coast Guard technicians, **Doug** learned that a new system will be in place in the future, with 'tiered access'. What this means for science is also unknown, and this won't likely be in place anytime soon.

Doug will set up an "internal" science network where we can hook all science computers together for data transfers and VNC use during cruises, this will include WiFi. Email access will likely return to everyone sharing a single account (ScienceLab) using the computers in the Officer's Lounge.

LaPerouse Project plug…

Finally, **Doug** gave a reminder that the LaPerouse project often has spare berths if anyone's interested in coastal work. They do 75+ stations, about 1/3 are rosettes, lots of plankton tows, 30-2000m. The sampling is somewhat flexible if you have something different to sample but the station locations and timing are pretty rigid. There's not a lot of spare time to go to other locations or do many extra casts.

The cruise is approximately 11 days long, preceding Line P in May and following it in September.

Meghan Cronin (NOAA/PMEL, Seattle): *Analyses currently underway using Station P mooring data.*

Meghan Cronin described analyses currently underway using Station P mooring data. The NOAA surface mooring carries a suite of sensors to monitor air-sea exchanges of heat, moisture, momentum, and carbon dioxide; upper ocean temperature, salinity and currents; ocean acidification, and key aspects of the carbon cycle. The Carbon group at PMEL is responsible for the air-sea pCO2 system, fluorometer and turbidity, and **S. Emerson**'s University of Washington group is responsible for the pH and GTD-CTD-O2 sensors. All data are publicly available through the PMEL websites or the OceanSITES or Carbon Dioxide Information Data Analysis Center websites. University of Washington also has a Datawell Waverider mooring next to the NOAA surface mooring. These Station #166 wave data are available through cdip.ucsd.edu. For more information, see the PMEL Ocean Climate Stations webpage: pmel.noaa.gov/ocs.

Three University of Washington graduate students are writing PhD dissertations using these data. **Meghan** is working on an upper ocean heat and salt balance. **Cronin**'s Ocean Climate Station group at PMEL maintains the buoy and is responsible for the meteorological and physical oceanography sensors. The APL wave group has several papers underway and submitted. There have also been a number of papers using the Papa meteorological data in combination with other OceanSITES data to assess global data products. **Meghan Cronin** is organizing a science workshop "Holistic Ocean Balances at Station P" to be held at PMEL in Seattle WA on April 4, 2013. Talk to **Meghan Cronin** (Meghan.F.Cronin@noaa.gov) if you are interested in participating. They are also hoping to start a University of Washington Station P working group that will meet ~once a month to discuss underway analyses. The NOAA Station Papa surface mooring needs to be refreshed in June 2013. **Jennifer Keene** and **Mike Craig** plan to participate on the June 2013 *CCGS Tully* cruise to perform these mooring operations. Thank you very much for making this possible!!

Uwe Send (Scripps Institution of Oceanography, San Diego, CA): *OOI observations at Station PAPA starting summer 2013.*

Uwe Send presented the plans of the National Science Foundation (NSF) Ocean Observatories Initiative (OOI) to install the first OOI infrastructure at station PAPA in the summer of 2013. A cruise on *RV Melville* from July 17 to August 3 (Seattle-San Diego) will deploy moorings and gliders at that site. Since NOAA PMEL is already operating a surface mooring there, the OOI will only add a "hybrid profiler" mooring and two "mesoscale flanking" moorings. The overall geometry sought is a triangle, with the surface and profiler moorings near one vertex, and the flanking moorings at the others, at an approximate mesoscale distance of 45 km.
The profiler mooring will carry a "surface piercing profiler" which is parked at about 150m depth on top of the mooring, and will then winch a sensor float with an antenna float to the surface, typically twice per day. The sensor float will initially carry only a CTD, and oxygen, and a CO2 sensor. Later deployments will add chlorophyll fluorescence/backscatter, optical absorption, spectral irradiance, and nitrate sensors. Below that on the mooring will be 2 "wire crawling" profilers, each covering nearly 2000m of the water column. These will carry CTD, chlorophyll fluorescence/backscatter, oxygen, and turbulent 3D velocity sensors. The mesoscale flanking moorings only have one biogeochemical sensor package at 30-40m depth, including chlorophyll fluorescence/backscatter, oxygen, and pH sensors, plus an upward-looking Longranger ADCP and 12 CTDs from 0 to 1500m depth. The 3 gliders will typically transect around the mooring triangle and also acoustically communicate with the flanking moorings.
Data will be available from the OOI ION site as soon as deployed, in the pre-commissioned test mode, with automated QC tests applied.

Jim Bishop (University of California – Berkeley): *Optical Sensing of PIC along Line P.*

James K. B. Bishop (UC Berkeley) wrote his presentation with contributions from **Todd Wood**, **Ernesto Martinez**, **Jill Sutton**, and **Gabrielle Weiss**.

Jim's talk reviewed the ocean carbon cycle and the need for observing particulate inorganic (PIC) and organic carbon (POC) on daily time scales. He presented achievements during the August 2012 (**Ernesto Martinez**) Line P expedition, early data from the deployments of Carbon Explorer floats Feb 13 2013 (**Jill Sutton**, **Todd Wood**) and plans/hopes for Line P in June 2013 and August 2013.
In August 2012, they CTD profiled a new particulate inorganic carbon sensor along line P. The new sensor detects calcium carbonate (CaCO3) particles using cross polarized transmitted light. Comparisons were made to a NASA 'calcite' product derived from contemporaneous MODIS/aqua imagery. While they found reasonable parallels in trends from P2 to P14, the correspondence of in-situ and satellite retrieved PIC broke down (satellite high) as p26 was approached. Their findings were presented at the ASLO meeting in New Orleans (**Martinez** et al. 2013).

They hope to continue the deployment of PIC/POC/scattering sensors on the CTD system and to collect calibration samples at major stations. Feb 2013 Tully data from Saanich Inlet demonstrated that PIC/POC/scattering signatures are clearly distinct, with the total loss of PIC in anoxic waters below 100 m.

Carbon Explorers (CEs) 14 and 15 are now deployed at PAPA as of Feb 13 2013. The floats carry POC/PIC/scattering sensors. (As of March 13, 4 weeks after deployment, the CEs are approximately 27 nmiles from PAPA, drifting to the NW at 3 cm/sec). One float's PIC sensor requires servicing to address a weakness discovered the day before float deployment. Other sensors are performing well.

In June 2013, **Jim**'s group would very much like to recover the two CE's to document their condition, particularly the optics of the new PIC sensor; they plan to refit the PIC sensor with new window systems and then redeploy. They also hope to deploy Carbon Flux Explorer (optical imaging sedimentation recorders) in June. They will continue the CTD optics program.

They are requesting 2 participants in June 2013, one of whom will be able to aide other programs, in particular, the trace metal ™ group. They requested one participant in August 2013. Their group anticipates continuing the Line P optics program in 2014.

Martinez, E.J., Bishop, J.K.B. Berneard, A., Wood, T.J., Robert, M. (2013) In-situ observations of particulate inorganic carbon in the subarctic north Pacific. New Orleans ASLO SS26

Noel Pelland (U. Washington): *Applying Seaglider data to analysis of 3D circulation and vertical mixing at Station P.*

The NOAA Ocean Station P mooring currently provides long-term in situ observations of the surface ocean; during the time period June 2008-February 2010 these were supplemented by three Seaglider deployments that orbited the mooring in a 50 x 50 km ‘butterfly’ pattern, providing horizontal gradient information to 1000 m depth. **Noel** describes analysis methods and early results of these data along with future research directions. Research on the combined moored and glider time series will focus on two primary scientific goals: 1) improving our understanding of horizontal advection of heat below the mixed layer in summer and fall; and 2) obtaining estimates of surface net community production of oxygen and, if possible, respiration at depth for summers 2008-09. Temperature-Salinity characteristics across the butterfly pattern indicate that water properties at mid-depth (100-300 m) transitioned from cool and fresh to warm and salty over the duration of the time series, and strong horizontal gradients in temperature/salinity on density surfaces were evident in certain periods, especially the fall and winter 2008-09. The warm/salty signature, along with coincident observations of low potential vorticity and oxygen, indicate the signature of coastal water and potentially the presence of a small eddy. An eddy signature is at times apparent in sea surface topography images although it is intermittent and inconclusive. The impact of the eddy on heat advection is as yet unclear and is the subject of ongoing study: monthly averages indicate that horizontal heat advection acts to cool the seasonal thermocline in both years, as in previous studies (e.g., Large *et al*., 1986), but the direction of advection and the temperature gradient differs between the two years. In order to resolve respiration at depth, diapycnal diffusivity has been estimated at multiple density levels, indicating values near the surface that correspond roughly with the **Cronin** *et al*. values at the mixed layer base. Vertical diffusivity will be used to compute a budget of oxygen at depths below the mixed layer; the residual of this budget is associated with biological respiration. An ongoing subject of research is incorporating all of the advective and diffusive terms in a mathematical optimization algorithm that would provide adjusted values of velocity, diffusivity, temperature, salinity, and oxygen that best satisfy a specified cost function. The results will then be applied to analysis of both of the scientific goals outlined above.

Roger François (U. British Columbia): *Particle flux in the mesopelagic zone at P26 estimated from ^{234}Th and ^{230}Th measurements.*

^{234}Th has been widely used to estimate export flux from surface water. **Roger** briefly outlined this approach and showed results from station P-26. He then discussed how a similar approach using ^{230}Th can be used to estimate fluxes in the mesopelagic zone and showed promising results from station P-26.

Roger then showed results obtained with an "off the cuff" method to sample Xlarge particles (multinets) that appear to throw a monkey wrench not just in the ^{230}Th method but also in the widely used ^{234}Th method, strongly suggesting that the latter has underestimated particle export flux significantly

Finally **Roger** wrapped up with some thought on what to do next.

Roberta Hamme (U. Victoria): *Denitrification in the Cascadia Basin.*

Roberta presented a new research objective for sample collection on Line P. She and **Steve Emerson** have been using measurements of dissolved N2/Ar to investigate the global nitrogen cycle. The marine nitrogen cycle is governed by inputs of N-based nutrients from N2 fixation and removal by denitrification-type processes, but both rates are very poorly known. **Roberta** and **Steve** observe that dissolved N2/Ar is clearly higher at Station P in the subarctic North Pacific than at Hawaii in the subtropics. These stations essentially have the same deep source waters, so the increase toward Station P must be an input of N2 by denitrification. The excess N2/Ar at Station P is centred relatively deep, up to 3000m, far below the oxygen minimum, and is therefore likely to be a sedimentary signal. The Bering Sea is known for high benthic denitrification and has a connection to the open North Pacific at depths up to 3000m. However, hydrographic analysis, mainly from dissolved silica, implies that water from the Bering Sea does not reach Station P. The Cascadia Basin, located just offshore of Vancouver Island and Washington State, has a significant area of sediments at 2000-3000 m, previous measurements of high denitrification rates, and is close to Station P. **Roberta** would like to test if Cascadia Basin is the source of excess N2 in the subarctic North Pacific by measuring N2/Ar at the major stations along Line P to see if a gradient exists from the basin into the deeper open ocean.

Robin Brown (IOS/DFO) – presenting for John Smith (BIO/DFO): *Detection of Radioactivity from the 2011 Fukushima Accident on Line P.*

An earthquake-triggered tsunami on March 11, 2011 caused extensive damage to the nuclear power facilities in Fukushima, Japan resulting in the discharge of large quantities of ^{137}Cs and other radionuclides directly into the western North Pacific Ocean during the month following the accident. The radioactivity plume was transported northeastward under the influence of the Kuroshio Current and was expected to approach the Canadian coastline several years after the accident. A Canadian monitoring program was established to detect the arrival of Fukushima radioactivity in the water columns of the eastern North Pacific and Arctic Ocean. Water samples were collected at stations on missions of the *CCGS Tully* in June, 2011 and June, 2012 to a location (Sta. P26), approximately 1500 km west of Victoria, BC for the extraction and detection of artificial radioactivity. ^{137}Cs concentrations measured to depths of 1000 m in June, 2011 are consistent with background fallout sources of radioactivity. However, Cs measurements on water samples collected in June, 2012 at Sta. P26 showed the presence of ^{134}Cs ($t_{1/2}$ = 2.1 y) at 0 m and 50 m at levels (0.2 mBq/l) indicating the presence of contamination from the Fukushima nuclear reactor accident. The trans-Pacific transit time for the arrival of this radioactivity signal at Sta. P26 of < 1.3 y is faster than predicted by most ocean transport models. These results suggest that a significant inventory of ^{137}Cs must have been deposited from the atmosphere to the ocean at locations downwind from Fukushima and then transported by advection to Sta. P26. Measurements are presently under way on water samples collected in the Arctic Ocean in September, 2012 to determine if atmospheric deposition of ^{134}Cs and ^{137}Cs was sufficiently great to produce elevated levels of Fukushima derived radionuclides in the surface mixed layer at high latitudes.

Christina Schallenberg (U. Victoria): *Iron (II) along Line P in June and August 2012 – the role of shelf sediments and suboxic conditions.*

Fe(II) was measured in June and August 2012 using the luminol method without sample acidification. Measurements were usually finished within 1 hour of the GoFlo bottles arriving on deck. However, the different sampling methods employed on the two cruises (GoFlos in the chains in June, trace metal rosette in August) may introduce some artifacts that require further investigation.

With this limitation in mind, some general trends are observed in the measured Fe(II) profiles. The June data for P16, P20 and P26 show a consistent Fe(II) maximum at 800-1000m that corresponds well with the maximum in Fe(II) half lives as calculated from oxygen, pH and temperature profiles. This Fe(II) feature was not as clearly resolved in the August data, possibly because crucial bottles either misfired or had contamination issues.

In general, the near-shore stations (P4 and even P12) showed higher Fe(II) concentrations than stations further offshore, which is a trend also observed in historical total dissolved iron concentrations. The higher concentrations of Fe(II) coincide with longer calculated Fe(II) half lives relative to the offshore stations, a feature mostly driven by the lower oxygen concentrations near shore. As well, at P4 in June, an increase in Fe(II) with depth was observed that culminated in the highest point being near the bottom, below the peak in Fe(II) half lives. The transmissometer data for this station indicates possible resuspension of shelf sediments near the bottom, which might be the source for this Fe(II) maximum.

Some features in the Fe(II) profiles remain unexplained for the time being but will be further explored, such as a subsurface maximum at P12 in June, and generally higher Fe(II) concentrations in August compared to June.

Dave Janssen (U. Victoria): *Dissolved zinc below the euphotic zone along Line P in August 2012.*

Dave Janssen presented zinc (Zn) data collected along Line P in August 2012. Special attention was given to the importance of a member of the trace metal group analyzing a highly contamination prone element (e.g. Zn, Fe) at sea to ensure samples are 'clean'. During the August 2012 cruise, problems were encountered with two bottles on the 12 bottle trace metal rosette.

One bottle was showing a low-level (~0.5 nM) Zn contamination and one position of the rosette showed signs of leaking independent of the bottle placed in that position. The Zn data measured at sea allowed for the identification of these problems and allowed for problematic bottles to be duplicated on subsequent casts to ensure trace metal depth profiles did not have mid-profile missing data. Without knowledge of these issues at sea, missing data in the samples collected would have obscured unique features in the depth profile. Zinc depth profiles were shown for the 5 major stations and represented the first dissolved Zn data below 400 m for the time series. The depth profiles showed a depletion of Zn relative to Silicate (Si) at depths coinciding with the top half of the Oxygen Minimum Zone (OMZ). This feature is also seen for Cadmium (Cd) and the macronutrient phosphate (PO_4). Future work along line P will target this trace metal depletion anomaly. **Dave** and the trace metal group are grateful to the captains, crew and officers of the *JP Tully* along with Marie, Wendy, and Kyle for their support.

David Semeniuk (U. British Columbia): *Environmental controls on microorganismal intracellular Cu requirements and uptake rates along Line P.*

There is strong laboratory evidence that copper (Cu) can be both a limiting and toxic micronutrient to isolated marine phytoplankton cultures, yet little is known about the Cu nutritional status of natural phytoplankton communities. The potential for Cu limitation or toxicity for a particular phytoplankton species depends on a number of variables, including: the chemical speciation of Cu, the phytoplankton species of interest, the rates of cellular Cu uptake, and the intracellular Cu concentration. To examine the role that Cu may play in controlling primary productivity on Line P – either through limitation or toxicity – **David** and his group measured *in situ* Cu uptake rates, intracellular Cu concentrations, primary productivity, species composition, and a suite of other environmental variables along the transect in August 2011. Analysis of the data available thus far indicates that cellular Cu covaries with total dissolved Cu concentrations, suggesting that a majority of dissolved Cu in seawater is bioavailable to marine phytoplankton. These data support **David**'s previous work at P26 that demonstrated the *in situ* dissolved Cu was likely bioavailable. They also found preliminary evidence that the rate of Cu efflux in picoeukaryotes – a defense mechanism against Cu toxicity – was negatively correlated with primary productivity, indicating that Cu may have been controlling the growth of picoeukaryotes along Line P. These data suggest that Cu may exert a significant effect on primary producers along Line P that has gone unrecognized to date.

Jason McAlister (U. British Columbia): *Stable Pb isotopes along Line P.*

Just as the health of fisheries is dependent on the foundational food pyramid initiated by phytoplankton and zooplankton, phytoplankton abundance is reliant on adequate nutrients including nitrate and phosphate. The northeast Pacific Ocean presents a conundrum, wherein seemingly adequate nitrate stocks are not utilized, inhibiting phytoplankton growth and therefore attenuating the food chain leading to salmon and other fish.

Seminal research conducted along the Line P oceanographic time series has demonstrated the requirement of iron (Fe) to allow utilization of available nitrate. Therefore, determining sources of Fe to the north east Pacific is vital to prediction and maintenance of fisheries. Iron sources to phytoplankton communities along Line P include processes of coastal upwelling, eddy transport, mobilization via sedimentary reduction, and windblown eolian sources.

Jason's work utilizes ratios of stable lead (Pb) isotopes to investigate the source of Fe to stations along Line P. Calculations indicate sources along Line P from the coast, an associated offshore eddy, and eolian Asiatic sources at the terminal Ocean Station Papa.

Outcomes of **Jason**'s research support increasingly routine analysis of Pb isotopes during trace metal sampling along Line P. Additionally, results of this work would not have been possible without high resolution sampling in the upper 150m of the water column. Therefore results of this work have inspired interest in a future integrative program of Shallow Isosurface Sampling of Trace Metals (SISTM) along Line P.

Nari Sim (U. British Columbia): *Dissolved Manganese along Line P.*

Manganese (Mn) is a trace metal found in the open ocean, existing at the nanomolar level. In conditions of high oxygen, Mn tends to form insoluble Mn oxide complexes. When the dissolved oxygen concentration is low, the more soluble Mn(II) is dominant (Sundal and Huntsman, 1994). In general, the concentration of Mn(II) is high at the surface (Landing and Bruland, 1980) and decreases rapidly with depth; however, Mn(II) increases dramatically at the oxygen minimum zone, near the continental shelf or in coastal regions at approximately 1000m deep (Statham *et al.*, 1998). In the deeper waters, Mn(II) is depleted to its minimum and remains constant. However, there is still disagreement over the sources of Mn and the mechanisms driving these distributions.

The purpose of **Nari**'s project is to measure the concentration of manganese along Line P and to determine its cycling, lateral and vertical transportation using sea water samples collected with Trace Metal Rosette (TMR). The Mn along line P in 2011 and 2012 show two maxima on its vertical profile at major stations – at the surface layer and slightly above OMZ. Surface maximum is mainly due to photoreduction (Sunda *et al.*, 1983), and atmospheric input (Baker *et al.*, 2006). However, the maximum slightly above OMZ is not clear at this stage of research. Reduction-oxidation cycling in sediments along the continental shelf and slope, as well as lateral transportation from reducing sediments to the open ocean are suspected as possible sources for this mid-depth maximum of Mn (Johnson *et al.*, 1992). However, further research is required to figure out what kind of mechanism derives it.

To acquire better knowledge about this element, collecting at least 18 seawater samples at major stations along Line P is recommended from surface to the bottom of the ocean. This year, in 2013 August, **Nari** is planning to do trace metal seawater sampling in high spatial resolution along depths, as well as collection of suspended particulates using pressurized Go-Flo bottle filtration.

Steven Hallam (U. British Columbia): *Oceans of Information: making sense of microbial community metabolism in the northeast subarctic Pacific.*

Background: Oxygen minimum zones (OMZ) are widespread oceanographic features arising from microbial respiratory demand during organic matter degradation in poorly ventilated waters. Operationally defined by oxygen (O_2) concentrations less than 20 μM, OMZs support thriving microbial communities[1]. OMZs are found throughout the Eastern Subtropical North Pacific (ESTNP), Eastern South Pacific (ESP), Northern Indian Ocean, and Southwest African shelf waters[2]. Moreover, climate change induced expansion and intensification of OMZ is unfolding on a global scale[3-6]. In the absence of O_2, alternative respiratory substrates are utilized in microbial energy metabolism in a defined order based on free energy yield. These include metals such as iron and manganese, nitrate (NO_3^-), nitrite (NO_2^-), sulfate (SO_4^{2-}) and carbon dioxide (CO_2). Within OMZs, the use of NO_3^- and NO_2^-, as terminal electron acceptors results in greenhouse gas production and biological nitrogen loss in the forms of nitrous oxide (N_2O) and dinitrogen gas (N_2) respectively. Both dissimilatory nitrate reduction (denitrification) and anaerobic ammonium oxidation (anammox) processes are known to mediate these transformations within OMZs[7-9]. Recent studies also posit an essential role for sulfur cycling in OMZs, coupling the production and consumption of reduced sulfur compounds to dissimilatory nitrate-reduction and dark CO_2 fixation[10-13]. The integration of C, N and S cycles represents a recurring theme within the O_2-deficient water column, where electron donors and acceptors are actively recycled between lower and higher oxidation states forming distributed networks of metabolite exchange between microbial community members. Determining how these networks form, function, and change over time promises to reveal otherwise hidden linkages between microbial diversity and higher order ecological and biogeochemical processes with important implications for nutrient and climate active trace gas cycling.

Current Research: Steven's group is exploring microbial community responses to OMZ expansion and intensification along the 1,425 km Line P transect. A unique feature of Line P is that it traverses three distinct oceanic regions that can be differentiated based on macronutrient supply and utilization: (i) coastal waters, which extend ~75 km across the continental shelf and where productivity is stimulated during summer by periods of upwelling, (ii) a 'transition' area unaffected by coastal upwelling and which experiences NO_3^- depletion in summer, and (iii) an open ocean region characterized by high macronutrients and low chlorophyll *a* (HNLC). The NESAP is characterized by strong stratification due to low salinity surface waters that are mixed to a maximum depth of 125-150 m during winter months. As such, the interior regions of the NESAP are insulated from the atmosphere, creating a vast OMZ centered at 1000 m with oxyclines extending from ~400-2000 m with O_2 concentrations ranging between ~9-60 µmol kg^{-1}. These O_2-deficient interior waters are sourced in the Sea of Okhotsk located in the western Pacific north of Japan, where well ventilated winter waters submerge into the interior of the Pacific and travel eastward, becoming isolated from the atmosphere and forming the North Pacific Intermediate Waters (NPIW). Further east, the NPIW mix with the O_2-deficient subtropical subsurface waters (SSW), and O_2 is further depleted by microbial degradation of organic matter sinking down from productive surface waters, creating a west-east gradient of declining O_2 concentrations. Oxygen concentrations within the NESAP OMZ declined by 22% and the hypoxic boundary layer (defined as ~60 µmol kg^{-1}) expanded upward from 400 m to 300 m between 1956 and 2006[4]. Multivariate statistical analysis combining small subunit ribosomal RNA sequences with environmental parameters indicated that microbial community structure and biogeochemical expression in NESAP waters closely resembled that of other coastal and open ocean OMZs[1, 11, 14, 15] making it a relevant model ecosystem.

Sample Archive: Over the past six years water samples have been captured using a standard CTD rosette containing 24 X 10 ℓ Niskin bottles deployed from the *CCGS John P. Tully*. From a single 10 ℓ Niskin bottle **Steven**'s group collect nutrient, dissolved gas and microbial biomass for a minimum of twelve depth intervals spanning the depth continuum at six stations (P4, P8, P12, P16, P20, P26) and one station in Saanich Inlet (SI03). Biomass for genomic DNA and RNA extraction is obtained from 24 X 10 ℓ Niskin bottles pooled from a single depth interval along Line P and 3 X 10 ℓ Niskin bottles in Saanich Inlet. Their samples traverse the depth continuum at a minimum of four depth intervals spanning oxic, hypoxic transition and anoxic regions of the water column. For DNA extraction, approximately 20-240 ℓ of seawater per depth interval is pumped through a 2.7 µM GF/D prefilter to remove large particulate material followed by microbial biomass accumulation on a 0.2 µM Sterivex filter using a low flow peristaltic pumping system (12-16 ℓ/hour). Waters passing through Sterivex filters are collected and concentrated to isolate the viral fraction by their collaborators at the University of British Columbia (Suttle) and the University of Arizona (Sullivan). GF/D prefilters along with 500 ml of unfiltered glutaraldehyde fixed waters are archived for downstream molecular and SEM/TEM studies of microbial eukaryote diversity by their collaborators at the Woods Hole Oceanographic Institute (Edgcomb). GF/D prefilters and Sterivex collection filters are stored in 2 ml of sucrose lysis buffer at -80°C prior to high molecular weight DNA extraction and purification. For RNA extraction they filter between 2 and 10 ℓ seawater depending on water column depth and historical cell abundance measures. Seawater for RNA extraction is filtered within 15 minutes of recovery on ship. Total RNA extraction methods have been tested using established protocols and JGI QC standards providing sufficient material (2-20 µg) for ribosomal RNA subtraction and linker amplification procedures[16, 17]. Additional samples for cell abundance, single-cell genomics, environmental DNA profiling, and mass spectrometry measurements of dissolved gases are collected at higher spatial resolution, typically 12-16 intervals based on water column depth. Membrane inlet mass spectrometry (MIMS), combined with GC-MS (gas chromatography- mass spectrometry) is performed in collaboration with the Tortell laboratory in the Earth & Ocean Science Department at UBC.

Beyond biomass filters and nucleic acid extracts approximately 344 human genome equivalents of environmental genomic sequence has been generated from NESAP ocean waters spanning vertical redoxclines and seasonal and spatial gradients. Moreover, several hundred glycerol stocks for single-cell genomic applications have been archived as a regular component of the time series program. For each of six depths at four stations 5x 1.5 ml glycerol samples are preserved at -80 °C in the field. They have demonstrated the effectiveness of this cryopreservation technique by generating over 4,608 FACS sorted cells and 2,304 single-cell amplified products spanning dysoxic (90-20 µmol kg^{-1}), suboxic (20-1 µmol kg^{-1}) and anoxic (less than 1 µmol kg^{-1}) water column conditions using the Bigelow Laboratory for Ocean Sciences single-cell genomics facility. PCR-based small subunit ribosomal RNA (SSU or 16S rRNA) gene screening followed by bi-directional end sequencing identified a total of 645 single-cell amplified genomes for downstream shotgun sequencing. These amplified genomes cover a wide range of taxonomic groups including numerous operational taxonomic units affiliated with taxa of emerging interest with OMZs throughout the global ocean including Marine Group A (MGA), SUP05, Arctic96BD-19, SAR11 and SAR406.

Data Products: Initial efforts to reconstruct taxonomic networks from molecular sequence information obtained from Line P waters sampled in 2007 and 2010 revealed distinct groups or operational taxonomic units (OTUs) partitioning by depth and season. Distinct subnetworks linking bacterial, archaeal and eukaryotic microogranisms were resolved in photic and dark ocean waters. Closer inspection of strongly correlating nodes identified bacterial OTUs as major hubs and archaeal OTUs as super connectors between hubs. MGA bacteria were prevalent members of this central network, existing as hubs, super connectors and radial members within nine of 12 subnetworks. Phylogentic placement of 290 MGA small subunit ribosomal RNA (SSU or 16S rRNA) genes recovered from NESAP clone libraries identified 5 previously described and 5 novel MGA subgroups. Most subgroups were negatively correlated with oxygen concentration consistent with specific metabolic adaptations to oxygen-deficiency. Complete sequencing of 14 large insert (fosmid) clones harbouring 16S rRNA genes sourced from NESAP waters identified two clones with the potential to encode polysulflide reductase (Psr), an enzyme complex implicated in dissimilatory S_n reduction to hydrogen sulfide. Pathway level analysis of fosmid end sequence data also identified an enrichment of polysulfide reduction potential in the core of the NESAP OMZ (1000m). Moreover, pathways for dissimilatory sulfate reduction and chlorate/perchlorate reduction and sulfide oxidation were identified in dark ocean waters. These observations suggest the potential for a cryptic sulfur cycle in NESAP waters. Additional process rate and trace metal observations are needed to further validate this claim. From a temporal perspective, NESAP waters displayed a remarkable overlap in pathway conservation. Approximately 74% of all predicted pathways (n = 622/840) were shared between June 2009, August 2009 and February 2010 combined depth intervals consistent with a stable metabolic core. Additional gene expression studies are needed to assess the level of differential pathway regulation between coastal to open ocean and photic to dark ocean samples. Single-cell genome sequencing efforts are also needed to provide fragment recruitment platforms for DNA and RNA data sets to more accurately bin environmental sequence information to distinct pathways within specific taxonomic groups. Future sampling efforts along the transect will include more emphasis on process rate and stable isotope probing methods to more effectively link field processes with microbial agents within the OMZ as well as coupled microbial and viral metagenome sample collection.

Steven would like to share these **Publications** from his group **(2012-present):**

Wright, J.J. K. Konwar, and S.J. Hallam. 2012 Microbial Ecology of Expanding Oxygen Minimum Zones. Nat. Rev. Microbiol. 10, 381-94

Orsi, W., Y.C. Song, S.J. Hallam and V. Edgcomb. 2012. Effect of Oxygen Minimum Zone Formation on Communities of Marine Protists. ISME Journal 6(8):1586-601

Allers, E†., J. J. Wright†, K. M. Konwar, C. G. Howes, E. Beneze, S. J. Hallam* and Matthew J. Sullivan*. 2012. Diversity and population structure of Marine Group A bacteria in the oxygen minimum zone of the Northeast subarctic Pacific Ocean. ISME Journal 7(2):256-268

Durno E., N. W. Hanson, K. M. Konwar. and S. J. Hallam. 2012. Expanding the boundaries of local similarity analysis. BMC Genomics 14 (Suppl 1), S3

Hurwitz, B.L., and M. J. Sullivan*. 2012. The Pacific Ocean Virome (POV): A Marine Viral Metagenomic Dataset and Associated Protein Clusters for Quantitative Viral Ecology. PLoS|One 8(2):e57355

References:

1. Wright JJ, Konwar KM, & Hallam SJ (2012) Microbial ecology of expanding oxygen minimum zones. *Nat Rev Microbiol* 10(6):381-394.
2. Paulmier A & Ruiz-Pino D (2008) Oxygen minimum zones (OMZs) in the modern ocean. *Progress in Oceanography* 80(113).
3. Stramma L, Johnson GC, Sprintall J, & Mohrholz V (2008) Expanding oxygen-minimum zones in the tropical oceans. *Science* 320(5876):655-658.
4. Whitney FA, Freeland HJ, & Robert M (2007) Decreasing oxygen levels in the interior waters of the subarctic Pacific. *Prog. in Oceanog.* 75:179-199.
5. Diaz RJ & Rosenberg R (2008) Spreading dead zones and consequences for marine ecosystems. *Science* 321(5891):926-929.

6. Brewer PG & Peltzer ET (2009) OCEANS. Limits to marine life. *Science* 324(5925):347-348.
7. Jayakumar A, O'Mullan GD, Naqvi SW, & Ward BB (2009) Denitrifying bacterial community composition changes associated with stages of denitrification in oxygen minimum zones. *Microb Ecol* 58(2):350-362.
8. Lam P*, et al.* (2009) Revising the nitrogen cycle in the Peruvian oxygen minimum zone. *Proc Natl Acad Sci U S A* 106(12):4752-4757.
9. Ward BB*, et al.* (2009) Denitrification as the dominant nitrogen loss process in the Arabian Sea. *Nature* 461(7260):78-81.
10. Lavik G*, et al.* (2009) Detoxification of sulphidic African shelf waters by blooming chemolithotrophs. *NAture* 457(7229):581-584.
11. Walsh DA*, et al.* (2009) Metagenome of a versatile chemolithoautotroph from expanding oceanic dead zones. *Science* 326(5952):578-582.
12. Canfield DE*, et al.* (2010) A cryptic sulfur cycle in oxygen-minimum-zone waters off the Chilean coast. *Science* 330(6009):1375-1378.
13. Stewart FJ, Dmytrenko O, Delong EF, & Cavanaugh CM (2011) Metatranscriptomic analysis of sulfur oxidation genes in the endosymbiont of solemya velum. *Front Microbiol* 2:134.
14. Zaikova E*, et al.* (2010) Microbial community dynamics in a seasonally anoxic fjord: Saanich Inlet, British Columbia. *Environ Microbiol* 12(1):172-191.
15. Walsh DA & Hallam SJ (2011) *Bacterial Community Structure and Dynamics in a Seasonally Anoxic Fjord: Saanich Inlet, British Columbia* (Wiley-Blackwell Hoboken, New Jersey).
16. Frias-Lopez J*, et al.* (2008) Microbial community gene expression in ocean surface waters. *Proc Natl Acad Sci U S A* 105(10):3805-3810.
17. Shi Y, Tyson GW, & DeLong EF (2009) Metatranscriptomics reveals unique microbial small RNAs in the ocean's water column. *NAture* 459(7244):266-269.

Moira Galbraith (DFO/IOS): *Bathypelagic zooplankton – why we do deep net tows.*

The large, boreal calanoid copepod Neocalanus makes up the majority of zooplankton biomass in the north Pacific but it spends a relatively small portion of its life cycle in the upper 250m. The majority is spent at depth at around 1000m in a form of hibernation called diapause. To assess peak biomass (and ergo potential food availability for larval and juvenile fish) it is necessary to determine where exactly in the water column is the majority of the population. *Neocalanus flemingeri* is first to arrive in the upper water column and first to leave, usually preceding *N. plumchrus* by several weeks. *N. cristatus* has a prolonged life cycle, many times separate cohorts overlap in distribution. By sampling at depth and comparing numbers to the surface tows **Moira** is able to determine peak biomass plus subsequent diapause timing and relate this to predator/prey match or mismatch.

Analyzing deep samples has led **Moira** to the discovery of new species and new range extensions; majority of animals being identified from Australian, New Zealand, Russian or Japanese taxonomic keys. In view of these findings, the deep tows have become a gold mine for species diversity. Preservation of deep plankton hauls will be done in conjunction with DNA sequencing. For now the aim is to build a genetic library in the hopes of future funding for analysis.

Future work with these deep samples will involve some collaboration with various researchers to determine seasonality and resident time; physical parameters affecting life cycle and depth distribution and food web hierarchy.
One side note from **Moira**'s work is the loss of trained taxonomists; finding experts who can identify to species zooplankton invertebrates is rare; let alone being able to identify animals from the bathypelagic zone. She also wishes to emphasize the importance of long time-series of data such as the Line P Program.

Karina Giesbrecht (U. Victoria): *Carbon, nitrogen and silicon ratios in phytoplankton and their response to environmental changes.*

Karina presented an aspect of her proposed PhD research along Line P involving investigation of the marine biogenic silica dynamics and comparison of elemental ratios in phytoplankton and how these ratios respond to changing environmental conditions. One of her main objectives is to characterize the silicon physiology of siliceous phytoplankton along Line P through measurements of the kinetics of Si uptake and Si limitation along Line P to elucidate the differences between iron-limited and iron-replete phytoplankton communities. Her second objective is to determine how changes in the concentration of micro and macronutrients affect the Si:C:N:P utilization ratios relative to the composition of these elements in the dissolved and particulate pools. She plans to accomplish this through simultaneous measurement of the Si:C:N:P ratios for gross and net nutrient utilization ratios and in particulate matter at the major stations along Line P. She is also interested in how these ratios will respond to changing environmental conditions with plans to conduct pCO_2 perturbation experiments on the natural phytoplankton communities at the major stations along Line P.