River Influences
on Shelf Ecosystems

RISE 1- W

CRUISE REPORT

R/V Wecoma W0407A

July 8-28, 2004

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Area of Operations:

Coastal waters off Washington and Oregon

Itinerary

Depart Newport, Oregon, July 8, 2004

Arrive Newport Oregon, July 28, 2004

Participating Organizations

University of California, Santa Cruz

Oregon State University

University of Washington

Chief Scientist

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

Personnel

Principle Investigators

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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: 121
Optical profiles: 40
Satellite-tracked drifter deployments: 19

Samples Collected

Chlorophyll samples:1402
Nutrient samples: > 1000
Microzooplankton samples: 13 profiles for microscopy, plus 12 dilution experiments
FlowCAM samples: ~500
Fe and Mn samples: ~600
Zooplankton net tows: 94 preserved (vertical plus bongo); 33 live tows

Cruise Summary

PROJECT OVERVIEW

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 first RISE cruise on the R/V Wecoma.

CRUISE SAMPLING OVERVIEW

The RISE1 R/V Wecoma cruise was highly successful, obtained data along a track covering the region from 47^{o} N to 46.5^{o} N out to longitude 125^{o} 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 sections (Section 1), underway surface surveys (macro and micro-nutrients as well as C, T) using a towed fish (Section 2), profiles of water properties (including optics and plankton) while following a drifter (Section 3), deployment of surface drifters (with C, T) (Section 4), satellite imagery (Section 5), and laboratory studies using water and plankton collected at selected sites (Section 6). Calibration CTDs with nutrients and fluorescence were taken near the three RISE moorings.

The setting of cruise sampling events within the wind environment during the cruise (upwelling or downwelling favorable) is shown in Figure 3. The sequence of weather conditions allowed a variety of water and plankton conditions to be sampled. Surveys and sampling were performed under intermittent upwelling and downwelling conditions (period 1), strong, strong downwelling conditions (period 2), and persistent upwelling conditions (period 3). 121 CTD/nutrient profiles were obtained. Over 1400 chlorophyll samples were made. Over 600 iron and manganese samples were taken. 40 optical optical profiles were made. 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.

1. Water Property Sections (entire RISE WECOMA team)

Patterns and variability of water properties with depth were examined along the plume axis (once only) and north (Grays Harbor, “GH”) and south (Cape Mears, “CM” of

the river mouth (twice in each location) (Fig. 4). Data collected at each station included conductivity (C), temperature (T), light transmission, PAR, oxygen and fluorescence (Fl) profiles, optical profiles and bottle samples for chlorophyll, plankton and macronutrients, all at selected depths. Both macronutrients and micronutrients were sampled at most stations using a towed fish operated in a vertical mode by slowly lowering the fish to 20 m. Vertical net tows for zooplankton community assessment were taken at most stations. Underway data included T, S and Fl pumped from a depth of about 4 m near the ship's bow as well as ADCP current profiles from both a 75 khz Ocean Survey broadband RDI ADCP and a 150 khz narrowband RDI ADCP. Preliminary water property sections for temperature, salinity, density, fluorescence, light transmission and oxygen versus depth are given on the web site with two scales, 0-30 m and 0-200 m). With one exception, profiles were taken only as deep as 200 m.

A list of CTD stations organized by sample line and including bottle sample types taken is given in Table 2. All lines were sampled from shallow to deep water.

CTD profiles were taken to 200 m where possible. 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 on four of the five sections (not CM second survey) and also on primary productivity casts. On the CM second survey, chlorophyll and plankton samples were taken near the surface, 5 m and 10 m.

Upper water column iron samples were taken at selected stations (Tables 1 and 2). These samples were obtained by weighting the iron "fish" below the surface (~4 m) while towing at a slow speed as the ship left station. Water was pumped for roughly 15 minutes to flush the lines thoroughly before samples were taken. Subsurface vertical iron profiles to greater depth were obtained at several stations by lowering the fish to the target depths (typically 6, 10, 15 and 20 m) while maintaining a slow forward speed. Along both the Gray's Harbor and the Cape Mears sections trace metal samples from the nepheloid layer were taken using GO-Flo bottles.

The data should be treated as occurring in one of three periods: intermittent upwelling (July 8-17), strong downwelling (July 18-20) and persistent upwelling (July 21-26) (Fig. 3). The first period includes sections along the plume axis (P), and south (CM) and north (GH) lines as well as two drift studies (DA and DC; note—DB was aborted before sampling), a time series and an underway fish survey (UW1). The strong downwelling period includes the remainder of drift DC, a second underway fish survey (UW3) and estuary samples. The strong, persistent upwelling period included a second sampling of sections CM and GH, a third short drift (DD) and two additional underway surveys (UW4 and UW5).

The CTD data were partially edited onboard ship. These data were used to construct the preliminary maps and sections appended to the report. Following the cruise, salinity calibration will be performed and more detailed editing completed. Although water property spatial patterns are likely robust, actual values may change slightly following the final editing which we hope to complete this fall. ADCP and nutrient data require more extensive processing.

Some Preliminary Results:

- The importance of high frequency internal wave activity to biological and

chemical sampling strategies was demonstrated. Sampling strategies were modified to accommodate such fluctuations. Subsequently, high frequency measurements of nutrients and optical properties were made simultaneously to sample these time scales.

- The importance of having continuous surface samples was demonstrated. A surface sampler for underway T, C was built en route by Geoff Smith.
- In this period the plume region had higher chlorophyll values than the adjacent shelves.
- Macronutrients appear to be higher on the Washington shelf than on the Oregon shelf.
- On strong tides, water is ejected from the river mouth at least 40 km seaward before turning north or south.
- Surface currents in which the plume resides are strongly influenced by surface winds.
- Copepod egg production is significantly higher inshore (~ 50 m) than near the shelf edge (~200 m).

2. Water PropertyTransects (Maeve Lohan, Geoffrey Smith, Tina Sobst, Kristen Buck, Ana Aguilar-Islas)

Water properties near the sea surface were surveyed on a number of transects over the plume and shelf regions (Fig. 5). These surveys are labeled sequentially (UW1, UW2, etc.) On these surveys macronutrients (NO_3, PO_4 , SiO_4) were sampled at 3-minute intervals. Samples for total dissolved iron and manganese were taken every 20 minutes except when strong gradients were observed and the sampling frequency was increased to 10 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. Underway data is also obtained from the ship at a depth of about 4 m. In several instances the transects were continued after some point with ships' underway data only.

3. Drift Surveys (McCabe, Hickey, drifters; whole team for water samples)

Four drift studies were performed. The goal was to follow patches of water from the plume near the river mouth over the continental shelf, examining water properties (salinity, nutrients and plankton) as the patches aged. Deployment and recovery times and deployment location are listed in Table 3. Drifter tracks and CTD stations taken during the drifts are shown in Appendix C.

A Brightwaters GPS-type drifter was deployed to follow water at ~1 m depth inside the river plume. CTD profiles, net tows, nutrient and chlorophyll bottle casts and macro and micronutrient samples with the towed 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 3-6 hour intervals for roughly a day to accumulate data on tidal changes, then at 12 hr intervals until the end of a drift.

Deckboard dilution experiments (Lessard) were run for 24 hours with water collected

at the beginning and end of each drifter 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 daily during the drift. Additionally, a large volume (20 L) growout was initiated with the first drift CTD cast, and monitored approximately every 6 hours for chlorophyll and nutrients, for up to 3 days (to the exhaustion of macronutrients and peak chlorophyll).

Some Preliminary Results*:*

Drift DA: The first drift study (DA, drifter #22300, CTDs 12-17) took place on July 10-11 during intermittent and weak upwelling, and downwelling. The drift was begun inside the mouth of the estuary on the lesser ebb tide during downwelling (CTD 12). The drifter swept westward at several miles per hour. By CTD 17 the drifter had left the fresh water, possibly swept across the front by a surface front that appeared to have no salinity difference across it and only a slight temperature change. CTD 17 provides good contrast with the plume water. The day following Drift DA the team sampled a fixed site where fresher water was found, P11, shoreward of the drifter on the track the drifter had made the previous day.

Drift DB: Another drift, DB, was attempted July 16 but aborted when we failed to find very fresh water (<20 psu) near the estuary mouth.

Drift DC: The second successful drift (DC, drifter #22301) was begun after a day of moderate upwelling (July 17) and extended for 36 hours. A strong downwelling event began on July 18 during the drift and continued to the end of the drift. The drift included CTDs 54-65, 67, 69-71 and 77.

Drift DD: The third drift (DD, drifter #22249) was begun at maximum ebb on a greater ebb near the river mouth on July 18 during a strong downwelling period. One CTD station was made upon deployment (CTD 68). The Pt. Sur made turbulence measurements accompanying this drift following a track around the Wecoma. The drifter headed due west at about 6 kn after deployment. The drifter was recovered early on July 19 (GMT).

Drift DE: This final drift took place after one day of strong upwelling winds on July 22. Upwelling winds continued during the drift. Three drifters were deployed across the estuary mouth. One of these drifters (#223000 was followed with CTD profiles (CTD 80, 81, 85).

3. Satellite Imagery (Kudela)

Satellite imagery during the cruise was provided by the Kudela group, who sent data to the Wecoma ftp site. The available imagery and an assessment of its quality are listed in Table 4. Both data sets proved to be valuable tools during the cruise. In particular, SST images were useful in locating plume water and, more important, in showing onset of upwelling. Turbidity images look promising for identification of plumes and separation of new and residual plumes.

4. Details of Individual Group Efforts

a) Chemical Analyses (Bruland Group: Maeve Lohan, Geoffery Smith, Bettina Sosht, Kristen Buck, Ana Aguilar-Islas)

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 shelf. 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. Nine surface transects were sampled (see Fig. 5). 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 on both the Cape Mears section and the Grays Harbor section. Particulate samples for trace metals were collected and filtered through 10 and 0.4 µm using trace metal clean techniques. A small sub-set of samples was also collected for iron speciation studies to investigate the concentration of organically complexed iron.

Water samples from the 'fish' were also collected for phytoplankton identification and enumeration by Lessard's research group and Chl a by Raphe Kudela's research group. Samples were taken for iron and manganese from the nepheloid layer along both the Cape Mears and Grays Harbor section using a 30 litre GO-Flo suspended on Kevlar wire and triggered using a Teflon messenger. The Cape Mears sections were first carried out during downwelling conditions and repeated later during upwelling, providing contrasting macro and micronutrient concentrations. The Grays Harbor sections were both obtained under weak upwelling conditions. 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' research group.

Vertical profiles of macro and micronutrients were also analyzed from the fish at 3 hr intervals at a drifter station over periods as long as 1.5 d. This was also repeated as a time series at one station close to the mouth of the estuary 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 nutrient, three stations within the estuary were sampled both prior to the ebb and flood tide. Prior to the flood tide it was also possible to use the CTD and collect nutrient concentration from both the surface and at depth. Trace metal samples were collected at 2 m using a GO-Flo.

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 160 µm. Nitrate concentrations are also higher closer to the mouth of the estuary (10 µM) but rapidly decrease with distance from the mouth of the plume. Nitrate concentrations are sub-micro-molar within plume waters as the plume drifts either south or north.

- Micronutrients: Total dissolved iron and manganese are also present at high concentrations during the ebb tide close to the mouth of the estuary (~ 20 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.

b) Primary Productivity and New Production (Kudela Group: Raphael Kudela, Atma Roberts, Andrea Vander Woude, Sherry Palacios)

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 bio-optical instrumentation to characterize the optical properties of the water column. Additionally, we tested several pieces of equipment, including a TRIOS UV-Nitrate sensor, Chelsea Instruments Fast Repetition Rate Fluorometer, and self-logging temperature-depth-light tags.

Some Preliminary Results:

- Remote Sensing: As expected, satellite imagery was somewhat haphazard, but we did havet several clear days of imagery (generally preceding the initiation of upwelling favorable conditions). 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 upatake 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 $15NO_3$ and $15NH_4$ to estimate nitrogen uptake. At selected stations we also measured 15N-urea and 32Si 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. At one station (the plume drift), we also conducted a 15NO3 and 32Si upate versus irradiance profile to complement the C14 PE curve. Together with Lessard's and Bruland's group, we also compared the TM-Fish sampling system to the CTD Niskin bottles for a single depth, using C14 and $15NO_3$.

- *Chl a* measurements were collected at typically 4 depths for most stations (0, 5, 10 m and the chlorophyll maximum) 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 5 µm and 1 µm filters were also collected. At productivity stations, biogenic silica, POC/PON, ammonium, urea, and total suspended solids were also measured. Chlorophyll and nutrient samples were also collected by the Dever group during mooring deployment; 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 3 optical packages, consisting of a WetLABS ac9, HOBI Labs HS-6, Satlantic HTSRB, and Biospherical Instruments PRR-600, to characterize the inherent and apparent optical properties of the water column. At select stations additional casts were conducted with the ac9/HS-6 to characterize end-member water masses (blue water, coastal upwelling water, and plume water). We also instrumented the CTD package with a HOBI Labs HS2, c-Beta, and WetLABS Wetstar CDOM fluorometer. 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, Michael Foy, Theresa Wood)

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 are using the dilution method to experimentally alter grazing pressure and determine grazing effects on net growth rate of the whole and size fractionated phytoplankton community, as well as specific species/groups of phytoplankton. We are using an imaging-in-flow cytometer (FlowCAM) as well fixed samples, to follow the in situ spatial and temporal changes in the abundance of the major phytoplankton and microzooplankton taxa.

We performed 12 dilution experiments in most of the hydrographic/chemical environments that we hoped to encounter: along the plume core, in the young plume, in an aging plume, Oregon coast upwelling, Washington coast downwelling and incipient upwelling conditions. An experiment was also run in blue water at the shelf break for comparison.

The FlowCAM was invaluable for providing near real-time assessments of plankton community composition, which helped guide our experimental planning. We processed over 500 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 all cases except the shelf break, chlorophyll was high (3-12 μg chlorophyll *a* l^{-1}) and the majority of phytoplankton chlorophyll (>95%) was >5 μm and primarily composed of large chain forming diatoms. During a plume drift, growth rates were initially high (1.7 d^{-1}) and grazing low; as the plume aged, growth rates declined and the grazing increased. However, grazing, and grazers were relatively low in all areas where we performed experiments, indicating we encountered relatively early stages of community development. In all experiments, we measured initial and final macronutrient concentrations (analysis kindly provided by the Bruland and Kudela group) which will enable us to compare nutrient utilization patterns with measured growth rates.

- One of the surprising observations we made was the ubiquity of the phytoplankton taxa. The same set of diatom taxa (*Thalasiosira*, *Skeletonema*, *Asterionella*, *Pseudo-nitzschia*) were found in the plume and the Washington and Oregon coasts, under both downwelling and upwelling conditions. None of these were found in the estuary surface waters, but were found immediately outside the mouth of the estuary, indicating that mixing must occur quite fast once the plume enters the coastal waters. *Pseudo-nitzschia* spp. were

abundant and ubiquitous; there was a shift in dominance over the course of the cruise from *P. fraudulenta* types to *P. deli* types.

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

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Macro-zooplankton research during the RISE-1-W cruise is directed at determining if there are regional differences in zooplankton biomass and/or 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 due to greater availability of iron or other nutrients in Washington shelf waters. Towards this end, we set forth the following research objectives:

1. Determine if zooplankton biomass is higher in coastal waters off Washington as compared to coastal waters off Oregon.
2. Determine if molting and egg production rates of several copepod species and one euphausiid species are higher in coastal waters off Washington as compared to coastal waters off Oregon.
3. Compare lipid classes in seston and euphausiids to determine what types of seston were fed upon by euphausiids.
4. Determine age of euphausiid spawners, using lipofuscin analysis.

Differences in distribution and abundance of zooplankton species were investigated by making plankton net tows at most of the CTD stations. In total, we collected 91 zooplankton net samples that were preserved in formalin for later analysis of zooplankton biomass, species composition and stage structure. Biomass will be calculated as the product of species abundance and the species and developmental stage-specific weights.

Growth rates of juvenile copepods were estimated by measuring their molting rates. Knowing the proportion of animals that molt into the next developmental stage and weight change between adjacent developmental stages, growth rate can be calculated. 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 eggs are produced daily, one can derive an estimate of daily growth rate.

Euphausiids are similar to copepods in that measurements of molting rates in short-term incubations can be converted into growth rates. For these measurements, 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 is growth. Length is converted to weight from established length-weight regresssions, then growth rate is calculated from data on the change in weight with time.

Adult female euphausiids, on the other hand, differ from copepods in that they do not produce eggs every day, rather on a ~ weekly basis. Since we cannot easily measure at sea the time elapsed between the production of broods (because this would require us to feed and maintain euphausiids from a given experiment for several weeks at sea), we measure brood size in 24 h incubations. Although brood size is not a rate, comparison of brood size should be a useful indicator of regional variations in euphausiid productivity.

We measured juvenile growth rates (as molting rates) and adult growth rates (as egg

production rates) for the copepod *Calanus marshallae* and egg production rates of the copepod *Centropages abdominalis* at more than 30 stations. We measured euphausiid molting rates (at 7 stations) and euphausiid brood size (at 11 stations) only on *Euphausia pacifica*. We seldom caught any individuals of the coastal species, *Thysanoessa spinifera,* despite our many attempts to sample their preferred habitat (mid to outershelf waters).

Multiple biochemical markers will be used to understand the relationship between age structure, diet history and nutritional status of euphausiids. Analysis of a suite of lipid biomarkers (including pigments, fatty acids and sterols) will be used to follow the feeding strategies and trophic transfer of carbon in euphausiids within the RISE study region. A wide size range of euphausiids was sorted to determine whether different size individuals have different feeding behaviors. All animals were frozen individually, at -80 C for later chemical analysis by Rodger Harvey and Se-Jung Ju, University of Maryland.

Euphausiids can be aged by measuring lipofuscein concentrations in their eyes. Lipofuscin is the debris that remains after cell division. It accumulates with age, thus knowledge of its concentration in cells can be used to estimate the age of individual euphausiids. Accurate determinations of age are necessary because euphausiids may either grow or shrink at each molt depending upon feeding conditions or reproductive activity during the days preceding the molt. Because of this, one cannot use size or stage-frequency analysis to determine the age of an individual euphausiid. Thus, in order to obtain accurate estimates of euphausiid production and mortality rates, we need estimates of the age of the animals where possible. We collected animals for age structure analysis in our plankton net tows to compare to animals frozen for lipofuscin analysis. In addition we froze females that had spawned in our brood size experiments for later determination of their age.

Some Preliminary Results:

Objective One: Plankton net sampling will allow us to examine changes in zooplankton abundance as part of the following RISE sampling efforts:

- Plume Axis (Stations P1-P9)
- Drifter "A" (Stations DA1-DA6)
- Time series in vicinity of canyon (D series)
- Time series (at station P12)
- Drifter "C" Time Series (Stations DC4-DC17)

and distribution and abundance along transects off Washington and Oregon:

- Grays Harbor Transect (GH 1-GH 9)
- Cape Meares (CM 1-CM 5)
- Cape Meares (CM 1-CM 7)
- Grays Harbor Transect (GH 1-CM 9)

In addition, on the Pt. Sur, we generated data on zooplankton distribution across fronts, along transects and vertically in the water column, using a Laser Optical Plankton

Counter

***Objective Two*:** Eggs produced by *Calanus marshallae* in 24 h incubations were counted each day at sea. Therefore we have estimates of its egg production rates. Egg production rates were less than previously determined maximum rates of 35 eggs per female per day at all but two stations (Fig. 6). Only the incubations at CM 3 and GH 2 had maximum rates. We saw a tendency for egg production to be highest nearshore, declining with water depth (Fig. 7). There was no apparent difference in egg production between stations in the north (Grays Harbor transect) and the south (Cape Meares transect) but there was a tendency for egg production to be lower in the vicinity of the mouth of the Columbia River.

Euphausiid brood sizes in the RISE study area were low compared to measurements made off Oregon from 2000-2003 (Fig. 8). Mean brood size for four years of measurements off Oregon is 143 eggs per brood. During the RISE cruise, we measured an average of 106 eggs per brood. Though this is less than the climatological mean of 143 eggs per female measured in Oregon waters, note that we have attempted to measure brood sizes of euphausiid on biweekly cruises off Newport since January of this year and have never (until the RISE cruise) found any spawning. Thus the fact that euphausids spawned at all is significant. We attribute the failure of euphausiids spawning in 2004 to lack of upwelling this year. The first significant upwelling events were initiated in late June, two months later than usual.

Objectives Three and Four will be met by colleagues at University of Maryland.

Future work in the shore-based laboratory:

Priorities for counting of the preserved samples:

- GH and CM Transects
- Time series on shelf south of Astoria Canyon (drifters etc...)
- Drifter "transects"
- Time series at P12

Copepod rate measurements:

- Count *Centropages* egg production experiments
- Count other copepod species
- Count copepod molting rate experiments
- Calculate euphausiid and copepod secondary production rates

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. With one exception, 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 Amy MacFadyen and Neil Banas. A few of the expendable drifters collected data through early September.

Some Preliminary Results:

July 9: Two expendable drifters (T only) were deployed in ~40 m of water north and south of the river mouth (drifters # 9123 – north; #9124 – south). A third drifter (CT, #22249) was deployed in plume water. A weak wind relaxation occurred and both expendable drifters beached almost immediately. The plume drifter moved south in the weak downwelling wind event that followed, becoming entrained into the counterclockwise eddy that appears to form between Tillamook Head and the river mouth. It was recovered on July 11.

July 10: Two CT drifters were deployed on an ebb tide. One (#22255) was deployed inside the river mouth by the R/V Forerunner, the other (#22300) was deployed near buoy G11 just outside the mouth by the R/V Wecoma. Drifter #22300 was followed for Drift DA. This drifter moved west to the head of Astoria canyon in a few hours before turning south. It was recovered on July 12. Drifter #22255 hugged the north side of the channel as it emerged from the estuary and was recovered in shallow water just north of the mouth the following day off Cape Disappointment.

July 12: An expendable drifter (#9121) was deployed on the Grays Harbor line in about 30 m of water at CTD station 24 (GH2). This drifter initially moved offshore and to the south but later beached in spite of weak upwelling winds.

July 14: Three CT drifters (#22300, #22255, #22249) were deployed across the estuary mouth near the start of ebb during the beginning of an upwelling event. All three drifters moved offshore and then southward. These drifters became entrained in a large eddy between Tillamook Head and the river mouth during a downwelling wind event on July 15-16. Drifters #22255 and #22300 beached.

July 17: One CT drifter (#22301) was deployed on an ebb tide for drift study DC during a brief upwelling event. The drifter moved rapidly westward to Astoria canyon where it milled around north and south for several days during a period of intermittent winds. It was replaced with expendable drifter #9127 on July 20. Drifter #9127 malfunctioned and did not successfully transmit data to the Argos satellites until August 11. This drifter moved well offshore to the southwest and timed out in early September.

July 18: One CT drifter (#22249) was deployed near the mouth at max ebb during a strong downwelling event for drift DD. The Pt. Sur made microstructure measurements for this drift. The drifter turned northward and then onshore north of the river mouth in a large eddy-like feature.

July 21: Three CT drifters (#22301, #22300, #22255) were deployed across the river mouth near maximum ebb during strong upwelling winds. All three drifters initially moved offshore. However, the northern-most drifter (#22301) tended north while the southern-most drifter (#22255) tended south. The central drifter moved westward over Astoria canyon. Note that at this time greater ebbs were becoming larger in comparison to earlier deployments. After their initial westward movement (~ 40 km for the north and central drifters), all three drifters turned and moved southwest until recovery (July 23, 24).

July 24: One expendable drifter (#22248) was deployed after a period of strong upwelling winds between stations GH2 and GH3. It initially moved offshore and southward along the 30 fathom isobath. This drifter later moved onshore during a period of downwelling winds and then north before washing ashore on Long Beach.

July 25: Two expendable drifters were deployed off the river mouth near RISE mooring RC in ~70 m of water during the persistent upwelling wind period. One was a surface drifter (#9121); the other (#7920) was drogued at an average depth of 20 m with a 10 m drogue (i.e. the drogue extended from 15 to 25 m). The two drifters immediately moved off in different directions – the surface drifter to the south, and the drogued drifter northward. Both drifters moved slightly onshore during a brief downwelling event. Drifter #9121 eventually beached near Bandon, Oregon, while #7920 ran aground just south of Grays Harbor. A third expendable drifter (#9124) was deployed during the strong upwelling event near the RISE mooring RS in about ~70 m of water. This drifter moved southward and slightly onshore during a brief downwelling event and beached near Manzanita, Oregon.

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

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