River Influences
on Shelf Ecosystems

RISE 4-W

CRUISE REPORT

R/V Wecoma W0605B

May 21-June 13, 2006

B. Hickey, E. Lessard, M, Lohan, P. MacCready, R. McCabe and T. Shaw, with support from K. Bruland, R. Kudela and W. Peterson

Area of Operations:

Coastal waters off Washington and Oregon

Itinerary

Depart Newport, Oregon, May 21, 2006
Arrive Newport, Oregon, June 13, 2006

Participating Organizations

University of California, Santa Cruz
Oregon State University
University of Washington

Chief Scientist

Dr. Barbara Hickey, School of Oceanography, University of Washington

Personnel

Principle Investigators

Dr. Evelyn Lessard, University of Washington
Dr. Parker MacCready, University of Washington

Staff

Megan Bernhardt, University of Washington
Dr. Elizabeth Frame, University of Washington (Post Doc)
John Kumpf, University of Washington
Dr. Maeve Lohan, University of Plymouth, England (team leader)
Jennifer Menkel, Oregon State University
Dr. Tawnya Peterson, University of California, Santa Cruz (team leader, Post Doc)
Jim Postel, University of Washington
Alice Roberts, University of California, Santa Cruz
Tracy Shaw, Oregon State University (team leader)
Geoffrey Smith, University of California, Santa Cruz
Bettina Sohst, University of California, Santa Cruz

Students

Ana Aguilar-Islas, University of California, Santa Cruz (grad)
Misty Blakely, University of California, Santa Cruz (grad)
Matt Brown, University of California, Santa Cruz (grad)
Ryan McCabe, University of Washington (grad)
Sherry Palacios, University of California, Santa Cruz (grad)
Kate Ruck, James Madison University, NSF REU (undergrad)

Cruise Objectives

The purpose of this cruise was to make physical, chemical and biological measurements within the plume of the Columbia River and over the shelves north and south of the river mouth, with the objective of determining the effect of the river plume on regional productivity. Historical observations have shown that in spite of weaker upwelling-favorable summer winds, the Washington shelf is more highly productive than much of the Oregon shelf. Comparative measurements of biological rates, chemical constituents including iron and other micro nutrients and plankton growth and grazing as well as community distributions were made in the three regions. These data complement data from three moored arrays deployed in the study area, data from a second ship, the R/V Point Sur, whose team focuses on mixing rates and large scale physical, nitrate and fluorescence surveys as well as frontal processes, and data from remote sensing and model studies.

The ship track and sampling stations are shown in Figure 1.

Operations

ADCP lines: entire ship track
Flow-Through system track with T,S,FL sensors: entire ship track
CTD casts: 268
Optical profiles: 14
Satellite-tracked drifter deployments: 19

Samples Collected

Chlorophyll samples: ~1000
Nutrient samples: >1400
Fixed plankton samples: 17 vertical profiles; 13 dilution experiments
FlowCAM samples: 800
Fe, Mn and Al samples: >500
Particulate trace metal samples: ~ 280
Macro zooplankton: 42 vertical net tows; 28 oblique Bongo net tows; 34 live incubations

CRUISE SUMMARY

RISE focuses on the highly productive Eastern Boundary river plume originating from the Columbia River – a plume sufficiently large to be of regional importance, yet small enough to allow determination of dominant processes affecting and/or resulting from river plumes, and to facilitate rate comparisons with regions outside the plume. Chlorophyll and primary productivity are not uniform along the U.S. Pacific Northwest coast– they are higher in the Columbia River plume and over the shelf north of the river mouth than south of the river mouth. The greater richness of the northern Pacific Northwest coast is particularly surprising because alongshore wind stress, the primary forcing responsible for macronutrient supply, increases in the opposite direction to the productivity. The overall goal of RISE is to determine the extent to which the regional productivity differences are a result of the presence of the river plume—e.g., it's turbidity, stratification, species composition and nutrient load, as well as its effect on mixing and advection.

RISE has three hypotheses:

- **During upwelling the growth rate of phytoplankton within the plume exceeds that in nearby areas outside the plume being fueled by the same upwelling nitrate.**
- **The plume enhances cross-margin transport of plankton and nutrients.**
- **Plume-specific nutrients (Fe and Si) alter and enhance productivity on nearby shelves.**

The hypotheses are being tested through a combination of field surveys, moored sensor arrays, drifters, remote sensing and biophysical modeling. The field studies use two vessels, one, the R/V Wecoma, obtaining primarily biogeochemical rate data; the other, the R/V Point Sur, obtaining synoptic mesoscale and fine-scale surveys as well as turbulent flux measurements. The sampling approach provides a Lagrangian history of mixing and biogeochemical transformations as well as the broader quasi-synoptic view. Comparative studies are being made between regions north and south of the plume where iron and other nutrient sufficiency may differ, as well as in

the plume. The time-space context of observed variability is being provided by an array of moored sensors deployed in the plume as well as on the shelf north and south of the plume, and by an array of long-range HF current-mapping radars producing hourly maps of regional surface currents. Satellite-derived AVHRR, chlorophyll, turbidity images as well as synthetic aperture radar (SAR) are being used to determine scales of spatial variability in the plume region and to relate it to primary productivity.

This report describes sampling on the fourth RISE cruise on R/V Wecoma. During this cruise the Point Sur had two science teams on different legs. From May 21 to June 1, the turbulence team was aboard; from June 1 to June 12, the TRIAXUS survey team was aboard.

Sampling Overview and Setting

The RISE 4 cruise on R/V Wecoma was highly successful, obtaining data along a track covering the region from 45.5° N to 48.2° N out to longitude 125.25° W (Fig. 1). Measurements included multi disciplinary vertical transects (CTD profiles, nutrients from CTD and a towed fish, net tows, plankton identification using a FlowCAM, optical profiles) and near surface underway surveys using a towed fish (macro and micro-nutrients as well as C, T), profiles of water properties (including optics and plankton) while following a drifter, deployment of surface drifters (with C, T), satellite imagery, and laboratory studies using water and plankton collected at selected sites.

Overall, we obtained 269 CTD/nutrient profiles, over 1000 chlorophyll samples, over 1400 macronutrient samples, over 500 iron, aluminum and manganese samples and 14 optical profiles. Satellite imagery (SST and chlorophyll a) was obtained on only a few days due to the generally poor weather. Cruise activities were recorded in a sequential "Event" log (Table 1) from which summary tables were derived.

The setting of cruise sampling events within the wind environment during the cruise (upwelling or downwelling-favorable) is shown in Figure 2. The cruise immediately followed several weeks of strong upwelling-favorable winds. However, only downwelling-favorable winds occurred over the first two weeks of the cruise. Modest upwelling winds returned during the last week, to be replaced with downwelling winds in the last few hours of the cruise. The data might be grouped as occurring in one of two periods: generally strong downwelling-favorable winds (May 22- June 4) and weak to modest upwelling-favorable winds (June 5-12). Actual upwelling on the inner shelf was never observed off Washington or Oregon, even at the last samples taken on June 12. The cruise thus provided an ideal end member for nutrient supply studies—riverine input and no upwelling: for a northward plume only (first period) and for a southwest tending plume (second period).

Riverflow was the highest seen to date in RISE cruises. Comparison with other years indicates flow was well above average for the first part of the cruise. The flow decreased substantially around June 1 but increased again in the last week of the cruise, although not to the level observed in the first week.

Cruise History

The cruise began with very strong downwelling winds (May 22-23) that mostly eliminated the plume south of the river mouth and caused a new plume to develop north of the river mouth. During this period we sampled the GH line and then the CM line. Because of rough weather we next did estuary sampling, traveling up the estuary to sample the freshwater. Since winds remained downwelling-favorable, the emphasis on the cruise turned to studying the north plume. After a few days this was the only Columbia plume water present on the coast. Ultimately the plume water was followed with drifters and then in situ measurements all the way to the Strait of

Juan de Fuca. Salinity was still < 27 psu next to the coast at these northern latitudes. The R/V Point Sur also made a series of transects across the north plume on the GH line during this period.

The first environmental period thus includes sections across the GH line (with vertical fish) and CM line (CTD only), surface transects and vertical sections across the north plume (south to north--CD, LB, GHN) with CTD, fish surface towing and vertical fish on most lines. Six expendable drifters were deployed along the GH or GHN and LB lines. Four of these six later returned south past the river mouth during the later period of upwelling-favorable winds. Note that the GHN line is 1 mile north of the GH line at the same latitude as the RISE RN mooring. Point Sur was working nearer the GH line so this latitude choice allowed our ships to pass each other safely.

On May 28, during spring tides, a 25 hr time series was obtained near the river mouth (TSS).

Following that study we resumed sampling of the north plume. Five C-T drifters, including one that was drogued to 25 m, were deployed on the KA line. Three of the drifters moved rapidly toward the beach and were recovered very close to shore (~10 m depth) near Cape Elizabeth. One drifter went off line and was lost. The last drifter was recovered the next day. The KA line was sampled, followed by LP and MB. Underway surveys were done between KA and LB (UW1) and from LB to MB (UW2). Surveys to the mouth of the Strait of Juan de Fuca and between MB and the strait (UW3) finished the study on May 31.

The ship returned to Astoria on June 1 for personnel swap and estuary sampling (E1,2,3 plus small boat samples on the tide flats for chemistry).

Because downwelling winds were still occurring on June 2, we decided to obtain comparative samples off Oregon just south of the river mouth (SL line). The only water below 31.5 psu appeared to come from the Stanley River rather than from the Columbia (very sharp east-west fronts). Few, if any, remnants of the southwest Columbia plume had survived the long period of downwelling-favorable winds.

On June 3 we obtained a 25 hr neap period time series (TSN) near the river mouth. That study was followed by a 4 unit C-T drifter deployment across the river mouth, still under downwelling wind conditions.

Winds turned upwelling-favorable on June 5, remaining in that direction until the last day of the cruise. The drifters deployed on the previous day at the river mouth had turned north and were between the LB line and the mouth in latitude. For that reason, and because Point Sur was sampling the LB line repeatedly hoping to see the northward plume “relax”, we collected fish surface data on a tow from LB line southeast and then across the plume toward the east. The surface survey was completed with ship’s underway data on a transit to LB1. We next sampled the LB line with CTDs, complementing TRIAXUS data being collected by the Point Sur, which could not sample in water shallower than about 40 m bottom depth. The C-T drifters were recovered and water was taken near Haystack Rocks. No upwelling was observed at that site (bottom temperature was 14 degrees in 20 m bottom depth, June 6).

Four C-T drifters were deployed at the river mouth again on June 7, for a 3-day study of the new southwest-tending plume. A fluorometer was installed on drifter 22300 for this and the two subsequent river mouth drifter deployments. The initial deployment was followed by a CTD, then a ~2 hr north-south fish tow, followed by additional CTDS. On the first day 4 fish tows were made across the emerging plume, with CTDs at the outer ends of the two transect and generally in the middle. All tows and mid transect CTDs were made behind the line of drifters, which appeared to track the emerging water well for the 3 days. The northern drifter turned in a clockwise circle, crossing the estuary mouth and was recovered. The other 3 drifters all moved south to southwest and were recovered in water with salinity of about 25 psu. The plume at this Pt and during the next several days resembled a Christmas stocking—where the stocking was the old plume off Washington, the heel was newly emerging water and the toe was water advected

south from the older Washington plume. This description was supported by our drifters. For example, drifters deployed in the original north plume during the first week of the cruise turned south again after winds changed to upwelling-favorable, traveling at speeds up to 1 kt along the outer shelf and slope. On the second day of the study, the emerging plume was studied with a fish tow across the entire plume and CTDs at either end and mid plume. On the third day, micro/macro nutrients were sampled with go flow bottles at CM stations 1-4. Drifters were recovered and a CTD was taken before pick up of drifter 22300 (with fluorometer). A final CTD was taken at drifter 09126, which had been deployed as an expendable replacement for a C-T drifter in the prior estuary mouth drifter study that began June 4.

Four C-T drifters were deployed again at the mouth on June 11 during very weak upwelling winds and a period of nearly spring tides. These drifters all turned in a clockwise circle over the ~9-11 hours they were tracked. Salinity at the first fish/CTD station was very low, 3 psu, reflecting the spring tides and higher riverflow during this period.

In the last 2 days of the cruise CTD/rosette and net tow sampling of the GH and CM line was done to complete the cruise.

Some Preliminary Results*:*

- The plume from the Columbia can extend as far north as the Strait of Juan de Fuca in summers with high riverflow. Plume salinity at the Strait was about 27 psu.
- On the initial shelf/slope survey, water was colder, saltier and higher in macro nutrients everywhere on the Washington shelf and slope than on the Oregon shelf and slope.
- Because of the complete lack of upwelling on the inner shelf on this cruise, nitrate was supplied entirely by the Columbia and (possibly) other rivers. During both spring and neap tides the river had high nitrate (10-13 μM); this nitrate appeared to be the only source for the chlorophyll observed in the plume for over 20 days.
- Total dissolved iron and manganese were also present at high concentrations during the ebb tide close to the mouth of the estuary (~25 and ~30 nM, respectively) and rapidly decreased as the plume moved offshore (~0.1 and 0.5 nM).
- Ammonium showed a distinct tidal signal near the river mouth, with higher values on ebb.
- In contrast to the healthy diatom-dominated communities in July 2004, the phytoplankton standing stock was composed of unhealthy appearing diatoms.
- There was an unusually high abundance of large (>100 um) mixotrophic ciliates in both fresh and aged plume waters. These mixotrophic ciliates seem to thrive under the oligotrophic, relatively turbid (low light) plume influenced waters.
- Phytoplankton growth rates were generally much lower (<0.8 d^{-1}) than on most previous cruises, possibly due to plume turbidity. In very new plume waters, the phytoplankton did not respond to nutrient additions.
- Micro zooplankton grazing rates were also generally lower than on previous cruises.
- Egg production rates of *Calanus pacificus* were significantly reduced in comparison to other years and many showed evidence of starvation. Few reproductively active euphausiids were observed and female euphausiid egg production was much lower than usual, possibly a response to the reduced food availability due to the lack of upwelling.

CRUISE MEASUREMENTS

CTD and Underway Data

Data collected at each CTD station included conductivity (C), temperature (T), light transmission, PAR, oxygen and fluorescence (Fl) profiles, optical backscatter, Fast Repetition Rate Fluorometer (FRRF), ISUS UV nitrate sensor, and bottle samples for chlorophyll, plankton and macronutrients at selected depths. Most profiles were taken only as deep as 200 m. Deeper stations (to 500 m) were taken on the Grays Harbor and Cape Meares lines on both occupations. For modeling purposes, one 1000 m profile was taken at GH11. The near surface sampling protocol was changed after station 106 during the cruise—at the start, due to rough weather the CTD rosette was kept below the water surface before starting the cast down. This was changed after about a week--the rosette was subsequently brought back up so the bottles were visible--for all except optics casts, so that subsequent profiles should better resolve the near surface layer. A list of CTD stations organized by sample line and including bottle sample types taken is given in Table 2.

Macro nutrients were taken at the surface, 5 m, 10 m, the chlorophyll maximum 15 m, 30 m, 50 m, 100 m, 150 m, 200 m, 250 m, 300 m, 500 m and ~5 meters above bottom if the bottom was less than 500 m deep and also on primary productivity casts. On the survey of the southwest plume (June 7-9), macronutrient samples were taken only in the upper 50 m. On estuary mouth drifter deployments, macro nutrients were collected with both fish and CTD rosette, with CTD rosette sample depths hand selected for each cast by Ryan McCabe.

Underway data included T, S and Fl (with beam transmission from 2 m) pumped from a depth of 4 m from shipboard sensors. In addition, the Kudela group installed a Seabird temperature and conductivity sensor (SBE-45), Turner fluorometer (Cyclops-7) and Wetlabs transmissometer, a variable fluorescence meter (Turner PhytoFlash!™ beta version), and a Trios ProPS UV-spectrometer at 2 m using the forward underway port. This shallower data was very useful for sampling the plume and is included on the CTD paper logs. Statistical comparison of 2 and 4 m underway salinity and temperature data indicated that they were both calibrated well enough to capture vertical gradients (i.e., few inversions were observed).

Bottle samples were taken for calibration of salinity CTD sensors. Salinity samples were taken at roughly every third station and processed onboard by Jim Postel. Chlorophyll *a* samples from the underway system were obtained periodically throughout the cruise to calibrate for different water types.

ADCP current profiles were obtained with both a 75 khz Ocean Survey broadband RDI ADCP and a 150 khz narrowband RDI ADCP. The 150 khz ADCP had only 3 beams working and will require post processing.

Optics casts were made between noon and 2 PM on most days. Sensors included a Wetlabs ACS, a Satlantic HyperPro II tethered profiling hyperspectral radiometer, a Wetlabs backscatter sensor, and a Wetlabs volume scattering function (VSF) sensor. Corresponding CTD profiles were obtained to accompany these casts.

Subsurface vertical iron profiles were obtained at many stations by lowering the fish to the target depths (typically 1 m, 4, 10, 20 m) while maintaining a slow forward speed. Along the Grays Harbor line, at Haystack Rocks and on the inner CM line (sta 1-4), trace metal samples were taken from the bottom nepheloid layer using GO-Flo bottles.

The CTD data were partially edited onboard ship. These data were used to construct preliminary maps and sections. Following the cruise, salinity calibration will be performed and more detailed editing completed. Although water property spatial patterns are likely robust, actual salinity values may change slightly (second decimal change) following the final editing. More important, surface and pycnocline inversions and other data problems will be eliminated in the final editing. ADCP data require more extensive processing.

Towed Fish Transects

Water properties near the sea surface were surveyed primarily on 14 transects over the plume and shelf regions (Fig. 5). On these surveys macronutrients (NO3, PO4, SiO4) were sampled at 2- minute intervals. Samples for total dissolved iron, manganese and aluminum were taken every 10 minutes except when strong gradients were observed and the sampling frequency was increased to 2 minutes. Measurements were made with a towed fish interfaced to Teflon tubing and pumped using a Teflon diaphragm pump. Underway temperature, salinity and fluorescence data were also collected on these surveys.

Drift Studies

Four interdisciplinary drift studies were performed: one in the northward plume during strong downwelling winds, one at spring tide, one at neap tide and one approaching spring tide. Deployment and recovery times and deployment location are listed in Table 3. The goal of these studies was to follow patches of water from the plume over the continental shelf, examining water properties (salinity, macro and micronutrients and plankton) as the patches aged. In the first study (May 27) five C-T Brightwaters GPS-type drifters were deployed in a developed northward plume on the GHN line. The drifters are designed to follow water at ~1 m depth inside the river plume. They are equipped with temperature and conductivity sensors, set to record at 3 min. intervals. The drifters passed through our sampling transects usually within a few hours of our transect CTD samples.

In the second, third and fourth study, four drifters were deployed along a north-south line just seaward of the river mouth. Following our 2005 protocol, in the three river mouth studies we followed a patch of drifters so that at least one to three drifters would likely remain in the new water. This strategy proved highly successful. In general we attempted to remain just behind the "front" of emerging drifters so as to sample the water as it aged behind that position.

CTD profiles, net tows, nutrient and chlorophyll bottle casts and macro and micronutrient profile samples with the iron fish were taken at the start of each drift and water was collected for incubation experiments during the drift. CTD profiles, nutrient and chlorophyll bottle samples and vertical net tows were taken at 1-4 hour intervals for intervals from 12 hours to 3 days. Deckboard dilution experiments (Lessard) were run for 24 hours with water collected at CTD stations during the drift. Samples for size-fractionated chlorophyll, picoplankton, nanoplankton and microplankton (FlowCAM and preserved) and macronutrients were taken in each experiment. Productivity (carbon, nitrogen, silicon) uptake experiments and carbon PE curves (Kudela) were also conducted during the drifts.

A number of expendable drifters were used to track the plume and regional currents during the cruise. Four remained in the water at the end of the cruise—two of these (10505 and 03794) were located on their return pathway southward after traveling north of La Push in the northward plume that dominated the cruise. CTD profiles (245 and 246) with nutrients and FlowCAM were obtained as these drifters passed offshore of Willapa Bay.

Time Series at Fixed Stations

25-hr time series were obtained at spring (May 28) and neap (June 3) tides. Hourly CTDs were obtained as well as hourly vertical fish samples for micro and macro nutrients. The Kudela group also obtained hourly vertical profiles of reduced nitrogen species (ammonium and urea) and chlorophyll *a*. At less frequent intervals (ca. 3-4 hr) rates of primary production were determined during the spring tide time series only.

Satellite Imagery

Satellite imagery during the cruise was provided by R. Kudela. The available images were sent to the Wecoma ftp site and an assessment of its quality will be made after the cruise. The weather was so poor that few good images were obtained. However, sea surface temperature images were useful in locating the north plume water. Due to the lack of upwelling, surface water temperatures were warm and relatively uniform, although the plume could still be detected as warmer water. MODIS 250 m true-color images were also provided.

DETAILS OF INDIVIDUAL TEAM MEASUREMENTS

Chemical Analyses (Bruland Group: Maeve Lohan, Geoffrey Smith, Bettina Sohst, Ana Aguilar-Islas, Matt Brown)

The primary objective of this component of RISE is to examine the influence of the Columbia River plume on macronutrients (nitrate, phosphate and silicic acid) and micronutrient (dissolved and particulate iron and manganese) concentrations on the Washington and Oregon shelves. Two different sampling strategies were undertaken: 1) surface transects using a towed 'fish' which utilizes a Teflon pumping diaphragm pump and Teflon tubing and 2) sub-surface vertical profiles obtained by lowering the 'fish' to 20 m and sampling at 1, 4, 10, and 20 m. Fourteen surface transects were sampled (see Fig. 4). Dissolved inorganic macronutrients were collected on-line and analyzed using appropriate colorimetric methods with a Lachat Instruments QuickChem 8000 Series Flow Injection Automated Ion Analyzer providing nutrients concentrations every 3 minutes. Total dissolved iron and manganese samples were collected discretely using trace metal clean techniques and analyzed onboard by flow injection analysis methods. Samples were also collected for dissolved aluminum analysis and will be run by flow injection analysis back in the laboratory. Detailed sub-surface vertical profiles of macro and micronutrients were also carried out along the Cape Meares section (stations 1-4), the Grays Harbor section, along two drifter studies close to the Columbia River mouth, within the estuary and up to 25 miles up river. Particulate samples for trace metals were collected and filtered through 10, 0.4 and 0.03 μm using trace metal clean techniques.

Water samples from the 'fish' were also collected for phytoplankton identification and enumeration by Lessard's group and for CDOM analysis by Kudela's group. Samples were taken for iron and manganese from just above and within the nepheloid layer on the Oregon shelf using 8 litre GO-Flo's suspended on Kevlar wire and triggered using a Teflon messenger. Nutrient concentrations were also analyzed onmost CTD casts and at the beginning (time zero) and end (time final) of all dilution experiments performed by Lessard's research group.

During both the spring and neap tides a 19-hr time series (sampling once an hour at 1, 4, 10, and 20 m) was carried out at one station close to the mouth of the estuary (TS) to investigate the effect of the tidal signal on macro and micronutrient concentrations. In order to provide the source concentrations of both trace metals and macronutrients, three stations within the estuary were sampled both prior to the ebb and flood tide. The riverine end-member sample was collected 30 miles from the estuary. Within the estuary and the river samples were collected for both macro and micronutrients from the "fish" sampler to a depth of 15 m. CTD's were also carried out at these stations. In order to examine the influence of photochemistry on both dissolved iron and manganese concentrations, samples were collected during spring tides from within the plume and incubated on deck in Quartz cells. Five different treatments were carried out in both the light and the dark.

Over 100 trace metal clean samples were also collected for Dr. Jessica Miller at Oregon State

University.

Some Preliminary Results*:*

- Macronutrients: Approximately 70% of collected samples were analyzed onboard and draft concentrations made available daily. The remaining 30% will be analyzed in the near future. The Columbia River plume is easily identified by silicic acid concentrations which exceed 180 µm in surface waters and concentration within the estuary are 242 µM. Nitrate concentrations were lower in the estuary compared to July last year (11 µM compared to 16 µM). Nitrate concentrations rapidly decreased with distance from the mouth of the plume.
- Micronutrients: All samples for dissolved iron and manganese were analyzed onboard. Total dissolved iron and manganese are also present at high concentrations during the ebb tide close to the mouth of the estuary (~ 20 and ~250 nM, respectively) and rapidly decrease as the plume moves offshore (~0.1 and 0.5 nM). In oceanic waters the iron concentration was in the pico-molar range while the manganese had decreased to 0.5 nM. .

Productivity and New Production (Kudela Group: Tawnya Peterson, Sherry Palacios, Atma Roberts, Misty Blakely; satellite images from Raphael Kudela)

The objectives of our component were three-fold. First, we provided near-real time remote sensing (satellite) support for the R/V Wecoma, and made the images available via the pigeon-drop system (shore-based ftp). Second, we conducted biological rate measurements at representative stations for carbon, silicon, and nitrogen (nitrate, ammonium, and urea), along with ancillary measurements such as chlorophyll *a*, particulate organic carbon and nitrogen, biogenic silica, and concentrations of ammonium and urea. We also provided the R/V Point Sur with our Satlantic ISUS UV-Nitrate sensor. Third, we deployed bio-optical instrumentation both *in situ* and in mapping mode in order to characterize the optical and chemical properties of the water column.

Our measurements of primary production rates relied on carbon-based and nitrogen-based methods. We examined relationships between production and light by conducting uptake versus irradiance (PE) experiments in waters collected near the surface and performed single-depth (50% light) measurements of primary production in order to achieve a broad spatial distribution of data. Typically we performed one full vertical profile (6 light depths) per day, incubating samples collected at 100, 50, 30, 15, 5 and 1% of surface irradiance using simulated *in situ* (deck-board) incubators. At many stations, we used the stable tracers $^{15}NO_3$ and $^{15}NH_4$ to estimate nitrogen uptake (see Table 4). At selected stations we also measured ^{15}N-urea and ^{32}Si uptake rates. Incubations were conducted using standard methods, for 3-24 hours. At a subset of stations, filtrate was collected for analysis of ammonium regeneration rates.

We participated in the two time series studies (spring and neap) with the aim of examining how tidal dynamics can influence the distributions of regenerated nitrogen compounds (ammonium and urea) and chlorophyll *a* during a period of high river flow. Ammonium levels and chlorophyll *a* were determined onboard the ship while urea concentrations will be measured in the laboratory at UC Santa Cruz.

Some Preliminary Results:

- Remote Sensing: Good satellite images were scarce due to cloud cover, a few clear days allowed identification of plume waters. Of particular interest was a nice image

showing the warm water of the northward-tending plume reaching Juan de Fuca Strait/Juan de Fuca eddy. A summary of good images will be provided post-cruise, and will be made available at http://oceandatacenter.ucsc.edu.

- Standing stocks: *Chl a* measurements (~1000) were collected from the upper water column for most stations with full profiles at productivity stations, and full profiles on the transect lines. Most chl *a* samples were collected on Whatman GF/F filters (nominal pore size 0.7 µm), but a subset of 20, and 5 µm filters were also collected. Chlorophyll *a* concentrations were generally quite low during our survey period.

  At productivity stations, biogenic silica, POC/PON, ammonium, urea, and total suspended solids were also measured. As part of the mooring deployment, chlorophyll *a* and nutrient samples were also collected by the Dever group; we processed the chlorophyll *a* data, and will process the (frozen) nutrient samples in the lab. Biogenic silica and particulate carbon/nitrogen samples will be analyzed in the laboratory at UCSC.

- Rate Measurements: A summary of the rate measurements conducted is provided in Table 4. Primary production was generally low; one exception includes GH6, occupied on May 22 (Figure K-1).

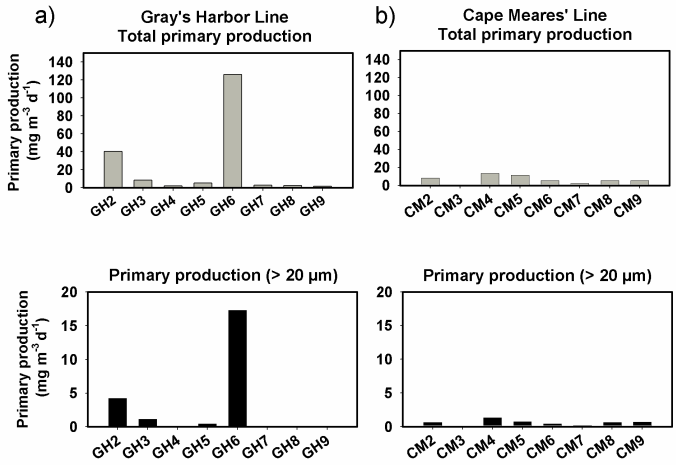

Figure K-1. Comparison of (a) Grays Harbor line primary production rate measurements (mg m^{-3} d^{-1}) with (b) Cape Meares Line. Surveys were conducted on May 22 and 23, respectively.

- Bio-Optics: Typically once per day (around local noon) we deployed optical packages (described above) to characterize the inherent and apparent optical properties of the water column. We also instrumented the CTD package with a HOBI Labs HS6 (backscatter meter), Chelsea FRRF, and Satlantic ISUS UV-Nitrate sensor. These were operating on most CTD casts. These instruments provide an estimate of the water color, particle backscatter, attenuation, and fluorescence. These data will be used primarily for validation of the satellite algorithms, and for characterization of the different water mass types. To complement the optical measurements, a series of discrete water samples were also collected for CDOM (colored dissolved organic material) and a* (particle absorption) spectra, typically at 0, 5, and 10 m depths.

We would like to gratefully acknowledge the assistance of Dave Gorman and John Kumph in trouble-shooting of the optical instruments.

Expected Data Availability:

All chlorophyll samples were processed on board, and will be available immediately after QA/QC of results. All ^{14}C samples were counted on board, and will be available immediately after QA/QC. The other rate measurement samples need to be processed in the lab, with final calculations dependent on the availability of final nutrient values. Bio-optical data and satellite imagery are available immediately, but need to be post-processed to include post-cruise calibration (optics). We will also produce time-averaged satellite imagery post-cruise.

Micro zooplankton and Plankton Community Structure, Growth and Grazing Rates (Lessard Group: Evelyn Lessard, Elizabeth Frame, Megan Bernhardt)

The main objective of this component of the RISE project is to determine and compare the growth and grazing mortality rates of phytoplankton and assess the community composition in the Columbia River plume, Washington and Oregon coasts. The results will help address our central hypotheses that the Washington coast is more productive than the Oregon coast due to the influence of the Columbia River Plume. We used the dilution method to experimentally determine the growth and grazing rates of the whole and size-fractionated phytoplankton community, as well as specific taxa. We used an imaging-in-flow cytometer (FlowCAM) as well as fixed samples, to follow the in situ spatial and temporal changes in the abundance of the major phytoplankton and microzooplankton taxa.

We performed 23 dilution experiments. The experiments were performed along the WA and OR coast, at the time series station at the mouth of the plume, and following drifters (Fig. 5).

The FlowCAM was invaluable for providing near real-time assessments of plankton community composition, which helped guide our experimental planning. We processed over 800 samples during surveys, both from the CTD and Fe fish sampler, which will be used to quantify patterns in distribution of the major taxa of phytoplankton and heterotrophic protists. This will give us an unprecedented fine scale map of plankton taxa tied to concurrent chemical (macronutrients and micronutrients) and hydrographic information.

Some Preliminary Results*:*

- In contrast to the healthy diatom-dominated communities in July 2004, the phytoplankton standing stock was composed of unhealthy appearing diatoms, presumably the remnants of the strong upwelling induced diatom blooms which occurred just prior to our cruise. There was an unusually high abundance of large (>100 um) mixotrophic ciliates in both fresh and aged plume waters. These mixotrophic ciliates seem to thrive under the oligotrophic, relatively turbid (low light) plume influenced waters. In some cases, we expect that the mixotrophic ciliates will contribute significantly to chlorophyll and productivity.
- Phytoplankton growth rates were generally much lower ($<0.8\ d^{-1}$) than on most previous cruises. Nutrient (sometimes phosphate, rather than nitrate) and light limitation due to plume turbidity appear likely causes of these low growth rates. In very new plume waters, the phytoplankton did not respond to nutrient additions.
- Grazing rates were also generally lower than on previous cruises.

Macro zooplankton (Peterson Group: Tracy Shaw, Jennifer Menkel and Kate Ruck)

1Zooplankton research during the RISE-2-W cruise was directed at determining whether there are regional differences in copepod and euphausiid production in shelf waters off

Washington and Oregon. This work addresses the RISE hypothesis that phytoplankton biomass and production should be higher off Washington than Oregon and that zooplankton production will in turn be higher as well. Towards this end, we set forth the following research objective:

to determine if molting and egg production rates of several copepod and euphausiid species are higher in coastal waters off Washington as compared to coastal waters off Oregon

Forty-three stations were occupied on this cruise, primarily at night. Operations carried out at each station are shown in Table 5. We conducted a total of 42 vertical plankton net tows and 28 oblique Bongo net tows. Live animals were incubated at 24 stations for egg production rates of *Calanus pacificus* and 10 stations for egg production by the euphausiid *Euphausia pacifica*.

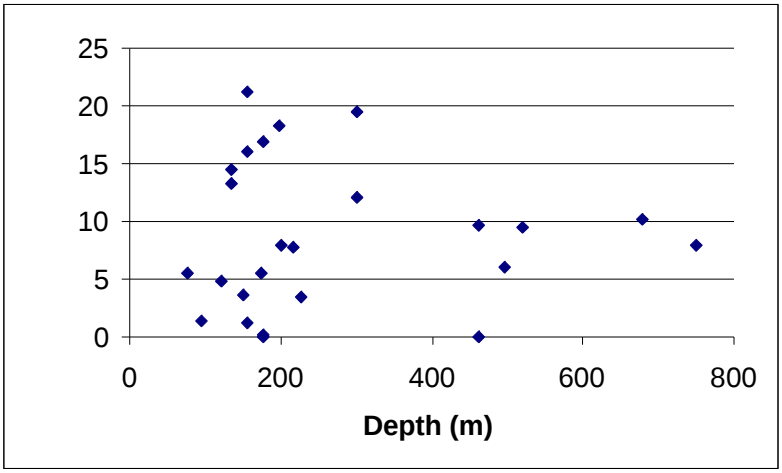

Figure P1. Egg production rates for the copepod *Calanus pacificus*.

Average production rates were higher at the nearshore stations, declining to lower levels at stations off the shelf. However, we often observed that the animals looked very "clear" (no food in their guts) and found a lot of females that laid no eggs during experiments, in contrast with other years. Copepods generally lay eggs every night, so the prevalence of females that laid no eggs suggests that they were severely limited by the lack of food in the form of phytoplankton that we observed during this cruise. Maximum rates for this copepod species are on the order of 50-60 eggs per day. Thus maximum rates were observed only rarely, indicating food limitation of egg production at most stations.

We observed very few reproductively active euphausiids during this cruise. This may be due to low food availability, as evidenced by the low chlorophyll levels observed during most of our sampling time on this cruise. *Euphausia pacifica* females produced an average of 108 eggs per female during this cruise. Our climatological average number of eggs per female for *E. pacifica* (based primarily on experiments off Newport, OR during the past five years) is on the order of 130 eggs per female. We did not see any reproductively active *Thysanoessa spinifera* females during this cruise.

The relationship between body length and egg production for *E. pacifica* during RISE 4W is shown in Figure P2 below. Overall, these results are comparable to our egg production data for *E. pacifica* from other areas. The surprising result of these experiments is how few spawning females we found throughout the study area during this cruise. Two weeks prior to this cruise, we had sampled in this area as part of another study and found spawning female *E. pacifica* throughout the area. At that time there was a phytoplankton bloom in conjunction with the

upwelling occurring along the coast. During RISE 4W upwelling had decreased considerably and the phytoplankton bloom was no longer in evidence. The decrease in spawning activity in this relatively short time period suggests that euphausiid spawning is highly dependent on an abundant supply of food in the form of phytoplankton.

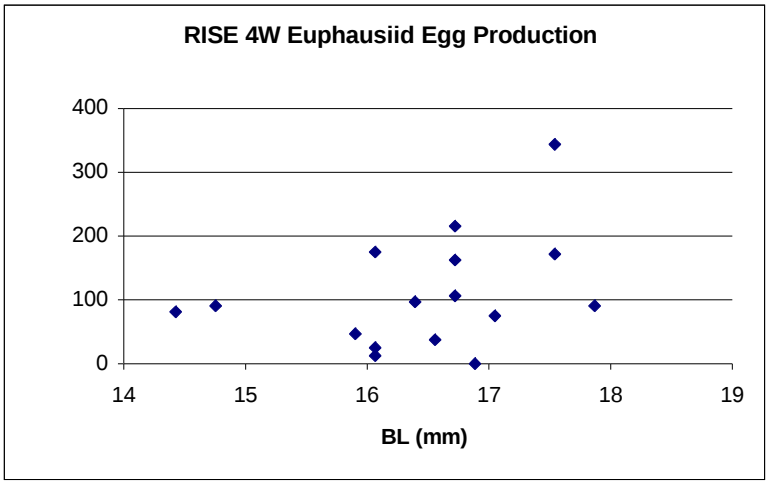

Figure P2. Number of eggs per body length for Euphausiids on RISE 4-W.

Drifter Deployments (McCabe, Hickey)

Brightwaters GPS drifters were deployed to delineate patterns and speeds of currents over the Washington and Oregon shelves and near the river mouth. All drifters were deployed to track the top ~1 m of water. Deployment times and positions as well as recovery times are listed in Table 3. All drifters measured temperature (T) and some were additionally outfitted with conductivity (C) sensors. For the C-T drifters, data were recorded internally at 3 minute intervals. Expendable drifters (T only) transmitted data every 30 minutes via Argos satellites. Satellite data were stored at UW and transmitted to the ship by Tom Connolly, Amy MacFadyen and Sue Geier. A few of the expendable drifters collected data through part of July.

Some Preliminary Results:

May 22 and 24: Two expendable drifters (T only) were deployed on the GH line at the mid and outer shelf (drifter 3774 at GH8 and 3974 at station GH5) to track higher salinity (non plume) water. These drifters initially moved north during the storm as well as the subsequent period of weaker downwelling-favorable winds. These drifters turned around north of La Push after upwelling winds began, eventually retracing their steps all the way down to Oregon. The salinity at 3974 was much fresher on the return trip than when it was deployed (27 vs. 31 psu, from CTD data). Two additional expendables were deployed on May 24 at LB 2 (9126) and LB4 (9121) in the now well developed north plume. However, 9126 entered Willapa bay, where it was recovered and returned to us by the BaPptista group in Astoria. 9121 traveled all the way north, crossing the Strait of Juan de Fuca and beaching at a park on the north side of the strait. It was recovered by lighthouse keepers and returned to us via our ECOHAB colleagues.

***May 29*:** Five C-T drifters, including one that was drogued to 25 m, were deployed on the KA line. All drifters initially moved north. Three of the drifters moved rapidly toward the beach and were recovered very close to shore (~10 m) near Cape Elizabeth. One drifter went off line and was lost. The last drifter (drogued) was recovered the next day. The KA line was sampled, followed by LP and MB, with drifters fortuitously moving northward through our sampling lines.

June 4-6: Four C-T drifters were deployed on a north-south line just offshore of the river mouth at maximum ebb. Winds were still downwelling-favorable. All four drifters headed straight north after an initial short right turn (an unusual pattern). The northernmost (on deployment) drifter continued north near the coast (3938). It was later recovered in a front and replaced with expendable 9126 at the instant of pickup. That drifter eventually moved offshore under upwelling winds, later turning south in plume water where it was recovered on June 10. The three other drifters turned west offshore of the Longbeach peninsula and then eventually turned south on the outer shelf, where they were recovered.

June 7: Four C-T drifters were deployed at the mouth again on June 7, for a 3-day study of the new southwest-tending plume. A fluorometer was installed on drifter 22300 for this and the subsequent mouth drifter deployments. The initial deployment was followed by a CTD, then a ~2 hr north-south fish tow, followed by additional CTDS. On the first day 4 fish tows were made across the emerging plume, with CTDs at the outer ends of the two transect and generally in the middle. All tows and middle CTDs were made behind the line of drifters, which appeared to track the emerging water well for the 3 days. The northern drifter turned in a circle, crossing the estuary mouth and was recovered. The other 3 drifters all moved south to southwest and were recovered in water with salinity of about 25 psu. The plume at this point and during the next several days resembled a Christmas stocking—where the stocking was the old plume off WA, the heel was newly emerging water and the toe was water advected south from the older WA plume. This description was supported by our drifters. For example, drifters deployed in the original north plume turned south again after winds changed to upwelling-favorable, traveling at speeds up to 1 kt along the outer shelf and slope. On the second day of the study, the emerging plume was studied with a tow across the entire plume and CTDs at either end and mid plume. On the third day drifters were recovered and a CTD was taken before pick up of drifter 22300 (with fluorometer). A final CTD was taken at drifter 09126, which had been deployed as an expendable replacement for a C-T drifter in the prior estuary mouth drift study on June 4; the drifter was not recovered.

June 11: Four C-T drifters were deployed on a north-south line across the river mouth on June 11 during very weak upwelling winds and a period of nearly spring tides and reasonably high riverflow. These drifters all turned in a clockwise circle over the ~ 9-11 hr they were tracked. The Baptista modeling group provided a prediction for this period: all but the most northern drifter track behaved similarly to the model predictions. Drifters were recovered after about 9-11 hr.

ADCP Transects (MacCready*)*

The ADCP data was partially processed onboard ship by Parker MacCready. Plan maps at 3 depths from the first cruise period are shown below (Fig. PM1).

The maps illustrate that in spite of the downwelling winds in this period, the baroclinic shelf break/slope jet was well developed below 20 m. A northward flowing wind and buoyancy driven coastal current can also be seen. Sections (Fig. PM2) shown that the California Undercurrent was well developed. One repeated section across Juan de Fuca canyon on our most northerly line, Makah Bay (48° 17.8’ N), with 3.6 hour mean spacing between re-occupations, showed marked changes in currents consistent with tidal effects.

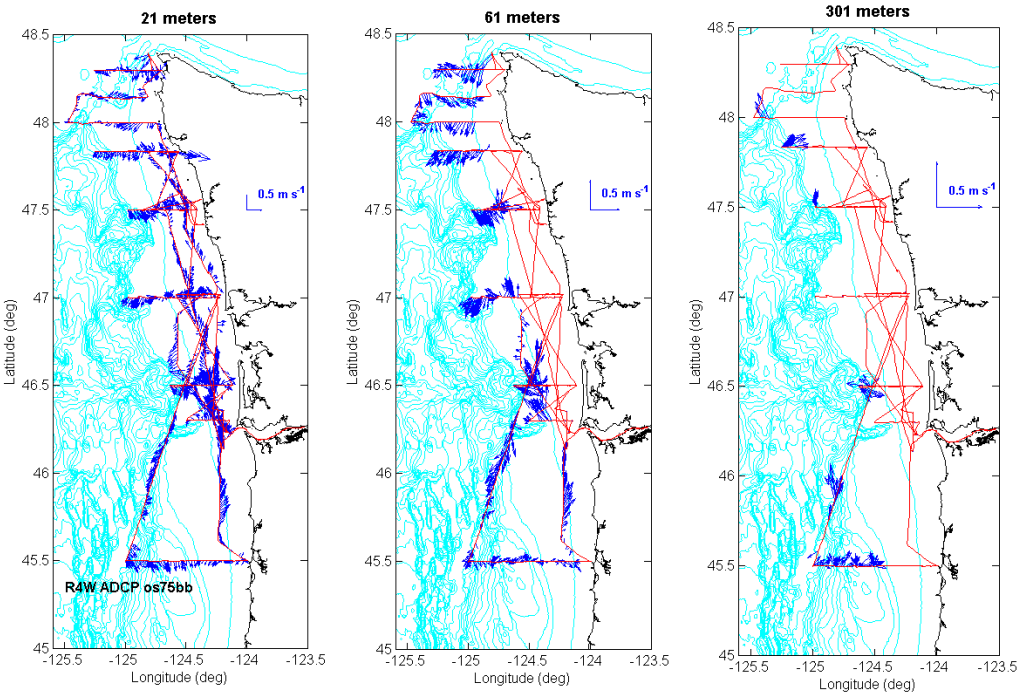

Figure PM1. Plan view of ADCP-derived currents at 3 depths during the downwelling wind phase of the cruise. Cruise track is shown in red.

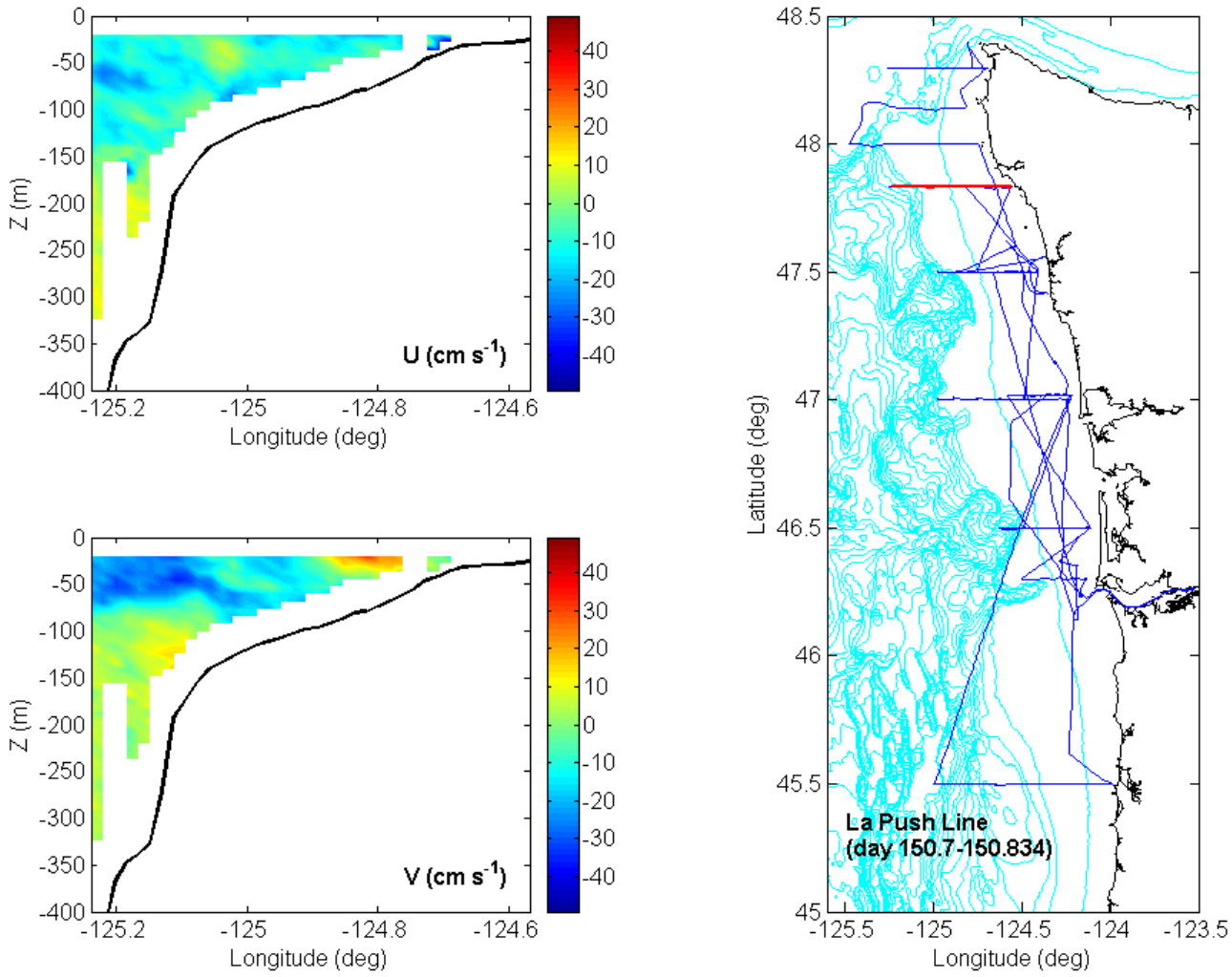

Figure PM2. Velocity from ADCP data on an east-west transect (location shown in red). North-south and east-west velocities are indicated by v and u, respectively. Note that east-west velocities are likely dominated by internal tidal velocities.

ACKNOWLEDGEMENTS

We would like to thank the captain and crew of the R/V Wecoma for their support and extra effort that made this cruise successful. This research was supported through the Coastal Ocean Processes Program (CoOP) of the National Science Foundation, Award No. 0239089.

List of Tables and Figures

Table 4. Kudela group data collection, primary productivity measurements

RISE-4W Incubations	14C			32Si		15N3		15N4		15Ur	
Cast #	Profile	50%	PE	Profile	50%	Profile	50%	Profile	50%	Profile	5
C04	X		X	X		X	X		X	X	
C06		X					X		X		
C07		X					X		X		
C08		X					X				
C10		X					X				
C11		X					X				
C12		X					X				
C13		X					X				
C15	X			X		X		X			
C16		X					X				
C18		X					X				
C19		X					X				
C20		X					X				
C21		X					X				
C22		X					X				
C24		X					X				
C26		X					X		X		
C27		X					X		X		
C40		X					X		X		
C41	X			X	X	X	X	X	X	X	
C43	X		X	X		X		X		X	
C47	X	X	X	X	X	X	X	X	X		
C48		X					X		X		
C50		X	X				X				
C51		X					X				
C60	X		X	X		X		X		X	
C70	X		X	X		X		X		X	
C72			X								
C80		X									
C83		X									
C88		X									
C90		X									
C91		X									
C92		X									
C93		X									
C94	X		X	X		X		X			
C95		X			X		X		X		
C96		X									
C97		X									
C98		X									
C100		X	X		X		X				
C101	X	X	X	X	X	X	X	X	X		

C102		X								
C106			X							
C105			X							
C107			X				X			
C117	X		X	X		X		X		
C118	X	X	X	X		X		X		
C119		X					X			
C120		X	X				X			
C121		X					X			
C122		X					X			
C123		X					X			
C124		X								
C126	X		X	X	X	X	X	X	X	X
C127		X					X			
C129		X					X			
C131		X					X			
C132		X					X			
C133		X					X			
C134		X					X			
C135		X					X			
C136		X					X			
C141	X		X	X		X		X		X
C142		X	X				X			
C143		X					X			
C144		X	X				X			
C146		X					X			
C148		X	X				X			
C151	X		X			X		X		
C152			X							
C155			X							
C159			X							
C164			X							
C190	X		X	X		X		X		
C202			X				X		X	
C211	X		X		X		X		X	
C220	X				X		X		X	
C222	X		X				X		X	
C227							X		X	
C249							X		X	
C251							X			

Table 5. Summary of zooplankton sampling effort from June 1-13 RISE 4-W.

Station	Latitude	Longitude	Depth	Vertical Net	Bongo Net	Live Net	Copepod EPR	Euphausiid growth rate (# incubated)	*E. pacifica* EPR (# incubated)
CR25	46 09.63	124 33.63	155	x	x		17		
CR30	46 09.45	124.40.7	283	x	x				
SL08	46 00.50	124 48.41	521	x	x		20		
SL07	46 00.51	124 39.99	199	x	x		20	30	4
SL06	46 00.48	124 28.99	150	x	x				
TSN	14.00	124 10.01	27			x			
LB06	46 29.94	124 37.63	750	x	x		17		1
LB05	46.29.99	124 30.11	250	x	x				1
LB04	46 29.97	124 20.07	77	x	x		16		
PP05	46 23.22	124 27.05	122	x	x		19		
PP06	46 23.24	124 33.50	151	x	x		16	30	2
PP07	46 23.31	124 37.07	678	x	x		20		5
CR30	46 09.59	124 40.80	301	x	x		20		7
CR25	46 09.59	124 33.62	156	x	x		20		
CR20	46 09.59	124 27.05	134	x	x		20		
HR5.5	45 51.98	124 35.98	176	x	x		20		
HR06	45 51.99	124 40.92	216	x	x		20		
HR07	45 52.01	124 45.49	463	x	x		20		
CM30	45 30.03	124 41.04	496	x	x		20		
CM20	45 29.98	124 26.02	226	x	x		20	30	
CM15	45 29.99	124 20.01	177	x	x		20		2
CR30	46 09.59	124 40.78	295	x	x		20		3
CR25	46 09.61	124 33.62	156	x	x		20		5
CR20	46 09.60	124 27.05	134	x	x		20		3
GH08	46 59.99	124 58.50	200	x	x		20		
GH07	47 00.02	124 53.21	173	x	x		20		
GH05	46 59.95	124 37.57	96	x	x		20		
GH01	47 00.00	124 13.33	18	x					
GH02	47 00.00	124 17.28	38	x					
GH03	47 00.33	124 21.66	48	x					
GH04	47 00.34	124 29.40	72	x					
GH06	47 00.03	124 45.29	134	x					
GH09	47 00.00	125 02.86	1073	x					
GH10	47 00.00	125 15.02	1679	x					
GH11	46 59.99	125 24.01	1954	x	x		20		
CM08	45 30.00	124 49.00	844	x					
CM07	45 30.00	124 38.98	483	x					
CM06	45 29.95	124 31.00	466	x					
CM05	45 30.01	124 23.12	193	x					
CM04	45 30.00	124 15.12	156	x					
CM03	45 30.00	124 07.09	98	x					
CM02	45 29.99	124 03.10	68	x					
NH05	44 39	124 10.6	60	x	x				

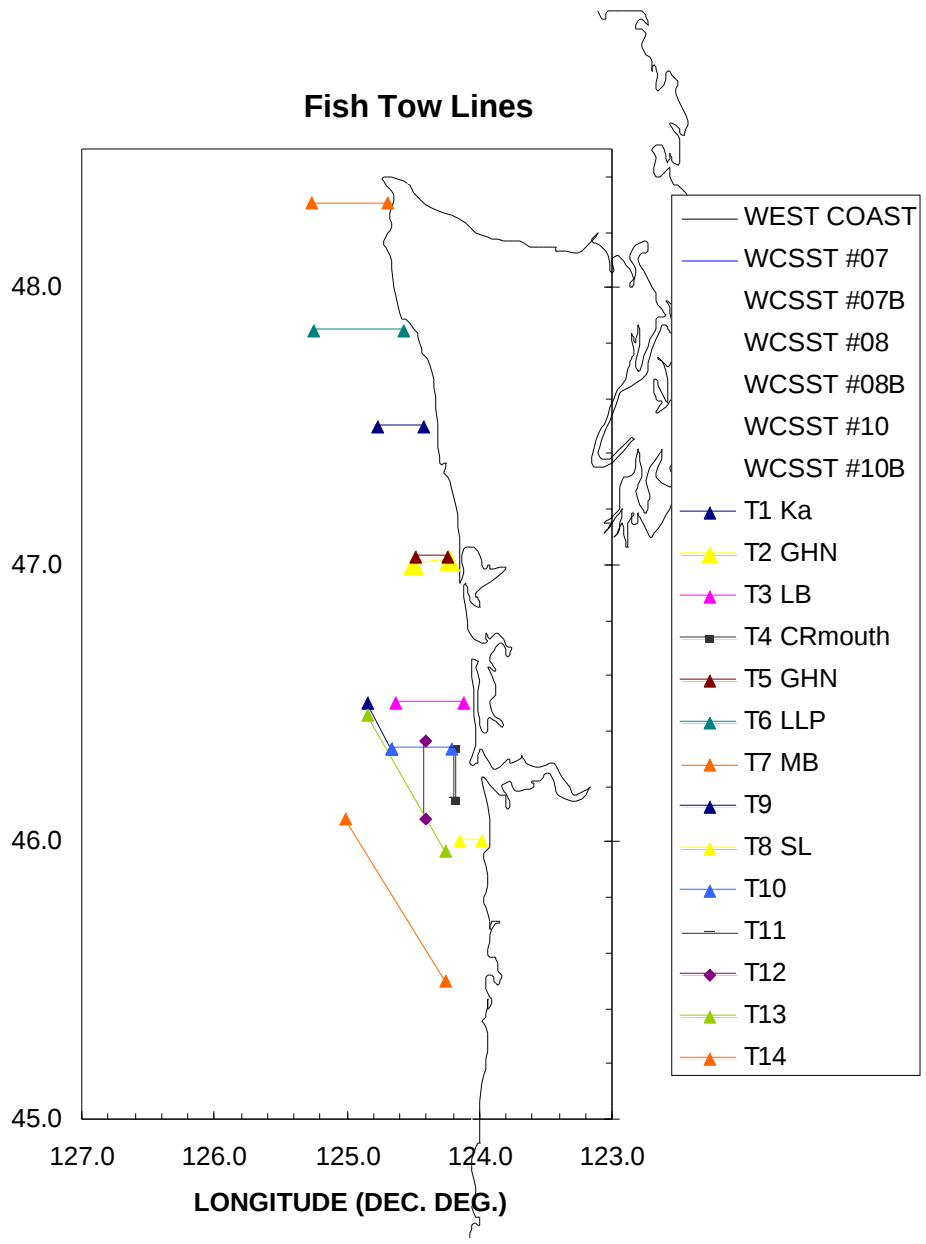

Figure 4. Transect lines for towed fish sampler (micro and macronutrients, T, C and transmissometry.

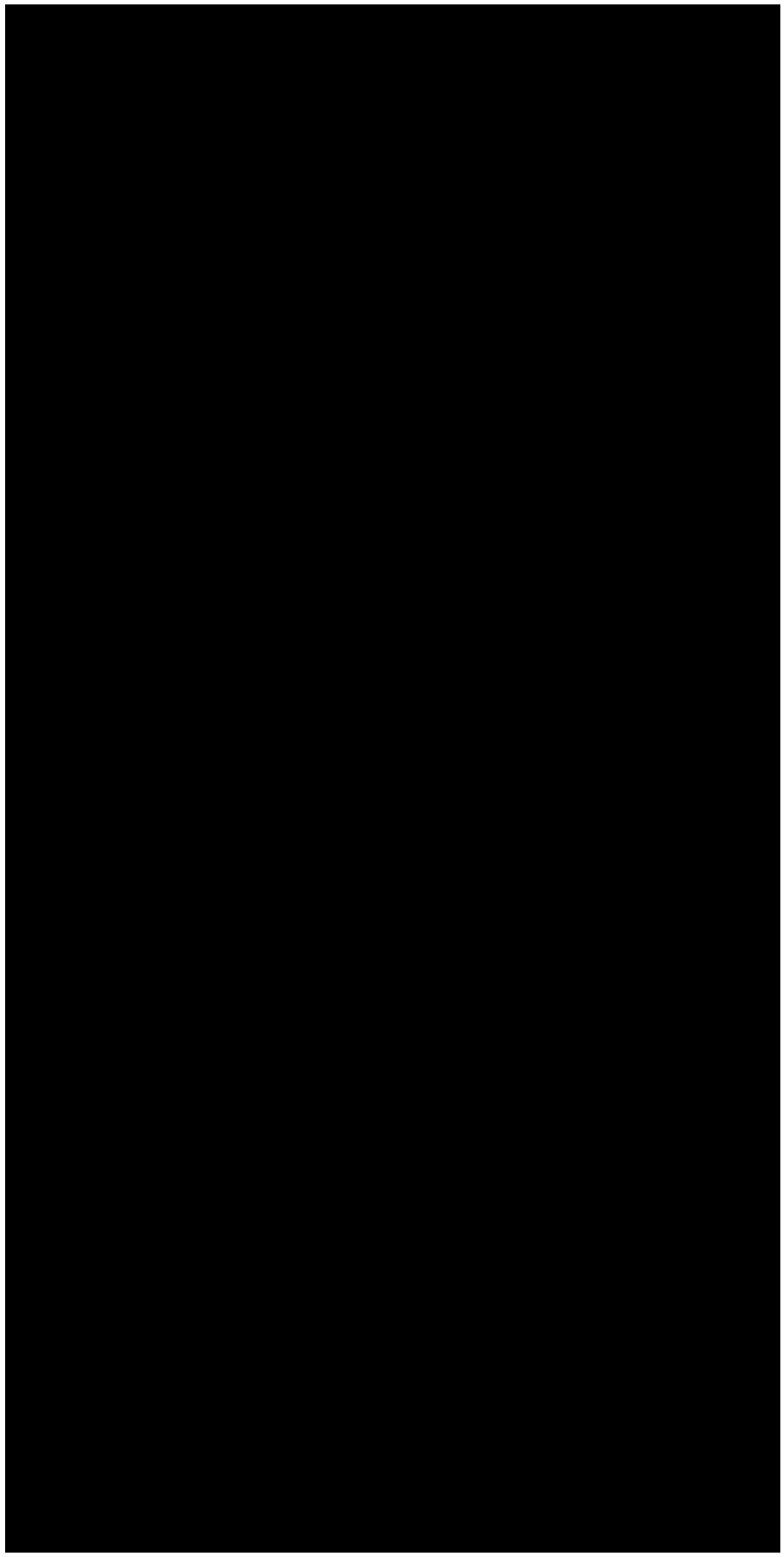

Figure 5. Map of Lessard group dilution micro zooplankton grazing experiments on RISE 4-W