

Zooplankton distribution, abundance and biomass relative to water masses in eastern and central Aleutian Island passes

KENNETH O. COYLE

Institute of Marine Science, School of Fisheries and Ocean Science, University of Alaska, Fairbanks, AK 99775-7220, USA

Correspondence. e-mail: coyle@ims.uaf.edu

Zooplankton in the Aleutian Islands

ABSTRACT

CTD, acoustic and net samples were taken through a series of passes in the eastern and central Aleutian Island archipelago to document regional differences in the physical and biological conditions. The water column in central passes had elevated salinity and depressed temperatures, indicating upwelling of deep water through the passes. The zooplankton community included the oceanic genera *Neocalanus* and *Eucalanus*, and the euphausiid *Euphausia pacifica*, all oceanic taxa. Eastern passes had significantly lower salinity and elevated temperature relative to the central passes, suggesting a more neritic environment. *Calanus marshallae*, *Pseudocalanus*, *Acartia* and *Thysanoessa inermis*, common neritic species, were observed in the eastern passes. Canonical correlation indicated that up to 50% of the observed variance in mean zooplankton abundance in the passes could be explained by salinity and temperature. Elevated sound scattering was observed in fronts and eddies in the passes, particularly at the northern ends of the passes, in association with elevated zooplankton abundance and biomass. The central passes were characterized as an oceanic environment, influenced primarily by Alaskan Stream water with its associated interzonal copepod species, while the eastern passes were influenced by the Alaska Coastal Current, which contains a mixture of oceanic and neritic zooplankton species.

Zooplankton, Hydrography, Aleutian Islands

INTRODUCTION

The Aleutian Islands, a narrow steep ridge of volcanic mountains, form the northern boundary of the Pacific rim between Alaska and Asia. Much of the island chain is undeveloped and an important habitat for a variety of fish, sea birds and mammals. Recently, Steller sea lion populations in the Aleutian Islands have undergone drastic declines (Merrick et al., 1987; York, 1994; York et al., 1996). Although the causes of the decline remain uncertain, climate-related changes impacting fish populations along the northern Gulf of Alaska (GOA) coast have been suggested as a contributing factor. Fish and invertebrate populations in the northern Gulf of Alaska ecosystem have undergone substantial changes. In the mid 1970's, crab and shrimp stocks declined while salmon and ground fish increased (Anderson and Piatt, 1999; Albers and Anderson, 1985; Blau, 1986; Hollowed et al., 1994; Thompson and Zenger, 1994; Francis and Hare, 1994). These changes coincided with decadal-scale North Pacific adjustments in the atmosphere and ocean (Trenberth and Hurrell, 1994; Mantua et al., 1997). Subsequent ecosystem changes followed in the 1980s with declines in marine mammal and seabird populations (Merrick et al., 1987; Hatch and Sanger, 1992; Springer, 1998). Such correlations suggest the potential for climate-related changes in the physical environment to impact animal populations from primary consumers to apex predators. Analysis of zooplankton abundance data from the North Pacific indicate that long-term changes are underway in the magnitude and timing of seasonal biomass peaks in key zooplankton taxa (Mackas et al., 1998, 2001; Brodeur and Ware, 1992). Such changes in zooplankton biomass, abundance and seasonality can impact marine fish, bird and mammal populations by altering energy flow through the food web to higher trophic-level consumers.

Recent studies of the population biology of Steller sea lions in the western portion of their range suggest that the population trajectories of sea lions may vary with rookery location (York et al. 1996). In the vicinity of Unimak Pass and the eastern Aleutian Islands, populations have remained stable (1974-1998). In contrast, in the central Aleutians, population trends are still strongly downward. This geographic variation in population trends suggests that sea lion habitat in the two regions may be different, and that a comparison of the two environments might help identify the differences and clarify factors related to the population trends. This article presents the results of research comparing zooplankton populations and physical oceanographic indices in the eastern and central Aleutian Islands. The results below outline differences in zooplankton species composition and abundance driven by differences in the physical environment, which may have influenced sea lion population trends.

The Aleutian Island archipelago consists of a volcanic mountain range forming a ridge dividing the Bering Sea from the Pacific Ocean basin. The peaks rise abruptly from the ocean floor to hundreds of meters above sea level and divide the ridge into submerged canyons and valleys forming the passes connecting the Bering Sea to the Pacific Ocean. The eastern Aleutian Islands are surrounded by a continental shelf, whereas the bathymetry surrounding the central and western islands is steep and rugged with little or no shelf. The major current systems include the Alaskan Stream, the Alaska Coastal Current and the Aleutian North Slope Current (Fig. 1).

METHODS

Sampling was done during May and June, 2001 and 2002 in and around passes in the eastern and central Aleutians (Fig. 1A). Both wide, deep and shallow, narrow passes were sampled (Table 1). The sample design consisted of CTD, MOCNESS, CalVET and acoustic transect lines run through the passes. A CTD sample was taken at each CalVET station to provide data on the physical conditions for interpretation of the zooplankton results. In addition, CalVET tows and CTD profiles were taken on the north and south sides of the Aleutian ridge, but not directly in the passes (Fig. 1A).

CTD and fluorescence profiles were taken with a Seabird model 911 Plus with conductivity, temperature and fluorescence sensors. Large zooplankton and micronekton were collected with a 1-m² MOCNESS (Wiebe et al. 1976) with 500 µm mesh nets. The MOCNESS was equipped with a flowmeter positioned outside the mouth of the net. Additional sensors included Seabird conductivity and temperature probes. The net was fished at night and five oblique samples were collected in 20 m increments from 100 m depth to the surface. The small zooplankton component was sampled with a 25 cm diameter CalVET system (CalCOFI Vertical Egg Tow; Smith et. al. 1985) having 150 µm mesh nets. Each net was equipped with General Oceanics flowmeters in the mouth of the nets to monitor volume filtered. The net was fished vertically from 100 m depth to the surface or from the bottom to the surface at depths less than 100 m. The samples were preserved in a 10% formalin seawater solution for later analysis.

The zooplankton samples were processed as follows: each sample was poured into a sorting tray and large organisms, primarily shrimp and jellyfish, were removed and

enumerated. The sample was then sequentially split using a Folsom splitter until the smallest subsample contained about 100 specimens of the most abundant taxa. The most abundant taxa were identified, staged, enumerated and weighed. Each larger subsample was examined to identify, enumerate and weigh the larger, less abundant taxa. The CalVET samples were subsampled with a Stempel pipet to produce subsamples with about 100 specimens of the most abundant taxa. Blotted wet weights of all specimens of each taxa and stage were taken on each sample and the coefficient of variation in average wet weight was computed. If the coefficient of variation for any given taxa and stage changed by less than 5% when additional weights were taken from subsequent samples, wet weights were no longer measured for that taxa for that cruise, and the wet weight biomass was estimated by multiplying the specimen count by the mean wet weight. In practice, only calanoid copepods had consistent wet weights after weighing each taxa and stage in about 10-15 samples. Therefore, wet weights on euphausiids, shrimp and other larger taxa were measured and recorded individually for each sample. Wet weight measurements were done on a Cahn Electrobalance or Mettler top loading balance, depending on the size of the animal. All animals in the samples were identified to the lowest taxonomic category possible. Copepodid stages were identified and recorded.

Only adult and occasionally stage V *Acartia* were identified to species. Younger copepodid stages were identified as *Acartia* spp. The specimens identified to species were *A. longiremis*, *A. hudsonica* and *A. tumida*. *Pseudocalanus* were not identified to species but referred to as *Pseudocalanus* spp. Species likely to occur in the northern Gulf of Alaska include *P. minutus*, *P. moultani*, *P. newmani* and *P. mimus*. Species previously identified from Shelikof Strait include all of the above except *P. moultani* (Siefert, 1994). Only stage

V copepodids of *Neocalanus plumchrus* and *Neocalanus flemingeri* were identified to species. Earlier copepodids were identified as *Neocalanus* spp. Therefore, *N. plumchrus* and *N. flemingeri* are referred to as *N. plumchrus-flemingeri*, to distinguish them from *Neocalanus cristatus* copepodids, all of which were identified to species.

The data were uploaded to a Microsoft Access database, and analysis was done with standard statistics software. The passes were divided into two categories: eastern and central (Table 1). Physical properties influencing zooplankton distribution were analyzed as follows.

The depths of the thermocline and halocline were computed for each station by locating the depth where dT/dZ or dS/dZ were maximum (T = temperature, °C; S = salinity; Z = depth, m). The thermocline depth, mean water column temperature above and below the thermocline, the halocline depth, and the mean salinity above and below the halocline were then computed. In addition, the mean salinity and temperature for the whole water column was determined. Analysis of variance was used to look for significant differences in mean physical properties by transect. The zooplankton abundance was power transformed to stabilize the variance. Canonical correlation was run on both CalVET and MOCNESS abundance data to look for relationships between the physical properties and abundance of the major zooplankton taxa.

Acoustic data were collected using a Hydroacoustic Technology Inc. (HTI) model 244 split-beam digital system. During 2001 the acoustic data were collected with four transducers: a 420 kHz 6° single beam, and 43 kHz 7°, 120 kHz 6° and 200 kHz 3° split-beam transducers. During 2002 the data were collected with 420 kHz 3°, 120 kHz 6° and 200 kHz 3° split-beam transducers. The transducers were towed beside the vessel at about 3

m sec⁻¹ in a dead-weight tow body about 4 m from the hull and 2 m below the surface. Acoustic transects were run through the passes during the day. Acoustic data were collected at night only during MOCNESS tows. The system collected 20 log R data for echo integration using 15 second time intervals and at 1 m depth intervals. The sample interval during transecting was thus about 45 m. System calibrations were applied before writing the averaged voltages to computer files. Differential GPS position and GMT from the ship's navigation system were appended to each record before writing the data to disk.

The data were converted from volume scattering to estimates of acoustically determined zooplankton biomass (ADB) by direct comparison of net data with the acoustic data from the corresponding depth and location. Software routines located the appropriate acoustic records corresponding to the time and depth of the MOCNESS data (Fig. 2). The MOCNESS data files included estimates of the volume fished, depth and time for each data record (2-5 second time interval). Volume scattering was multiplied by the volume of water fished at each depth interval and time mark, and the results were summed over the net track. Mean volume scattering for each net was calculated. The net database was queried to extract wet weight biomass estimates of the major taxonomic groups from each sample. The groups included fish, thecate pteropods, calanoid copepods and euphausiids. In practice, only copepods and euphausiid were abundant enough to give consistent results.

Neural network analysis was used to relate the volume scattering in the acoustic data to the corresponding wet weight biomass from each net. The technique makes no linearity or normality assumption about the data. It simply generated an algorithm, which maximized correlation of the acoustic data to the net data (Fig. 2). The network was generated using the MatLab neural network toolbox and contained eight layers having 4, 5, 6, 8, 8, 6, 5, 4 neurons

per layer. Networks with more or fewer layers did not converge or converged more slowly to a solution. All transfer functions were logsig, except for the final layer, which was linear. Tansig transfer functions did not result in a good solution. A total of 128 samples were used to train the network. Consistent results were obtained when applying a resilient back-propagation learning algorithm. Conjugate learning algorithms did not produce consistent solutions. The resulting algorithm was applied to the acoustic transect data to convert volume scattering to ADB (g m^{-3}) along the transect lines.

RESULTS

The physical features and zooplankton composition for an eastern and central pass are illustrated by transects through Akutan and Seguam Passes respectively (Figs 1, 3 - 7). The sampling design was similar for all passes. Zooplankton abundance and biomass in all regions were dominated by copepods and euphausiids.

Seguam is a relatively narrow pass in the central Aleutian archipelago (Fig. 1). The transect extended from the oceanic-slope region on the Pacific side, over the Aleutian ridge, to the Bering Sea basin on the north side. The water column on each side of the pass was stratified, with strongest stratification on the south side (Fig. 3). Elevated fluorescence was observed in the stratified region on both sides of the pass. The elevated salinity and lower temperatures observed between km 20 and 60 are indicative of upwelling of oceanic, subpycnocline water by turbulent flow through the pass. The oceanic, subpycnocline water in the pass had lower fluorescence, ADB and zooplankton abundance relative to stratified condition north of the pass (Fig. 3, 4). A frontal region between km 60 and 70 was observed as a transition zone between unstratified conditions in the pass and stratified conditions north of the pass (Fig. 3). Zooplankton abundance and biomass were particularly elevated in the frontal region near km 60 and 70 (Fig 4).

Akutan Pass, on the eastern Aleutian shelf, is relatively shallow and narrow (Fig. 5). The transect line extended from the south Aleutian shelf through the pass and over the shelf break and slope on the Bering Sea side of the Aleutian ridge. Stratified conditions were observed on the northern and southern ends of the transect line (Fig. 6). The water column between km 20 and 45 was unstratified due to turbulent flow mixing Aleutian shelf water as it moved northward through the pass. The frontal system between km 40 and 60 on the north

half of the transect formed the boundary between unstratified Aleutian shelf water and the water mass comprising the Aleutian North Slope Current (ANSC, Fig. 1). Elevated fluorescence was observed in the frontal regions on both ends of the transect. An epibenthic zooplankton layer attributed to copepods was observed between km 20 and 30 on the south side of the pass (Fig. 7). In addition, patches of elevated subsurface copepod and euphausiid ADB were observed between km 40 and 60 on the north side of the pass and appeared to be associated with the high-salinity ANSC water intruding onto the north Aleutian shelf (Fig. 6, 7). Decorrelation analysis done on vertically integrated acoustic data indicated that copepod patch sizes were on the order of 1 km and euphausiid patch sizes were about 10 km. Zooplankton abundance showed an increasing trend from south to north through the pass. The elevated biomass between km 5 and 10 on the south side of the pass was due to aggregates of the euphausiid *Thysanoessa inermis*. The elevated copepod abundance and biomass near km 50 (Fig. 7) was associated with a front dividing Aleutian shelf and ANSC water (Fig. 6), which had high biomass of *Eucalanus bungii*.

Analysis of variance by transect revealed significant differences in water column temperature and salinity between central and eastern passes during May-June 2002 (Fig. 8). Salinity was significantly higher ($P \leq 0.05$) in Tananga, Seguam and Amukta passes than in Unimak, Akutan, Samalga and Umnak passes. In contrast, temperature was significantly ($P \leq 0.05$) lower at Amukta, Tananga and Seguam passes relative to Unimak, Akutan, Samalga and Umnak passes. Temperature had significantly increased in Unimak and Akutan passes between late May and mid June.

Analysis of variance revealed substantial trends in mean copepod abundance relative to species and transect. *Calanus marshallae* and *Pseudocalanus* tended to be more abundant

in CalVET samples from Akutan Pass and Unimak Pass relative to Seguam Pass and Amukta Pass during June 2001 (Table 2). *Calanus marshallae* was also higher in Akutan and Unimak passes relative to the Bering Side of the Aleutian ridge. In contrast, *Eucalanus bungii* was more abundant in Seguam and Amukta passes than in Akutan and Unimak. In most cases, the differences were significant (Table 2). Similar comparisons on MOCNESS data, which sampled the larger, late-stage copepods and euphausiids, also revealed significant trends between species by transect. *Calanus marshallae* and *Thysanoessa inermis* were more abundant in Akutan and Unimak passes than in Seguam Pass (Table 3). *Euphausia pacifica* was more abundant at Seguam and Unimak passes than at Akutan and *Neocalanus cristatus* and *Metridia* were more abundant at Seguam than at Akutan (Table 3). Differences in abundance of major species in CalVET tows from the Pacific and Bering Sea sides of the Aleutian ridge were not significant (Table 2).

Species abundance during May-June 2002 showed both temporal and regional trends. Abundance of *Neocalanus plumchrus-flemingeri* in MOCNESS tows showed a consistent decline from maximum values at Unimak (first visit), Akutan (first visit) and Tananga Passes to minimal values at Seguam, Samalga, Unimak (second visit) and Akutan (second visit) (Table 4). In contrast, *C. marshallae* showed increasing abundance with time, having minimal values during the first visit to Akutan and Unimak, and significantly higher values during the second visit (Table 4). Note that distinct increases in abundance of *C. marshallae* were confined to Akutan and Unimak Passes. Highest concentrations of *T. inermis* were observed in the eastern passes (Unimak and Akutan) while higher concentration of *E. pacifica* were observed in the central passes (Tananga and Seguam). *Neocalanus cristatus* tended to be higher in the central passes, particularly relative to the second visit to Unimak and Akutan,

where one comparison was significant (Table 4). Similar trends were observed in the CalVET data, where *Pseudocalanus*, *C. marshallae* and *Acartia* spp. were more abundant and *N. plumchrus-flemingeri* were less abundant during the second visit to Unimak and Akutan (Fig. 9).

Canonical analysis revealed strong and significant correlations between physical variables and the abundance of major zooplankton taxa (Tables 5 and 6). Physical variables could account for about 50% and 45% of the observed variance for MOCNESS and CalVET data respectively. Abundances of *C. marshallae* and *T. inermis* were positively correlated to temperature and negatively correlated to salinity, whereas abundances of *E. pacifica* and *N. cristatus* were negatively correlated to temperature and positively correlated to salinity (Table 7). *Neocalanus plumchrus-flemingeri* showed negative correlations to temperature but little correlation to salinity. Of the smaller taxa, *Pseudocalanus* and *Acartia* were negatively correlated to salinity and positively correlated to temperature (Table 8).

DISCUSSION

The eastern and central Aleutian Islands are influenced by three major currents, the Alaskan Stream, the Aleutian North Slope Current (ANSC) and the Alaska Coastal Current (ACC) (Fig. 1; Stabeno et al., 1999). These current systems influence zooplankton community composition by determining source populations. The ACC is generated by fresh water discharge and cyclonic wind stress; it is a narrow, low-salinity current running westward along the coast from southeastern Alaska to the eastern Aleutian shelf (Royer, 1981, Johnson et al., 1988; Stabeno et al., 1995). Although much of the flow goes through Unimak Pass and onto the southeastern Bering Sea shelf (Stabeno et al., 1999), some of the fresh-water transport by the ACC apparently influences water mass properties on the eastern Aleutian shelf, as indicated by the significantly lower salinity between Unimak Pass and Samalga Pass, relative to that of passes to the west (Fig. 8). Intense turbulence in the passes apparently mixes water from above and below the thermocline, resulting in lower mean salinity on the eastern Aleutian shelf.

The Alaskan Stream is an intense westward flowing current characterized by water temperatures above 4°C to 200 m depth (Reed, 1984). It flows along the shelf break from the eastern Gulf of Alaska to the western Aleutian Islands and forms the northern boundary of the North Pacific Subarctic Gyre. The central Aleutian passes are strongly influenced by the Alaskan Stream (Stabeno et al., 1999). Alaskan Stream water is transported through the passes and forms the eastward flowing ANSC (Fig. 1). The ANSC flows along the north ridge of the Aleutian arch between Amchitka Pass in the west and the southeastern Bering Sea shelf break in the east, where it turns north to form the Bering Slope Current (Ladd et al., 2005). The westward flowing ACC and Alaskan Stream link the zooplankton community in

the Aleutian islands and the ANSC to source populations along the northern GOA coast, hundreds of kilometers to the east.

The zooplankton community along the northern GOA shelf consists of both neritic and oceanic species. Neritic copepods are common in the ACC, particularly in mid to late summer, when they can dominate copepod abundance on the inner GOA shelf (Coyle and Pinchuk, 2005). *Pseudocalanus*, *Acartia* and *C. marshallae*, observed on the eastern Aleutian shelf, are typical neritic taxa common in GOA shelf waters. The significantly lower abundance of these species in samples from central passes is indicative of substantially different source populations for zooplankton in the central Aleutians. In addition to significantly lower abundance of neritic species, the zooplankton community in the central passes is dominated by large oceanic copepod species of the genera *Neocalanus* and *Eucalanus*, species typical of the Alaskan Stream, particularly during spring when they can dominate the biomass (Coyle and Pinchuk, 2003; Cooney, 1986a, 1986b; Incze et al., 1996). The oceanic species are also an important component of the ACC zooplankton assemblage during spring (Coyle and Pinchuk, 2005; Incze et al., 1996). Their presence on the shelf is the result of cross-shelf transport from Alaskan Stream waters and from over wintering populations in deep coastal fjords (Cooney et al, 2001; Coyle and Pinchuk, 2003). *Neocalanus* complete their foraging cycle and undergo an ontogenetic migration to depths of 300 to 600 m starting in May and June (Tsuda et al. 1999; Kobari and Ikeda, 2001a; Kobari and Ikeda, 2001b). The declines observed in *Neocalanus* abundance between late May and mid June on the eastern Aleutian shelf are most likely the result of this migration; these declines generated the observed negative correlations between *Neocalanus* abundance and temperature (Table 7). The increases observed in *Pseudocalanus*, *Acartia* and *C. marshallae*

abundance on the eastern Aleutian shelf between late May and mid June are also typical of seasonal population trends on the northern GOA shelf during spring and summer (Coyle and Pinchuk, 2003).

Canonical correlation revealed highly significant relationships between a series of physical parameters characterizing water mass properties and zooplankton abundance and biomass in the passes. About 45-50% of the observed variance in zooplankton abundance could be explained by physical variables. These correlations reflect the temperature-salinity characteristics of specific water masses and the occurrence of these species in those water mass types. *Neocalanus cristatus* was negatively correlated to temperature and positively correlated to salinity. This pattern conforms to its occurrence in oceanic water masses during spring (Mackas, 1993; Coyle, 1998). In contrast, *C. marshallae*, *Pseudocalanus* and *Acartia* were positively correlated to temperature and negatively correlated to salinity in conformity to their preference for neritic waters during summer (Coyle and Pinchuk, 2003; Coyle and Pinchuk, 2005). The euphausiid species *Thysanoessa inermis* was positively correlated to temperature and negatively correlated to salinity, in contrast to *Euphausia pacifica*, which was positively correlated to salinity and negatively correlated to temperature. This pattern again conforms to the occurrence of the former in deep shelf environments and the latter in more oceanic habitats (Coyle and Pinchuk, 2005).

Historical observations from the 1950s and 1960s in the upper 80 m north and south of the Aleutian chain revealed consistently higher zooplankton biomass in the Bering Sea relative to the Pacific (Motoda and Minoda, 1974). Dense scattering layers of *Neocalanus cristatus* and *Neocalanus plumchrus-flemingeri* have been documented in Bering Sea Basin (BSB) water north of Kiska Island during June (Coyle, 1998; Coyle et al. 1998; Coyle and

Hunt, 2000). In contrast to the above studies, we found no significant differences in zooplankton biomass from north and south of the central and eastern Aleutian ridge. In addition, mean temperature below the pycnocline was over 5°C both north and south of the ridge and analysis of variance revealed no significant differences in temperature between samples taken on either side of the ridge. BSB water is distinctive from ANSC water in having a cold intermediate layer with temperatures under 4°C between 50 and 200 m depth (Luchin et al., 1999; Pavlov and Pavlov, 1996). The above observations indicate that our samples from north of the ridge were taken in ANSC water, with zooplankton source populations from Alaskan Stream water. Although the ANSC is well developed in the central and eastern Aleutians between 175°W and 167°W, it is weak or absent west of Amchitka Pass (Stabeno et al., 1999), where resident Bering Sea zooplankton in BSB water are observed in close proximity to the north sides of the islands (Coyle et al. 1998; Coyle and Hunt, 2000).

In addition to the large-scale geographic differences in zooplankton abundance and biomass, there is evidence of small-scale patchiness related to fronts and eddies in the passes. Acoustic data through the passes revealed regions of elevated scattering, often associated with fronts between unstratified water in the passes and stratified water to the north of the passes. The eddies and fronts are apparently generated by flow through the passes and are a specific feature of the pass environment. In addition to physical concentration of plankton by circulation in eddies and fronts, elevated fluorescence in the fronts indicates a favorable feeding habitat for zooplankton grazers. Flow regimes, which upwell or concentrate prey, are known to be important foraging habitat for a variety of consumers (e.g. Hunt et al., 1998; Coyle et al., 1992; Vermeer, 1987). Thus, the data suggest that eddies and fronts generated by circulation in the passes can result in dense zooplankton aggregations, which may be

favorable foraging habitats for planktivorous fish, an important component in the food web supporting Steller sea lions.

A number of studies have attempted to link temporal variability in zooplankton biomass in the North Pacific to climate anomalies (Conversi and Hameed, 1997; Brodeur and Ware, 1992; McGowan et al., 1998; Royer et al., 2001). A long-term trend toward warmer, less saline surface waters, lower nitrate and silicate concentrations in the upper mixed layer during winter, and less macronutrient utilization have been observed in the northeast subarctic Pacific, suggesting the possibility of long-term declines in overall primary production and possible shifts in the size and species composition of the phytoplankton (Whitney and Freeland, 1999). Similar warm, fresh, low-nutrient anomalies were accompanied by shifts in the species composition of the zooplankton community along the British Columbia coast (Mackas et al., 2001). In addition, long-term observations in the North Pacific Subarctic Gyre indicate that the timing of the annual copepod biomass peak may change by weeks to months (Mackas et al., 1998). Long-term observations on the GOA shelf are not available. Nevertheless, significant interannual differences in the abundance and biomass of major zooplankton taxa on the central GOA shelf (Coyle and Pinchuk, 2003) suggest the potential for climate-related shifts in the food web relationships in the sea lion habitat. While localized vertical mixing with its associated nutrient flux in Aleutian passes is largely determined by flow regimes in the passes, climate-related shifts in water column stability of the surrounding ocean may impact sea lions by constricting their foraging range to specific regions in the passes, where fronts and eddies concentrate zooplankton and their forage fish predators.

ACKNOWLEDGEMENTS

This research was conducted on the R. V. *Alpha Helix*. Technical support was provided by the captain, crew and ship's technician (Dave Aldridge). Additional help at sea was provided by Leandra de Sousa and Amanda Byrd. Aid in sample processing and data entry was provided by Chris Stark, Janet Ballek, Carla Del Fino and Elizabeth Stockmar. The research was multidisciplinary, involving the cooperation of a number of researchers and institutions. They included Phyllis Stabeno, Sigrid Salo and Nancy Kachel from Pacific Marine Environmental Lab; George Hunt, Lucy Vlietstra and Jaime Jahncke from University of California Irvine; Sue Moore and colleagues from the National Marine Mammal Laboratory, and Steve Zeeman from University of New England. We thank all of the above for their participation in this research effort. This research was funded by a NOAA grant through CIFAR (award number NA17RJ1224).

Figure Legends

Fig. 1. A. Passes sampled and major currents in the Aleutian Islands (red dots indicate CalVET CTD stations taken in June 2001 north and south of the ridge outside of passes). B. MOCNESS and acoustic transect line through Seguam pass, taken in June 2001 (black dots are locations of MOCNESS tows, black line is the acoustic transect).

Fig. 2. A. Results of the neural network conversion of volume scattering to biomass. B. Volume scattering (dB) along the net track of MOCNESS tow 18. Vertical lines indicate a net cycle. Sloping line is the net track from 85 m to the surface.

Fig. 3. CTD transect from south to north through Seguam Pass, June 2001. Filled triangles indicate station locations. Fluorescence is in volts.

Fig. 4. Acoustically determined copepod and euphausiid biomass, and abundance and biomass (MOCNESS data) of major zooplankton taxa along a transect taken in June 2001 through Seguam Pass. Data are plotted from south to north.

Fig. 5. MOCNESS and acoustic transect line through Akutan Pass, taken in June 2001 (black dots are locations of MOCNESS tows, black line is the acoustic transect) .

Fig. 6. CTD transect from south to north through Akutan Pass, June 2001. Filled triangles indicate station locations. Fluorescence is in volts.

Fig. 7. Acoustically determined copepod and euphausiid biomass, and abundance and biomass (MOCNESS data) of major zooplankton taxa along a transect taken in June 2001 through Akutan Pass. Data are plotted from south to north.

Fig. 8. Mean water column temperature and salinity in the upper 100 m of the eastern and central Aleutian passes in May-June 2002 by transect. Error bars indicate 95% confidence intervals. UpperMixedTemp = Temperature in upper mixed layer; LowerMixedTemp = mean

temperature below the thermocline; MeanTemp = mean water column temperature; UpperMixedSal = salinity above the halocline; LowerMixedSal = salinity below the halocline; MeanSal = mean water column salinity.

Fig. 9. Mean abundance (CalVET data) of major zooplankton taxa in the central and eastern Aleutian passes (May – June 2002) by transect. Error bars are 95% confidence intervals. Transect designators: Ak1 = Akutan 1, Un1 = Unimak 1, Tng = Tananga, Sgm = Seguam, Akm = Amukta, Smg = Samalga, Unk = Umnak, Ak2 = Akutan 2, Un2 = Unimak 2. See Table 1 for sampling dates and sample sizes. Pass Type: S = Shallow, D = Deep, C = Central, E = Eastern.

REFERENCES

- Albers, W. D. and Anderson, P. J. (1985) Diet of pacific cod, *Gadus macrocephalus*, and predation on the northern pink shrimp, *Pandalus borealis*, in Pavlof Bay, Alaska, U.S. *Fish. Bull.* **83**:601-610.
- Anderson, P. J. and Piatt, J. F. (1999) Community reorganization in the Gulf of Alaska following ocean climate regime shift. *Mar. Ecol. Prog. Ser.* **189**:117-123.
- Blau, S. F. (1986) Recent declines of red king crab (*Paralithodes camstchatica*) populations and reproductive conditions around the Kodiak Archipelago, Alaska. *Can. Spec. Publ., Fish. Aquat. Sci.* **92**:360-369.
- Brodeur, R.D. and Ware, D.M. (1992) Interannual and interdecadal changes in zooplankton biomass in the subarctic Pacific Ocean. *Fish. Oceanogr.* **1**:32-38.
- Conversi, A. and Hameed, S. (1997) Evidence for quasi-biennial oscillations in zooplankton biomass in the subarctic Pacific. *J. Geoph. Res.* **102**:15659-15665.
- Cooney, R. T. (1986a) The seasonal occurrence of *Neocalanus cristatus*, *Neocalanus plumchrus* and *Eucalanus bungii* over the northern Gulf of Alaska. *Cont. Shelf Res.* **5**:541-553.
- Cooney, R. T. (1986b) Zooplankton. In: *The Gulf of Alaska, Physical Environment and Biological Resources*. D. W. Hood and S. T. Zimmerman (eds.), MMS/NOAA, Alaska Office, Anchorage: OCS Study MMS 86-0095, pp. 285-303.
- Cooney, R.T., Coyle, K.O., Stockmar, E., and Stark, C. (2001) Seasonality in the surface-layer net zooplankton communities in Prince William Sound, Alaska. *Fish. Oceanogr.* **10**(Suppl.1): 97-109.
- Coyle, K.O. and A. I. Pinchuk. (2005) Cross-shelf distribution of zooplankton relative to water masses on the northern Gulf of Alaska shelf. *Deep Sea Res. II* (in press).
- Coyle, K. O. and A. I. Pinchuk. (2003) Annual cycle of zooplankton abundance, biomass and production on the northern Gulf of Alaska shelf, October 1997 through October 2000. *Fish. Oceanogr.* **12**:327-338.
- Coyle, K. O. and Hunt, J. L. Jr. (2000) Seasonal differences in the distribution, density and scale of zooplankton patches in the upper mixed layer near the western Aleutian Islands. *Plankton Biol. Ecol.* **47**:31-42.
- Coyle, K. O. (1998) Acoustic assessment of *Neocalanus* scattering layers near the western Aleutian Islands. *J. Plankton Res.* **20**:1189-1202.

Coyle, K. O., Weingartner, T. J. and Hunt, G. L. Jr. (1998) The distribution of acoustically determined biomass and major zooplankton taxa in the upper mixed layer relative to water masses in the western Aleutian Islands. *Mar. Ecol. Prog. Ser.* **165**:95-108.

Coyle, K. O., Hunt, G. L. Jr., Decker, M. B. and Weingartner, T. J. (1992) Murre foraging, epibenthic sound scattering and tidal advection over a shoal near St. George Island, Bering Sea. *Mar. Ecol. Prog. Ser.* **83**:1-14.

Francis, R.C., and Hare, S. R. (1994) Decadal-scale regime shifts in the large marine ecosystems of the North-east Pacific: a case for historical science. *Fish. Oceanogr.* **3**:279-291.

Hatch, S. A. and Sanger, G. A. (1992) Puffins as samplers of juvenile pollock and other forage fish in the Gulf of Alaska. *Mar. Ecol., Prog., Ser.* **80**:1-14.

Hollowed, A. B., Wilson, C. W., Brown E. and Megrey, B. A. (1994) Walley Pollock, In: *Stock Assessment and Fishery Evaluation Report for the 1995 Gulf of Alaska Groundfish Fishery*, Anchorage: North Pacific Fishery Management Council.

Hunt, G. L. Jr., Russell, R. W., Coyle, K. O. and Weingartner, T. (1998) Comparative foraging ecology of planktivorous auklets in relation to ocean physical and prey availability. *Mar. Ecol. Prog. Ser.* **167**:241-259.

Incze, L. S., Siefert, D. W. and Napp, J. M. (1996) Mesozooplankton of Shelikof Strait, Alaska: abundance and community composition. *Cont. Shelf Res.* **17**:287-305.

Johnson, W. R., Royer, T. C. and Luick, J. L. (1988) On the seasonal variability of the Alaska Coastal Current. *J. Geophys. Res.* **93**:12423-12437.

Kobari, T. and Ikeda, T. (2001a) Ontogenetic vertical migration and life cycle of *Neocalanus plumchrus* (Crustacea: Copepoda) in the Oyashio region, with notes on regional variations in body sizes. *J. Plank. Res.* **23**:287-302.

Kobari, T. and Ikeda, T. (2001b) Life cycle of *Neocalanus flemingeri* (Crustacea: Copepoda) in the Oyashio region, western subarctic Pacific, with notes on its regional variations. *Mar. Ecol. Prog. Ser.* **209**:243-255.

Ladd, C., Hunt Jr., G., Mordy, C., Salo, S., and Stabeno, S. 2005. Marine Environment of the eastern and central Aleutian Islands. *Fish Oceanogr.* (this issue)

Luchin, V. A., Menovshchikov, V. A. and Lavrentiev, V. M. (1999) Thermohaline structure and water masses in the Bering Sea. . In: *Dynamics of the Bering Sea*, Loughlin, T. R. and Ohtani, K. (eds), University of Alaska Sea Grant, Fairbanks, Alaska, pp. 61-91.

Mackas, D. L., Sefton, H., Miller, C. B. and Raich, A. (1993) Vertical habitat partitioning by large calanoid copepods in the oceanic subarctic Pacific during spring. *Prog. Oceanogr.* **32**:259-294.

Mackas, D. L., Goldblatt, R. and Lewis, A. G. (1998) Interdecadal variation in the developmental timing of *Neocalanus plumchrus* populations at Ocean Station P in the subarctic North Pacific. *Can. J. Fish. Aquat. Sci.* **55**:1878-1893.

Mackas, D.L., Thomas, R.E., and Galbraith, M. (2001). Changes in the zooplankton community of the British Columbia continental margin, 1985-1999, and their covariation with oceanographic conditions. *Can. J. Fish. Aquat. Sci.* **58**:685-702.

Mantua, N., Hare, S. R., Zhang, Y., Wallace, J. M. and Francis, R.C. (1997) A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Am. Met. Soc.* **78**:1069 – 1079.

McGowan, J. A., Cayan, D. R. and Dorman, L. M. (1998) Climate-ocean variability and ecosystem response in the northeast Pacific. *Science* **128**:210-217.

Merrick, R. L., Loughlin, T. R. and Calkins, D. G. (1987) Decline in the abundance of the northern sea lion, *Eumetopia jubatus*, in Alaska, 1956-86, U.S. *Fish. Bull.* **85**:351-365.

Motoda, S. and T. Minoda. (1974). Plankton of the Bering Sea. In: *Oceanography of the Bering Sea with emphasis on renewable resources: Proceedings of an international symposium, Hokkaido, Japan, 1972*. D. W. Hood and E. J. Kelley (eds) Univ. Alaska Inst. Mar. Sci. Occas. Publ. 2, Fairbanks, pp. 207-241.

Pavlov, V. K. and Pavlov, P. V. (1996) Oceanographic description of the Bering Sea. In: *Ecology of the Bering Sea: a review of the Russian literature*. Matheson, O. A. and Coyle, K. O. (eds), University of Alaska Sea Grant, Fairbanks, Alaska, pp. 1-95.

Reed, R. K. (1984) Flow of the Alaskan Stream and its variations. *Deep Sea Res.* **31**:369-389.

Royer, T. C., Grosch, C. E. and Mysak, L. A. (2001) Interannual variability of northeast Pacific coastal freshwater and its implications on biological productivity. *Prog. Oceanogr.* **49**:95-111.

Royer, T. C. (1981) Baroclinic transport in the Gulf of Alaska, Part II. Freshwater driven coastal current. *J. Mar. Res.* **38**:251-266.

Siefert, D. L. (1994) The importance of sampler mesh size when estimating total daily egg production by *Pseudocalanus* spp. in Shelikof Strait, Alaska. *J. Plank. Res.* **16**:1489-1498.

Smith, P.E., Flerx, W., and Hewitt R.P. (1985) The CalCOFI vertical egg tow (CalVET) net.

In: *An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy *Engraulis mordox**. Lasker R. (ed.). Washington, D.C.: NOAA Tech. Rep. NMFS 36, US Dept. Commer., pp. 23-33.

Springer, A.. (1998) Is it all climate change? Why marine birds and mammal populations fluctuate in the North Pacific. In: *Biotic Impacts of Extratropical Climate Variability in the Pacific*. Holloway, G., P. Müller, and D. Henderson (eds). Manoa: Proceedings 'Aha Huliko'a Workshop, U. Hawaii SOEST, pp. 109 – 120.

Stabeno, P. J., Schumacher, J. D. and Ohtani, K. (1999) The physical oceanography of the Bering Sea. In: *Dynamics of the Bering Sea*, Loughlin, T. R. and Ohtani, K. (eds), University of Alaska Sea Grant, Fairbanks, Alaska, pp. 1 – 28.

Stabeno, P. J., Reed, R. K. and Schumaker, J. D. (1995) The Alaska Coastal Current: continuity of transport and forcing. *J. Geophys. Res.*, **100**:2477-2485.

Thompson, G. G. and Zenger, H. H. (1994) Pacific Cod, In: *Stock Assessment and Fishery Evaluation Report for the 1995 Gulf of Alaska Groundfish Fishery*. Anchorage: North Pacific Fishery Management Council.

Trenberth, K. E. and Hurrell, J. W. . (1994) Decadal atmosphere-ocean variations in the Pacific. *Clim. Dyn.*, **9**:303-319.

Tsuda, A., Saito, H., and Kasai, H. (1999) Life histories of *Neocalanus flemingeri* and *Neocalanus plumchrus* (Calanoida: Copepoda) in the western subarctic Pacific. *Mar. Biol.* **135**:533-544.

Vermeer, K., Szabo, I. and Greisman, P. (1987) The relationship between plankton-feeding Bonaparte's and mew gulls and tidal upwelling at Active Pass, British Columbia. *J. Plankton. Res.* **9**:483-501.

Whitney, F. A. and Freeland, H. J. (1999) Variability in the upper ocean water properties in the NE Pacific Ocean. *Deep Sea Res. II* **46**:2351-2370.

Wiebe, P.H., Burt, K.H., Boyd, S.H., and Morton, A.W. (1976) A multiple opening/closing net and environmental sensing system for sampling zooplankton. *J. of Mar. Res.* **34**:313-325.

York, A.E. (1994) The population dynamics of northern sea lions, 1975-1985. *Marine Mammal Science*, **10**:38-51.

York, A.E., R.L. Merrick, and T.R. Loughlin. (1996) An analysis of the Steller sea lion metapopulation in Alaska. In: *Metapopulations and Wildlife Conservation and Management* (D. McCullough, ed.). Island Press, Covelo, California, pp. 259-292.

Table 1. Transects through passes in the eastern and central Aleutian archipelago. Numbers 1 and 2 indicate the first and second visits to the pass in 2002, respectively. MOCNESS and CalVET columns list the number of tows for each gear type respectively.

Transect	Cruise	Sampling Dates	MOCNESS	CalVET & CTD	Description
Akutan Pass	hx245	14 - 16 June 2001	12	17	Eastern Shallow
Unimak Pass	hx245	18 - 20 June 2001	5	12	Eastern Deep
Seguam Pass	hx245	9 - 11 June 2001	8	14	Central Shallow
Pacific Side	hx245	7 - 8 June 2001		10	Outside Passes
Bering Side	hx245	13 - 18 June 2001		10	Outside Passes
Amukta Pass	hx245	12 June 2001		14	Central Deep
Akutan Pass 1	hx259	21 - 25 May 2002	8	12	Eastern Shallow
Akutan Pass 2	hx259	13 - 17 June 2002	6	6	Eastern Shallow
Unimak Pass 1	hx259	19 - 25 May 2002	7	11	Eastern Deep
Unimak Pass 2	hx259	12 - 19 June 2002	6	6	Eastern Deep
Tananga Pass	hx259	28 - 30 May 2002	9	10	Central Deep
Seguam Pass	hx259	2 - 4 June 2002	9	11	Central Shallow
Amukta Pass	hx259	5 - 6 June 2002		8	Central Deep
Samalga Pass	hx259	7 - 9 June 2002		9	Eastern Shallow
Umnak Pass	hx259	10 June 2002		8	Eastern Shallow

Table 2. Mean abundance (no m⁻³) and Bonferonni test for differences between transects, CalVET data from the eastern and central Aleutian Islands in June 2001. Pacific and Bering stations shown in Fig. 1. Pass locations and types: S = shallow, E = Eastern, D = deep, C = Central (see Table 1)

Taxon	Transect						Bonferonni Test $P \leq 0.05$
	Akutan	Unimak	Seguam	Amukta	Pacific	Bering	
	S/E (1)	D/E (2)	S/C (3)	D/C (4)	(5)	(6)	
<i>O. similis</i>	427.8	536.6	695.3	796.9	583.0	564.0	4 > 1
<i>Pseudocalanus</i> spp.	405.2	574.2	112.4	226.4	282.4	308.3	1 & 2 & 5 & 6 > 3; 2 > 4
<i>Neocalanus</i> spp.	9.6	5.6	12.6	0.5	21.4	2.4	No Differences
<i>Metridia</i> spp.	53.3	54.3	198.9	180.4	72.0	133.7	3 > 1
<i>N. cristatus</i>	0.1	0.1	1.9	1.2	0.8	0.04	No Differences
<i>E. bungii</i>	183.5	201.0	575.4	678.4	139.7	315.5	3 & 4 > 1 & 2 & 5
<i>C. marshallae</i>	5.2	44.3	0.05	0	10.4	0.2	1 > 4; 2 > 3 & 4 & 6
<i>Acartia</i> spp.	60.9	61.2	16.4	44.0	43.5	41.7	No Differences
Calanoid nauplii	584.7	445.2	368.7	1094.6	496.7	854.5	4 > 2=3

Table 3. Mean abundance (no m⁻³) and Bonferonni test for differences between transects, MOCNESS data from the eastern and central Aleutian Islands in June 2001. Pass locations and types: S = shallow, E = Eastern, D = deep, C = Central (see Table 1).

Taxon	Transect			Bonferonni Test $P \leq 0.05$
	Seguam S/C (1)	Akutan S/E (2)	Unimak D/E (3)	
<i>Thysanoessa inermis</i>	3e-5	0.2	0.4	2 = 3 > 1
<i>Euphausia pacifica</i>	0.04	3e-5	0.02	1 = 3 > 2
<i>N. plumchrus-flemingeri</i>	32.6	27.3	40.2	No Differences
<i>N. cristatus</i>	3.9	1.6	2.2	1 > 2
<i>Metridia</i> spp.	46.2	14.8	38.9	1 > 2
<i>Eucalanus bungii</i>	123.7	102.6	246.8	No Differences
<i>Calanus marshallae</i>	2.8	29.8	49.9	2=3>1

Table 4. Mean abundance (no m⁻³) and Bonferonni test for differences between transects, MOCNESS data from the eastern and central Aleutian Islands May – June 2002. Pass locations and types: S = shallow, E = Eastern, D = deep, C = Central (see Table 1).

Taxon	Transect							Boneronni Test <i>P</i> ≤ 0.05
	Unimak 1	Akutan 1	Tananga	Seguam	Samalga	Unimak 2	Akutan 2	
	D/E (1)	S/E (2)	D/C (3)	S/C (4)	S/E (5)	D/E (6)	S/E (7)	
<i>T. inermis</i>	0.08	0.08	8e-8	8 e-7	7e-3	0.02	0.06	3=4<1=2=7
<i>E. pacifica</i>	3e-4	2e-4	0.05	0.05	2e-3	2e-6	6e-5	3=4 > 6
<i>Neocalanus</i> spp.	100.4	74.6	80.2	47.6	29.8	37.9	38.2	1>5=6=7
<i>N. cristatus</i>	4.2	4.5	9.7	8.0	5.5	2.0	3.4	3 > 6
<i>Metridia</i> spp.	52.2	31.0	35.7	50.9	16.0	33.2	28.8	No Differences
<i>E. bungii</i>	32.9	34.0	56.0	53.6	114.2	57.9	92.2	5 > 1 & 2
<i>C. marshallae</i>	8.3	9.2	2.3	1.3	5.5	74.9	62.6	1=2=3=5>4 6=7> 1 - 5

Table 5. Canonical correlation summary relating physical variables to the abundance of major zooplankton taxa (Table 7) in MOCNESS tows taken in the Aleutian Islands during May and June, 2002: Canonical R: 0.91968; $\text{Chi}^2(56)=170.27$, $p=0.0000$

n = 50	Physical Data	Species Abundance
No of variables	8	7
Variance extracted	98.9717%	100.000%
Total Redundancy	60.9794%	49.1852%

Table 6. Canonical correlation summary relating physical variables to the abundance of major zooplankton taxa (Table 8) in CalVET tows taken in the Aleutian Islands during May and June, 2002: Canonical R: 0.73910; $\text{Chi}^2(24)=119.28$ $p=0.0000$; HX259

N = 81	Physical Data	Species Abundance
No of variables	8	3
Variance extracted	62.2477%	100.000%
Total Redundancy	29.9226%	44.4506%

Table 7. Correlations between the physical data and species abundance from MOCNESS tows taken in the Aleutian Islands during May and June, 2002. T. iner = *T. inermis*, E. pac = *E. pacifica*, N. spp. = *N. plumchrus-flemingeri*, N. cris = *N. cristatus*, Metri = *Metridia* spp., E. bung = *E. bungii*, C. mars = *C. marshallae*. (Correlation above 0.5 in bold)

N = 50 Physical Data	Species						
	T. iner	E. pac	N. spp.	N. cris	Metri	E. bung	C. mars
Thermocline Depth (m)	0.223	-0.064	0.072	-0.114	-0.136	0.281	0.200
Upper Mixed Temp (°C)	0.243	-0.329	-0.382	-0.192	-0.137	0.245	0.586
Lower Mixed Temp (°C)	0.385	-0.486	-0.493	-0.461	-0.278	0.213	0.780
Mean Temp (°C)	0.403	-0.497	-0.419	-0.442	-0.259	0.240	0.765
Halocline Depth (m)	-0.268	0.573	0.200	0.304	0.348	0.270	-0.380
Upper Mixed Salinity	-0.685	0.696	0.292	0.536	0.317	0.143	-0.758
Lower Mixed Salinity	-0.700	0.681	0.273	0.559	0.286	0.163	-0.770
Sal Above Thermocline	-0.672	0.691	0.295	0.563	0.281	0.209	-0.768

Table 8. Correlations between the physical data and species abundance from CalVET tows taken in the Aleutian Islands during May and June, 2002. (Correlation above 0.5 in bold)

Physical Data	Species		
	<i>O. similis</i>	<i>Pseudocalanus</i>	<i>Acartia</i>
Thermocline Depth (m)	-0.058	-0.116	-0.166
Upper Mixed Temp (°C)	0.402	0.369	0.449
Lower Mixed Temp (°C)	0.100	0.453	0.634
Mean Temp (°C)	0.232	0.467	0.557
Halocline Depth (m)	0.159	0.018	-0.087
Upper Mixed Salinity	0.134	-0.315	-0.570
Lower Mixed Salinity	0.114	-0.403	-0.550
Mean Sal	0.118	-0.370	-0.563

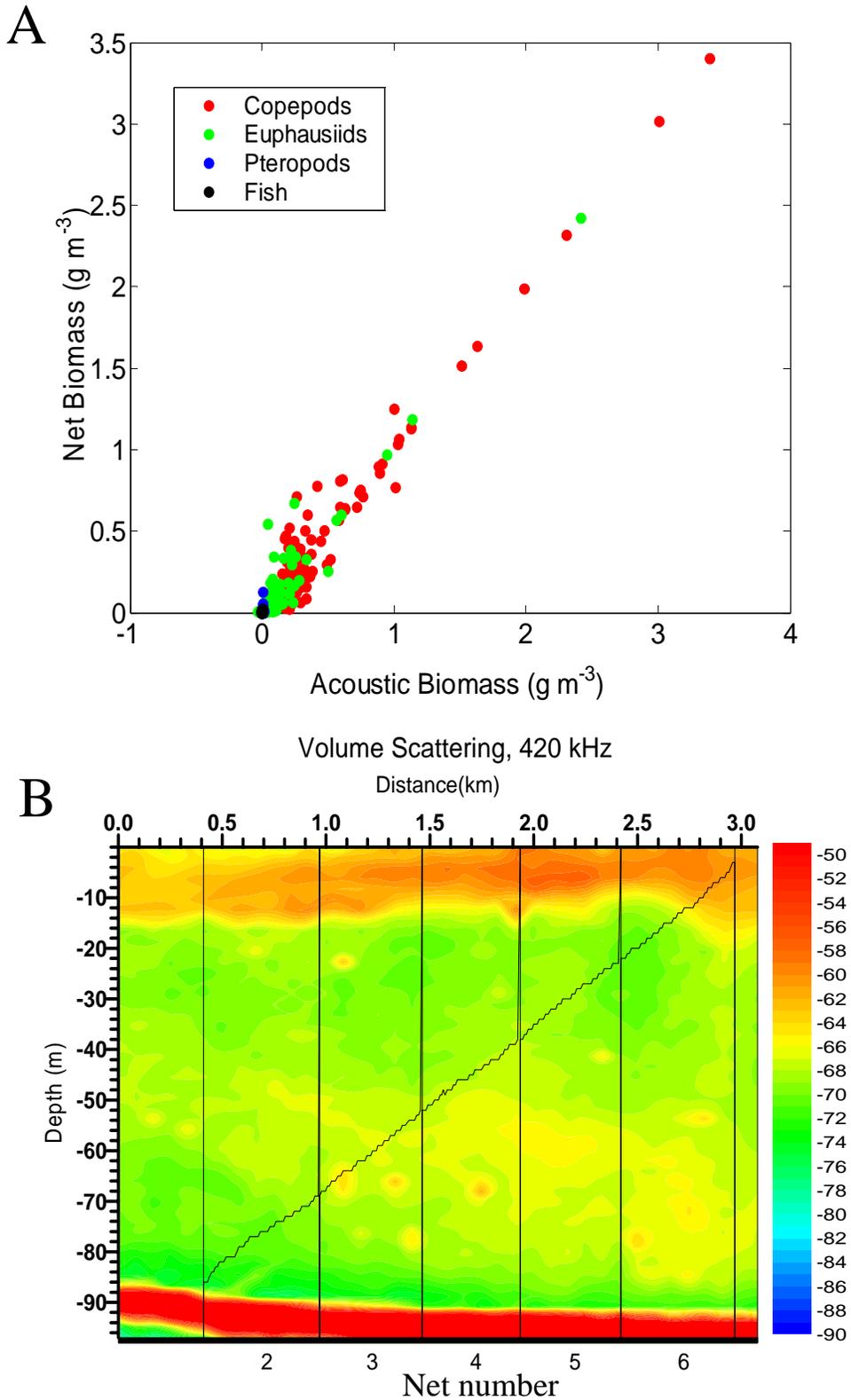


Fig. 2. A. Results of the neural network conversion of volume scattering to biomass. B. Volume scattering (dB) along the net track of MOCNESS tow 18. Vertical lines indicate a net cycle. Sloping line is the net track from 85 m to the surface.

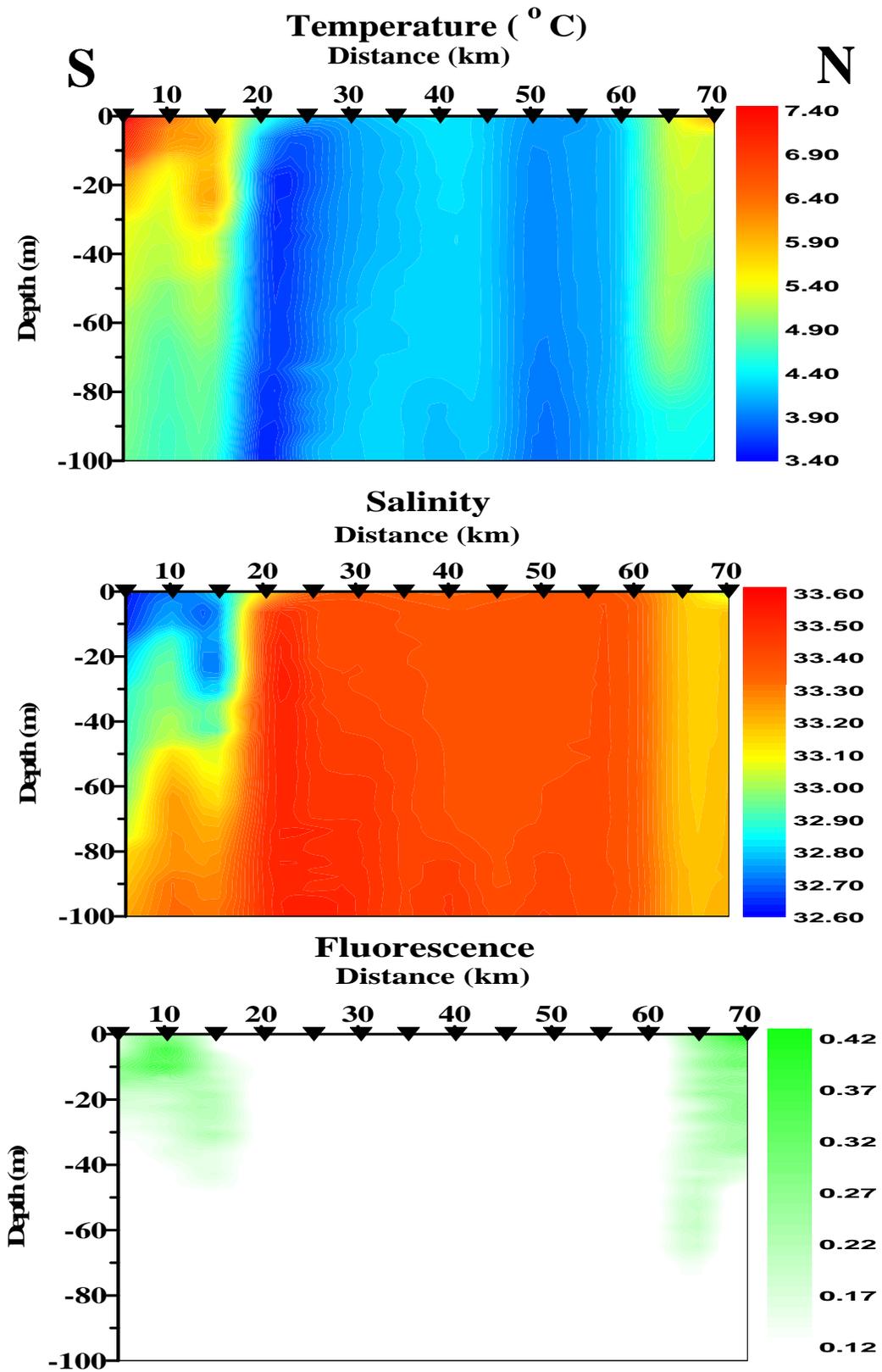


Fig. 3. CTD transect from south to north through Seguam Pass, June 2001. Filled triangles indicate station locations. Fluorescence is in volts.

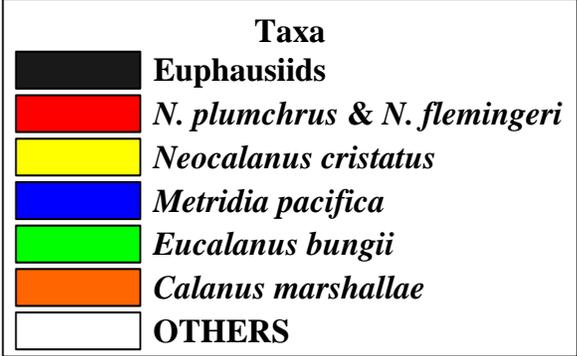
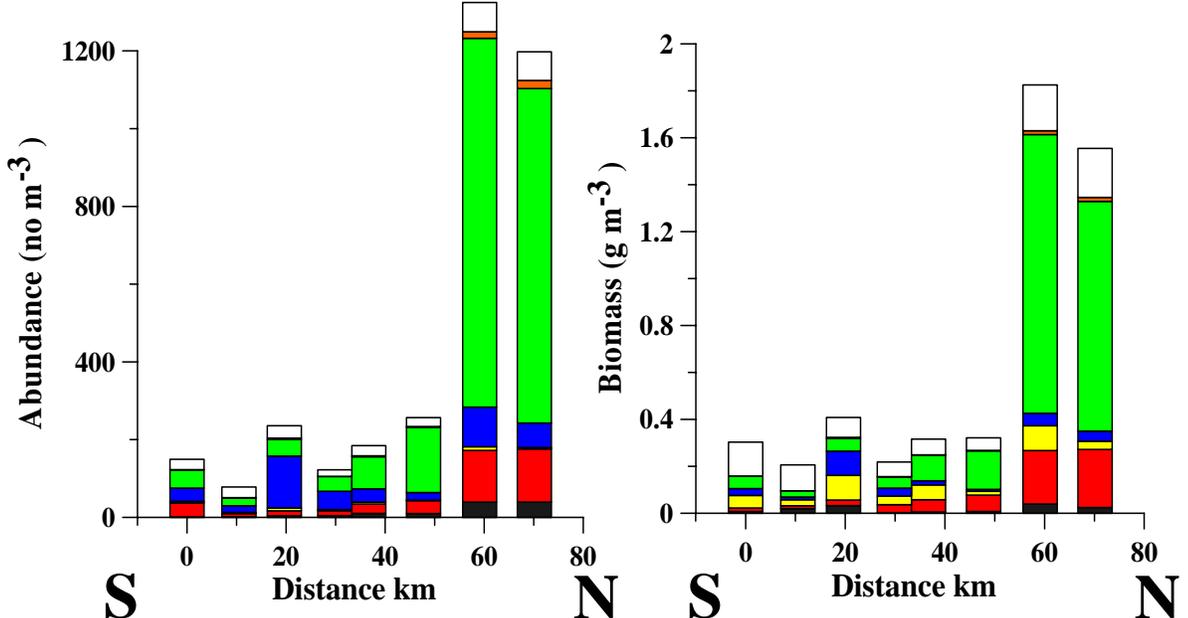
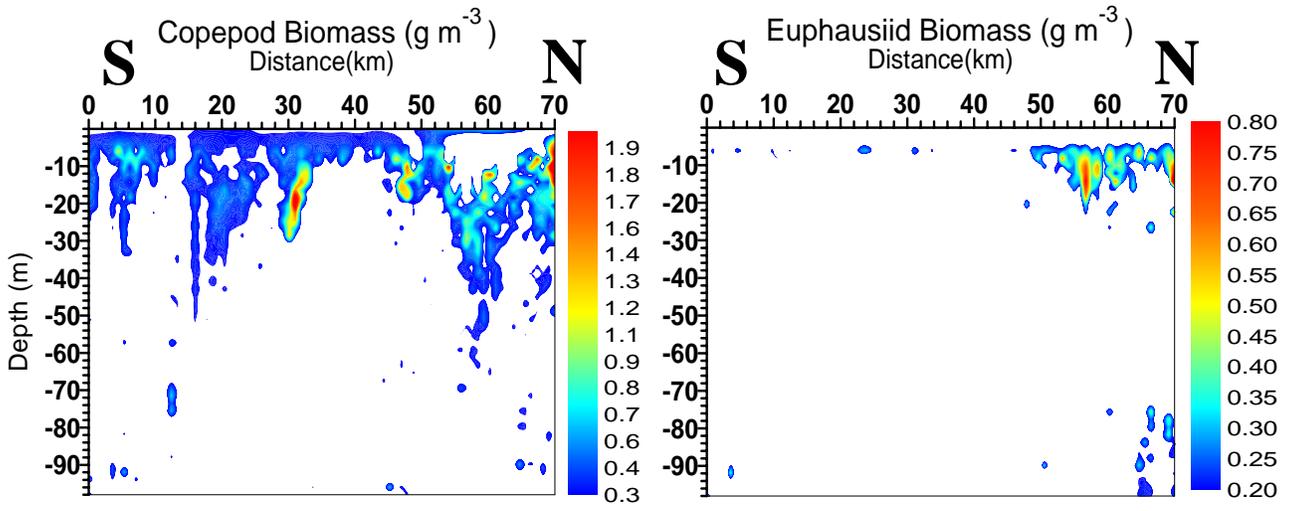


Fig. 4. Acoustically determined copepod and euphausiid biomass, and abundance and biomass (MOCNESS data) of major zooplankton taxa along a transect taken in June 2001 through Seguam Pass. Data are plotted from south to north.

Akutan Pass MOCNESS Stations

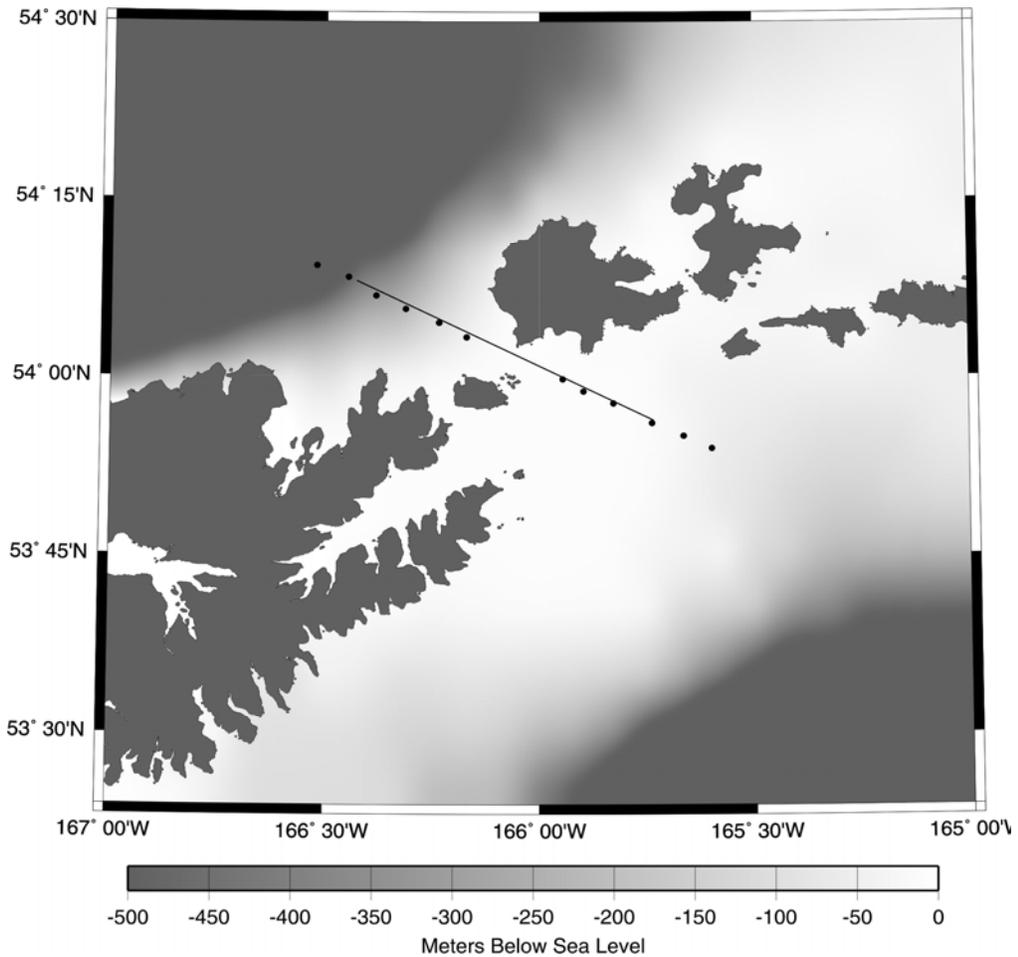


Fig.5. MOCNESS and acoustic transect line through Akutan Pass, taken in June 2001 (black dots are locations of MOCNESS tows, black line is the acoustic transect) .

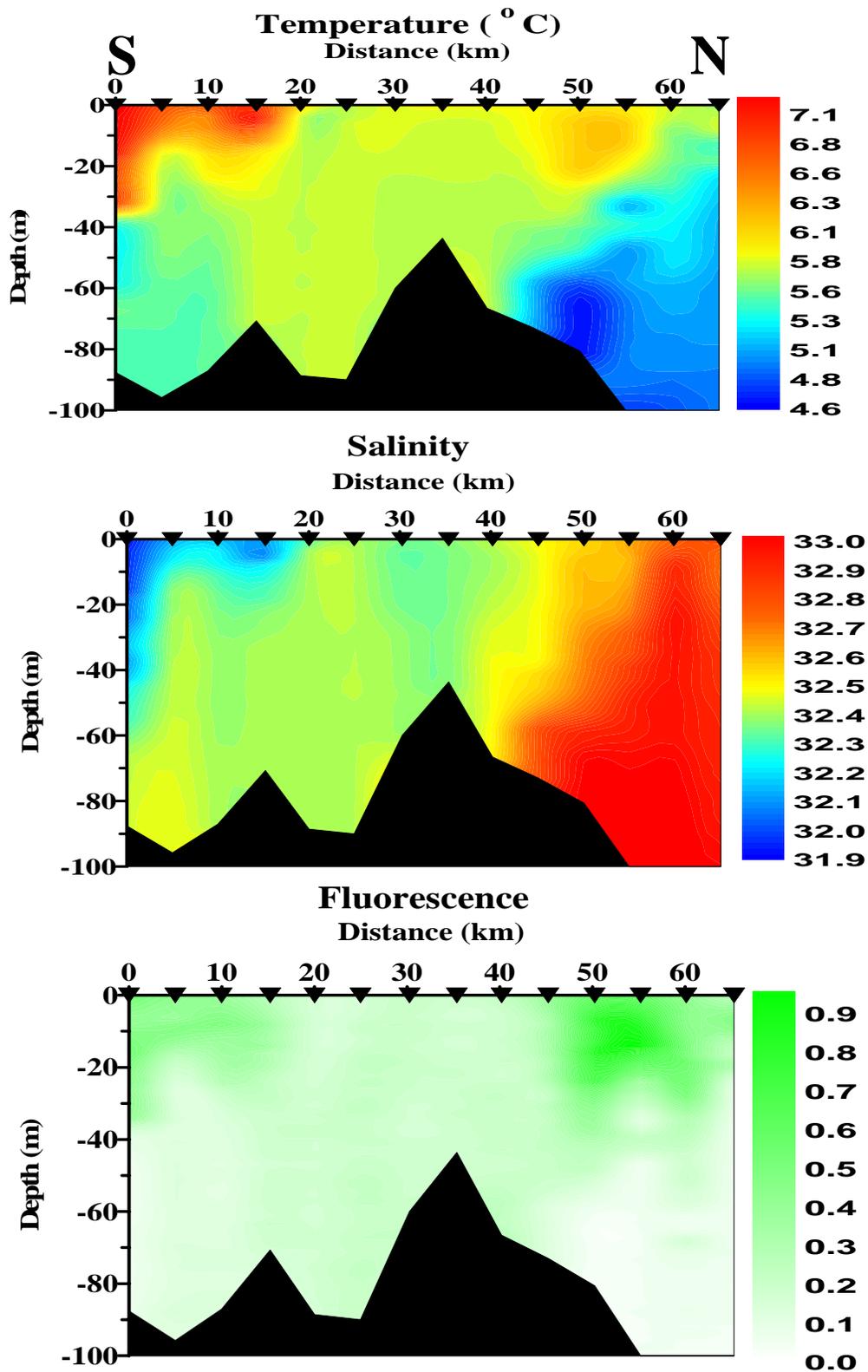


Fig. 6. CTD transect from south to north through Akutan Pass, June 2001. Filled triangles indicate station locations. Fluorescence is in volts.

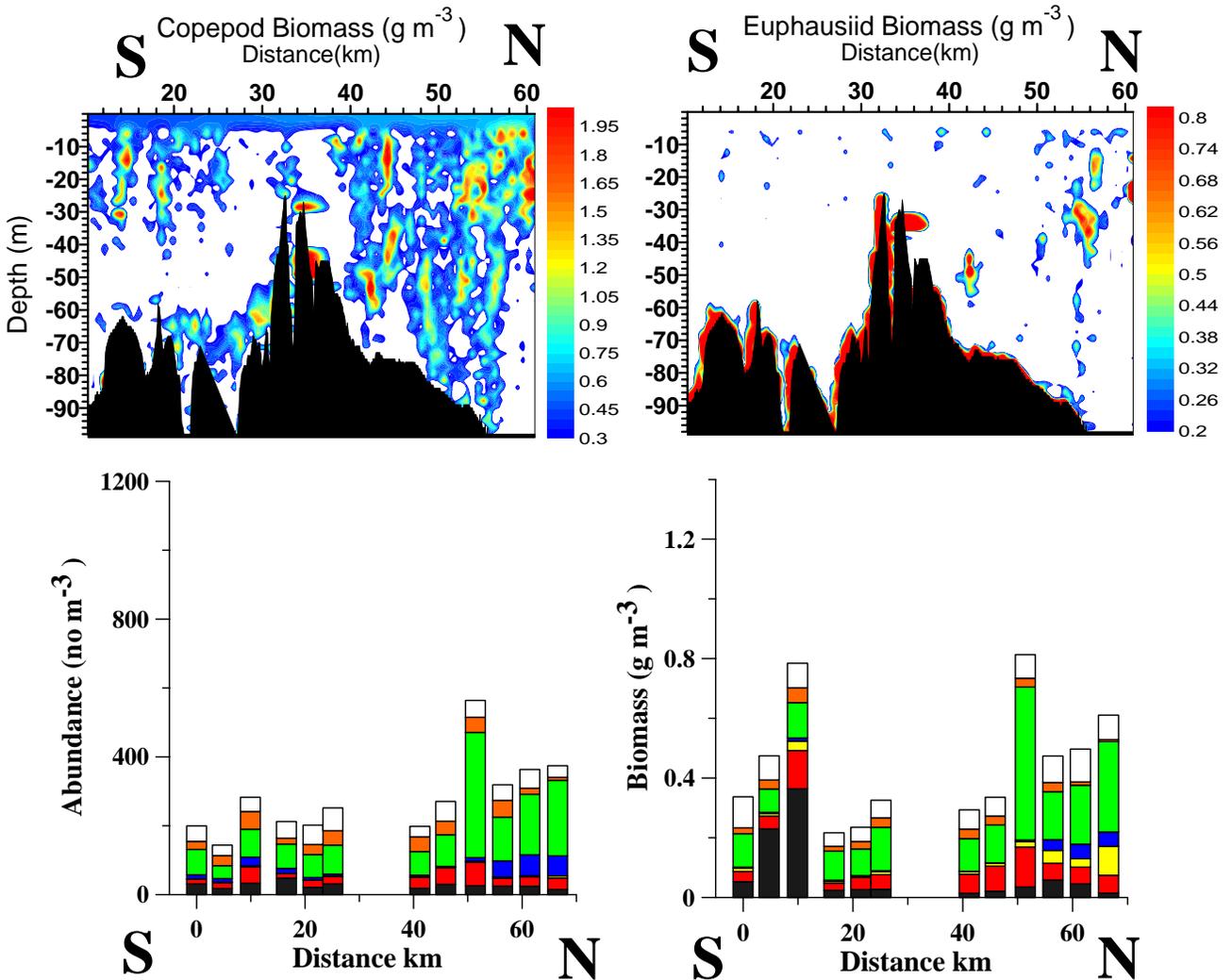
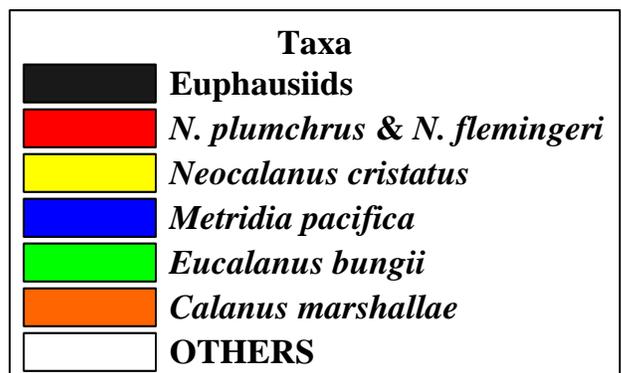


Fig.7. Acoustically determined copepod and euphausiid biomass, and abundance and biomass (MOCNESS data) of major zooplankton taxa along a transect taken in June 2001 through Akutan Pass. Data are plotted from south to north.



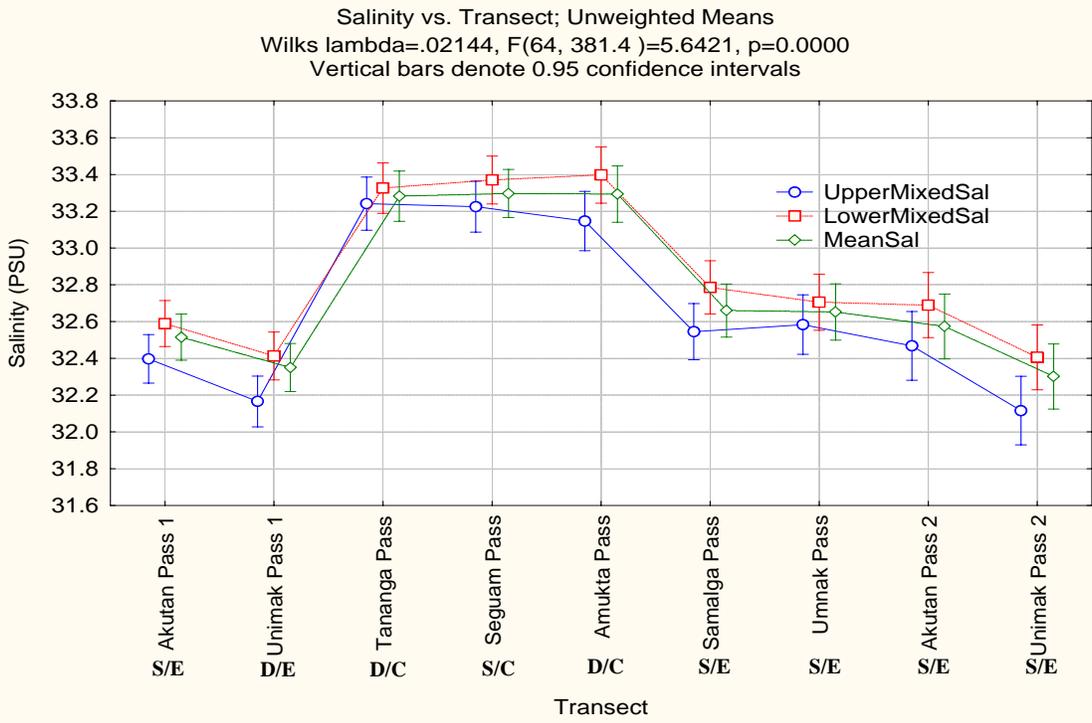
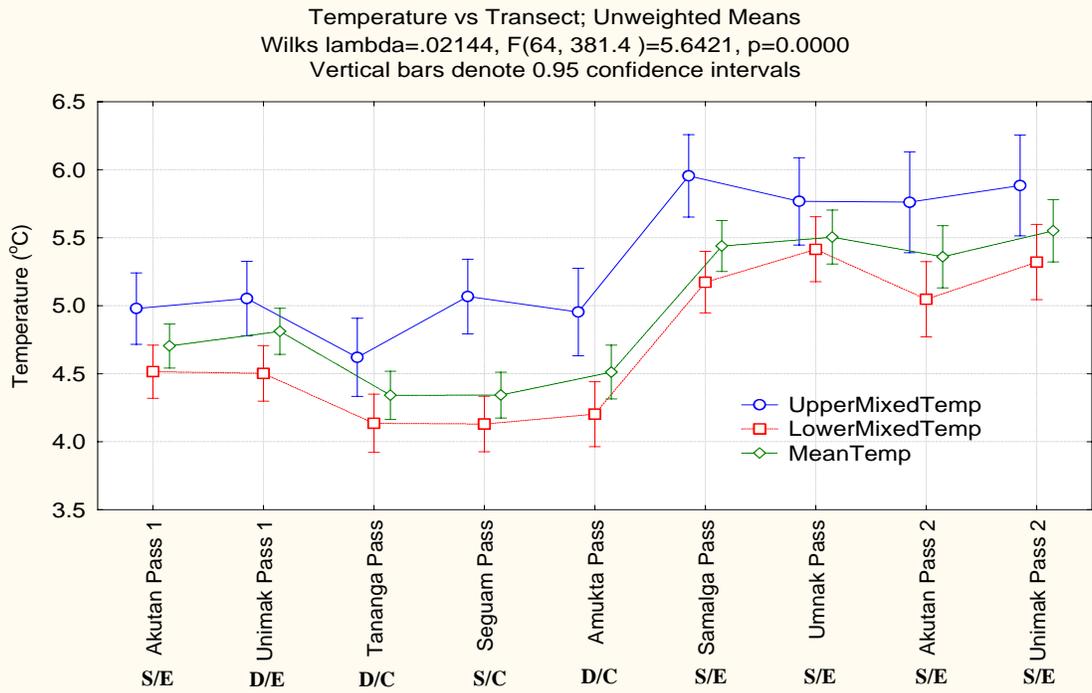


Fig. 8. Mean water column temperature and salinity in the upper 100 m of the eastern and central Aleutian passes in May-June 2002 by transect. Error bars indicate 95% confidence intervals. UpperMixedTemp = Temperature in upper mixed layer; LowerMixedTemp = mean temperature below the thermocline; MeanTemp = mean water column temperature; UpperMixedSal = salinity above the halocline; LowerMixedSal = salinity below the halocline; MeanSal = mean water column salinity. Pass Types: S = Shallow, D = Deep, E = Eastern, C = Central

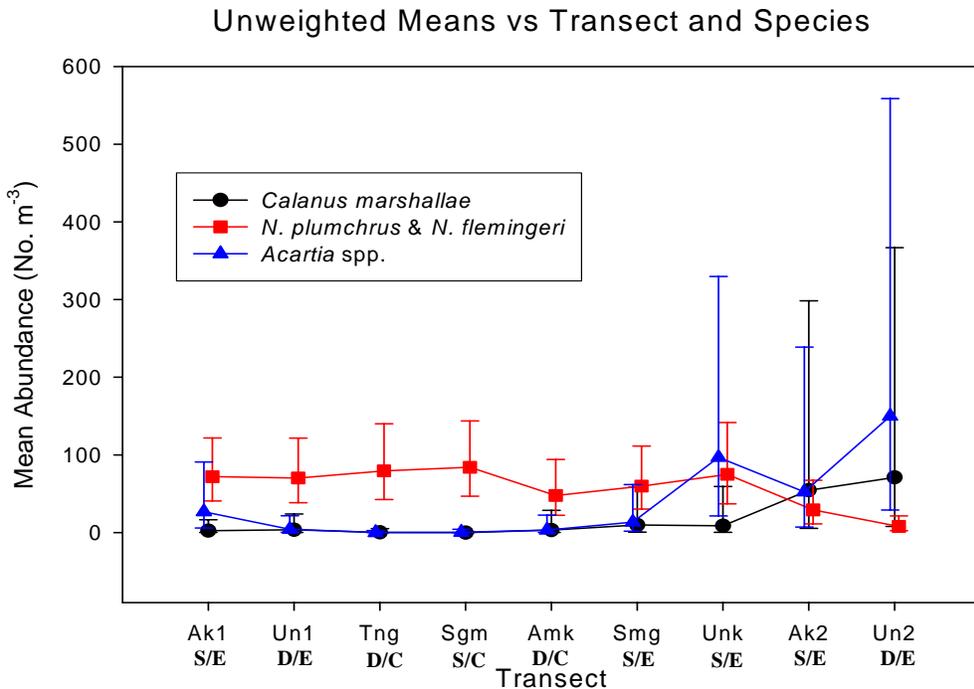
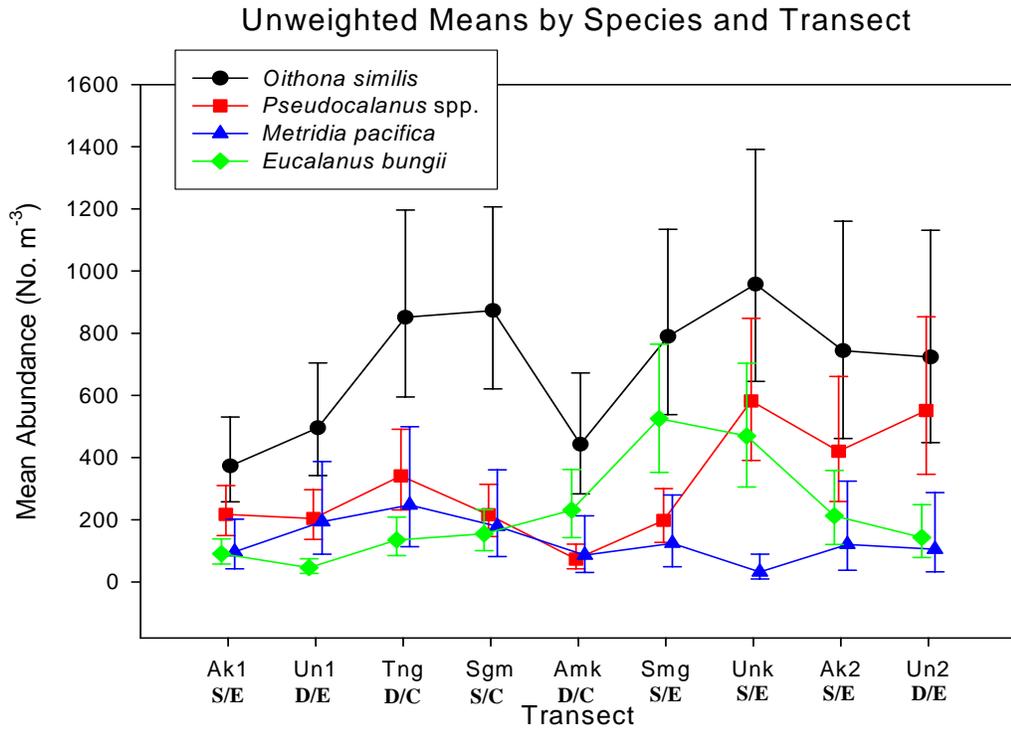


Fig. 9. Mean abundance (CalVET data) of major zooplankton taxa in the central and eastern Aleutian passes (May – June 2002) by transect. Error bars are 95% confidence intervals. Transect designators: Ak1 = Akutan 1, Un1 = Unimak 1, Tng = Tananga, Sgm = Seguam, Amk = Amukta, Smg = Samalga, Unk = Umnak, Ak2 = Akutan 2, Un2 = Unimak 2. See Table 1 for sampling dates and sample sizes. Pass Type: S = Shallow, D = Deep, C = Central, E = Eastern.