River Influences
on Shelf Ecosystems

RISE 4- W

CRUISE REPORT

R/V Wecoma W0505C

May 21-June 13, 2006

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Area of Operations:

Coastal waters off Washington and Oregon

Itinerary

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

Participating Organizations

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Oregon State University
University of Washington

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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 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 Pt. Sur, that focused on mixing rates and large scale physical, nitrate, 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:
Satellite-tracked drifter deployments: 19

Samples Collected

Chlorophyll samples: ~1000
Nutrient samples:
Microzooplankton samples: 13 profiles for microscopy, plus 12 dilution experiments
FlowCAM samples: ~
Fe and Mn samples: ~
Particulate Trace metal samples: ~
Zooplankton net tows: 66 preserved (vertical plus bongo)

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 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 PNW coast is particularly surprising because alongshore wind stress, the primary forcing responsible for macronutrient supply, increases in the opposite direction to the productivity. Historical data have suggested that the Columbia River itself provides little nitrate to the coast, although it does supply large amounts of silicate and as much dissolved iron as the Mississippi River. 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 uses two vessels, one, the R/V Wecoma, obtaining primarily biogeochemical rate data; the other, the R/V Pt. Sur, obtaining synoptic mesoscale and fine-scale surveys as well as turbulent flux measurements (Fig. 2) The sampling approach will provide 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.

Sampling Overview and Setting

The RISE 4 cruise on R/V Wecoma was highly successful, obtaining data along a track covering the region from 45.2º N to 48.2º N out to longitude 125.5º W (Fig. 1). Measurements included multi disciplinary data (CTD, nutrients from CTD and a towed fish, net tows, plankton identification using a FlowCAM, optical profiles) from vertical sections and underway surveys (macro and micro-nutrients as well as C, T) using a towed fish, 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 ?? CTD/nutrient profiles, over ?? chlorophyll samples, over ?? iron and manganese samples and ?? 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 discussed below 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 2 weeks of the cruise. Modest upwelling winds returned during the last week. 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 at the coast did not occur until the last 2 days of the coast and was never observed off Washington (WA). Thus the cruise thus provided an ideal end member for nutrient supply—riverine input and no upwelling: for a northward plume only (first half) and for a southwest tending plume (second half).

Riverflow was the highest we have 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 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 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 (with vertical fish) and CM (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. Also, Pt. Sur was working nearer the GH line so this latitude choice allowed our ships to pass safely. On May 28, a spring tide, 25 hr time series was obtained near the 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) 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 (OR) 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 to upwelling-favorable on June 5, remaining in that direction for the rest 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 Pt Sur was sampling the LB line repeatedly, we collected fish surface data on a tow from LB 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 data being collected by the Pt. Sur, which could not sample in water shallower than about 40 m bottom depth. The C-T drifters were collected 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 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, micro/macro nutrients were sampled 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 on 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.

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.

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.
- Based on eight experiments, phytoplankton growth rate was consistently higher (though still low) on the Washington coast (GH line) than the Oregon coast (CM line), where there was little or no measurable phytoplankton growth.
- On the Washington and Oregon coasts, grazing generally was a significant fraction of the phytoplankton growth rates. In the new plume waters around the CR mouth, grazing was low relative to growth, and grazers sparse, indicating that the community was in an early stage of development.
- In many instances, diatoms and protist grazers appeared healthier and were more abundant in the layer below the fresh plume.
- Nitrate was near zero on the initial line surveys off WA and OR (and in the upper 30 m at the end of the cruise) and temperatures were more uniform than normal, a marked change from July 2004. This difference appears to be an interannual difference, perhaps a residual from the El Nino of the preceding winter.
- During both spring and neap tides the river had high nitrate (14-16 μM), but low/undetectable ammonium; this nitrate appeared to be the 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 (~ 16 and 110 nM, respectively) and rapidly decreased as the plume moved offshore (~ 1 and 8 nM).
- Egg production rates of *Calanus pacificus* were significantly related to latitude and are evidence that egg production increases northward. These observations support our hypothesis that secondary production is higher off the Washington coast than off the Oregon coast.

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, all 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. The sampling protocol was changed during the cruise—at the start, due to rough weather the CTD rosette was not returned to above the water surface before starting the cast. This was changed at station ?? for all except optics casts, so that subsequent profiles should better sample surface layers.

Macro nutrients were taken at the surface, 5 m, 10 m, the chlorophyll maximum 15 m, 30 m, 50 m, 100 m, 150 m and ~5 meters above bottom if the bottom was less than 200 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 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. Bottle samples were taken for calibration of salinity CTD sensors. Chlorophyll *a* samples from the underway system were obtained periodically throughout the cruise to calibrate for different water types.

Salinity samples were taken at roughly every third station and processed onboard by Jim Postel.

~~On underway surveys the Kudela group frequently deployed the FRRF (Fast Repetition Rate Fluorometer) at nighttime as well as optical packages (Wetlabs ACS; hyperspectral absorption/attenuation meter) and an ISUS (in full spectrum mode to capture CDOM as well as to measure nitrate). Discrete CDOM samples were taken on the TRIOS props in benchtop mode.~~

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 most days. Sensors included a Wetlabs AC~~9~~S, a Satlantic HyperPro II tethered profiling hyperspectral radiometer, a Wetlabs backscatter sensor, and a Wetlabs volume scattering function (VSF) sensor. ~~Matching~~ Corresponding CTD profiles were ~~also~~ obtained to accompany these casts.

A list of CTD stations organized by sample line and including bottle sample types taken is given in Table 2.

Subsurface vertical iron profiles were obtained at many stations by lowering the fish to the target depths (typically 2 m, 4, 10, 15 and 18 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 and nutrient data require more extensive processing. Careful 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).

Towed Fish Transects

Water properties near the sea surface were surveyed primarily on five transects over the plume and shelf regions (Fig. 4) (the GH line, the CM line and the axis of a southwest tending plume, as well as a large scale survey over both the Oregon and Washington shelves). On these surveys macronutrients (NO3, PO4, SiO4) were sampled at 2-minute intervals. Samples for total dissolved iron and manganese were taken every 15 minutes except when strong gradients were observed and the sampling frequency was increased to 5 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 drift studies were performed: one at spring tide, one at neap tide and one approaching spring tide. The goal 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. In the second, third and fourth study, four drifters were deployed along a north-south line just seaward of the river mouth. Deployment and recovery times and deployment location are listed in Table 3. 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.

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 minute intervals.

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. 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 in the survey. 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 conducted during the drift.

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 FloCam were obtained at sites offshore of Willapa Bay.

Time Series

25 hr time series were obtained at spring (May28) and neap (June 3) tides. Hourly CTDS were obtained as well as hourly vertical fish samples for micro and macro nutrients. ~~OTHER SAMPLES—TAWNYA??~~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 h) rates of primary production were determined during the spring tide time series only.

Satellite Imagery

Satellite imagery during the cruise was provided by R. ~~the~~ Kudela ~~group, who sent data to the Wecoma ftp site~~. The available images~~ry~~ were sent to the Wecoma ftp site and an assessment of its quality ~~are listed in Table 5~~will be forthcoming shortely after the cruise. The weather was so poor that few good images were obtained. However, SST images were useful in locating the north plume water. Due to the lack of upwelling, surface water temperatures were relatively uniform, although the plume could still be detected as warmer water. For 2005, we also provided MODIS 250 m true-color images, which were useful for identifying the plume under clear conditions (although rarely during the cruise period).

DETAILS OF INDIVIDUAL TEAM MEASUREMENTS

a) Chemical Analyses (Bruland Group: Maeve Lohan, Geoffery Smith, Bettina Sohst, Ana Aguilar-Islas, Carolyn Berger)

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 2, 4, 6, 8, 15 and 20 m. Six 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. Detailed sub-surface vertical profiles of macro and micronutrients were also carried out the Cape Meares section, the Grays Harbor section, plume axis and over many of the smaller sections. 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 Chl a by Kudela's group. Samples were taken for iron and manganese from just above and within the nepheloid layer throughout the cruise on both the Oregon and Washington shelves using 8 litre GO-Flo's suspended on Kevlar wire and triggered using a Teflon messenger. Nutrient concentrations were also analyzed on all 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 16-hour time series (sampling once an hour at 2, 4, 10, and 18 m) was carried out at one station close to the mouth of the estuary (P12) 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, during both spring and neap tides. Within the estuary samples were collected for both macro and micronutrients from the "fish" sampler down a depth of 10 m. CTD's were also carried out at these stations. Vertical profiles of macro and micronutrients were also analyzed from the fish at 1-4 hr intervals over 18 hours. In order to examine the influence of photochemistry on both dissolved iron and manganese concentrations, samples were collected during spring and neap tides from within the plume and incubated on deck in Quartz cells. Seven different treatments were carried out in both the light and the dark.

Some Preliminary Results:

- Macronutrients: Approximately 90% of collected samples were analyzed onboard and draft concentrations made available daily. The remaining 10% will be analyzed at UCSC in the near future. The Columbia River plume is easily identified by silicic acid concentrations which exceed 100 µm in surface waters and concentration within the estuary are 220 µM. Nitrate concentrations were higher in the estuary compared to July last year (16 µM compared to 7 µM). Nitrate concentrations rapidly decreased with distance from the mouth of the plume.
- Micronutrients: Total dissolved iron and manganese are also present at high concentrations during the ebb tide close to the mouth of the estuary (~ 16 and 110 nM, respectively) and rapidly decrease as the plume moves offshore (~ 1 and 8 nM). In

oceanic waters the iron concentration was in the pico-molar range while the manganese had decreased to 1 nM. It was not possible to analyze all samples collected and these will be analyzed at USCS within the next month. All estuarine samples will be analyzed back at UCSC as these need to be matrix modified and analysis will be carried out using inductively coupled plasma mass spectrometry (ICP-MS).

b) Primary 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 X). 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 for the identification of plume waters. Of particular interest was a nice image showing high chlorophyll *a* within the northward-tending plume that reached 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 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).

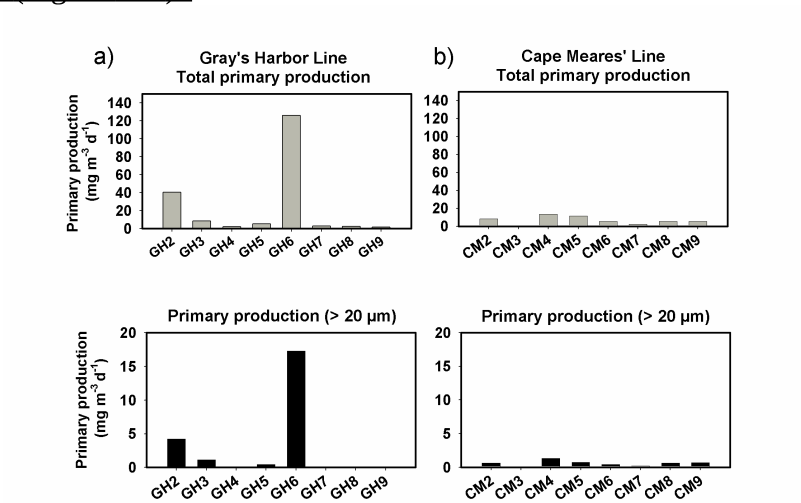


Figure K-1. Comparison of (a) Gray's Harbor Line primary production rate measurements (mg m^{-3} d^{-1}) with (b) Cape Meares' Line. Surveys were conducted on May 22 and 23, respectively.

- ***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 O'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.

~~b) Primary Productivity and New Production (Kudela Group: Raphael Kudela, Atma Roberts, Sherry Palacios, Tawnya Peterson, Joe Quartini, Megan Wehrenberg, Laura Bodensteiner)~~

~~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, 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 in situ and mapping bio-optical instrumentation to characterize the optical and chemical properties of the water column.~~

~~*Some Preliminary Results:*~~

- ~~Remote Sensing: As expected, satellite imagery was somewhat haphazard, but we did have some clear days when the plume was identifiable (Table 4). The turbidity product from MODIS is particularly promising, and appeared to provide a good indicator of the Columbia River plume, as well as the remnants of previous plumes. A summary of good images will be provided post-cruise, and will be made available at http://oceandatacenter.ucsc.edu.~~

- ~~*Rate Measurements*: A summary of the rate measurements conducted is provided in Table 5. We emphasized measurement of primary production using a combination of uptake versus irradiance (PE) curves from single depths, single-depth (50% light) measurements for larger surveys, and typically one full vertical profile (6 light depths) per day, incubated using simulated in situ (deckboard) incubators. At several stations, we used the stable tracers $^{15}NO_3$ and $^{15}NH_4$ to estimate nitrogen uptake. 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. Primary production was generally low, and showed less of an onshore-offshore trend than in 2004. There was very little difference between Cape Meares and Grays Harbor lines.~~
- ~~*Chl a* measurements 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, 10, 5 and 1 µm filters were also collected. At productivity stations, biogenic silica, POC/PON, ammonium, urea, and total suspended solids were also measured. As part of the mooring deployment, chlorophyll and nutrient samples were also collected by the Dever group; we processed the chlorophyll data, and will process the (frozen) nutrient samples in the lab.~~
- ~~*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.~~

~~*Expected Data Availability:*~~

~~All chlorophyll samples were processed on board, and will be available immediately after QA/QC of results. All C14 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.~~

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

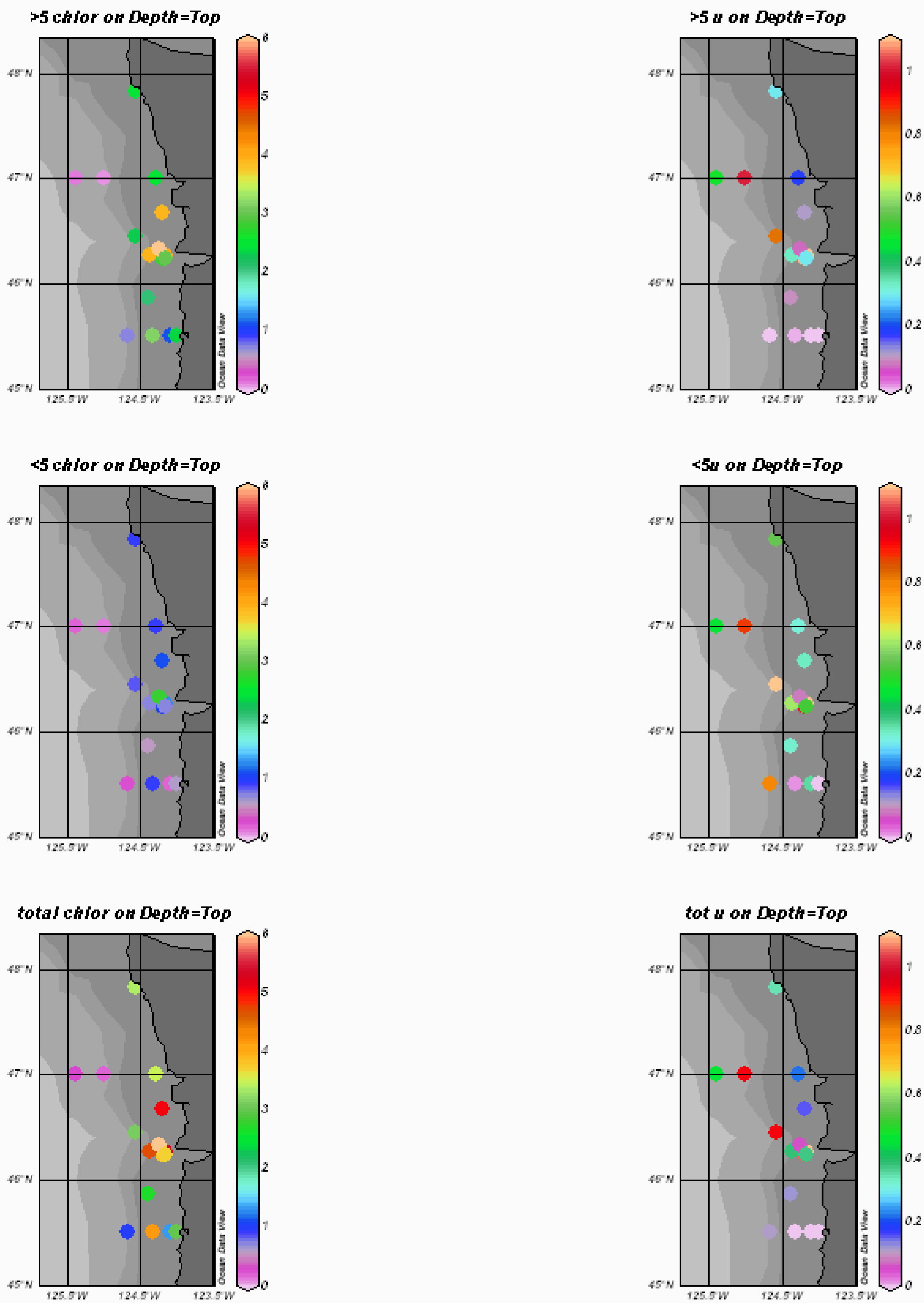
The main objective of this component of the RISE project is to determine and compare the growth and grazing mortality rates of phytoplankton and assess the community composition in the Columbia River plume, Washington and Oregon coasts. The results will help address our central hypotheses that the Washington 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 20 dilution experiments. Eight were performed on the Grays Harbor (WA) line and Cape Meares (OR) lines, as well as four others along the Washington and Oregon coasts. Nine experiments were run in or near the Columbia River mouth, at different times of the tidal cycle and following drifters. Dilution experiment locations, chlorophyll biomass as well as preliminary growth and grazing rates of the total, >5 μm and <5 μm chlorophyll are shown in the figure below.

The FlowCAM was invaluable for providing near real-time assessments of plankton community composition, which helped guide our experimental planning. We processed over 700 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, phytoplankton standing stock was relatively low, and >5 µm phytoplankton (mainly diatoms) comprised a smaller proportion of the total (ca. 75% vs 95%). In coastal and aged plume waters, nitrate was not detectable, diatoms looked unhealthy, and growth rates were low (<0.2 d^{-1}) and nutrient-limited.
- Phytoplankton growth rates were high (>1 d^{-1}) and not nutrient limited only in newer (fresher) plume waters where nitrate was measurable.
- Based on eight experiments, phytoplankton growth rate was consistently higher (though still low) on the Washington coast (GH line) than the Oregon coast (CM line), where there was little or no measurable phytoplankton growth.
- On the WA and OR coast, grazing generally was a significant fraction of the phytoplankton growth rates. In the new plume waters around the CR mouth, grazing was low relative to growth, and grazers sparse, indicating that the community was in an early stage of development.
- In many instances, diatoms and protist grazers appeared healthier and were more abundant in the layer below the fresh plume.



Size-fractionated chlorophyll biomass, growth and grazing rates from dilution experiments.

d) Macrozooplankton (Peterson Group: Bill Peterson, Leah Feinberg)

1Zooplankton research during the RISE-2-W cruise was directed at determining if 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.

Growth rates of adult copepods were estimated by measuring their egg production rates in 24 h incubations. Growth can be estimated in this manner because copepods cease to grow once adulthood is reached and partition all excess energy into reproduction. Thus, measurement of copepod egg production rate is a measure of adult female growth rates. Since female copepods produce eggs every day, measurements of egg production are a measure of daily growth rate.

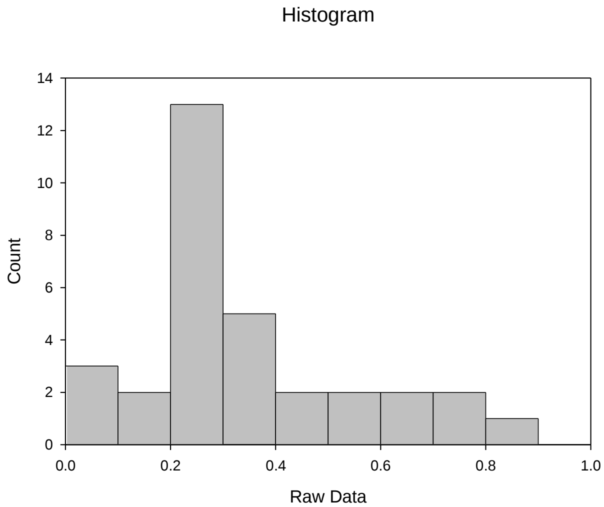
For the euphausiids, we measured both molting rates and egg production rates. Molting rates are measured in short-term incubations (48 h). We incubate 30 animals individually in 500 ml jars, monitor the incubations at 12 h intervals for 48 h, and recover the molts at each time point. Length of the molt is measured as is the length of the molter. The difference in length represents a measure of an individual's growth. Length is converted to weight from established length-weight regressions, then growth rate is calculated from data on the change in weight with time.

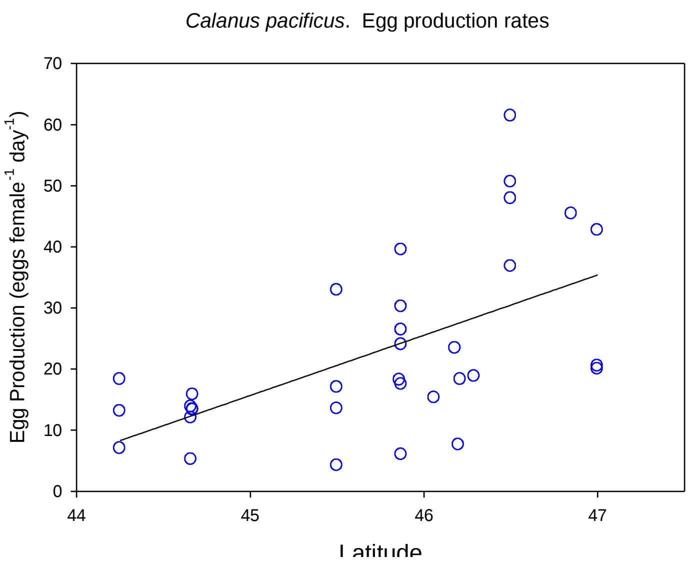
Euphausiids produce a brood of eggs on an approximately weekly basis (with interbrood periods ranging from 3 to 40 days), thus measurements of brood size are viewed more as an index of growth rate, rather than a direct measure of growth rate. Since we have now measured brood size of hundreds of females, we know the overall mean (and variance) of brood size thus any new measurements are expressed in terms of anomalies from the long-term mean. This approach allows use of brood size measurements as an indicator of regional variations in euphausiid productivity. During the RISE-2W, we measured egg production rates for the copepods *Calanus pacificus* and *C. marshallae*, and molting rates and brood sizes of the euphausiids, *Euphausia pacifica* and *Thysanoessa spinifera.*

Zooplankton were also surveyed on two other cruises, one immediately prior to RISE 2W (NOAA Ship McArthur) and one during the RISE cruise (Fishing Vessel North Star). Since zooplankton were sampled extensively during those other cruises, we did not do as much plankton net sampling on RISE 2W as was done last year. We did make rate measurements on the McArthur cruise and include those data here.

Some Preliminary Results:

The Northeast Pacific was in an unusually warm state during spring and early summer of 2005 and in many respects, the ecosystem appeared to be under the influence of a major El Nino event. However, there was no El Nino at the equator and thus no forcing of the NE Pacific through on oceanic pathway. Perhaps there existed an atmospheric teleconnection. Whatever the cause of the warm ocean in 2005, the zooplankton community composition was quite anomalous. Warm water copepod species dominated the planktonic ecosystem whereas cold water species which are usually present at this time of year, were either rare or absent. Thus, our egg production measurements were made chiefly on the warm water *Calanus pacificus* with only a few measurements on the cold water species, *Calanus marshallae.* As for the euphausiids, there were no differences in species composition however the dominant species, *Euphausia pacifica*, were smaller in size in June 2005 compared to other years at this time.

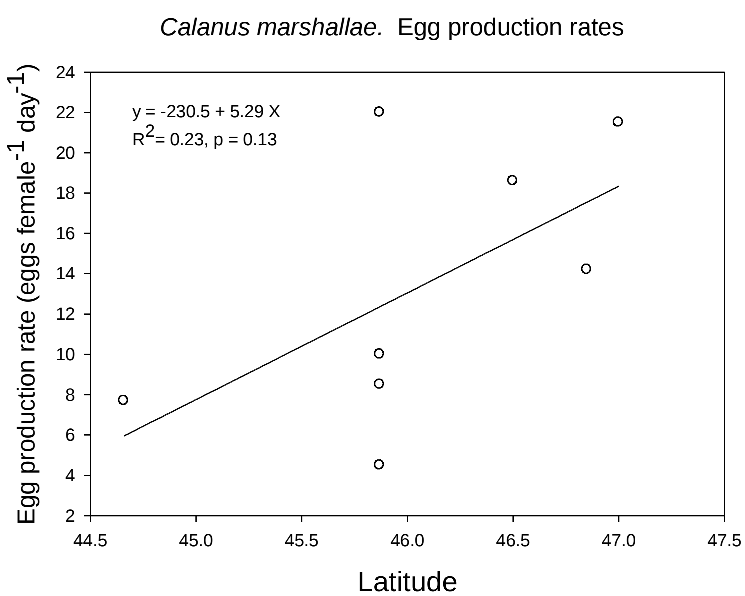




Eggs produced by the copepods and euphausiids were counted each day, therefore we can present here our estimates of egg production rates (copepods) and brood sizes (krill). However, the molting rate data have not yet been analyzed as this involves careful measurements of molts back in the shore-based laboratory and these have not been completed.

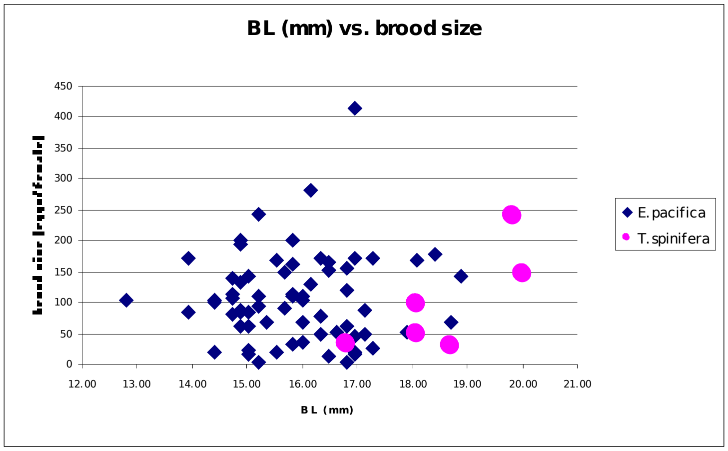
For *Calanus pacificus*, we completed 33 incubations on a total of 426 females. The histogram to the left shows the distribution of the data in units of proportion of the maximum rate. The average was 22.7 eggs per female per day and this value is about 0.37 of the maximum rate. Thus, egg production rates were very low in June 2005.

Egg production rates of *Calanus pacificus* were significantly related to latitude (see below) and are evidence that egg production is higher off Washington than Oregon. These observations support our hypothesis that secondary production is higher in coastal of Washington as compared to Oregon. A chart showing spatial variations is given in a figure at the end of this report.



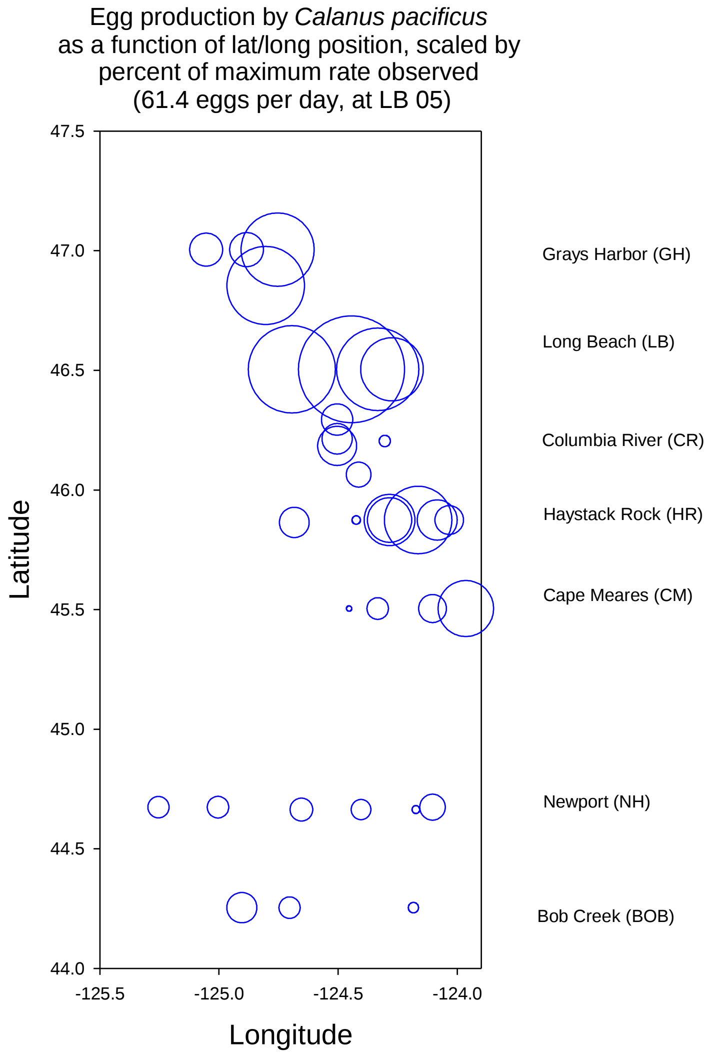
For *Calanus marshallae*, the mean egg production rate was 13.4 eggs per female per day. As with *Calanus pacificus*, this value is quite low, and was similar to *C. pacificus* in that the mean rate was 0.38 of the maximum rates (of 35 eggs per female per day).

Brood sizes for *Euphausia pacifica* in the RISE study were low compared to measurements made off Oregon from 2000-2004. Mean brood size for four years of measurements off Oregon is 152 eggs per brood. During the RISE cruise, we measured an average of 106 eggs per brood, and coincidentally, this is exactly the same brood size as measured last year on RISE 1W. These values are 70% of the climatological mean of 152 eggs per female measured in Oregon waters, suggesting that brood sizes in both 2004 and 2005 are lower than the climatological average.



We only incubated 6 female *Thysanoessa spinifera* indicated by the pink circles in the figure to the left. The mean brood size was 93.3 eggs per female. This value is 80% of the climatological mean of 115 eggs per female.

We found no relationship between euphausiid brood size and either water depth or latitude for either species.



"Chart" showing spatial variations in egg production of the copepod *Calanus pacificus*. Note that egg production was far higher off Washington (Long Beach) than off Oregon. Data were collected from both the R/V Wecoma (RISE 2W) – Cape Meares to Grays Harbor and on the R/V McArthur just prior to the Wecoma cruise (Bob Creek and Newport).

e) Drifter Deployments (McCabe, Hickey)

Brightwaters GPS drifters were deployed to delineate patterns and speeds of currents over the Washington and Oregon shelves and near 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 CT drifters, data were recorded internally at 3 min intervals. Expendable drifters (T only) transmitted data every 30 min 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 downwelling 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). Two additional expendables were deployed on May 24 at LB 2 (9126) and LB4 (9121) in the now well developed north plume. However, 8852 moved onshore north of the river mouth.

***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 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 (3938) continued north near the coast. 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.

Because Pt Sur was sampling the LB line repeatedly during this period, we collected fish surface data on a tow from LB 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 data being collected by the Pt. Sur, which could not sample in water shallower than about 40 m bottom depth.

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, micro/macro nutrients were sampled 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 on 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.

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 hours 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 hours.

ACKNOWLEDGEMENTS

We would like to thank the captain and crew of the R/V Wecoma for their support and extra effort that made the June 2005 cruise successful. This research was supported through the Coastal Oceanographic Processes Program (CoOP) of the National Science Foundation, Award No. 0239089.

List of Tables and Figures with Captions and Appendices (web site only)

Data figures are included in text portion (Lessard, Peterson).

Table 5. 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	50%	Notes
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				2 X 100% Io samples lost overboard
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			-Filtered later than 24h -Placed bottles in Lessard incubator during transect through estuary
C27		X					X		X		X	
C40		X					X		X		X	
C41	X	~~X~~		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										Time series, spring
C94	X	~~X~~	X~~X~~	X	~~X~~	X	~~X~~	X	~~X~~			Time series, spring
C95		X	~~X~~	~~X~~	X	~~X~~	X	~~X~~	X			Time series, spring
C96		X										Time series, spring
C97		X										Time series, spring
C98		X										Time series, spring
C100		X	X		X		X					Time series, spring
C101	X	X	X~~X~~	X	X	X	X	X	X			Time series, spring
C102		X										Time series, spring
C106			X									~~2-DEPTH PE CURVE~~
C105~~C107~~			X~~X~~									~~2-DEPTH PE CURVE~~
C107			X				X					
C117	X		X	X		X		X				
~~C114~~C118	X	X	X	X		X		X				
C119		X					X					
C120		X	X				X					
C121		X					X					
C122		X					X					
C123		X					X					
~~C1254~~		~~X~~					~~X~~		~~X~~			
C124		X										
C126	X	~~X~~	X	X	X	X	X	X	X	X		
C127		X					X					
C129		X					X					
~~C128~~		~~X~~					~~X~~					
~~C130~~		~~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		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							Time series, neap
C155			X							Time series, neap
C159			X							Time series, neap
C164			X							Time series, neap
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		X	
C249							X		X	
~~C250~~					~~X~~		~~X~~		~~X~~	
C251					~~X~~		X		~~X~~	
~~C252~~							~~X~~		~~X~~	~~No diatoms, no 32Si~~
~~C255~~							~~X~~		~~X~~	~~No diatoms, no 32Si~~