NORTH PACIFIC RESEARCH BOARD PROJECT FINAL REPORT

A cooperative pollock acoustic biomass survey for management of fisheries interactions with Steller sea lions in the Aleutian Islands

NPRB Project 730 Final Report

Elizabeth A. Logerwell[1], Steven J. Barbeaux[1] and Lowell W. Fritz [2]

[1] National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, Resource Ecology and Fisheries Management Division, 7600 Sand Point Way NE, Seattle, WA 98115. (206) 526-4231, Libby.Logerwell@noaa.gov

[2] National Oceanic and Atmospheric Administration, National Marine Mammal Laboratory, Alaska Fisheries Science Center, Alaska Ecosystems Program, 7600 Sand Point Way NE, Seattle, WA 98115.

December 2009

Abstract

The objective of our project was to investigate whether cooperative biomass surveys can be an effective way to manage fisheries at the local scales that are important to predators such as Steller sea lions. To satisfy this objective we conducted wintertime acoustic surveys of pollock in the central Aleutian Islands from a NOAA research vessel and from a commercial vessel equipped with scientific quality ES60 echosounders. The surveys took place in February and March 2008. We also collected data on sea lion distribution and diet during the pollock surveys. Multiple calibrations of the acoustic system on the fishing vessel used for the cooperative survey indicated that the system was scientifically reliable. The survey was conducted in a sufficiently brief span of time that there was likely little bias in the biomass estimates due to fish migration. With the NOAA vessel and fishery vessel acoustic data, we documented the distribution of wintertime aggregations of spawning pollock in the central Aleutian Islands, aggregations that were stable within the season and consistent between years. The composition of sea lion diet showed a response to the distribution of pollock, however the distribution of sea lion abundance did not. The distribution of sea lions appeared to be driven by the distribution of Atka mackerel, a prey of Steller sea lions during all seasons. This suggests that sea lion diets respond to small-scale distribution of prey and that seasonal diet changes reflect differences in availability due to seasonal differences in spawning and aggregating of prey species.

Key Words

Walleye pollock (*Theragra chalcogramma*), Steller sea lion (*Eumetopias jubatus*), Aleutian Islands, fisheries interactions, distribution, diet, fisheries acoustics, aerial survey, scat collections, oceanography

Citation

Logerwell, E.A., S.J. Barbeaux and L.W. Fritz. 2009. A cooperative pollock acoustic biomass survey for management of fisheries interactions with Steller sea lions in the Aleutian Islands. North Pacific Research Board Final Report 730, 106 p.

Table of Contents

Tables and Figures

Study Chronology

Reporting period	Specific dates	Activities and accomplishments
	9/1/07	▪ Grant Period start
12/31/07 – 7/1/08	1/15/08	▪ Progress Report submitted
	1/19/08	▪ Poster presentation at AKMSS, S. Barbeaux
	2/16 – 2/29	▪ *RV Oscar Dyson* pollock survey
	3/22 – 3/28	▪ *FV Muir Milach* pollock survey
	3/24 – 3/29	▪ NMML aerial Steller sea lion survey
	4/2 – 4/12	▪ NMML Steller sea lion scat collections
		▪ Pollock acoustic data from both surveys QA/QC, distributions mapped, biomass estimates made
		▪ Pollock maturity and length data QA/QC and analyses conducted
		▪ Steller sea lion aerial survey data QA/QC and distributions mapped
	7/1/08	▪ Progress Report submitted
7/1/08 – 12/31/08		▪ Steller sea lion scat samples analyzed at Pacific ID
		▪ Sea lion diet data analyses conducted: % frequency of occurrence calculated and Principal Component analysis conducted
	1/15/09	▪ Progress Report submitted
1/1/09 – 7/1/09	1/19/09	▪ Poster presentation at AKMSS, E. Logerwell
		▪ Oceanographic data from pollock surveys analyzed
	6/17/09	▪ Progress Report submitted
	9/10/09	▪ Oral Presentation at the Museum of the Aleutians, Dutch Harbor S. Barbeaux
	9/30/09	▪ Grant Period end
	12/18/09	▪ Final Report
	1/18/10	▪ Oral presentations at AKMSS, Barbeaux and Logerwell

Introduction

The Alaska population of Steller sea lions has declined by more than 80% since the 1970s (Loughlin 1998). In 1997 the western population (west of longitude 144° W) was listed as endangered under the Endangered Species Act (ESA). In November 2000 the ESA consultation prepared by the National Marine Fisheries Service (NMFS) concluded that the Alaska groundfish fishery posed a threat to the recovery of the Steller sea lion population (N.M.F.S. 2000). A suite of protection measures was put in place to mitigate potential competition between fisheries and sea lions. These measures included trawl exclusion zones around sea lion rookeries and haulouts to protect sea lion critical habitat (National Research Council 2003). Implicit in the designation of the trawl exclusion zones, which are 10- to 20-nmi in radius, is that competition between fisheries and sea lions is expected to occur at local scales. Global control rules are used to manage rates of fishing mortality at the basin scale (i.e., Bering Sea/Aleutian Islands or Gulf of Alaska) and thus help preserve sufficient prey for sea lions at the large scale. However, there remains concern that local fisheries effects, such as localized depletion or disruption of sea lion prey could impact sea lion foraging success. Thus, advances in Alaska groundfish fisheries management with regard to their impacts on Steller sea lions require new management strategies for assessing groundfish abundance and allocating catch at local scales.

Our primary goal was to investigate whether cooperative biomass assessments and surveys can be an effective way to manage fisheries at the local scales that are important to predators such as Steller sea lions. We addressed this goal by conducting a wintertime acoustic survey of pollock in the central Aleutian Islands from a commercial vessel equipped with scientific quality Simrad ES60 echosounders. Our long-term vision is that one or more commercial fishing vessels conducts hydroacoustic surveys in specific areas of Steller sea lion critical habitat prior to commercial fishing beginning in these areas. Data from the surveys would be used to estimate a biomass for the specific area and these biomass estimates would then be used by to set a quota for the area surveyed that does not jeopardize the foraging success of Steller sea lions. This project was the next step towards this goal of creating a cooperative system for managing fisheries within Steller sea lion critical habitat at finer temporal and spatial scales.

<u>The Aleutian Islands Cooperative Acoustic Survey Study (AICASS)</u>

In March-April 2006 the first AICASS was conducted to assess the feasibility of using a small (< 35 m) commercial fishing vessel to estimate the abundance of pollock in waters off Atka Island in the central Aleutian Islands (Barbeaux and Fraser 2009). Using fishing vessels to collect scientific data for management purposes is a growing trend worldwide (O'Driscoll and Macaulay 2005). For the foreseeable future NMFS does not have sufficient resources to conduct acoustic surveys of pollock stocks throughout the Aleutian Islands, and using fishing vessels to conduct surveys may be a viable alternative. Thus, the AICASS was envisioned as a first step in the development of a cooperative management and monitoring system that would involve the Aleut Enterprise Corporation (the local Alaskan native corporation that has been allocated the Aleutian Islands pollock quota), local fishermen, and NMFS. To verify the acoustic data and provide revenue to offset the vessel costs of the survey, 1,000 mt of walleye pollock was allocated to be harvested within Steller sea lion critical habitat in March 2006. A total of six acoustic surveys were successfully completed and the data were of sufficient quality to calculate estimates of pollock biomass in the surveyed areas over time. Another successful AICASS was conducted in 2007 that covered a larger area of the Aleutians, from Amukta Pass to Amchitka Pass (Romain et al. in prep). The project described in this report represents an expansion on previous AICASS, by combining the acoustic survey with data on sea lion diet and habitat use that is integral to formulating a local-scale pollock and sea lion management strategy.

<u>National Marine Mammal Laboratory (NMML) Steller sea lion studies</u>

Aerial surveys of Steller sea lions on terrestrial haul-out and rookery sites in the Aleutian Islands, and collections of scat for diet information, have been conducted by NMML primarily in spring and during the summer breeding season. While summer aerial survey data are useful for population trend analyses (Fritz and Stinchcomb 2005), winter survey data are crucial to our understanding of responses by lactating, pregnant adult females and recently weaned juveniles to the harsher environmental conditions at this time of year (Kumagai et al. 2006). Steller sea lions are more dispersed in winter than in summer (Sease and York 2003) and spend a greater proportion of their time at-sea foraging for prey that it is also more dispersed and further offshore than in summer (Merrick and Loughlin 1997; Sinclair and Zeppelin 2002). To date, NMML's opportunities to collect information in the Aleutian Islands in winter have been limited. The most recent winter aerial surveys were conducted in March 1993 and March 1999. Scats have been opportunistically collected in winter as part of other winter field work, but due to weather and logistical constraints, only 301 samples have been collected since 1999 in the entire central and western Aleutian Islands. Scat collections indicate that pollock are an important sea lion prey item year-round in the Aleutians (Sinclair and Zeppelin 2002).

This project was designed to obtain fine-scale distribution and diet information and thus to increase our understanding of Steller sea lion predation of patchily distributed pollock as well as the factors affecting their use of terrestrial haul-outs in winter in the Aleutian Islands. This approach has proven successful for understanding Steller sea lion habitat use in Southeast Alaska (Womble and Sigler 2006), and the Gulf of Alaska (Wynne and Foy 2002), but has not been employed in the Aleutian Islands where ~50% of the western Steller sea lion stock in Alaska resides (Fritz and Stinchcomb 2005) and where a commercial pollock fishery operating out of Adak is expected to develop.

Fishery Interaction Team (FIT) studies

To investigate whether fisheries cause local depletions or disruption of sea lion prey fields, FIT has conducted field experiments using a before-after control-impact (BACI) design. This design allows for the comparison of sea lion prey fields before and after commercial fishing in fished and unfished areas. The results of FIT studies to date indicate geographic and temporal variability in the potential response of sea lion prey to commercial fishing (Wilson et al. 2003; McDermott et al. 2005; Conners and Munro 2008). Ancillary data on fish movement, habitat selection, food habits and reproduction have proven useful in interpreting the results of the fisheries interaction studies. Information on local ecology of fish could be used to construct a spatially-explicit model of sea lion prey field dynamics that could predict spatial and temporal shifts in the distribution and abundance of sea lion prey and potential effects of fishing on these prey fields. The research described in this report will provide data on local distribution, abundance, movement and reproduction of pollock in the Aleutian Islands, and thus allow for the first steps in the development and quantification of such a model.

Objectives

This study was a feasibility assessment of a cooperative management system. In order to design an effective cooperative biomass survey we need to know whether the survey data collected by commercial vessels is of sufficiently high quality and resolution, and sufficiently low variability to conduct a biomass assessment at local scales. We also need to know where the fishery would be expected to operate and where Steller sea lions rely on pollock for foraging. Specific information gained from the feasibility study included:

- The scientific quality and statistical properties of the acoustic data
- How long it takes fishing vessels to survey the region
- The biomass of pollock in the region
- The location of pollock aggregations that fisheries would be expected to exploit
- The spatial variability of pollock aggregations
- Which pollock aggregations are important for sea lion foraging

Our secondary research objective was to investigate how local-scale information on fish ecology can be used to assess the potential for fisheries to impact prey availability for top trophic level consumers. We envision a conceptual model of local fish ecology. The conceptual model would incorporate local-scale information on the distribution, abundance and movement of pollock. The conceptual model would also incorporate environmental effects (e.g. oceanographic variability) and biological effects (e.g. spawning behavior of fish). Incorporating commercial fishing into the conceptual model would then allow for the development of scenarios of potential fishing effects on prey availability. A conceptual model that incorporates local fish abundance, behavior, oceanography and fishing could be used to formulate specific hypotheses that could be tested in the field. A conceptual model could also be used to extrapolate the general conclusions from one study area to another. This study provided the following information, useful to designing and potentially quantifying such a conceptual model for the Aleutian Islands:

- Local-scale distribution and abundance of pollock
- Pollock movement
- Spatial and temporal variability in oceanographic conditions
- Spatial and temporal variability in pollock spawning state
- Response of sea lions to variability in pollock abundance and/or spawning condition

Finally, the study provided information needed to evaluate whether a before-after-control-impact (BACI) experiment of the effects of commercial fishing can be designed for the Aleutian Islands. For such a design to be feasible it is necessary that sufficiently similar fished and unfished areas can be designated. It is also critical that there is no movement of fish between these areas. It is important that there is sufficient fishing activity in the study area and that the survey method provides sufficient statistical power to detect an effect. Finally, it is desirable that the BACI study be conducted in an area used by foraging Steller sea lions.

Methods

Study area

The study was conducted during February-March 2008 in the central Aleutian Islands between Amukta Pass and Amchitka Pass (Fig. 1). There are 147 terrestrial haul-out sites used by Steller sea lions in the Aleutian Islands. Of these, 53 are located in the study area; 7 surround Kanaga Sound at Kanaga Island and 9 are in the Atka Island area. The study area also encompasses the possible fishing range of catcher vessels delivering pollock to Adak Island, so it is appropriate for examining the potential impacts of the developing Adak Island small boat fishery. The summer AFSC Aleutian Island bottom trawl survey in recent years (2000, 2002 and 2004) shows high catches of pollock in our study area, particularly in Seguam Pass and in the Delarof Islands. An acoustic survey conducted in winter 2002 on the Japanese R/V Kaiyo Maru showed high densities of pollock north of Atka Island (Barbeaux et al. 2005). The AICASS conducted in winter 2007 indicated that dense aggregations of pollock were likely to occur in discrete locations throughout the study area. To insure the necessary overlap in sea lion and pollock data sets, all efforts were made to synchronize and spatially coordinate the acoustic pollock survey, sea lion aerial surveys and sea lion scat collections (pending favorable weather conditions).

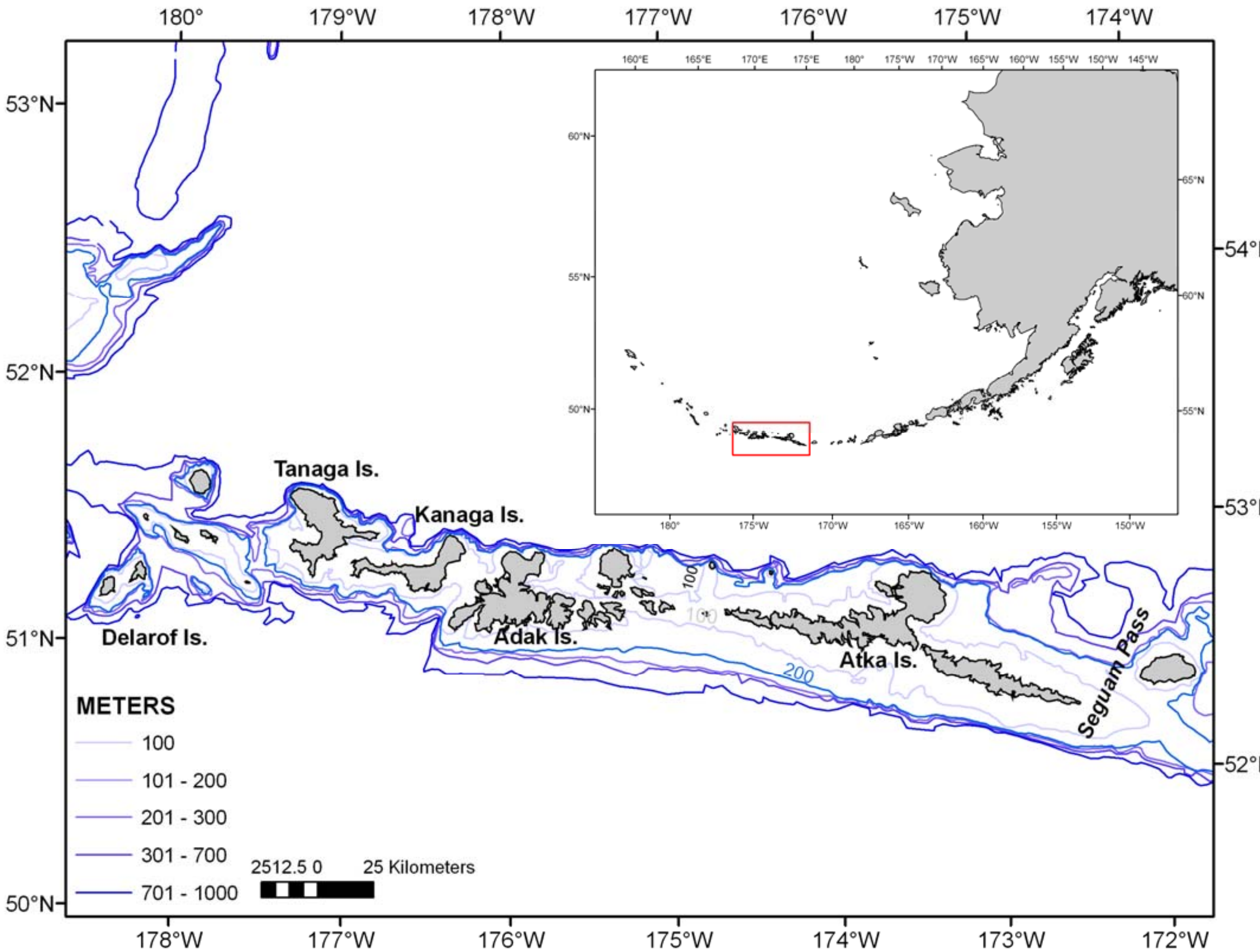


Figure 1. Study area in the central Aleutian Islands (delineated by red box in inset map)

Pollock acoustic surveys

The cooperative acoustic survey was conducted on a commercial fishing vessel in March, at a time consistent with cooperative surveys conducted in 2007 and at a time thought to be near the peak pre-spawning aggregation. An additional survey, supported primarily with NOAA operation funds, was conducted before the cooperative survey on the NOAA research vessel *Oscar Dyson*. Because the *Oscar Dyson* survey occurred before the spawning season, comparing the results of the two surveys allowed for an assessment of pollock movements related to the formation of spawning aggregations and the potential for monthly-scale predictability in pollock distribution to influence sea lion haul-out patterns and diet.

Oscar Dyson survey

During 16-29 February 2008, pollock were surveyed by the *Oscar Dyson* using calibrated scientific echosounders at multiple frequencies, following standard AFSC acoustic survey methodology (Honkalehto et al. 2005). Survey operations were conducted 24 hours per day. The primary echo integration-trawl (EIT) survey operations were conducted during night-time hours (approximately 12 hours per day). Acoustic data were collected continuously along a series of parallel transects. Transect spacing was 2.5 nm. See Figure 2 for transect locations. Transects were sometimes broken to conduct mid-water or bottom trawls for acoustic verification. Transects then resumed at break point when trawling was completed.

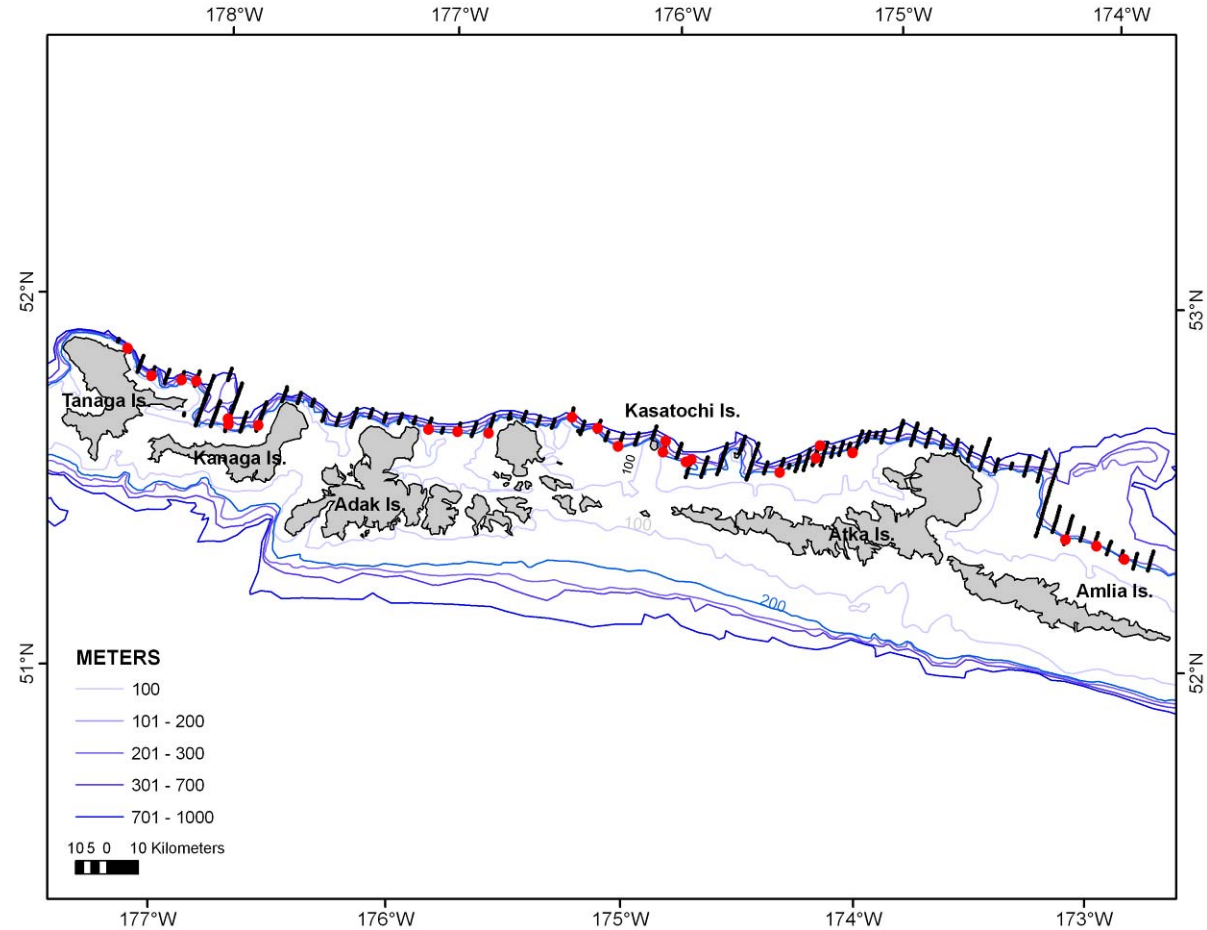


Figure 2. Locations of acoustic transects (black lines) and conductivity-temperature-depth (CTD) stations (red circles) during the *Oscar Dyson* cruise, February 2008.

Acoustic data were collected with a Simrad ER60 quantitative echosounding system. Five split-beam transducers (18, 38, 70, 120, and 200 kHz) were mounted on the bottom of the vessel's retractable centerboard, which extended 9 m below the water surface. System electronics were housed inside the vessel in a permanent laboratory space dedicated to acoustics. Acoustic data were logged using SonarData EchoLog 500. Echo integration data were collected from 14 m (45.9 ft) below the surface to 0.5 m (1.6 ft) off the bottom. Echo integration data were collected simultaneously for all sounder-transducer combinations.

Mid-water and near-bottom echosign was sampled using an Aleutian Wing 30/26 Trawl (AWT). This trawl was constructed with full-mesh nylon wings and polyethylene mesh in the codend and aft section of the body. The headrope and footrope each measured 81.7 m (268 ft). Mesh sizes tapered from 325.1 cm (128 in) in the forward section of the net to 8.9 cm (3.5 in) in the codend. The net was fitted with a 1.3-cm

(0.5-in) codend liner. The AWT was fished with 82.3 m (270 ft) of 1.9-cm (0.75-in) diameter (8x19 wire) non-rotational dandylines, 170.1-kg (250-lb) tom weights on each side, and 5-m^2 Fishbuster trawl doors [1,247 kg (2,750 lb) each]. Vertical net opening and depth were monitored with a Simrad FS70 third wire trawl monitoring system attached to the trawl headrope. The vertical net opening for the AWT trawl ranged from 15-25 m (52-105 ft).

Demersal echosign was sampled with a poly nor'eastern bottom trawl (PNE) with roller gear. The PNE was a high-opening trawl equipped with roller gear and constructed with stretch mesh sizes that ranged from 13 cm (5 in) in the forward portion of the net to 89 mm (3.5 in) in the codend. The codend was fitted with a 3.2 cm (1.25 in) nylon mesh liner. The 27.2-m (89.1-ft) headrope held 21 floats [30-cm (12-in) diameter]. A 24.7-m (81-ft) chain fishing line was attached to a 24.9-m (81.6-ft) footrope constructed of 1-cm (0.4-in) 6 x 19 wire rope wrapped with polypropylene rope. The trawl was rigged with triple 54.9-m (180-ft) galvanized wire rope dandylines. The roller gear was attached to the fishing line using chain toggles [2.9 kg (6.5 lb.) each] comprised of five links and one ring. The 24.2-m (79.5-ft) roller gear was constructed with 36-cm (14-in) rubber bobbins spaced 1.5 to 2.1 m (5 to 7 ft) apart. A solid string of 10-cm (4-in) rubber disks separated some of the bobbins in the center section of the roller gear. Two 5.9-m (19.5-ft) wire rope extensions with 10-cm (4-in) and 20-cm (8-in) rubber disks were used to span the two lower flying wing sections and were attached to the roller gear. The net was fished with the 5-m^2 Fishbuster trawl doors. The vertical net opening and depth were monitored with a Furuno netsounder system attached to the headrope. The PNE trawl vertical mouth opening ranged from 6-8 m (16-23 ft).

Trawl hauls using the midwater and bottom nets were conducted to identify echosign and to provide biological samples (a.k.a. "verification tows"). Individual pollock from verification tows were sampled to determine sex, fork length, body weight, age, and maturity. Maturity was determined by visual inspection and categorized as immature, developing, pre-spawning, spawning, or post-spawning. Other scatterers, primarily Pacific ocean perch (*Sebastes alutus*) were sampled for sex and fork length.

Pollock backscatter was scaled to biomass using pollock biological data from the verification trawls conducted in the study area (Traynor 1996). All fork lengths were binned to the nearest centimeter (cm). Number (N) of pollock at fork length *l* was estimated as:

$$N_{il} = \frac{p_l \times s_A}{4\pi \times 10^{TS_l/10}},$$

where TS_l is the target strength at fork length *l* estimated by using the pollock target strength to length relationship (TS_l = 20 $\log_{10}$ FL – 66 decibels (dB); Traynor 1996), s_A (nautical area scattering coefficient, m^2/nmi^2 ; MacLennan et al. 2002) is the estimated backscatter of pollock, and p_l is the proportion of backscatter attributable to pollock at fork length *l* estimated as:

$$p_l = \frac{f_l\left(10^{TS_l/10}\right)}{\sum f_l\left(10^{TS_l/10}\right)},$$

where f_l is the number of pollock at fork length *l* in the length frequency sample. Biomass (*B*) in metric tons (t) was then estimated as:

$$B = \sum_{l=0}^{\max(l)} N_l \times \frac{\hat{W}_l}{1000},$$

where $\hat{W}_l$ is the weight (kg) at fork length *l* calculated using data aggregated from all verification trawls through a linear regression of the log transformed weight at length data [$\log\left(\hat{W}_l\right) = \alpha + \beta\log\left(FL\right)$ and therefore $\hat{W}_l = e^{\alpha} \times FL^{\beta}$]. An estimate of the variance of the backscatter (σ^2) was derived for each survey using a one-dimensional (1d) geostatistical method (Petigas 1993; Williamson and Traynor 1996). The 1d geostatistical method was used to compute a measure of precision because it takes into account the spatial structure of the pollock aggregations and survey design. It should be noted that the variance of the estimation only quantifies transect sampling variability and does not include other sources of error (e.g. target strength, trawl sampling).

Water temperature and salinity profile data were collected at selected locations with the vessel's Sea-Bird conductivity-temperature-depth (CTD) system. CTDs were deployed opportunistically throughout the survey, primarily during the day, at water depths from 100 to 200 meters (Fig. 2). Additional CTD casts were made at selected areas, shown on Figure 2. In these areas, CTDs were deployed at water depths around 100 to 200 meters and around 500 meters. A total of 26 CTD casts were made during this cruise. Water samples for chlorophyll and salinity were collected during CTD casts using Niskin bottles on the CTD rosette.

Chlorophyll biomass was obtained from satellite-collected data. CoastWatch offers chlorophyll-a concentration from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on NASA's

Aqua satellite. NASA's Goddard Space Flight Center (GSFC) receives raw satellite data. Processing is accomplished using the SeaWiFS Data Analysis System (SeaDAS) software (Fu et al. 1998). An atmospheric correction is applied to the data to yield a measurement of water leaving radiance (Gordon and Wang 1994, Shettle and Fenn 1979). These radiances are processed to chlorophyll-a concentration using the NASA developed OC3M algorithm (O'Reilly 2000). Validation is accomplished by comparison with in situ ocean color measurements. In situ measurements are gathered by buoys as part of the Marine Optical Characterization Experiment (MOCE). Data is made available at 5.5km resolution for the Pacific basin. Chlorophyll-a concentrations are accurate to within 40%. The data are mapped to an equal angle grid of 0.05 degrees latitude by 0.05 degrees longitude using simple arithmetic means to produce composite images of various duration (8-day and monthly). Because clouds obscured much of the survey area during the time of the survey, we examined the monthly composite for February 2008.

We had intended to release three satellite-tracked drifters at points distributed throughout the survey area, but the purchase order was not initiated in time for the drifters to be delivered from the manufacturer and shipped to Alaska for the survey.

Muir Milach survey

A cooperative acoustic survey of pollock in the Aleutian Islands was conducted from 23-27 March, 2008 on the fishing vessel *Muir Milach*. In previous years (2006-2007) the survey was executed under an exempted fishing permit (EFP) granted to the Aleut Enterprise Corporation. However, results from the winter 2007 cooperative survey indicated that it was not likely that pollock biomass inside sea lion critical habitat would be sufficient to allow for an EFP. Instead, the vessel was chartered to conduct the survey. The survey focused on the portion of the central Aleutian Islands where large aggregations of spawning pollock were observed in winter 2007. This is the area from Kanaga Sound to North Cape of Atka Island (Fig. 3). The vessel conducted the acoustic survey with 2.5 nm transect spacing (the same transects as the *Oscar Dyson* survey conducted earlier), covering the study area in approximately 4 days.

The FV *Muir Milach* was equipped with Simrad ES60 echosounders with 38 kHz split beam transducers (sphere calibrated prior to survey), and was equipped for pelagic pollock fishing. All verification tows were conducted using one of two Aleutian wing pelagic trawls with 8.9 cm mesh codends equipped with 3/8” knotless net liners. The trawls were commercial fishing trawls constructed with full-mesh nylon wings, and polyethylene mesh in the codend and aft section of the body. Mesh size of the net tapered from 110 cm in the forward section to 8.9 cm in the codend. Verification tows were conducted during the

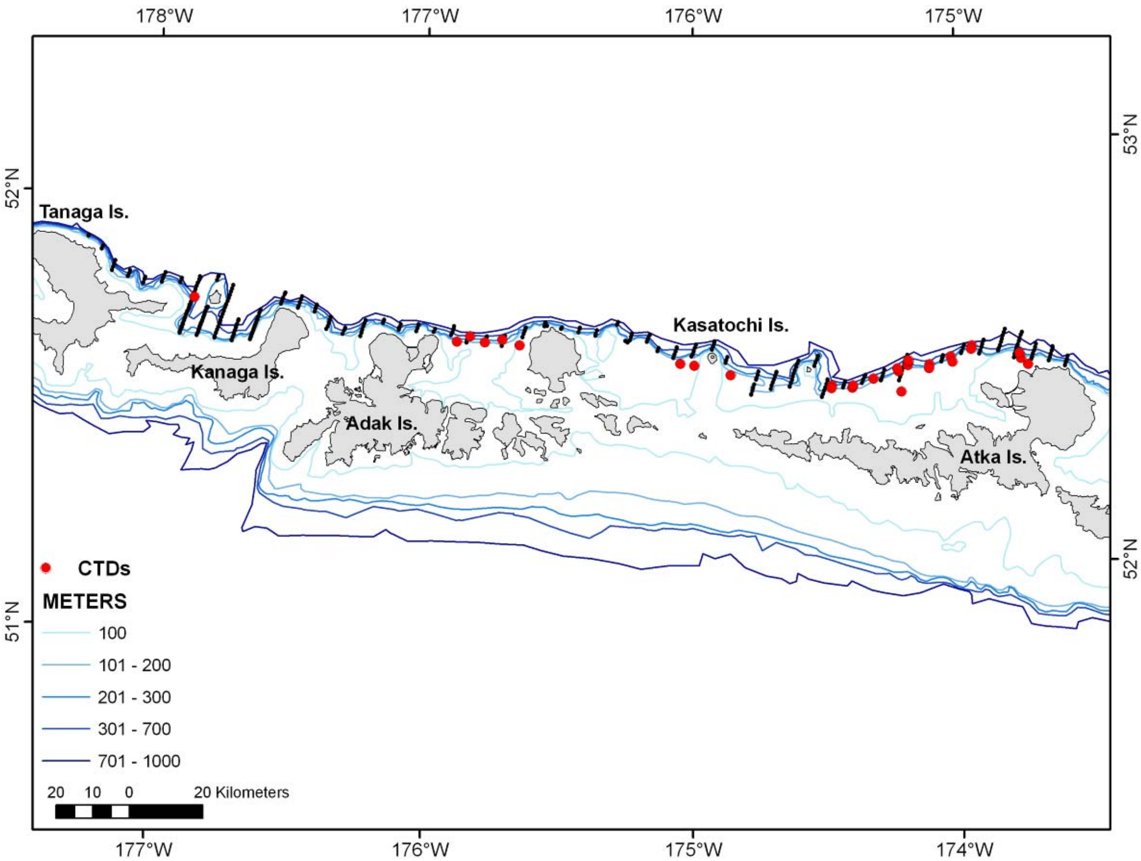


Figure 3. Locations of acoustic transects (black lines) and conductivity-temperature-depth (CTD) stations (red circles) during the *Muir Milach* cruise, March 2008.

survey to determine the species composition and biological attributes of the observed acoustic sign. All verification catch was accounted for by weighing it at sea on a motion-compensated platform scale and discarded at sea.

A sonar-self noise test for the *Muir Milach* acoustic system was conducted on 15 February 2006 when the vessel was being evaluated for use in this study (Barbeaux and Fraser 2009). Data were recorded while the echosounder was set to passive and the engine throttle was increased in 200 rpm increments every 2 minutes until maximum engine speed was reached. The data were imported into Echoview and the time-varied gain (TVG) and absorption were removed throughout the range of the data to obtain a reference noise estimate (S_v dB re $1m^{-1}$) at 1 m from the transducer for every second of data collection. Noise level at a range of 500 m was simulated by adding the expected time varied gain (TVG) and absorption at 500 m to the reference noise estimate using the formula:

$$s_v @ 500m = s_v @ 1m + [20\log_{10}(500)] + [2\alpha(500)],$$

where α = absorption coefficient, here 0.00975 dBm^{-1} (Simmonds and MacLennan 2005). Since our integration threshold levels were to be set at -70 dB, a value of -80 dB was chosen as a maximum noise level at 500 m in order to attain at least a 10:1 signal to noise ratio and the rpm level which came closest to but did not exceed this level was chosen as the optimal surveying speed. During the survey the signal to noise ratio was regularly checked visually between transects by setting the system to passive, resetting the integration threshold to -80db and reviewing the data for any signal above the threshold at depths less than 500 m.

Standard sphere calibrations (Foote 1985) of the echosounder system were conducted before the survey in Scabbard Bay on Adak Island, Alaska. The *Muir Milach* was anchored by the bow and stern during the calibrations. Acoustic system settings were recorded and physical oceanographic conditions were measured using the Sea-Bird CTD system. A 38.1 mm tungsten carbide sphere was suspended below the transducer using three manual downriggers. The calibration sphere was stabilized in the water column by suspending a 2.2 kg lead sphere on the same line 5 m below the calibration sphere. On-axis measurements were recorded for 10 minutes, and then the calibration sphere was moved systematically through the acoustic beam in order to map the beam pattern.

Biological data were collected from all echosign verification hauls including species composition, pollock fork length (300 per tow to the nearest cm), pollock individual weight (50 per tow measured on an electronic motion-compensated scale to 0.01 kg), and pollock otoliths (for age determination - 50 per tow). Maturity was assessed for all measured female pollock by visual inspection and categorized as immature, developing, pre-spawning, spawning, and post spawning. Fork length measurements of other dominant species, such as Pacific ocean perch were made.

Processing the *Muir Milach* acoustic survey data entailed removing the ES60 triangle wave dither, scrutinizing the data, creating bottom lines, and producing spatially and temporally indexed backscatter densities. The ES60Adjust Version 1.6 software package (Kieth et al. 2005) was used to remove the triangle wave dither. The data was scrutinized using Echoview software, removing areas of incomplete transmission (missing pings) and partitioning the data into regions of pollock, non-pollock (e.g. Pacific ocean perch, myctophidae, etc.), and small unidentified scatterers based on the species composition of verification trawls. Each transect was divided into 0.5 nm horizontal elementary sampling distance units

(ESDU). The depth limit of data analysis was 500 m. Pollock backscatter was scaled to biomass using pollock biological data from the verification trawls and an estimate of the variance of the backscatter was derived for the survey using a 1-d geostatistical method, as described for the *Oscar Dyson* survey.

Water temperature and salinity profile data were collected at selected locations with a calibrated Sea-Bird SBE19-plus conductivity-temperature-depth (CTD) probe housed in a protective cage. CTDs were deployed opportunistically throughout the survey at water depths from 100 to 600 meters (Fig. 3). A total of 30 CTD casts were made during this cruise. Satellite-derived chlorophyll data were obtained as described above for the *Oscar Dyson* survey. Examination of 8-day and monthly composites revealed that the best data coverage (least amount of survey area obscured by clouds) was for the 8 day composite from February 26 to March 4, 2008. So although this time period was before the late March *Muir Milach* survey, we opted to use these data to optimize spatial coverage.

Comparison of pollock distributions

To evaluate whether significant changes in pollock geographical distribution occurred between the two acoustic surveys, a statistical test was used which is based on a modified Cramer-von Mises (CvM) statistic (Syrjala 1996). This test is dependent on the spatial scale selected. This procedure calculates a test statistic as the sum of the squares of the differences between the cumulative distribution functions of walleye pollock biomass from the two samples. Significance of the test statistic is determined with a randomization test. Because sea lion behavior can result in an integration of environmental effects over space, pollock distribution data was analyzed at a variety of scales from individual transects to aggregations over several transects at 2.5-, 5-, 10-, 20-, 40-, and 80-nm longitudinal blocks.

<u>Steller sea lion surveys</u>

Aerial surveys for abundance, distribution and age/sex composition

The aerial photographic Steller sea surveys were conducted using a Canon EOS-1DS Mark II digital camera (using a 50 mm lens, manual focus set to infinity, with forward image motion compensation) mounted in the belly (vertical photographs) of a NOAA AOC Twin Otter (N56RF). The camera was set to aperture priority and aperture was set at 5.6. Most sites were photographed at an altitude of 750 ft with the exception of some sites which were photographed in the 850-1000 ft range due to local topography. Known rookery and haul-out sites were surveyed in the Central Aleutian Islands from Seguam Island through the Delarof Islands (52.359°N 172.316°W to 51.216° 179.128°W). A total of 59 sites were successfully surveyed either by recording the number of animals present if there were less than 10 animals or by taking digital photographs when there were more than 10 animals at a site.

A complete survey of all 59 Steller sea lion haulout sites in the study area was completed on 24-25 March 2008; sites west of Adak were surveyed on 24 March and sites east of Adak were surveyed on 25 March. A second, replicate survey was attempted on 26 and 29 March, but low ceilings, wind, and snow limited the replicate survey to 39 of the 59 sites in the area. Due to icing conditions, wind, and fog, we were able to fly on only 4 of the 10 survey days available to us in Adak.

Diet studies

A total of 301 scat (fecal) and 5 spew samples were collected at 10 haulout sites in the study area between Kanaga and Amlia Islands from 2-12 April, 2008. These samples were individually collected and labeled by site, shipped back to Seattle where identifiable hard parts were screened and sent to Pacific ID (Vancouver BC) for prey species identification.

Because we only had 10 spatially distinct diet samples, we were unable to analyze scat data at a variety of scales (1-, 2-, and 4-degree longitudinal blocks) as proposed. Instead, we used principal component (PC) analysis to investigate the spatial and diet differences in the survey area. All species or species groups with a % frequency of occurrence (%FO) greater than 10% were used in the PC analysis, a threshold also used by (Sinclair and Zeppelin 2002). The species included were Atka mackerel (*Pleurogrammus monopterygius*), rockfish sp. (*Sebastes* sp.), pollock, Pacific cod (*Gadus macrocephalus*), Irish lord sp. (*Hemilepidotus* sp.), smooth lumpsucker (*Aptocyclus ventricosus*), and salmon.

<u>Hypotheses tested</u>

Analyses of the sea lion, pollock and oceanographic data were directed by the following conceptual model: Geographic patterns in Steller sea lion haul-out and diet composition are directly related to pollock distribution/abundance; and indirectly related to water column structure, and satellite-derived chlorophyll. Specific hypotheses to be explored are:

1) sea lions are more abundant at haul-outs near areas where pollock are more abundant,

2) pollock are more abundant where the water column is mixed, surface temperatures are cold and satellite-derived chlorophyll is high,

3) sea lions are more abundant at haul-outs near areas where pollock are aggregated for spawning compared to areas where pollock are not aggregated,

4) the proportion of spawning pollock is higher where the water column is mixed, surface temperatures are cold, and satellite-derived chlorophyll is high,

5) pollock occur more frequently in the diets of sea lions at haul-outs where pollock are more abundant,

6) sea lions are more abundant at haul-out near areas where pollock distribution is predictable (at the temporal scale of months).

Results

<u>Acoustic calibration and self-noise tests</u>

Acoustic system calibrations were conducted throughout the survey studies (Table 1), two in 2006, one in 2007, and one in 2008. S_A plus gain correction factors between -2.11 dB and -2.15 dB were obtained for the four calibrations with a mean of -2.14 dB. There were no significant differences in gain parameters or transducer beam characteristics observed for all calibrations (Figs. 4 and 5). The point estimate for the 2008 S_A plus gain calibration correction factor was the same as the initial 2006 calibration point estimate to the nearest 0.01 dB. The higher variance of the 2008 estimate can be explained by some fish interference with the calibration sphere and more movement of the sphere during calibration.

Table 1.Simrad ES 60 38kHz acoustic system settings on the FV *Muir Milach* during 2006-2008 AICASS and results from standard on-axis sphere calibrations

		Calibrations			
	Survey System Settings	March 10, 2006	April 5, 2006	April 14, 2007	March 23, 2008
Echosounder:	Simrad ES 60	--	--	--	--
Transducer:	ES38B	--	--	--	--
Frequency (kHz):	38	--	--	--	--
Absorption coefficient (dB/km):	10	--	--	--	--
Pulse length (ms):	1.024	--	--	--	--
Band width (kHz):	2.43 (wide)	--	--	--	--
Transmitted power (W):	2000	--	--	--	--
Angle sensitivity:	21.9	--	--	--	--
2-way beam angle (dB):	-20.6	--	--	--	--
Transducer gain (dB):	26.5	25	25	25	25
S_A Correction (dB):	--	-0.65	-0.61	-0.62	-0.65
Total S_A + Gain Correction	--	-2.15	-2.11	-2.12	-2.15
Number of single targets		1,822	326	1742	857
σ of S_A +Gain Correction	--	0.02	0.02	0.01	0.04
Range (m)	500	--	--	--	--
Post-processing Sv threshold (dB):	-70	--	--	--	--
Standard sphere TS (dB):	--	-42.50	-42.60	-42.52	-42.73
Mean TS (dB)from calibration	--	-45.32	-45.23	-45.28	-45.54
Range of measured TS (dB):	--	0.2	0.2	0.2	0.9
Sphere range from transducer (m)	--	19.25	21.5	17.2	30.5
Water temp (^oC)					
at transducer:	--	3.55	3.89	3.9	2.62
at sphere:	--	3.6	3.78	3.75	2.78
Water salinity (PSU)					
at transducer:	--	32.33	33.15	33.12	32.88
at sphere:	--	33.13	33.21	33.19	32.95
Absorption dB/m	--	0.00994	0.01024	0.01024	0.01038
Speed of sound m/s	--	1461.33	1463.8	1463.67	1459.55

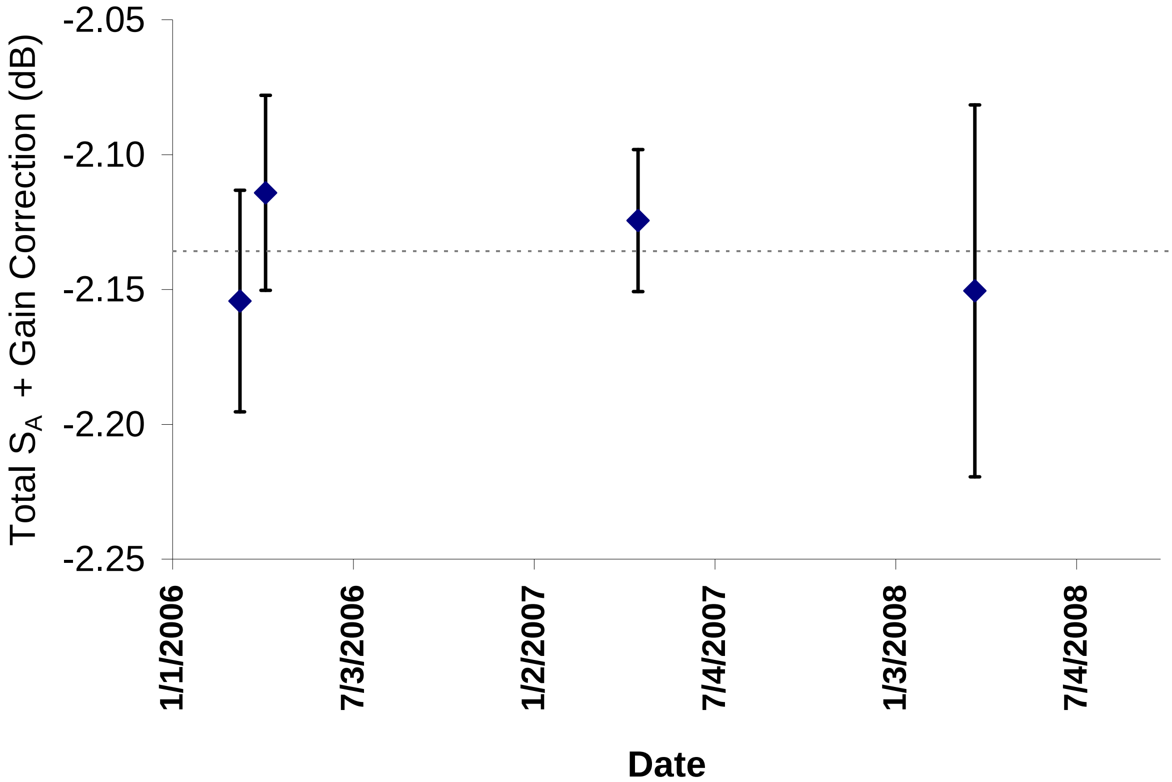


Figure 4. Total S_A plus gain correction for the calibration of the *Muir Milach* 2006 through 2008 with a normal approximation of the 95% confidence intervals for each. The dotted line is the mean (-2.14 dB) for the four calibrations.

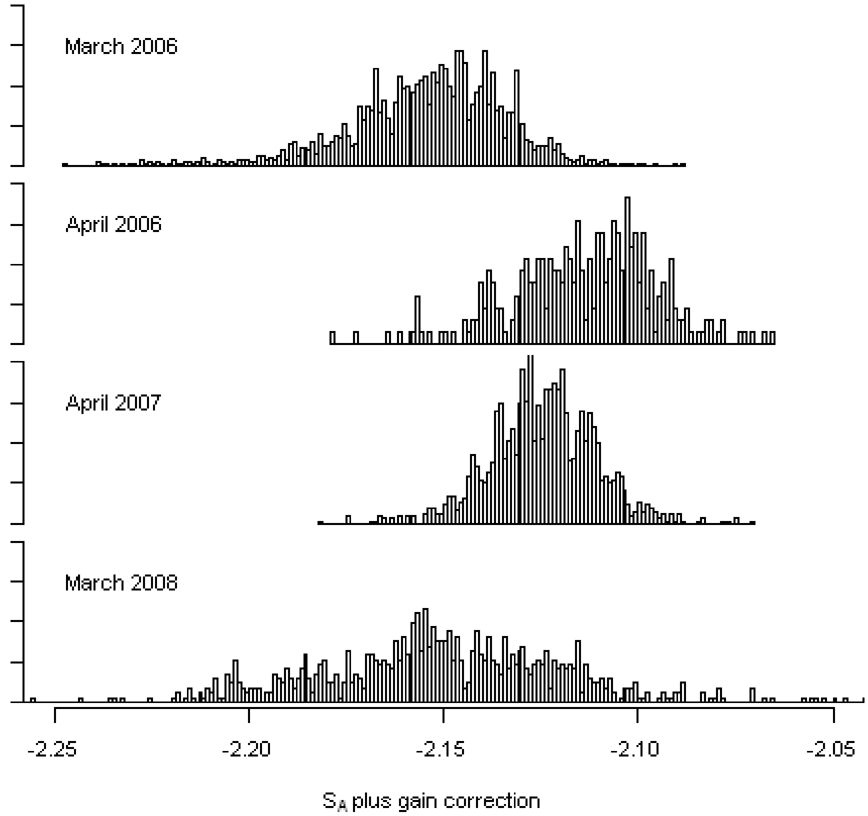


Figure 5. Distribution of SA plus gain correction (dB) for individual single targets for 2006 through 2008 calibrations of the *Muir Milach*.

A sonar-self noise test was conducted on 15 February 2006 in approximately 60 m of water. The test revealed a steep incline in noise with increases in engine rpm (Fig. 6). It was determined for optimum performance the engine speed needed to remain below 1,200 rpm while conducting the survey. This engine rpm level resulted in a surveying speed of between 4 and 8 knots, depending on the direction and speed of the current and wind. During calibration it was discovered that an air compressor needed for the steering hydraulics was installed to a bulkhead near the transducer and created a significant amount of noise, greatly affecting the acoustic data quality. The running compressor vibrated the transducer casing introducing interference physically through the receiver. This wasn't discovered during the sonar-self noise test because the compressor was intermittent with a cycle of about 10-15 minutes. To eliminate this noise source the compressor was taken off-line while surveying and the hydraulics were connected to a smaller compressor located away from the transducer. The noise characteristics of the vessel were checked intermittently throughout the duration of the studies by running the echosounder with the transponder turned off and assessing the received noise levels. Besides the problem with the compressor, no other noise-related problems were encountered. Noise checks were conducted repeatedly during the 2008 study during cross transects by setting the transducer to receive only, setting the minimum threshold value to -80 dB, and running the vessel at 1,200rmp. The noise levels remained below the threshold levels to a range of 500 m for all checks.

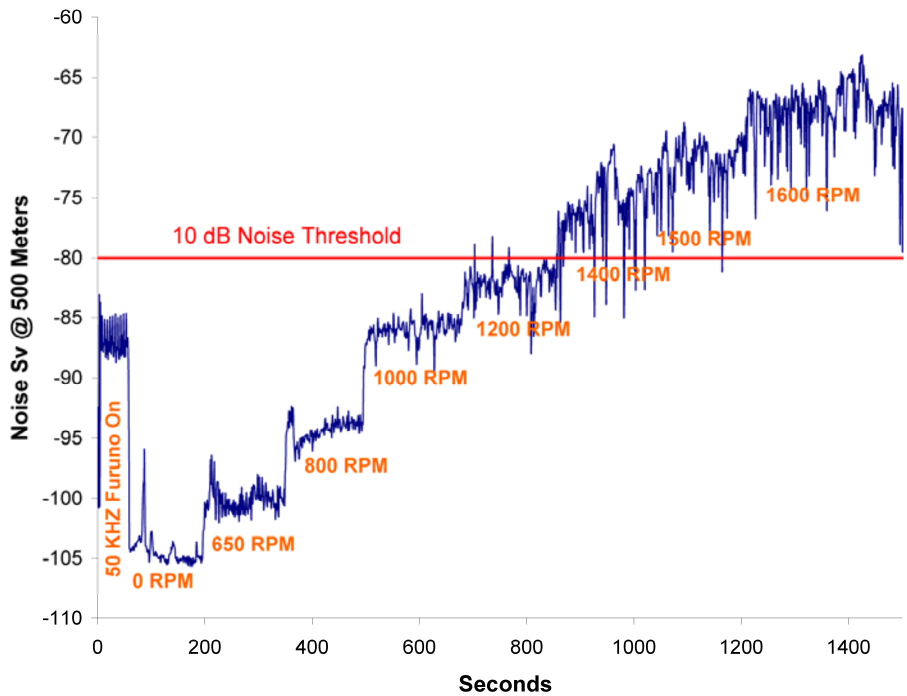


Figure 6. *Muir Milach* sonar-self noise test with -80 dB threshold.

<u>Pollock acoustic surveys</u>

Both of the 2008 pollock acoustic surveys conducted under the NPRB grant were completed successfully. The first survey, conducted by the *Oscar Dyson* 16-29 February collected acoustic data on 2.5 nm spaced parallel transects for the area between 173° W and 178° W longitude. A total of 14 verification trawls were conducted resulting in 6,504 kg of catch, composed of 45 species or species groups. A total of 99% of the catch was composed of six species (49% Walleye pollock (pollock; *Theragra chalcogramma*), 29% Pacific ocean perch (POP; *Sebastes alutus*), 17% Pacific cod (*Gadus macrocephalus*), 3% northern rockfish (*Sebastes polyspinus*), 1% arrowtooth flounder (*Atheresthes stomias*), and 1% Northern lanternfish (*Stenobrachius leucopsaurus*)). Measurements of length and individual weights were taken on pollock, POP, and Pacific cod. Length measurements were also taken on all species of Myctophidae encountered, northern smoothtongues (*Leuroglossus shmidti)*, arrowtooth flounder, and northern rockfish. The *Oscar Dyson* acoustic survey resulted in a pollock biomass estimate of 36,135 t for the entire surveyed area (Table 2). Five main pollock aggregations were apparent from the *Oscar Dyson* survey (Fig. 7a); the first, and largest, was located inside Barbarof Island north of Kanaga Island (Kanaga aggregation; ~17,161 t centered at 177.8° W longitude; ~90 km from the port of Adak by boat), the second aggregations was north of Adak Island (Adak aggregation; ~3,409 t centered at 176.6° W longitude; ~20 km from the port of Adak by boat), the third aggregations was on either side of Kasatochi Island (Kasatochi aggregation; ~2,738 t between 175.4° W to 176 ° W longitude; ~90 km from the port of Adak by boat), the fourth aggregations was located north of Atka Island west of North Cape, on what fishers refer to as “The Knoll” (Atka aggregation; ~3,681 t centered at 174.5° W longitude; ~140 km from the port of Adak by boat), and the fifth aggregations was located north of Amlia Island east of Nazan Bay, on what fishers refer to as “Atka flats” (Amlia aggregation; ~8,982 t centered at 173.5° W longitude; ~200 km from the port of Adak by boat).

The second survey, conducted by the *Muir Milach* 23-27 March, collected acoustic data on the same parallel transects as the previous survey but for a smaller region (174.17° W to 178° W longitude). A total of 4 verification tows were conducted resulting in 5,294 km of catch composed of seven species; 84% pollock, 15% POP, 1% Pacific cod, and the remaining 1% composed of smooth lumpsucker (*Aptocuclus ventricosus*), northern smoothtongue, unidentified squid (*Teuthoidae sp.*) and Myctophidae species.

Table 2. Abundance of pollock in the 2008 pollock acoustic surveys

Region	*Oscar Dyson* 2008			*Muir Milach* 2008	
	Pollock Biomass (t)	Prop of Exp Survey	Prop of Survey	Pollock Biomass (t)	Prop of Survey
Expanded Survey (173°-178° W)	36,135	1			
Survey (174.2°-178° W)	27,128	0.75	1	29,041	1
Kanaga (Trans. 1-15)	16,927	0.47	0.62	14,260	0.49
Adak (Trans. 16-28)	3,409	0.09	0.13	1,984	0.07
Kasatochi (Trans. 30-40)	2,738	0.08	0.10	520	0.02
Atka (Trans. 41-58)	3,681	0.10	0.14	12,224	0.42
Amlia (Trans. 60 - 73)	8,982	0.25			

Measurements of length and individual weight were taken on pollock, Pacific ocean perch, and Pacific cod. The *Muir Milach* acoustic survey resulted in a biomass estimate of 29,041 t (±15,666 t) (Table 2). This survey covered a smaller area than that covered in the first survey and excludes the region in which the Amlia aggregation was located. For the same transects and area covered, the *Oscar Dyson* survey had a biomass estimate of 27,128 t (±10,522 t). Because we used a 1 d geostatistical method for estimating error between surveys, the increase in the estimated error between the first and second survey was due to an increase in the patchiness of the distributions and does not reflect a change in measurement error between vessels. The CvM statistic revealed no significant difference between the distribution of pollock observed by the two surveys with $\psi = 1.19$ (p-value = 0.11) at the individual transect level (2.5 nmi spacing). The CvM statistic increased with decreasing resolution (Table 3). Although the general areas of distribution remained the same (Fig. 7a), the cumulative distribution plots of proportion of the pollock biomass by transect for the two surveys (Fig.7b) show an apparent eastward shift in biomass concentration from the Kanaga , Adak, and Kasatochi aggregations to the Atka aggregation between the first and second survey. For the *Muir Milach* survey the Kanaga aggregation remained the largest with ~14,397 t, the Atka aggregation was second with ~12,217 t, the Adak and Kasatochi aggregations had ~1,984 t and 520 t respectively. It should be noted that the Kasatochi aggregation was nearly dissipated during the *Muir Milach* survey and probably would not have been set apart as a distinct aggregation had it not been observed in the previous surveys.

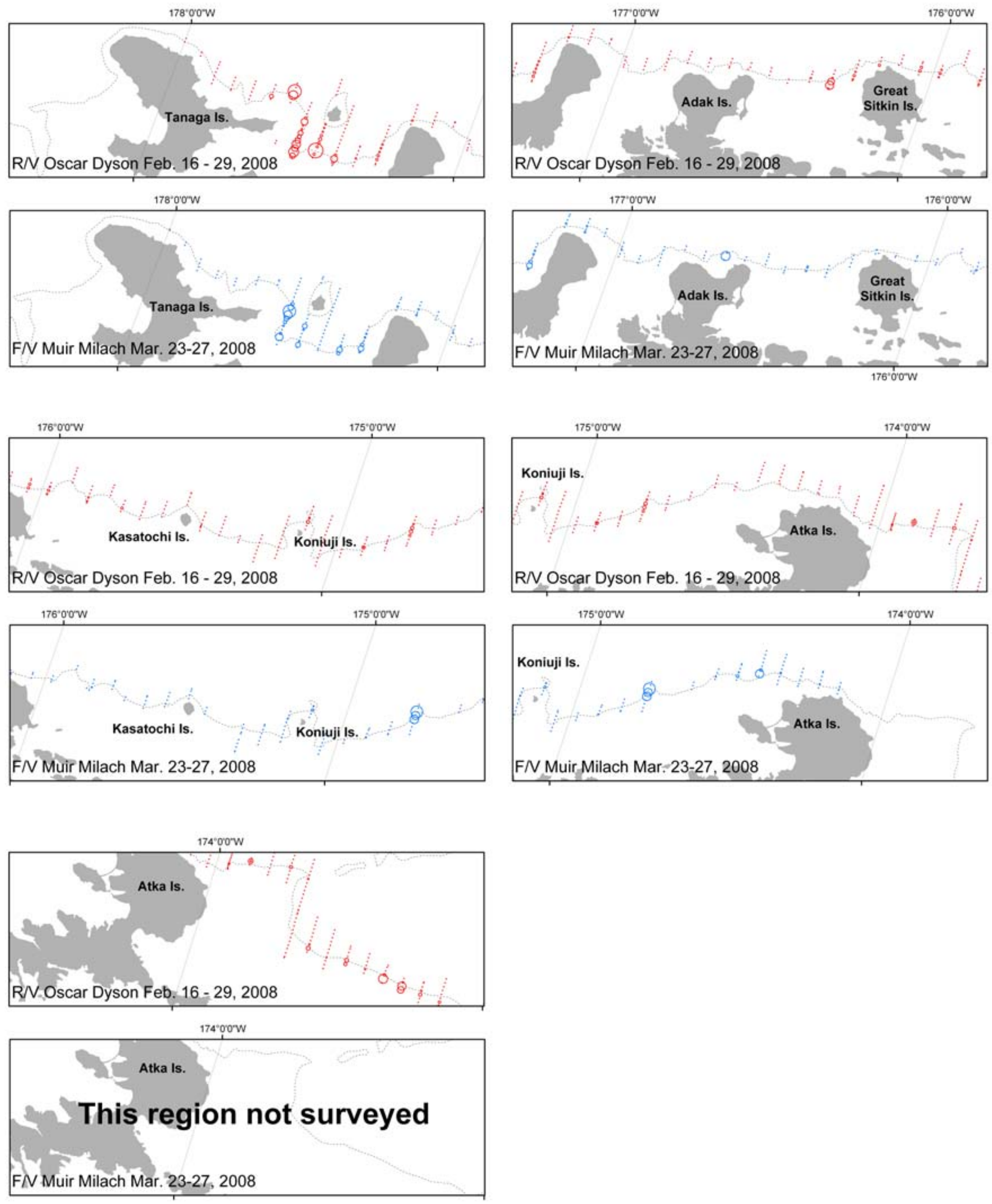


Figure 7a. Plots of pollock biomass by 0.5 nmi elementary sampling distance units (EDSU) along transect. Bubbles are proportional to pollock biomass.

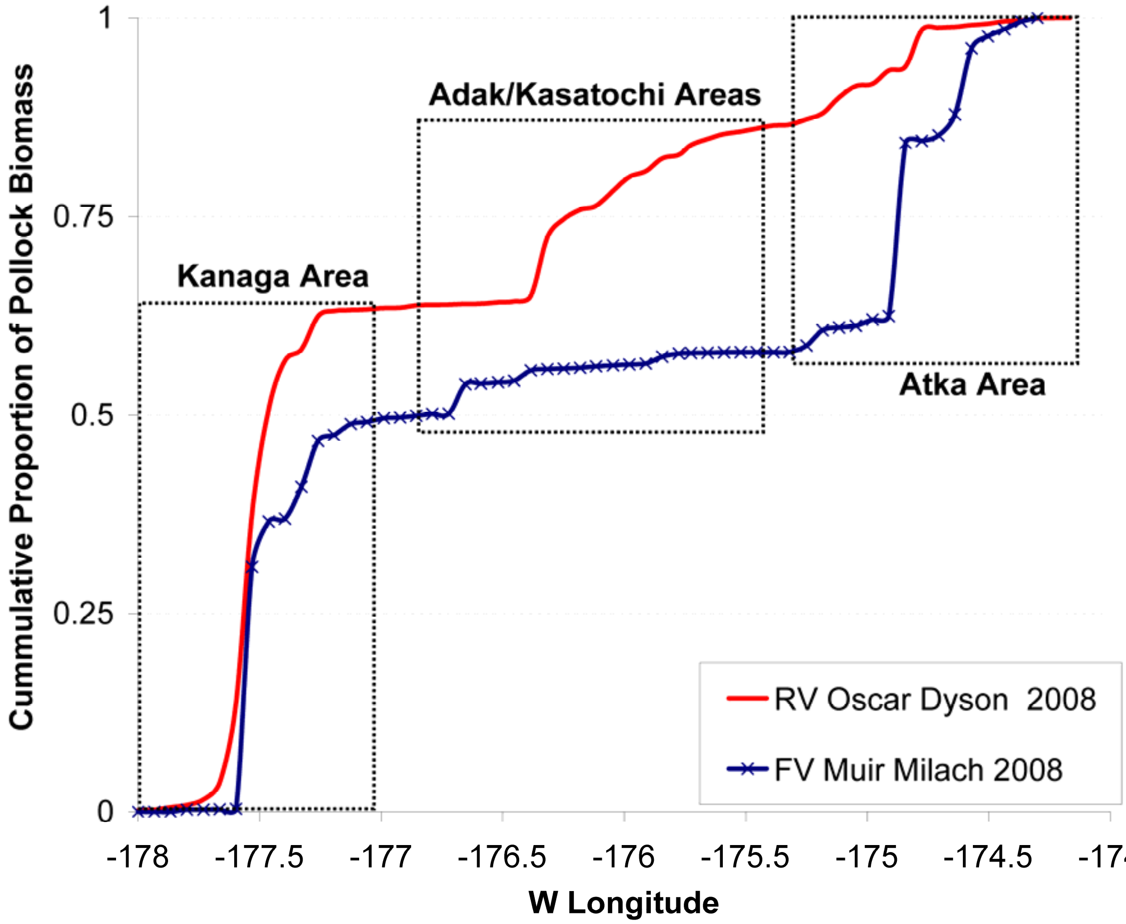


Figure 7b. Cumulative proportion of pollock abundance by transect from west to east for the *Oscar Dyson* and *Muir Milach* surveys.

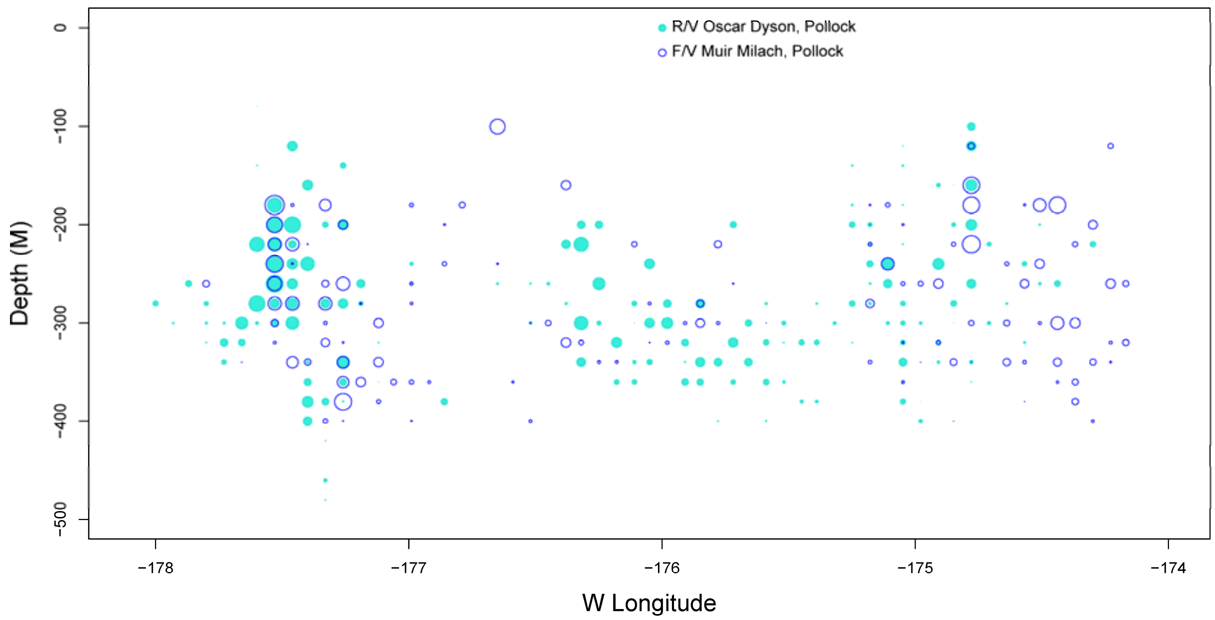


Figure 8. Distribution of walleye pollock by transect and depth for the *Oscar Dyson* and *Muir Milach* surveys binned at 20 meter depth increments. Icon size is the log transformed biomass estimate ($\log_{10}$(biomass/10)).

Table 3. Cramer-von Mises (CvM) statistics and corresponding p-values at different spatial scales.

Scale	CvM statistic (ψ)	p-value
2.5km	1.189	0.110
5 km	0.603	0.166
10 km	0.326	0.191
20 km	0.192	0.227
40 km	0.114	0.248
80 km	0.094	0.498

The pollock in both surveys were distributed vertically between 100 and 400 meters depth throughout the survey areas (Fig. 8). Night-time pollock distributions were less concentrated and more vertically spread out than daytime distributions with pollock located very close to bottom during the day and then spreading up towards the thermocline during the night. The thermocline appeared to restrict pollock vertical distribution with very few pollock located above it. This behavior was consistent throughout both survey periods.

The *Muir Milach* and *Oscar Dyson* surveys observed mean fork length of pollock at 60.04 cm (σ = 4.24, n=1,248) and 60.27 cm(σ = 4.98, n=925) respectively (Fig. 9). The mean fork length was not significantly different between the two surveys (Mann-Witney p-value = 0.25). Pollock length ranged from 35 cm to 76 cm during both surveys. The mean weight of pollock between the two surveys was not significantly different (Mann-Whitney p-value =0.78) with 1.85 kg (σ = 0.55, n=620) and 1.84 kg (σ = 0.46, n=171).

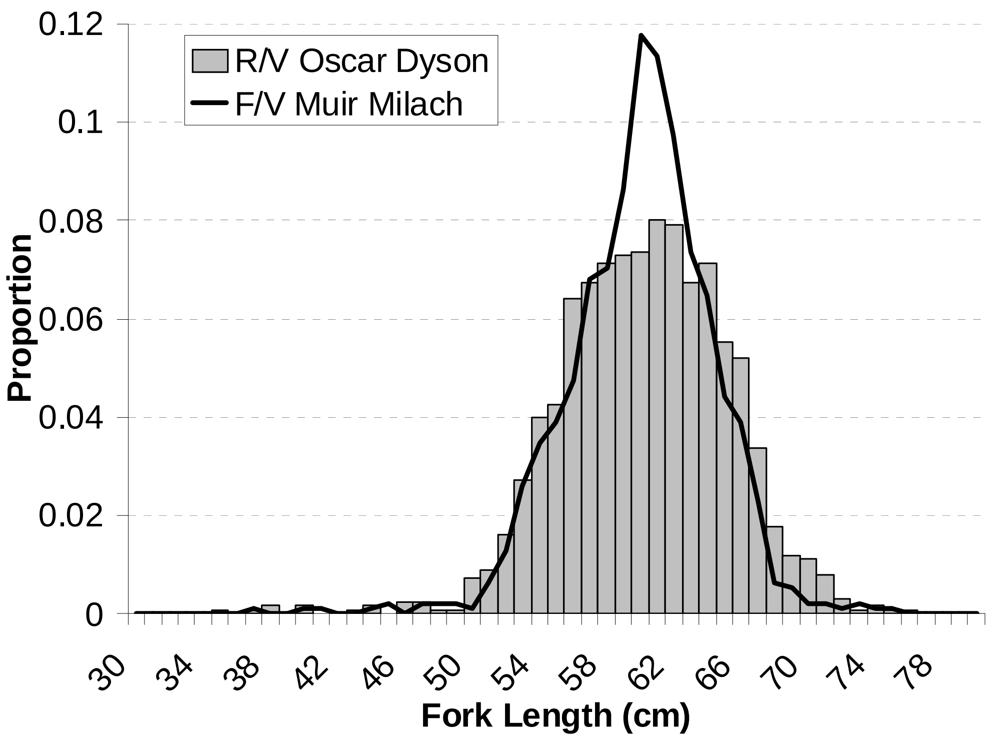


Figure 9. Length distribution of pollock during the February *Oscar Dyson* cruise and the March *Muir Milach* cruise.

Observations of pollock actively spawning were rare during both cruises, so the relative abundance of pollock in the pre-spawning stage was used as an indicator of the location of spawning times and areas. There was an increase in the proportion of pre-spawning fish from the *Oscar Dyson* cruise in February to the *Muir Milach* cruise in March (Fig. 10), from 81% to 98% indicating a seasonal progression of spawning. During the *Oscar Dyson* cruise the proportion of pre-spawning fish was greater in areas where pollock biomass was greater (i.e., near Kanaga Island, Atka Island and Amlia Island) consistent with fish aggregating to spawn (Fig. 11a). Nearly all the fish sampled during the *Muir Milach* cruise were in a pre-spawning state (Fig. 11b).

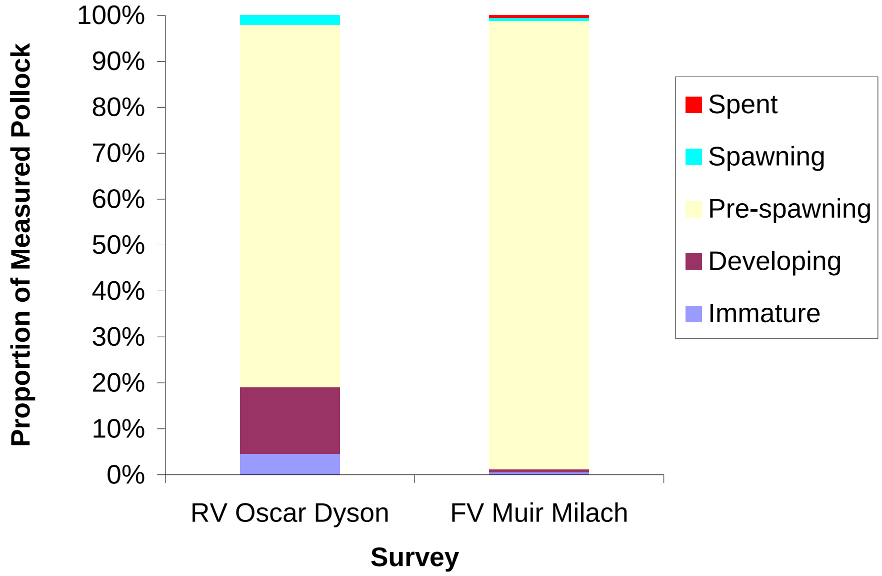
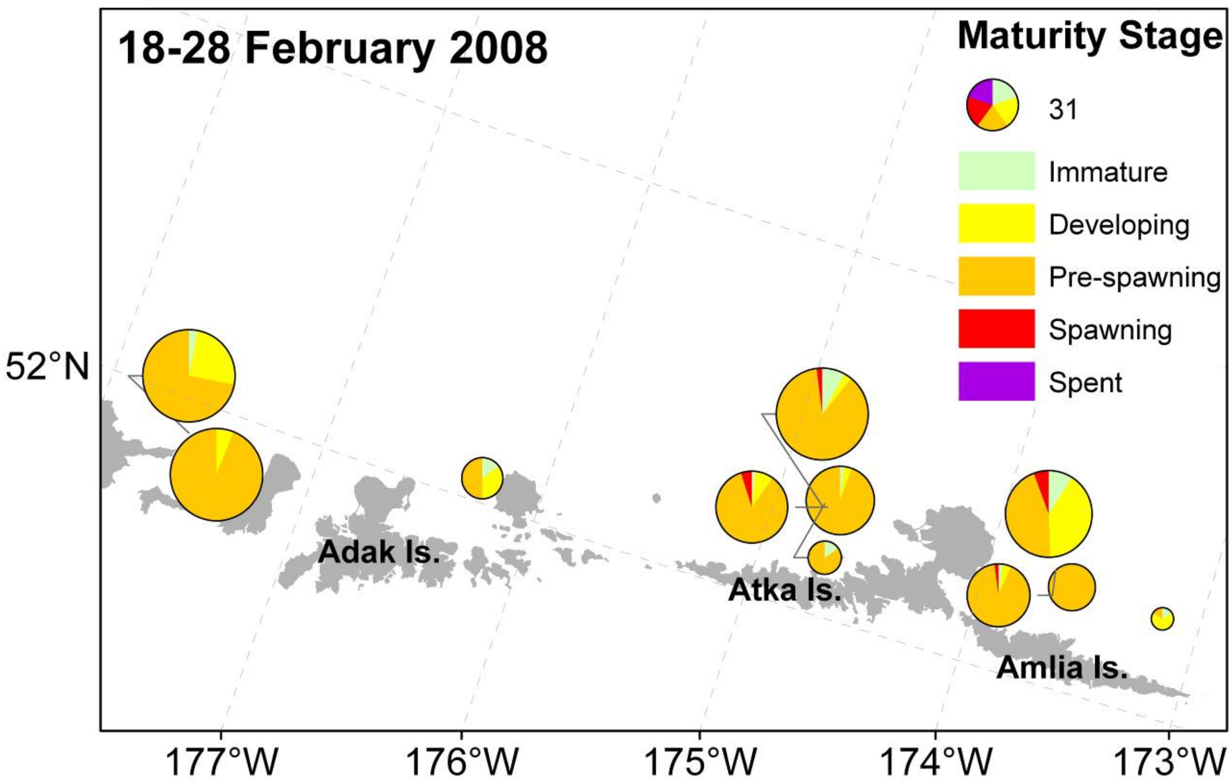


Figure 10. Pollock maturity stage for measured fish in both surveys.

a.



b.

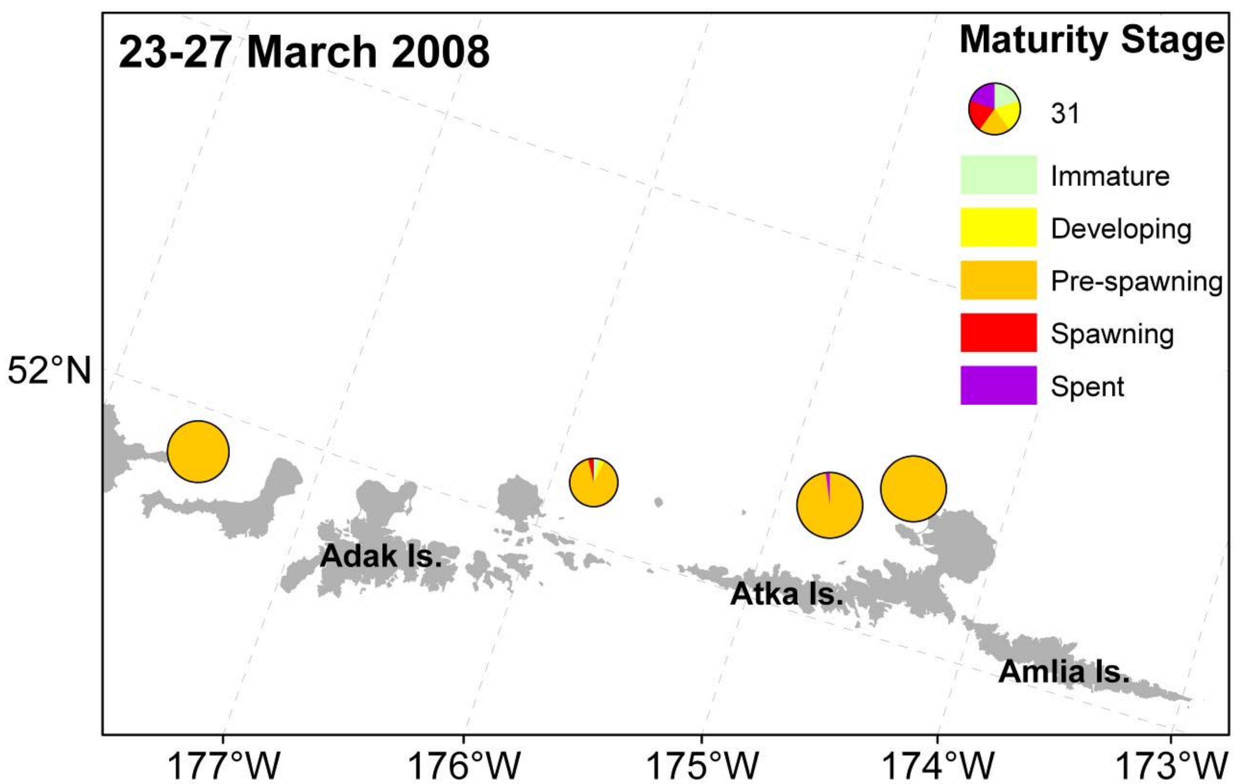


Figure 11. The distribution of pollock by maturity stage. a. *Oscar Dyson* survey, b. *Muir Milach* survey. The size of the circle is proportional to sample size.

Besides pollock, Pacific ocean perch (POP; *Sebastes alutus*) and a scattering layer mainly composed of Myctophidae species were observed in both surveys. Unfortunately, target-strength to length models have not yet been well established for these species, and therefore we are unable to provide biomass estimates. We are however able to discuss relative abundance and distribution within the survey areas for Pacific ocean perch and for the “Myctophidae” layer. The *Muir Milach* observed approximately 1.5 times as much POP backscatter as the *Oscar Dyson* in the area covered by both surveys. The *Oscar Dyson* survey observed POP in two main aggregations. One was located between 176.7°W and 177°W longitude (Fig. 12). This is the area of the slope north of Adak Island to Great Sitkin Island. A second aggregation was a continuous band of fish along the slope north of the chain from 173.6°W to 174.8°W longitude. The POP tended to be deep at between 250 and 450 m in the western portion of the survey between 177°W to 173.9 °W longitude. The vertical distribution of POP east of 173.9 °W longitude became shallower with POP observed as shallow as 100 m. For this survey the shallowest POP aggregation was observed on the slope directly north of Atka Island’s North Cape. The distribution of POP changed between surveys, both horizontally and vertically. The western aggregation north of Adak was observed in the same location for both surveys, but the large aggregation located between 174.2°W (easternmost extent of this survey) to 174.8°W was not observed in the second survey. The *Muir Milach* survey observed a large aggregation of POP located on either side of Kasatochi Island, the same location where the *Oscar Dyson* survey had observed concentrations of pollock. POP during the *Muir Milach* survey were distributed shallower than those observed during the first survey with fish located vertically throughout their horizontal range at depths between 100 and 350m.

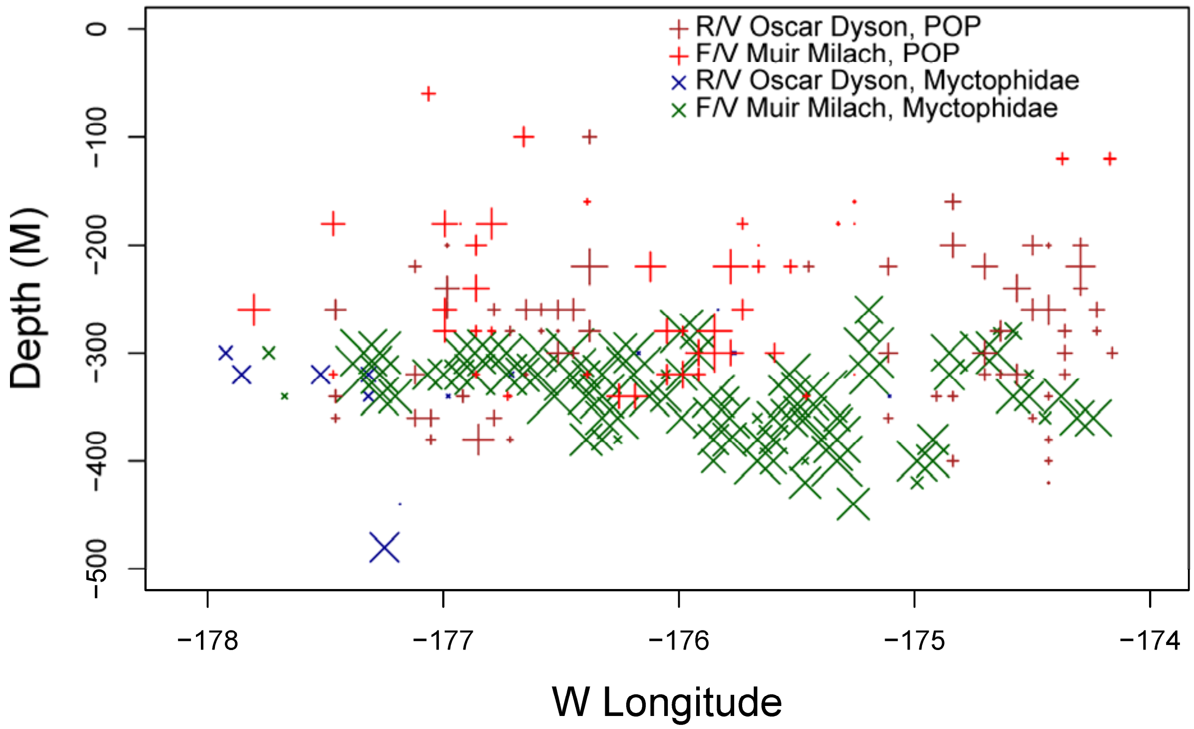


Figure 12. Distribution of the Pacific ocean perch and the Myctophidae layer by transect and depth for the *Oscar Dyson* and *Muir Milach* surveys binned at 20 meter depth increments. Icon size is the log transformed abundance estimate ($\log_{10}$(abundance/10)).

The scattering layer mainly composed of Myctophidae species was limited in the *Oscar Dyson* survey to the western-most transects, between 177°W and 178°W longitude at a depth between 300 and 500m (Fig. 12). The layer was generally over deeper water (greater than 1000 m), away from the slope, but intersected with the pollock and POP aggregations near the slope. The *Muir Milach* survey observed a very large scattering layer located north of the slope over depths greater than 1000m at between 280 to 420m for the entire survey except in the area west of 177 °W longitude. The layer often intercepted pollock and POP aggregations near the slope. This scattering layer would spread out vertically at night up to a thickness of between 30 and 50m then condense during the daytime to a thickness of less than 10 m.

<u>Steller sea lion data</u>

Aerial survey for abundance, distribution and age/sex composition

All adult and juvenile Steller sea lions on digital images from the complete first survey and second incomplete survey were counted by two independent counters. Counts of sea lions at all photographed sites during the two surveys by the two counters were not significantly different from each other (N=58, paired sample t-test, t=0.78, p=0.44). The average total count for the complete survey was 3,236 sea lions with site totals ranging from 0 – 372 animals (Table 4, Fig. 13). More than 150 sea lions were counted at individual sites near Seguam Pass (Agligadak), Atka Island (North Cape and Kasatochi), Adak Island (Kagalaska and Lake Point), and Kanaga Island (Ship Rock). The average total number of animals counted in the second incomplete survey was 2,169 (Table 5). The average count at these same sites during the first survey was 2,086, a difference of 85, or less than 4%.

Steller sea lions on digital images were assigned to 1 of 4 age/sex classes: juveniles of both sexes, sub-adult males, adult females and adult males (bulls). There were significant differences between counters in age-sex class designations, particularly when deciding between juveniles and females, and between sub-adult males and bulls. However, there was consistency between counters in the combined juvenile/female and sub-adult/adult male counts at each site. The combined juvenile/female group comprised between 86-90% of all sea lions counted on haulout sites (variation was due to counter assignment to age-sex class), while sub-adult and adult males comprised only 10-14% (Fig. 14). Only two sites, Adak/Head Rock and Atka/Cape Korovin, had a significant number of sub-adult and adult males, while all others were comprised of predominately of adult females and juveniles (Fig. 14).

Table 4. Counts of adult and juvenile Steller sea lions by age/sex class (Juvs=juveniles, Fems=adult females, SAMs=sub-adult males, Bulls=adult males, Unk=Unknown) and site on 24-25 March 2008 during Pass 1.

				Age/Sex Class					
Location Name	Lat N	Long W	Date	Juvs	Fems	SAMs	Bulls	Unk	Total
Adak/Argonne Point	51.83	-176.91	24-Mar-08	0	0	0	0	0	0
Adak/Cape Moffet	51.97	-176.72	24-Mar-08	0	0	0	0	0	0
Adak/Cape Yakak	51.59	-176.95	24-Mar-08	16	42	7	3	8	75
Adak/Crone Island	51.67	-176.61	24-Mar-08	47	34	3	2	0	85
Adak/Head Rock	51.92	-176.53	25-Mar-08	17	17	23	27	5	89
Adak/Lake Point	51.62	-176.99	24-Mar-08	120	46	4	3	0	173
Agligadak	52.10	-172.90	25-Mar-08	96	231	28	18	0	372
Amatignak/Knob Point	51.25	-179.07	24-Mar-08	0	0	0	0	0	0
Amatignak/Nitrof Point	51.22	-179.13	24-Mar-08	23	49	1	0	0	73
Amlia/Cape Misty	52.04	-173.83	25-Mar-08	49	24	7	11	0	89
Amlia/East Cape	52.10	-172.98	25-Mar-08	15	30	1	3	0	48
Amlia/Sviech. Harbor	52.03	-173.40	25-Mar-08	61	28	5	2	1	96
Amtagis	52.02	-174.43	25-Mar-08	0	0	0	0	30	30
Anagaksik	51.85	-175.88	25-Mar-08	31	45	13	7	1	96
Atka/Cape Korovin	52.31	-174.46	25-Mar-08	6	7	28	21	0	60
Atka/North Cape	52.40	-174.30	25-Mar-08	102	67	6	5	0	179
Bobrof	51.90	-177.45	24-Mar-08	0	0	0	0	0	0
Chugul	51.92	-175.77	25-Mar-08	5	10	2	4	0	20
Fenimore	51.98	-175.54	25-Mar-08	14	5	4	1	1	24
Gareloi	51.75	-178.77	24-Mar-08	0	0	0	0	0	0
Gramp Rock	51.48	-178.34	24-Mar-08	37	38	10	6	0	90
Great Sitkin	52.10	-176.18	25-Mar-08	0	0	0	0	0	0
Igitkin/SW Point	51.98	-175.96	25-Mar-08	0	0	0	0	0	0
Ikiginak	51.98	-175.48	25-Mar-08	0	0	0	0	0	0
Ilak	51.48	-178.31	24-Mar-08	21	30	3	0	0	53
Kagalaska	51.87	-176.31	24-Mar-08	120	74	8	4	0	205
Kanaga/Cape Chunu	51.66	-177.64	24-Mar-08	0	0	0	0	0	0
Kanaga/N Cape	51.94	-177.15	24-Mar-08	8	8	4	0	0	19
Kanaga/Cape Miga	51.94	-177.18	24-Mar-08	5	9	7	0	0	20
Kanaga/Ship Rock	51.78	-177.35	24-Mar-08	111	59	3	1	2	175
Kasatochi/North Point	52.19	-175.52	25-Mar-08	84	63	13	14	0	173
Kavalga	51.58	-178.86	24-Mar-08	47	23	4	2	0	76
Koniuji/North Point	52.23	-175.14	25-Mar-08	0	0	0	0	0	0
Little Tanaga Strait	51.82	-176.23	24-Mar-08	64	28	5	4	0	99
Ogliuga	51.62	-178.66	24-Mar-08	0	0	0	0	0	0
Oglodak	51.98	-175.44	25-Mar-08	69	61	8	2	0	140
Sagchudak	52.03	-174.49	25-Mar-08	20	15	1	1	0	37

Table 4 continued

Location Name	Lat N	Long W	Date	Age/Sex Class Juvs	Fems	SAMs	Bulls	Unk	Total
Sagigik	52.01	-173.16	25-Mar-08	16	42	1	0	1	59
Salt	52.18	-174.64	25-Mar-08	46	56	5	5	0	110
Seguam/Finch Point	52.39	-172.46	25-Mar-08	0	0	0	0	0	0
Seguam/Lava Cove	52.27	-172.48	25-Mar-08	0	0	0	0	0	0
Seguam/Lava Point	52.28	-172.40	25-Mar-08	0	0	0	0	0	0
Seguam/Saddleridge	52.35	-172.57	25-Mar-08	0	0	0	0	0	0
Seguam/SW Rip	52.26	-172.63	25-Mar-08	17	19	3	2	1	40
Seguam/Turf Point	52.26	-172.52	25-Mar-08	0	0	0	0	3	3
Seguam/Wharf Point	52.36	-172.32	25-Mar-08	28	21	4	2	0	54
Silak	51.82	-176.25	24-Mar-08	18	13	1	3	0	34
Skagul/S. Point	51.58	-178.57	24-Mar-08	0	0	0	0	0	0
Atka/SW	51.98	-175.43	25-Mar-08	0	0	0	0	7	7
Tag	51.56	-178.58	24-Mar-08	45	32	3	0	1	80
Tagalak	51.96	-175.62	25-Mar-08	41	20	8	5	0	73
Tanadak (Amlia)	52.07	-172.96	25-Mar-08	0	0	0	0	7	7
Tanaga/Bumpy Point	51.92	-177.98	24-Mar-08	0	0	0	0	0	0
Tanaga/Cape Sasmik	51.60	-177.93	24-Mar-08	7	21	1	0	0	29
Ugidak	51.58	-178.51	24-Mar-08	4	11	1	1	0	16
Ulak/Hasgox Point	51.32	-178.98	24-Mar-08	59	34	5	4	0	101
Unalga+Dinkum Rocks	51.56	-179.07	24-Mar-08	12	19	0	0	0	31
TOTALS				1471	1324	222	155	66	3236

Table 5. Counts of adult and juvenile Steller sea lions by age/sex class (Juvs=juveniles, Fems=adult females, SAMs=sub-adult males, Bulls=adult males, Unk=Unknown) and site on 26 and 29 March 2008 during Pass 2.

				Age/Sex Class					
Location Name	Lat N	Long W	Date	Juvs	Fems	SAMs	Bulls	Unk	Total
Adak/Argonne Point	51.83	-176.91	26-Mar-08	8	8	2	0	0	18
Adak/Cape Moffet	51.97	-176.72	26-Mar-08	0	0	0	0	0	0
Adak/Cape Yakak	51.59	-176.95	26-Mar-08	58	68	9	9	0	143
Adak/Crone Island	51.67	-176.61	26-Mar-08	53	49	7	3	2	113
Adak/Head Rock	51.92	-176.53	26-Mar-08	14	28	28	21	0	90
Adak/Lake Point	51.62	-176.99	26-Mar-08	95	86	2	3	0	186
Amlia/Cape Misty	52.04	-173.83	29-Mar-08	32	26	18	12	4	90
Amlia/Sviech. Harbor	52.03	-173.40	29-Mar-08	61	73	7	3	0	144
Amtagis	52.02	-174.43	29-Mar-08	0	0	0	0	3	3
Anagaksik	51.85	-175.88	26-Mar-08	41	41	7	12	0	100
Atka/North Cape	52.40	-174.30	29-Mar-08	0	0	0	0	55	55
Bobrof	51.90	-177.45	26-Mar-08	32	22	0	0	0	54
Chugul	51.92	-175.77	26-Mar-08	6	6	0	4	0	16
Fenimore	51.98	-175.54	26-Mar-08	19	12	3	6	0	39
Gareloi	51.75	-178.77	26-Mar-08	0	0	0	0	0	0
Gramp Rock	51.48	-178.34	26-Mar-08	40	37	3	3	5	86
Igitkin/SW Point	51.98	-175.96	26-Mar-08	0	0	0	0	0	0
Ikiginak	51.98	-175.48	26-Mar-08	0	0	0	0	0	0
Ilak	51.48	-178.31	26-Mar-08	23	26	1	2	4	56
Kagalaska	51.87	-176.31	26-Mar-08	0	0	0	0	100	100
Kanaga/Cape Chunu	51.66	-177.64	26-Mar-08	0	0	0	0	7	7
Kanaga/N Cape	51.94	-177.15	26-Mar-08	0	0	0	0	0	0
Kanaga/Cape Miga	51.94	-177.18	26-Mar-08	0	0	0	0	25	25
Kanaga/Ship Rock	51.78	-177.35	26-Mar-08	68	83	3	1	0	154
Little Tanaga Strait	51.82	-176.23	26-Mar-08	51	51	1	1	0	103
Ogliuga	51.62	-178.66	26-Mar-08	0	0	0	0	0	0
Oglodak	51.98	-175.44	26-Mar-08	67	62	4	3	0	135
Sagchudak	52.03	-174.49	29-Mar-08	18	22	3	1	0	44
Sagigik	52.01	-173.16	29-Mar-08	5	9	3	0	28	44
Seguam/Lava Point	52.28	-172.40	29-Mar-08	43	55	9	2	0	108
Seguam/Lava Cove	52.27	-172.48	29-Mar-08	0	0	0	0	0	0
Seguam/Turf Point	52.26	-172.52	29-Mar-08	0	0	0	0	25	25
Silak	51.82	-176.25	26-Mar-08	14	17	1	0	0	31
Skagul/S. Point	51.58	-178.57	26-Mar-08	0	0	0	0	0	0
Tag	51.56	-178.58	26-Mar-08	33	33	1	0	0	67
Tagalak	51.96	-175.62	26-Mar-08	26	25	3	3	0	57
Tanaga/Bumpy Point	51.92	-177.98	26-Mar-08	0	0	0	0	0	0

Table 5 continued

Location Name	Lat N	Long W	Date	Age/Sex Class Juvs	Fems	SAMs	Bulls	Unk	Total
Tanaga/Cape Sasmik	51.60	-177.93	26-Mar-08	26	28	1	0	0	55
Ugidak	51.58	-178.51	26-Mar-08	9	8	6	1	4	27
				839	869	116	85	261	2169

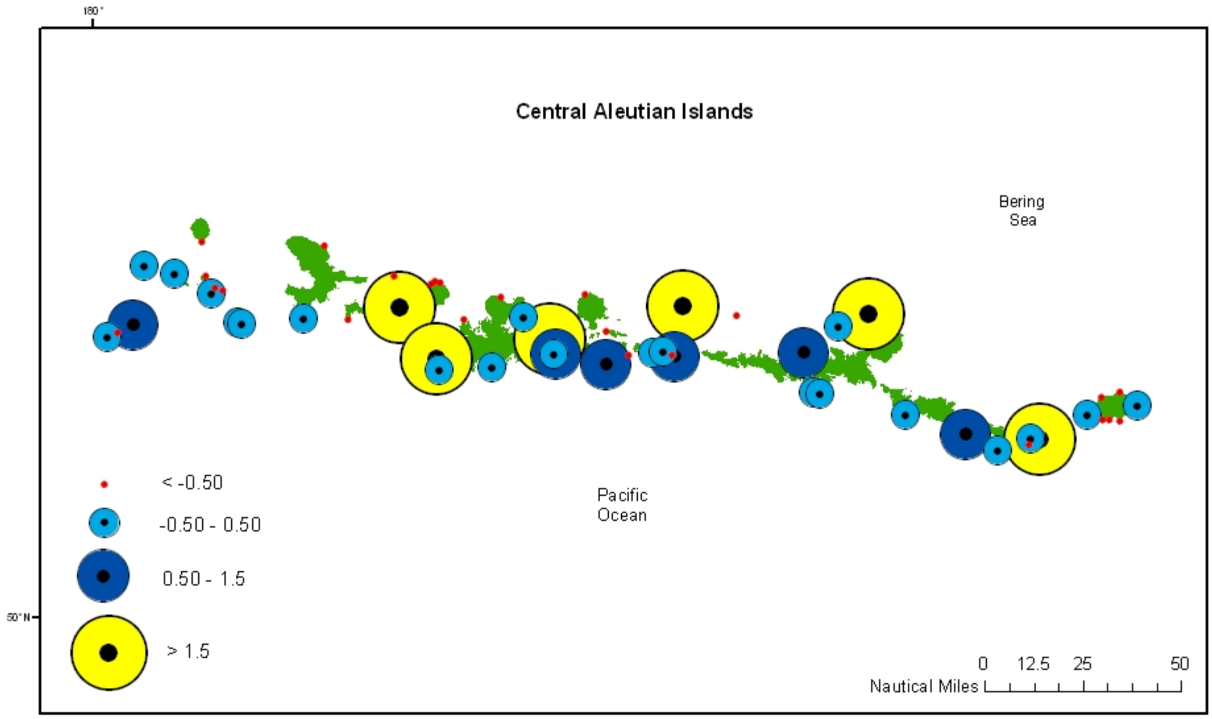


Figure 13. Mean number of adult and juvenile Steller sea lions counted during Pass 1 (24-25 March 2008) at each haulout in the Central Aleutian Island survey area. Symbol sizes are scaled by 0.5 standard deviation (SD) units ± the mean count at all sites (mean = 55 animals per site; st. dev = 70)

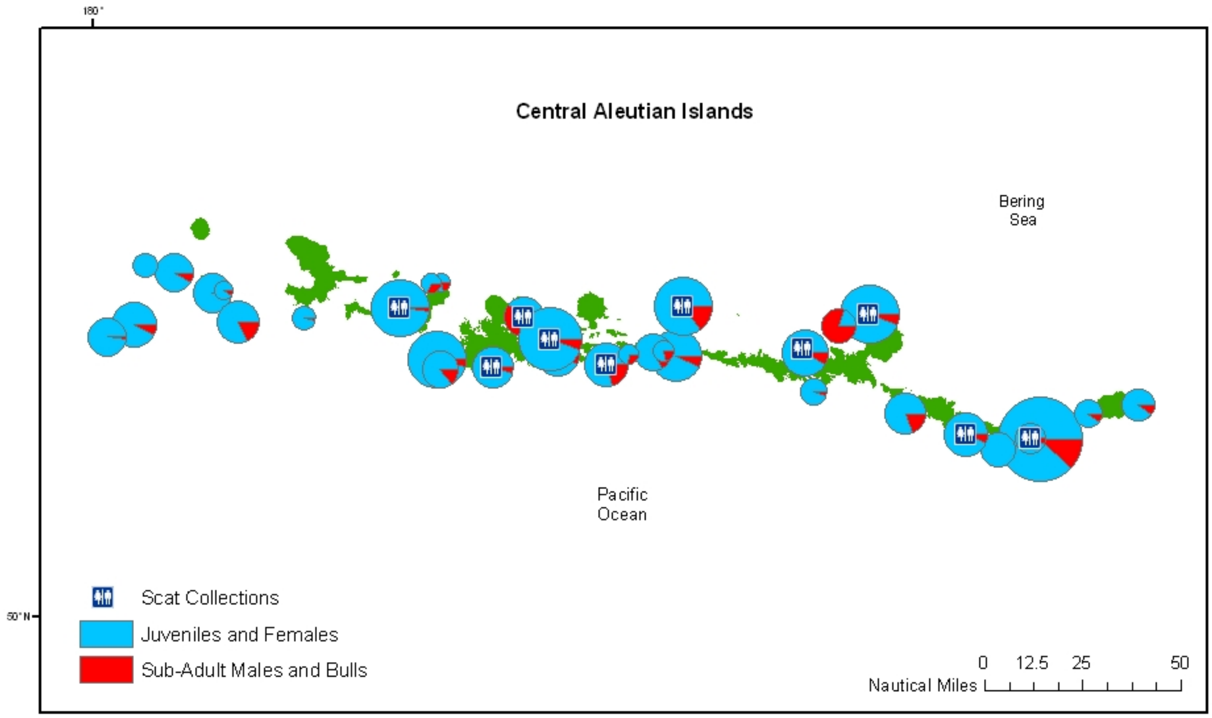


Figure 14. Averaged age class composition scaled to the total count of adult and juvenile sea lions at each site during Pass 1 (24-25 March 2008).

Spatial differences in diet relative to pollock aggregations

A total of 301 scat (fecal) and 5 spew samples were collected at 10 haulout sites in the survey area between Kanaga and Amlia Islands from 2-12 April, 2008 (Table 6; Fig. 15). A total of 41 different species or groups of prey were identified, with the most common being the commercially-important Atka mackerel, a rockfish species (most likely Pacific ocean perch), Pacific cod and pollock (Table 7).

When analyzed by species (Fig. 16), there was marked separation of Atka mackerel from almost all other species (except for salmon) on PC 1, followed next by pollock on PC 2. These results indicate that Atka mackerel and pollock tended not to be associated with each other in the diets of Steller sea lions, which likely reflects differences in the spatial distribution of the two species. When the food habits data were analyzed by site using PC (Figs. 15 and 17), three groups of sites were revealed based primarily on the relative frequency of occurrence (FO) of pollock and Atka mackerel:

- High pollock and low Atka mackerel: All located near Atka and Adak pollock aggregations (Pollock FO>35% FO and Atka mackerel FO<20% FO)
    - Atka-North Cape
    - Salt
    - Kagalaska and Adak-Head Rock (combined)
- High pollock and high Atka mackerel: Located near Kanaga pollock aggregation (pollock and Atka mackerel FOs >40% FO)
    - Kanaga-Ship Rock
- High Atka mackerel and low pollock: Not located near a pollock aggregation (Atka mackerel FO > 40% FO and pollock FO<15%)
    - Amlia-East Cape
    - Amlia-Sviechnikof Harbor
    - Kasatochi
    - Anagaksik
    - Adak-Crone Island

Table 6. Number of food habits samples collected at central Aleutian Island Steller sea lion haul-out sites.

Site	Scat	Spew
Kanaga/Ship Rock	30	4
Adak/Crone Island	30	
Adak/Head Rock (Kuluk Bay)	31	
Kagalaska	11	
Anagaksik	27	
Kasatochi/North Point	33	
Salt	38	
Atka/North Cape	31	1
Amlia/Sviech. Harbor	37	
Amlia/East Cape	33	

Table 7. Overall percent frequency of occurrence (% FO) of prey species in the 305 Steller sea lion food habits samples with identifiable prey from collections in the central Aleutian Islands, 2-12 April 2008.

Species	% FO
ATKA MACKEREL	53%
ROCKFISH SP	30%
POLLOCK	26%
PACIFIC COD	26%
IRISH LORD SP	23%
SM. LUMPSUCKER	15%
SALMON	11%
SKATE	9%
SNAILFISH SP	8%
ROCK SOLE	8%
NORTH.LAMPFISH	5%
ANOTHER FISH SP	5%
UNIDENT FISH	5%
CEPHALOPOD	3%
POLYCAETE UNID	3%
GREENLING SP	2%
ROCK GREENLING	2%
FLATFISH SP	2%
GADID	2%
SAND FISH	2%
CAPELIN	1%
ANOTHER SCUL.01	1%
KELP GREENLING	1%
OCTOPOD SP	1%
RED IRISH LORD	1%
SQUID UNIDENT	1%
CRESTED SCULPIN	1%
HIGH COCKSCOMB	1%
SABLEFISH	1%
SEARCHER	1%
GREAT-TYPE SCUL	1%
ARROWTOOTH FL	1%
GUNNEL	0%
GUNNEL/PRICKLEB	0%
GYMNOCANTHUS SP	0%
HERRING	0%
N.SMOOTHTONGUE	0%
SARDINE	0%
SCULPIN,TP type	0%
SEARCHER TYPE	0%
UNKN PRICKL.#2	0%

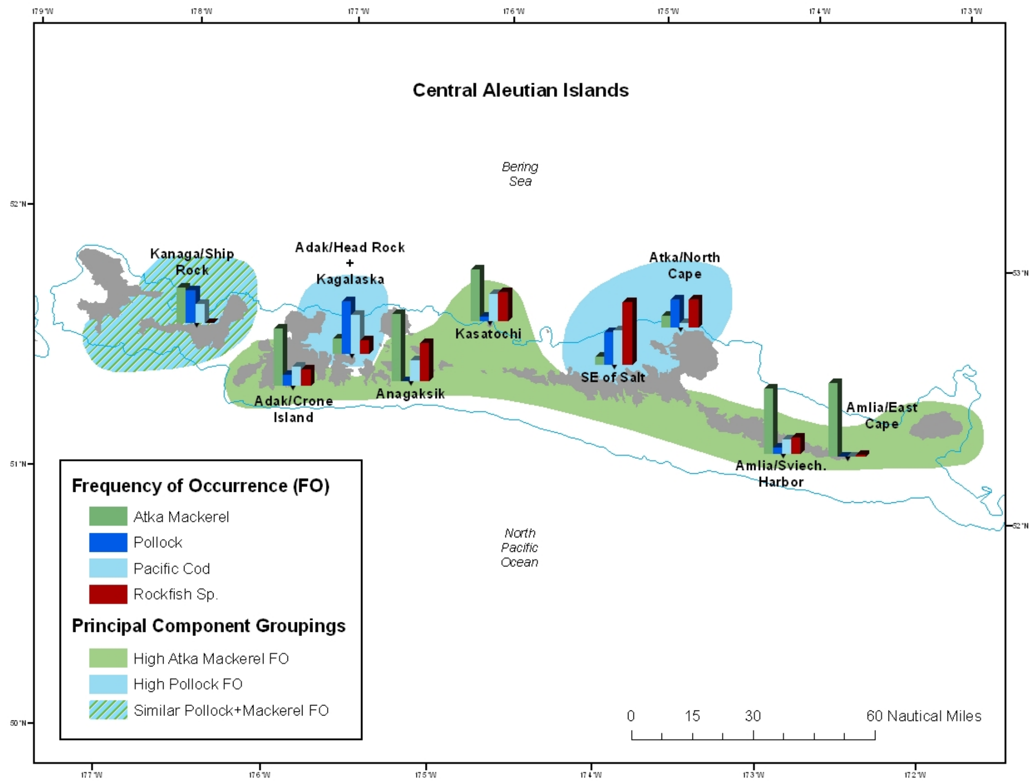


Figure 15. Location of food habits ('scat') collection sites in the central Aleutian Islands and the percent frequency of occurrence of the 4 most common prey species overall. Food habits were collected 2-12 April 2008. Shading of area and sites represents principal component clusters shown in Figure 17.

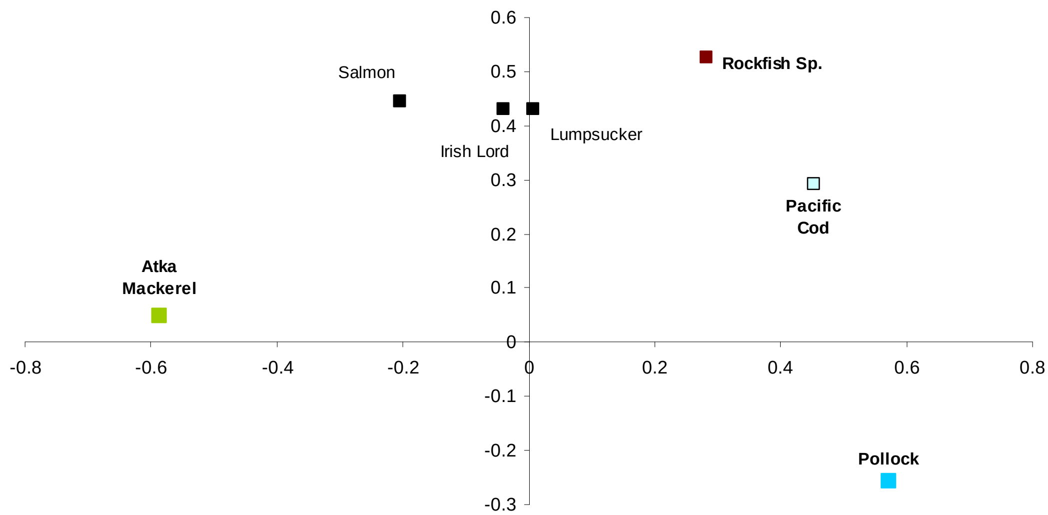


Figure 16. Principal component 1 vs. 2 from analyses of Steller sea lion food habits data by species.

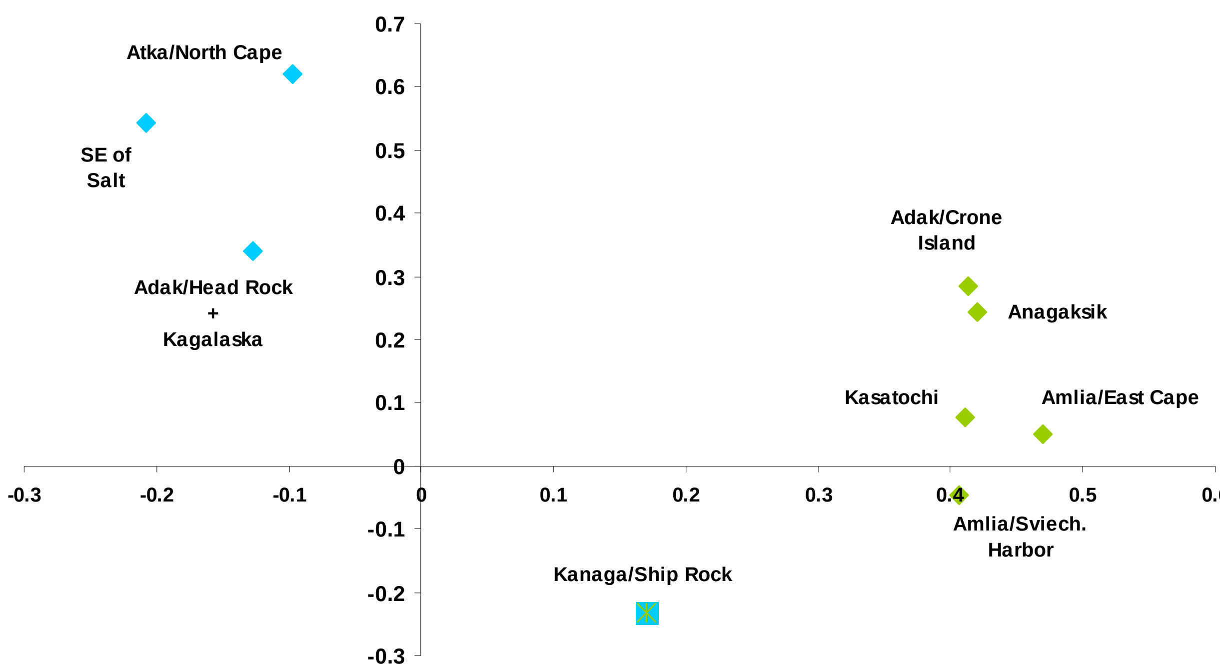


Figure 17. Principal component 1 vs. 2 from analyses of Steller sea lion food habits data by haul-out site. Sites plotted with green diamonds had a high %FO of Atka mackerel and low pollock. Sites plotted with blue diamonds had a high %FO of pollock and low Atka mackerel. Kanaga/Ship Rock was the only site that both high mackerel and high pollock. Each of the 3 collection sites with high pollock %FO was located near a pollock spawning aggregation.

Sizes of commercially important species consumed

Analysis of information on sizes of commercially important fish consumed by Steller sea lions indicated strong overlap with commercial fisheries for Pacific cod, pollock, and rockfish (most likely Pacific ocean perch), and considerable overlap with Atka mackerel (Fig. 18; Zeppelin et al. 2004; Spencer and Ianelli 2008; Lowe et al. 2008; Thompson et al. 2008; this study). This conclusion does not consider the extent to which true bone size may be underestimated due to erosion during digestion, thus underestimating the size of the fish when eaten (Zeppelin et al. 2004). Diagnostic bones were measured and assigned to size bins by Pacific ID based on regressions of bone size and fish size. Descriptive bone size bins were pooled as shown below, along with the corresponding total fish length ranges for each of the commercially important groundfish species.

Species	VLG & LG*	MEDIUM	SMALL
Atka mackerel	> 35 cm	26-35	< 26
Pacific cod	> 26	21-26	< 21
Pollock	> 30	21-30	< 21
Rockfish	> 50	31-49	< 31

*Very large and large

While > 40% of all Atka mackerel eaten were of commercial size (> 35 cm), sea lions also consumed large numbers of < 36 cm Atka mackerel (Fig. 18 top). Zeppelin et al. (2004), after applying digestion correction factors, estimated a 53% overlap with commercial Atka mackerel fisheries. Over 12% of all individual prey items identified in the scat samples collected during this survey were Atka mackerel > 35 cm long (Fig. 18 bottom).

Greater than 80% of all Pacific cod and pollock eaten by sea lions were > 26 cm and 30 cm long, respectively (Fig. 18 top). Furthermore, 77% of all Pacific cod consumed were > 50 cm long, indicating a strong overlap with commercial fisheries (Thompson et al. 2008). Very few fish < 30 cm long of either gadid species were consumed. Zeppelin et al. (2004), after applying digestion correction factors, estimated a 68% overlap with commercial pollock fisheries. Approximately 17% of all individual prey items identified in the scat samples collected during this survey were Pacific cod or pollock of commercial size.

Greater than 90% of all rockfish eaten by sea lions were between 31 and 49 cm long (Fig. 18). Most Pacific ocean perch taken by commercial fisheries are > 30 cm (Spencer and Ianelli 2008). Approximately 10% of all individual prey items identified in the scat samples collected during this survey were rockfish (presumably Pacific ocean perch) of commercial size.

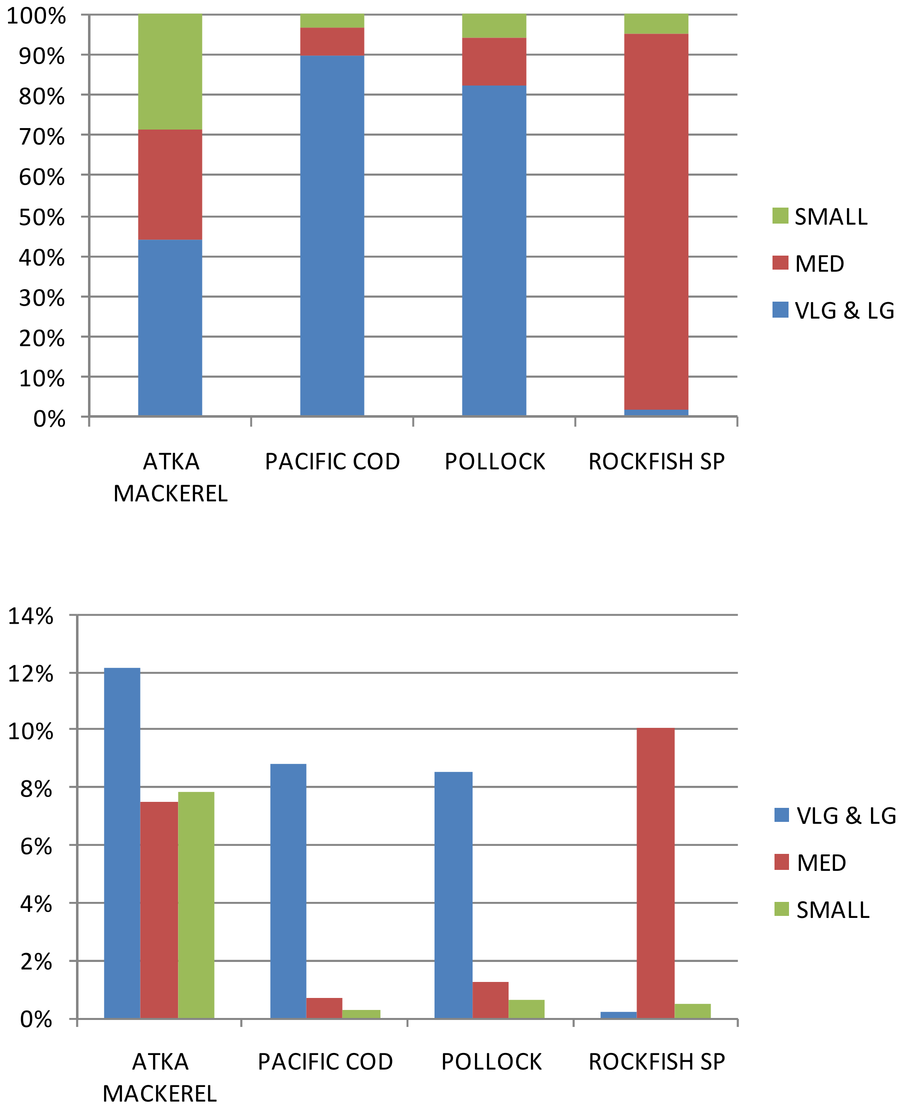


Figure 18. Sizes of commercially important groundfish eaten by Steller sea lions in the central Aleutian Islands, April 2008 (VLG & LG = "very large and large"). Top: Percentage by size range of each species. Bottom: Percentage that each size range comprises of all prey items consumed and identified.

Steller sea lion abundance and diet areas

The three SSL diet areas that resulted from the PC analysis encompass 45 of the 59 sites surveyed during Pass 1 (Fig. 15). A total of 2,716 of the total (3,236) number counted during Pass 1 were within the three diet areas. Sites not included in the diet areas were west of Tanaga Island in the Delarof Islands. The surveyed sea lion populations in the three diet areas can be described as follows:

- High pollock and low Atka mackerel area had 10 sites and 29% (776) of the sea lions, for an average of 78 per site
    - 28% of all juveniles and females, and 42% of all males counted
- High pollock and high Atka mackerel area had 7 sites and 9% (242) of the sea lions, for an average of 35 per site
    - 10% of all juveniles and females, and 4% of all males counted
- High Atka mackerel and low pollock area had 28 sites and 63% (1,698) of the sea lions, for an average of 61 per site
    - 62% of all juveniles and females, and 54% of all males counted

The distribution of age/sex classes and total population indicates that about two-thirds of all sea lions in the food habits survey area were in the high Atka mackerel area, while the remaining one-third were in the two areas with high pollock. Males tended to be present within the high pollock areas in greater proportions than the population as whole, with an aggregate of 46% as opposed to 38% for the entire population. Females and juveniles, since they made up the bulk of the population, were distributed similarly to the population as a whole.

<u>Oceanographic data</u>

Temperature and salinity profiles

Comparison of vertical profiles of temperature and salinity collected during the *Oscar Dyson* survey in areas of high pollock biomass (Kanaga Island (Fig. 19b), Adak Island (Fig. 20), Atka Island (Fig. 23), and Amlia Island (Fig. 24)) with profiles in areas of low pollock biomass (Tanaga Island (Fig. 19a) and Kasatochi Island (Figs. 21 and 22)) showed no consistent difference in the degree of stratification. Similarly, vertical profiles during the *Muir Milach* survey in areas of high pollock biomass (Kanaga Island (Fig. 25) and Atka Island (Fig. 28)) and profiles in areas of low pollock biomass (Kasatochi Island (Fig. 27)) showed no differences. In other words, during both cruises areas of high pollock biomass did not have more mixed (or more stratified) waters than areas of low pollock biomass.

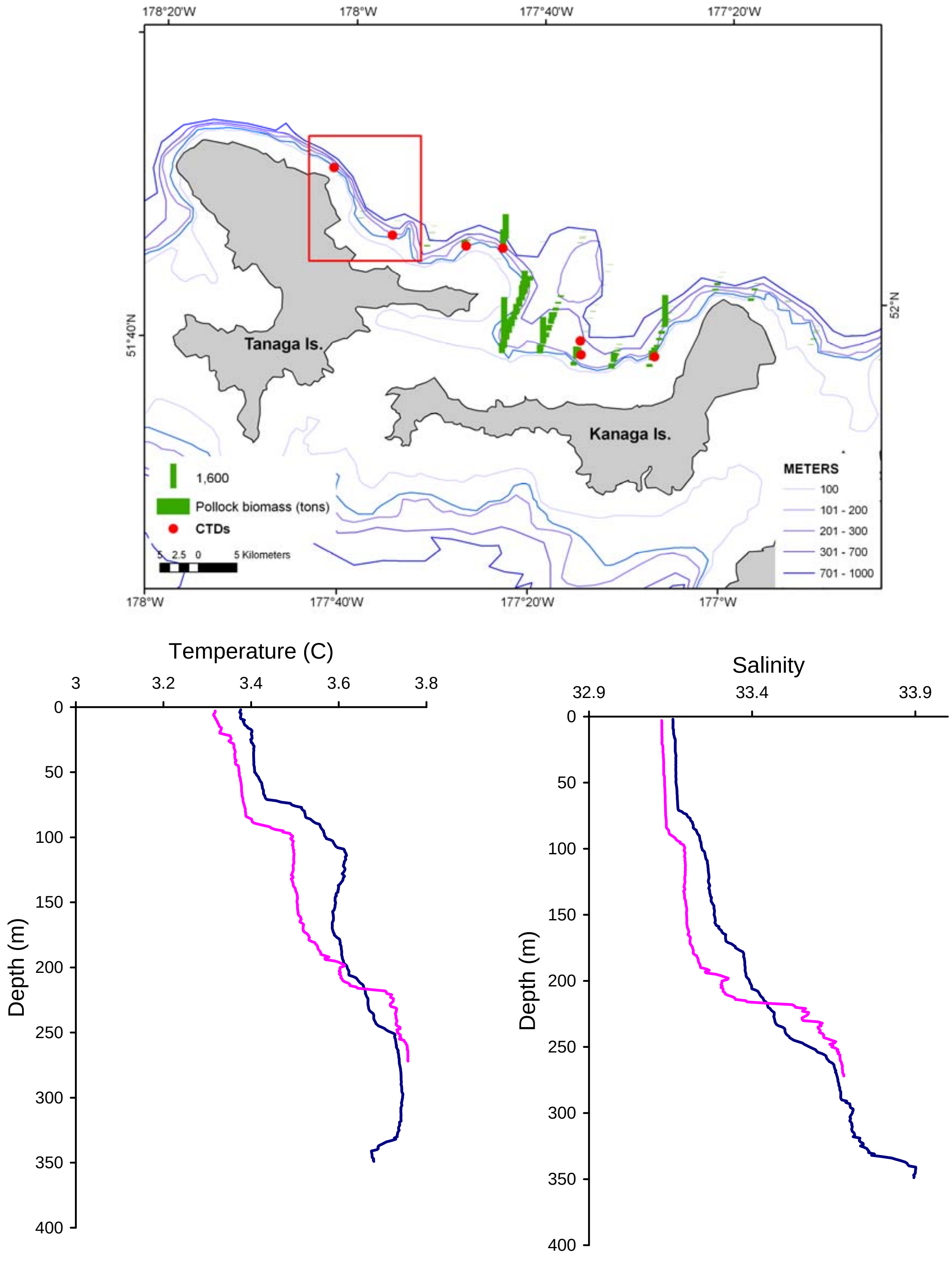


Figure 19a. Temperature and salinity profiles from CTD stations in the Tanaga Island area. Map above shows location of CTD stations (inside red square) and acoustic estimates of pollock biomass from the *Oscar Dyson* survey.

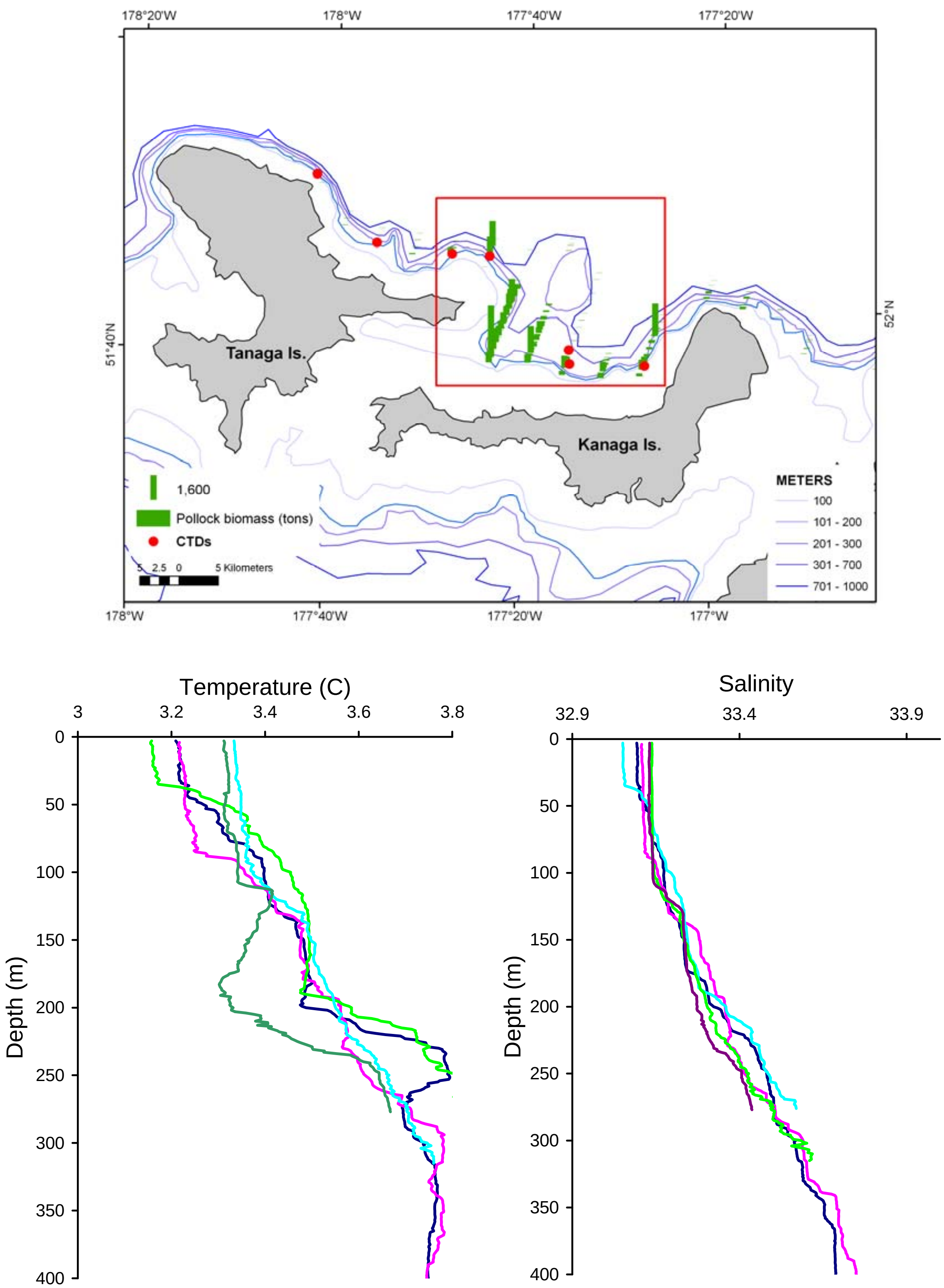


Figure 19b. Temperature and salinity profiles from CTD stations in the Kanaga Island area. Map above shows location of CTD stations (inside red square) and acoustic estimates of pollock biomass from the *Oscar Dyson* survey.

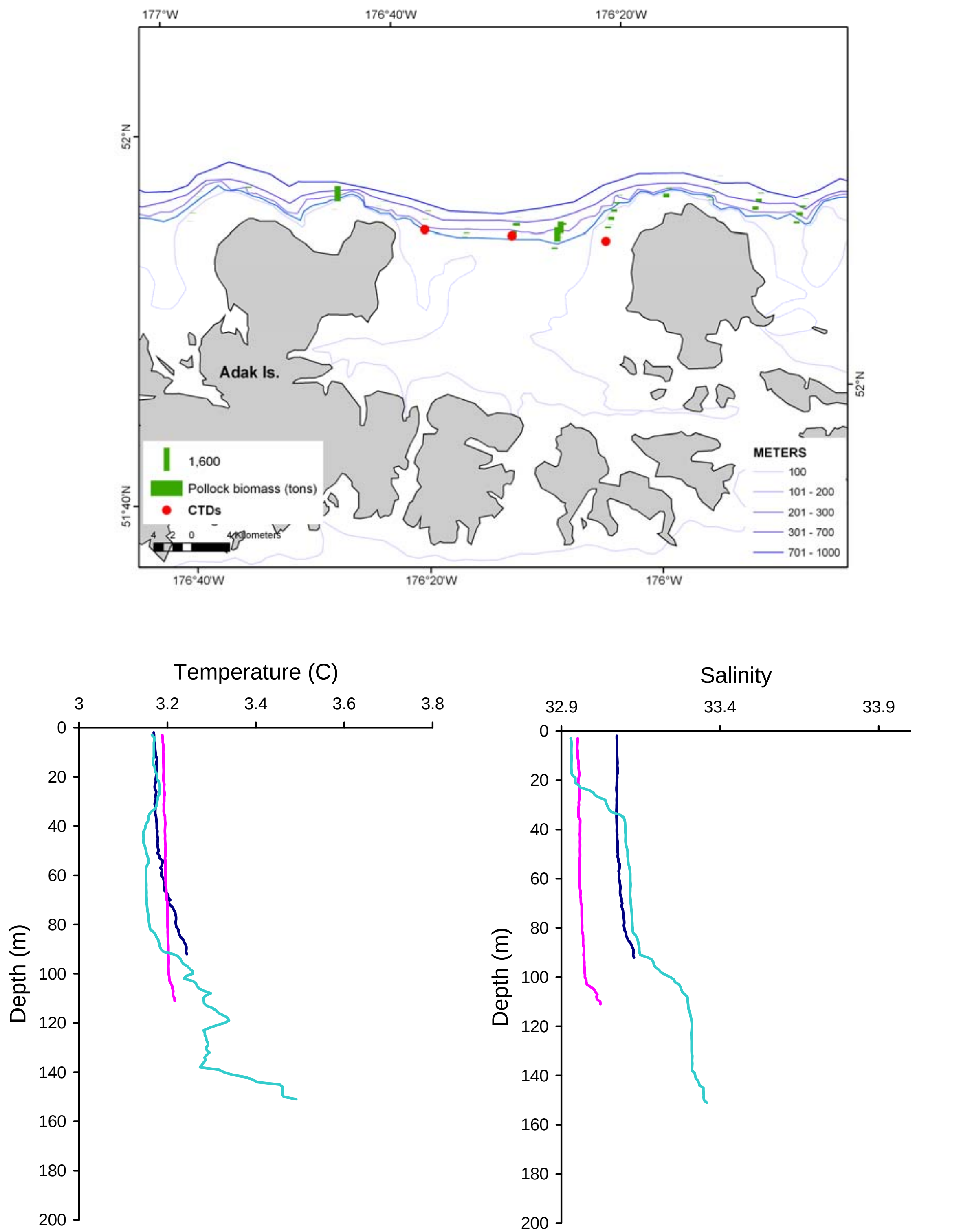


Figure 20. Temperature and salinity profiles from CTDs near Adak Island. Map above shows location of CTD stations and acoustic estimates of pollock biomass from the *Oscar Dyson* survey.

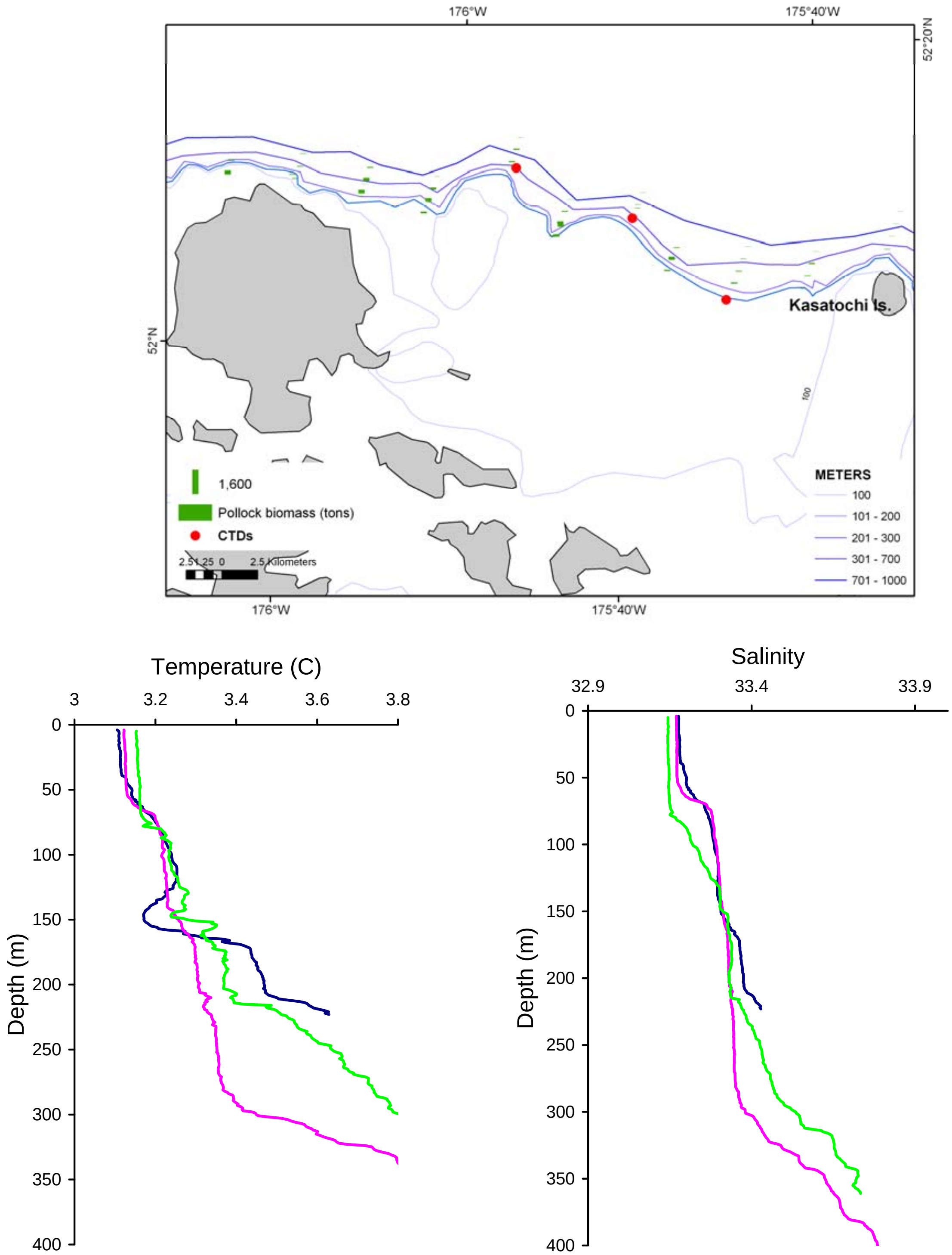


Figure 21. Temperature and salinity profiles from CTDs west of Kasatochi Island. Map above shows location of CTD stations and acoustic estimates of pollock biomass from the *Oscar Dyson* survey.

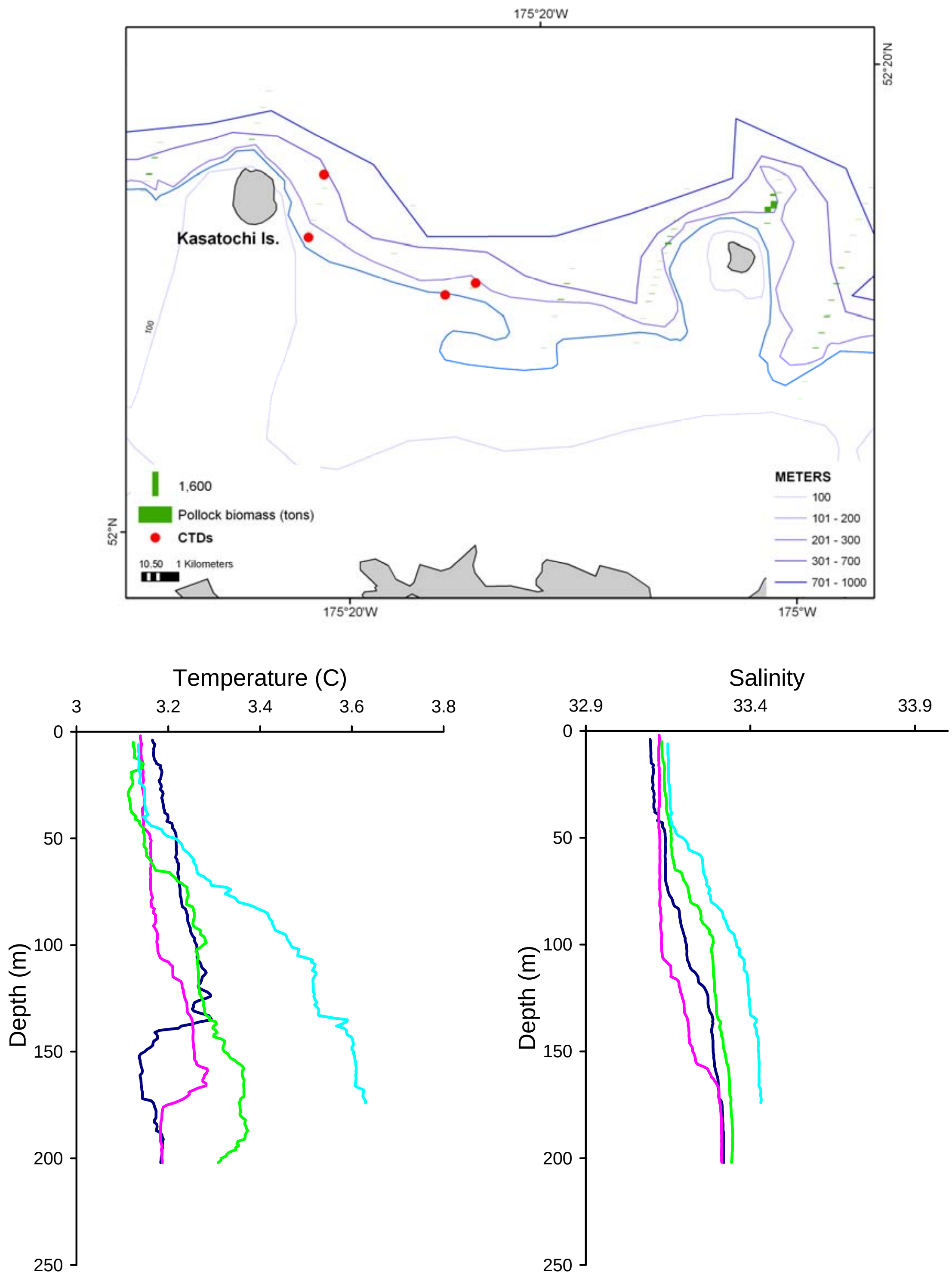


Figure 22. Temperature and salinity profiles from CTDs east of Kasatochi Island. Map above shows location of CTD stations and acoustic estimates of pollock biomass from the *Oscar Dyson* survey.

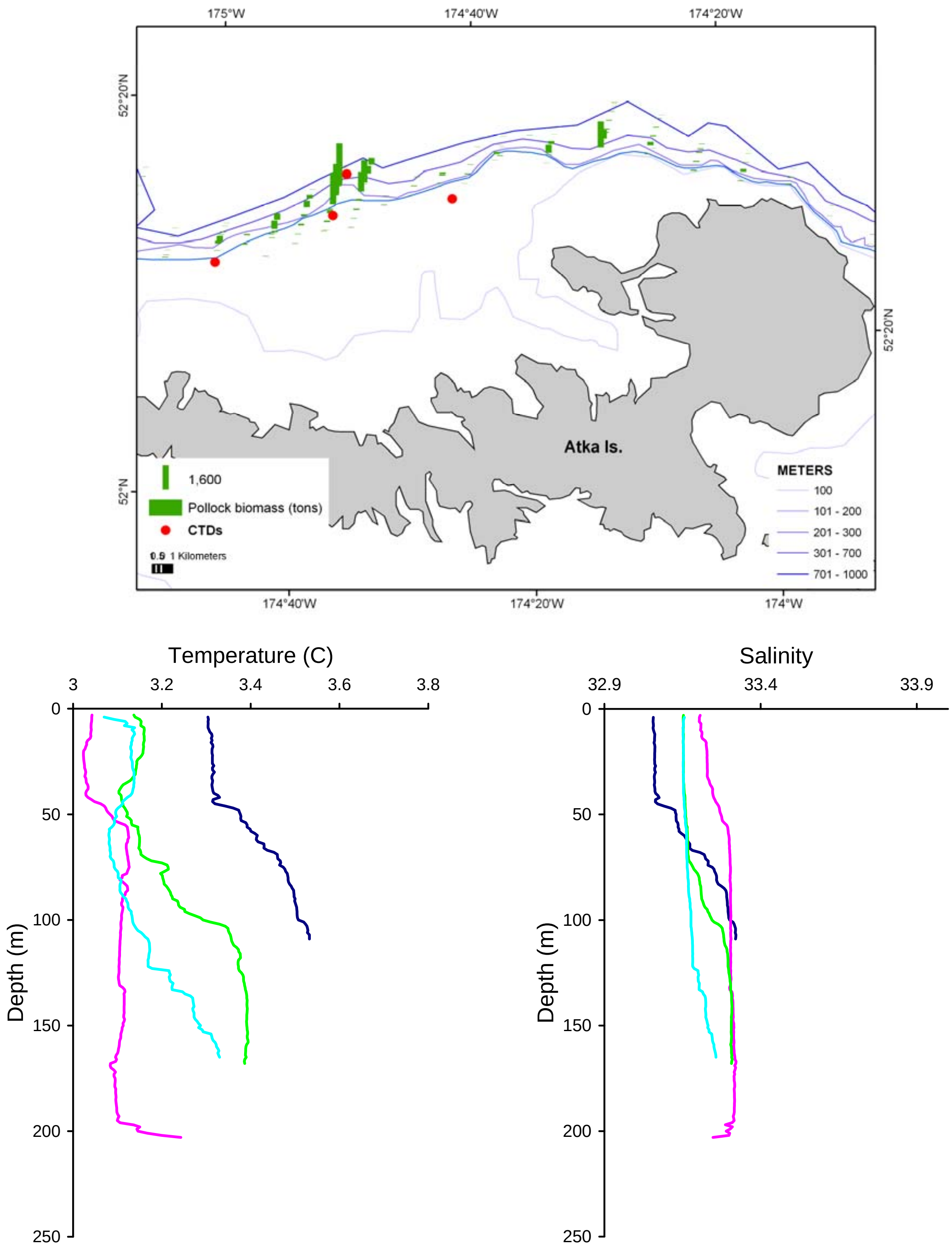


Figure 23. Temperature and salinity profiles from CTDs near Atka Island. Map above shows location of CTD stations and acoustic estimates of pollock biomass from the *Oscar Dyson* survey.

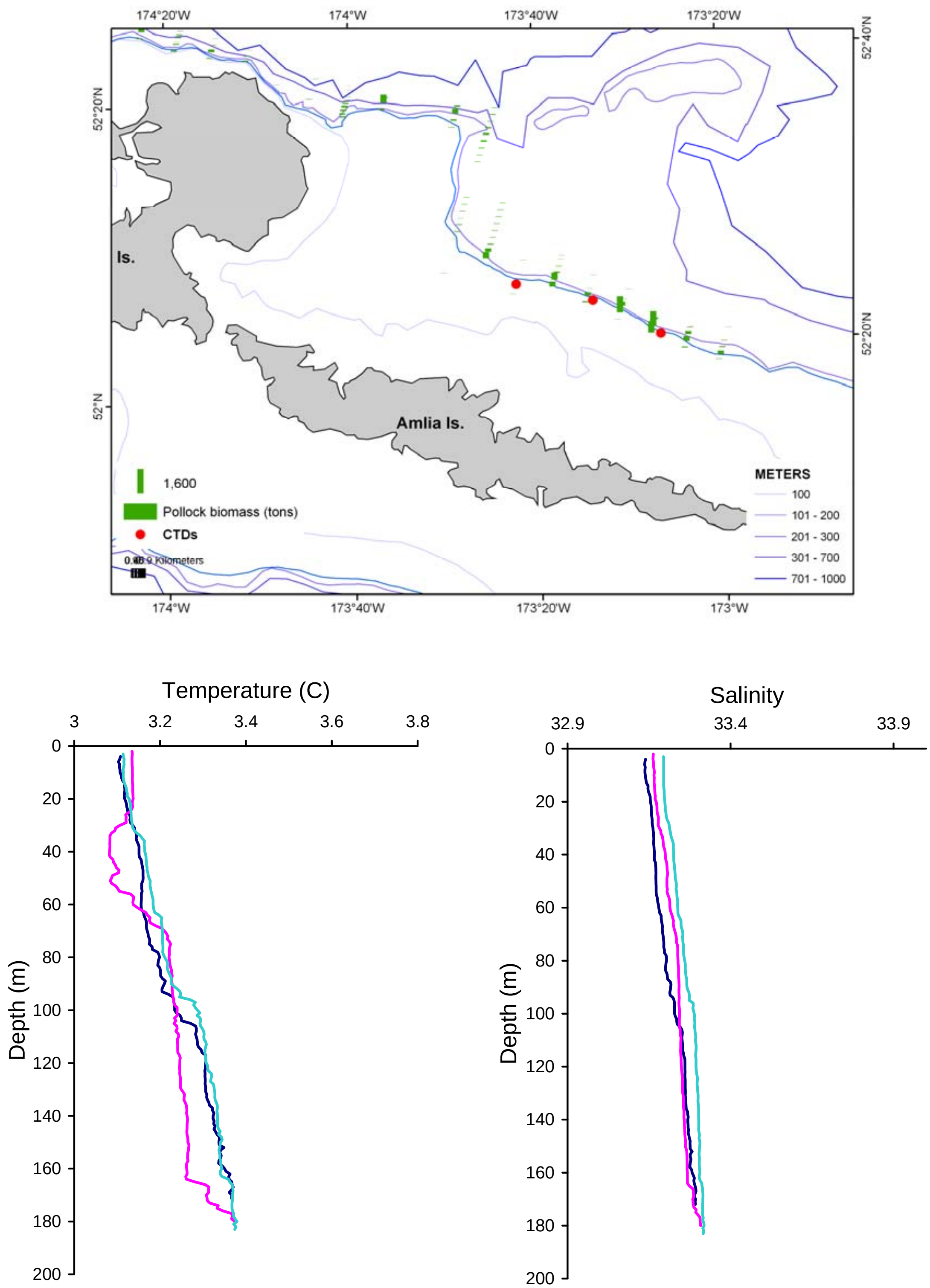


Figure 24. Temperature and salinity profiles from CTDs near Amlia Island. Map above shows location of CTD stations and acoustic estimates of pollock biomass from the *Oscar Dyson* survey.

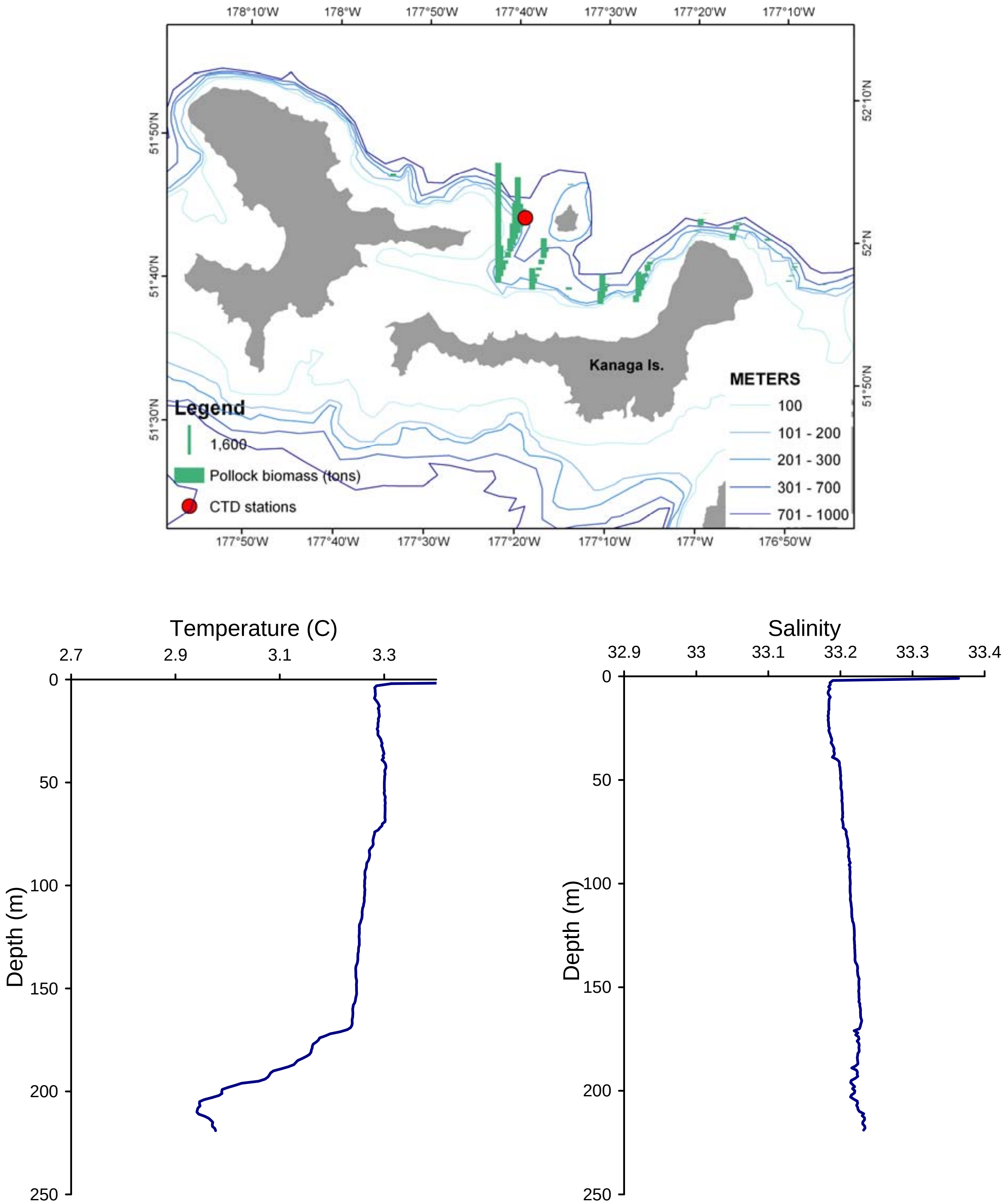


Figure 25. Temperature and salinity profiles from CTD station at Kanaga Island. Map above shows location of CTD station and acoustic estimates of pollock biomass from the *Muir Milach* survey.

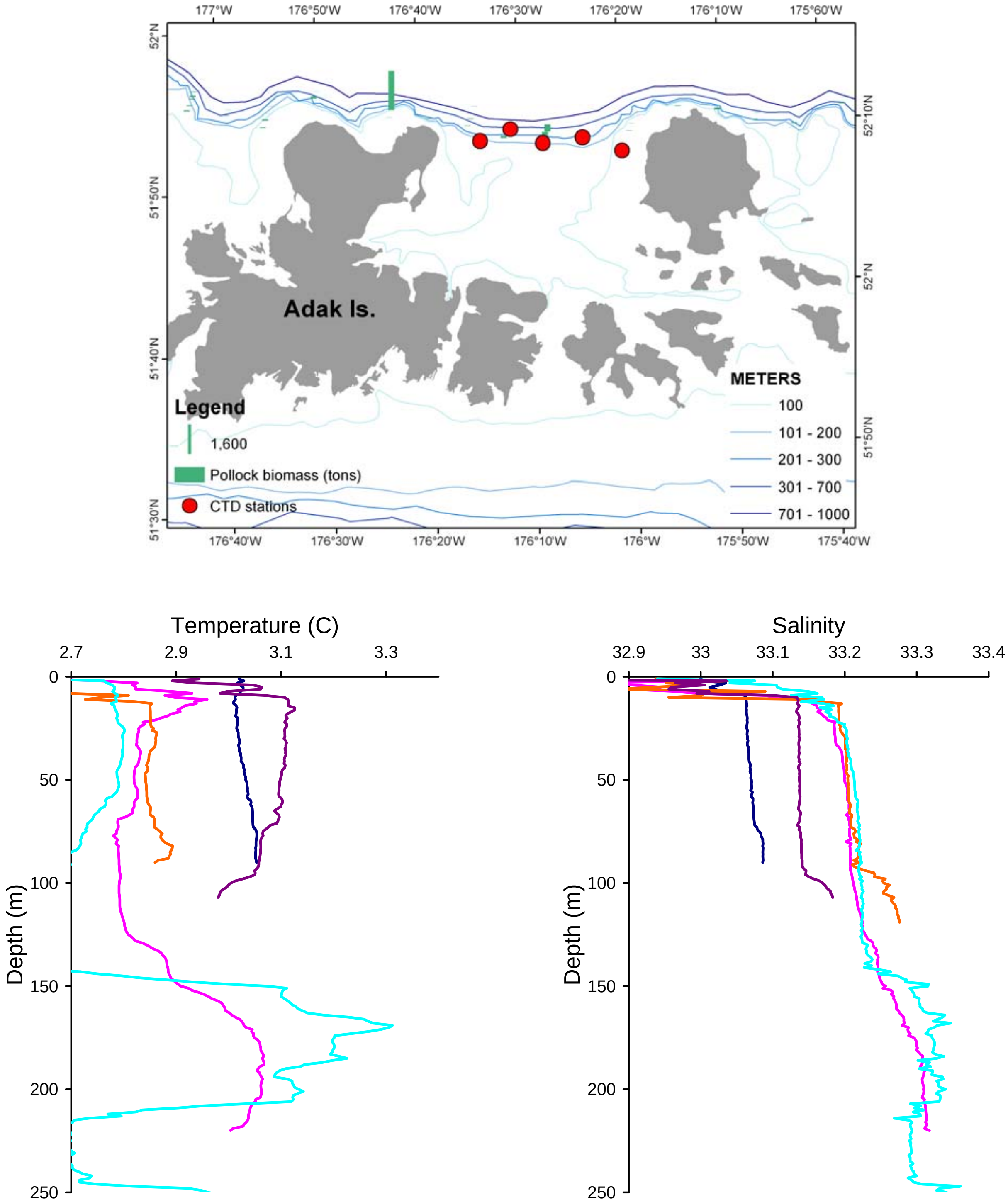


Figure 26. Temperature and salinity profiles from CTDs at Adak Island. Map above shows location of CTD stations and acoustic estimates of pollock biomass from the *Muir Milach* survey.

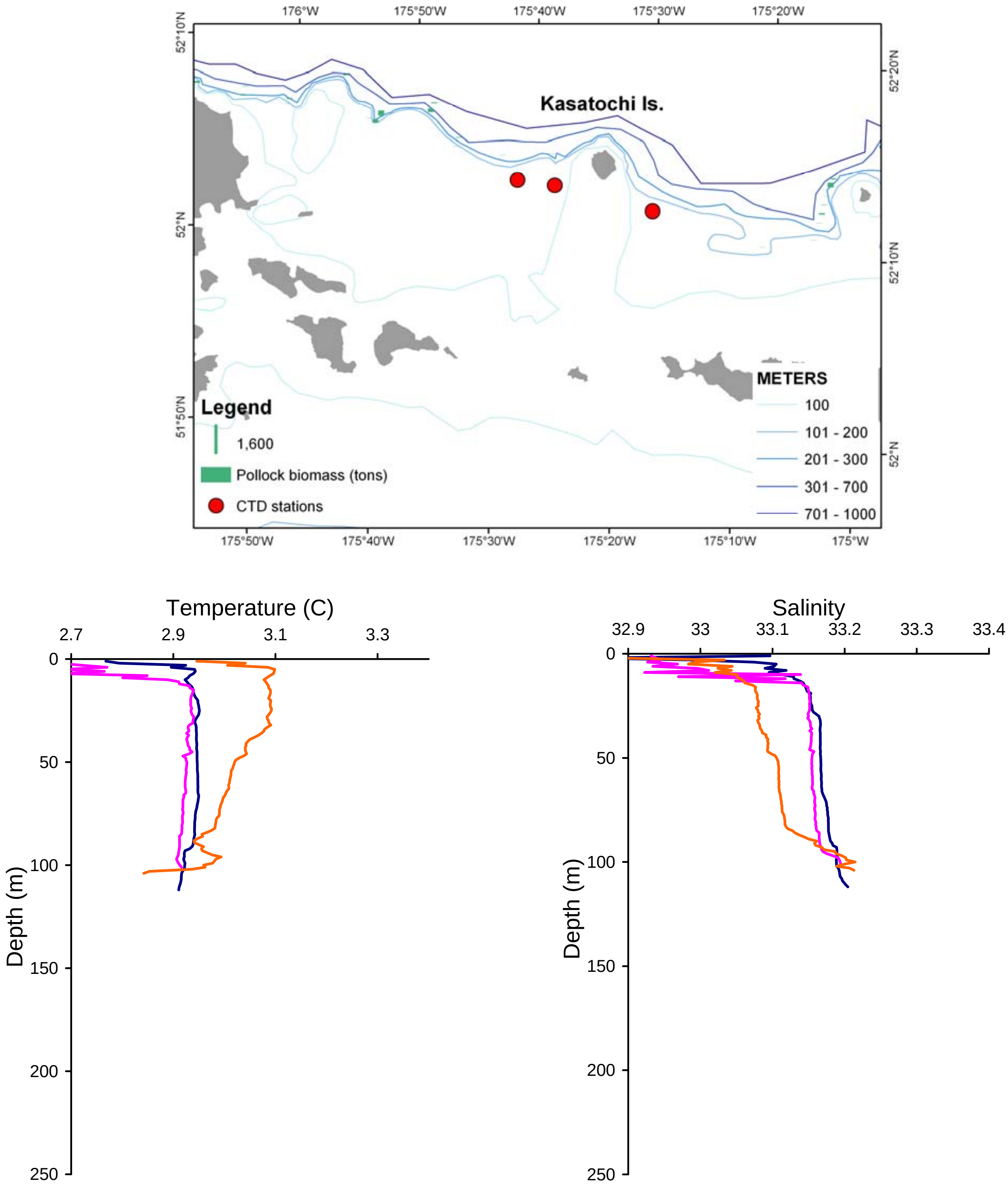


Figure 27. Temperature and salinity profiles from CTD stations near Kasatochi Island. Map above shows location of CTD stations and acoustic estimates of pollock biomass from the *Muir Milach* survey.

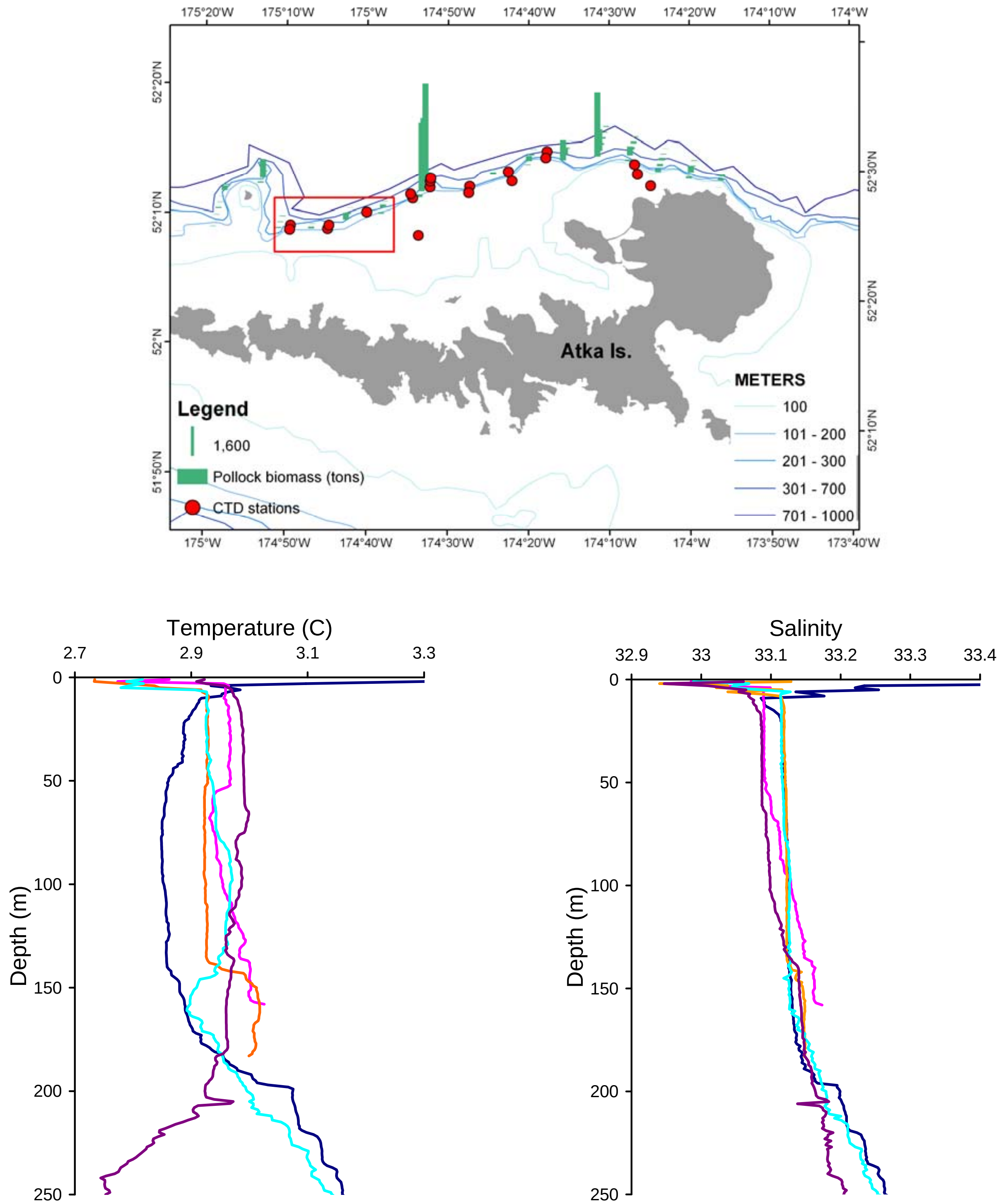


Figure 28a. Temperature and salinity profiles from CTD stations in the western Atka Island area. Map above shows location of CTD stations (inside red square) and acoustic estimates of pollock biomass from the *Muir Milach* survey.

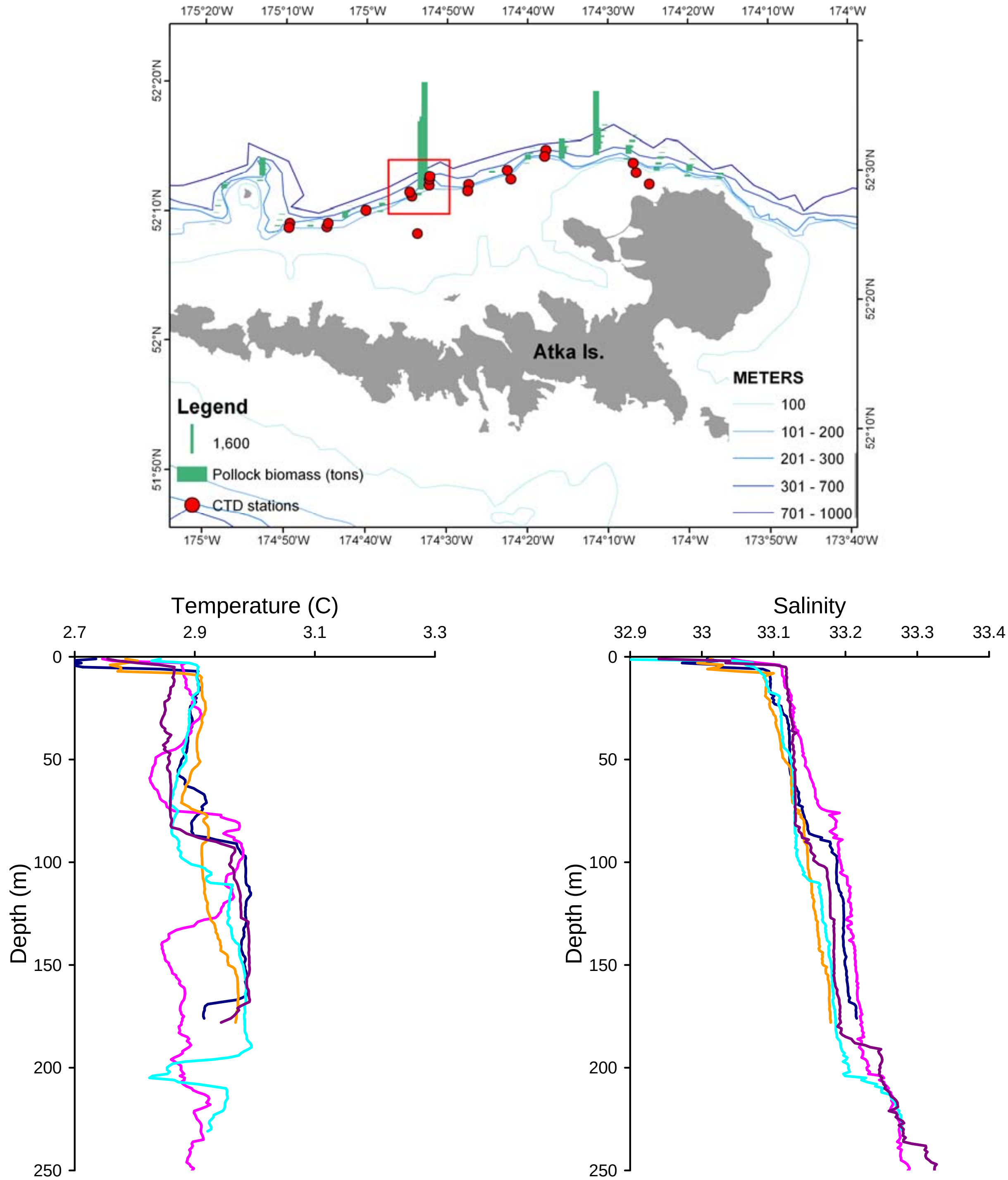


Figure 28b. Temperature and salinity profiles from CTD stations in the central Atka Island area. Map above shows location of CTD stations (inside red square) and acoustic estimates of pollock biomass from the *Muir Milach* survey.

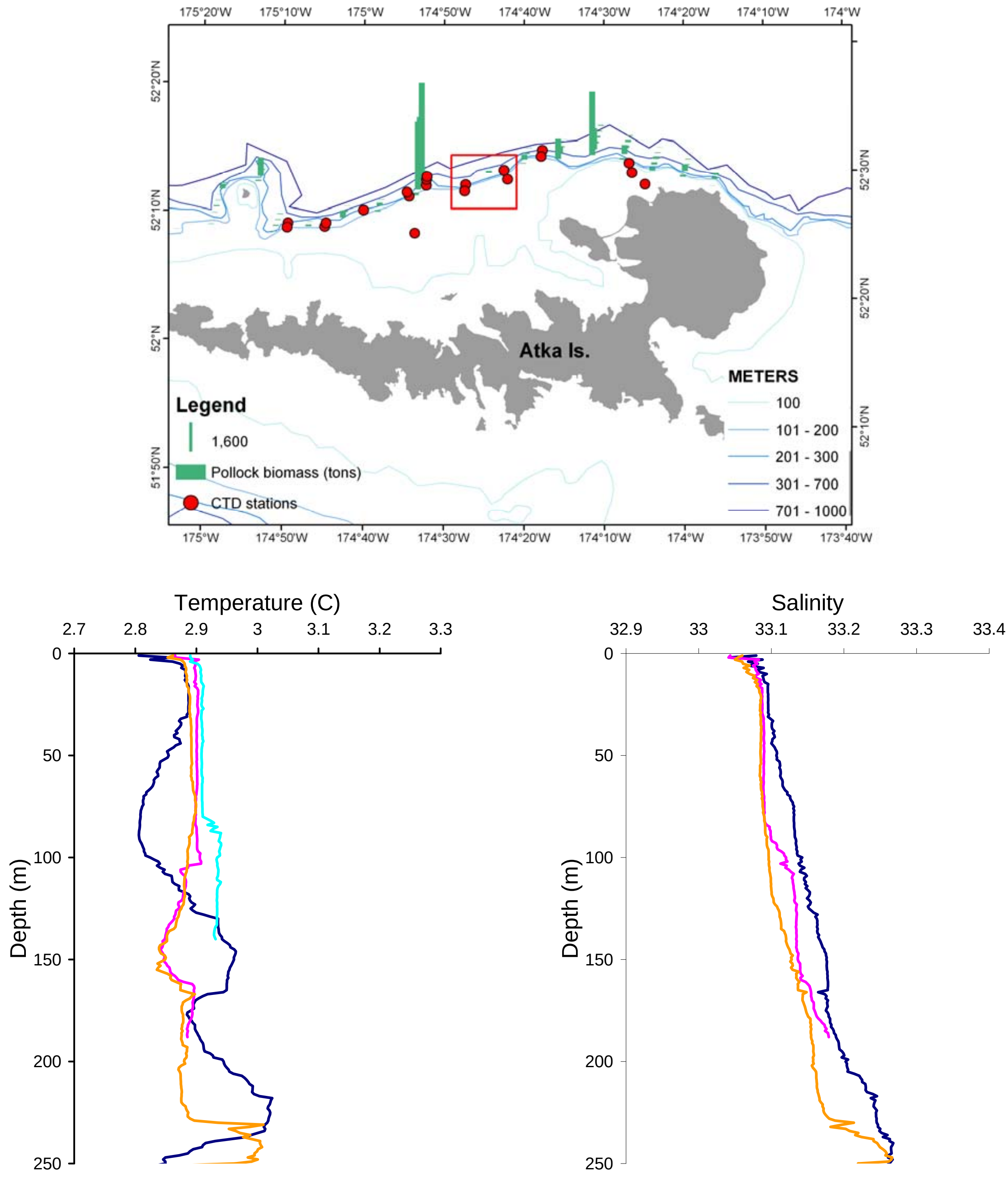


Figure 28c. Temperature and salinity profiles from stations in the central Atka Island area. Map above shows location of CTD stations (inside red square) and acoustic estimates of pollock biomass from the *Muir Milach* survey.

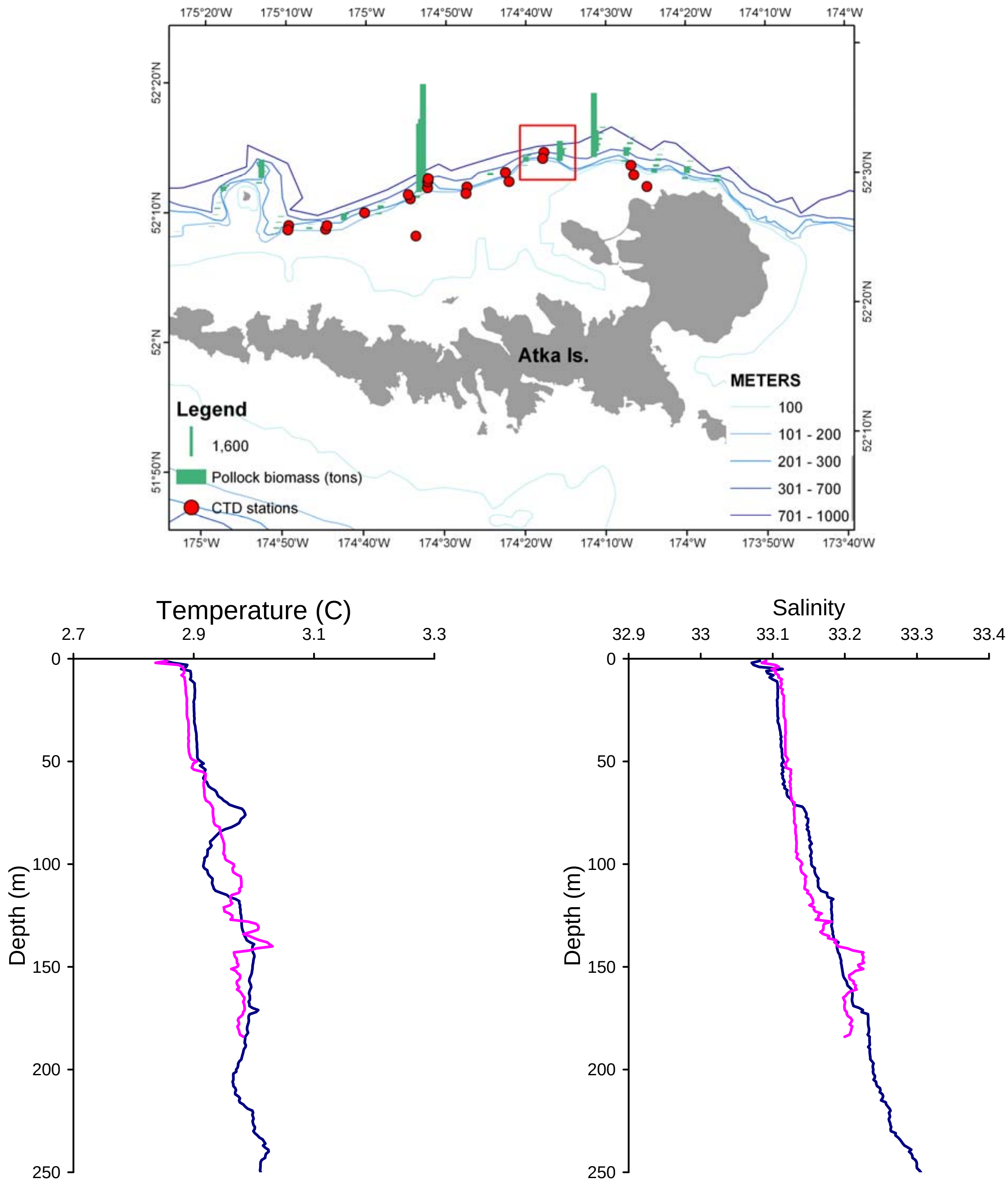
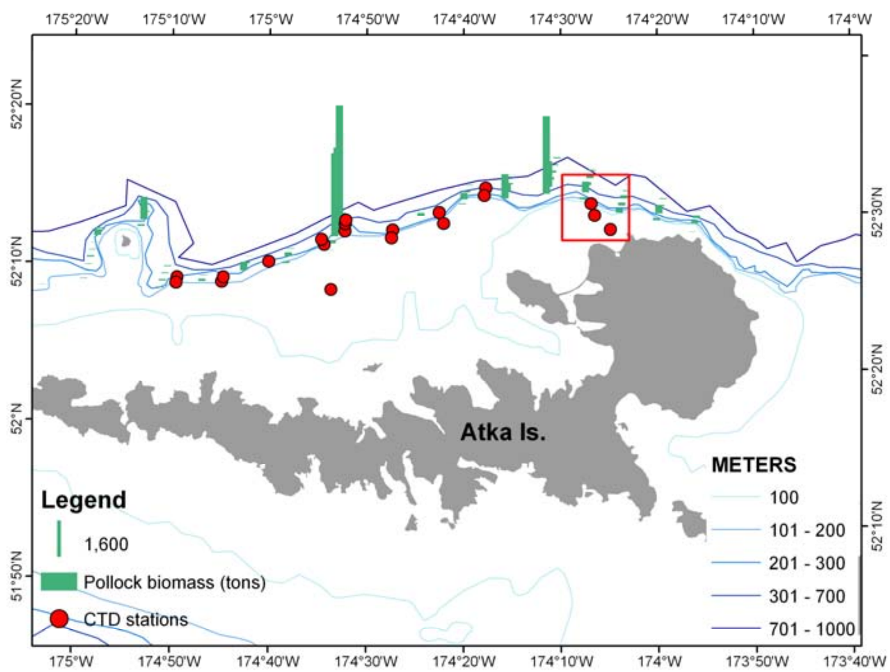
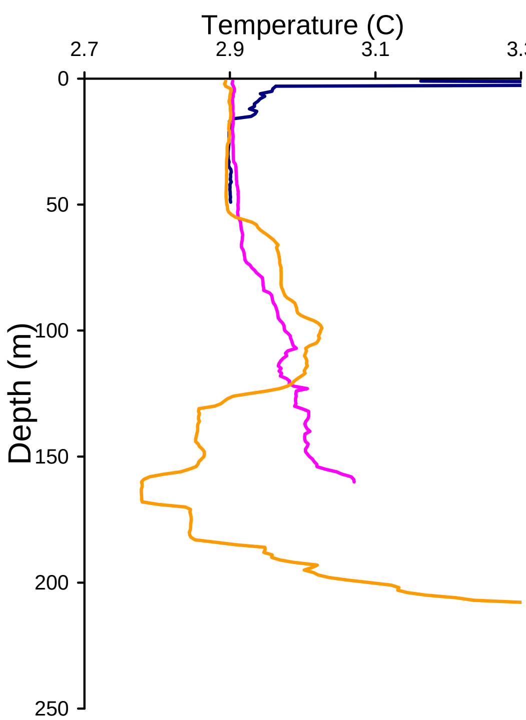


Figure 28d. Temperature and salinity profiles from CTD station in the eastern Atka Island area. Map above shows location of CTD stations (inside red square) and acoustic estimates of pollock biomass from the *Muir Milach* survey.





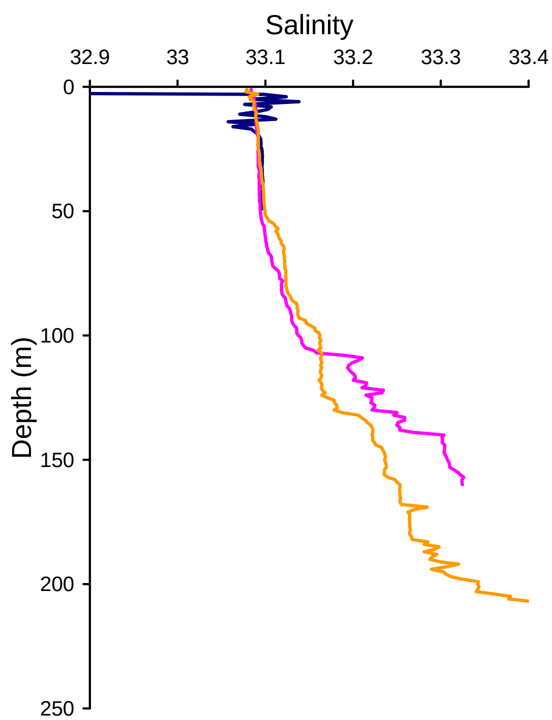


Figure 28e. Temperature and salinity profiles from CTD stations in the eastern Atka Island area. Map above shows location of CTD stations (inside red square) and acoustic estimates of pollock biomass from the *Muir Milach* survey.

Spatial patterns in temperature and salinity at surface and at depth

During the *Oscar Dyson* cruise, pollock biomass did not appear to be related to surface temperature (Fig. 29). Surface temperature was high at Kanaga but low at Amlia, Atka and Adak, all areas of relatively high pollock biomass. Surface temperature was high at Tanaga, where pollock biomass was low. Instead of a relationship between pollock biomass and temperature, there was a longitudinal cline in surface temperature decreasing from the west to the east. Temperature at depth showed similar patterns (Fig. 30). Pollock biomass distribution was not related to surface salinity (Fig. 31). For example, surface salinity was similarly high at Amlia and Atka but low at Adak, all areas of high pollock biomass. Similar to the temperature patterns, salinity at depth showed no consistent relationship to pollock biomass but did show a longitudinal cline, decreasing from west to east (Fig. 32). These patterns are summarized in the bar graphs of among-station mean temperatures and salinities at the surface and at depth in each area (Fig. 33). One sample Kolmogorov-Smirnoff Test of Composite Normality indicated that the oceanographic data were not normally distributed, so the non-parametric Kruskal-Wallis Rank Sum Test was used to test for statistical significance among areas:

Variable	Kruskal-Wallis chi-square	df	p
Surface temperature	15.3	5	0.009
Temperature at depth	12.2	5	0.033
Surface salinity	11.1	5	0.048
Salinity at depth	18.8	5	0.002

The differences in temperature and salinity at the surface and at depth among areas were statistically significant, but the patterns (described above) did not support our hypothesis that pollock biomass would be higher in areas of low temperature

During the *Muir Milach* cruise, surface temperature showed no consistent differences between areas of high and low pollock biomass. Surface temperature was high at Kanaga, one area of high pollock biomass, but not at Atka, another area of high biomass (Fig. 34). Temperature (Fig. 35) and salinity (Fig. 37) at depth (defined as the maximum depth of the CTD cast, or 300 m, whichever was shallowest) were slightly higher at Atka than in areas of low pollock biomass, but not higher at Kanaga another area of high pollock biomass. Surface salinity, however, was consistently higher in the Kanaga and Atka areas where pollock biomass was highest (Fig. 36). These patterns are also shown in bar graphs of among-station mean temperatures and salinities at the surface and at depth in each area (Fig. 38). One sample Kolmogorov-Smirnoff Test of Composite Normality indicated that the oceanographic data were not normally distributed, so the non-parametric Kruskal-Wallis Rank Sum Test was used to test for statistical significance among areas:

Variable	Kruskal-Wallis chi-square	df	p
Surface temperature	3.1	3	0.370
Temperature at depth	5.9	3	0.117
Surface salinity	9.3	3	0.026
Salinity at depth	0.5	3	0.915

There was a statistically significant difference in surface salinity among areas which supports our hypothesis that pollock biomass would be higher in areas of elevated salinity which are indicative of water column mixing.

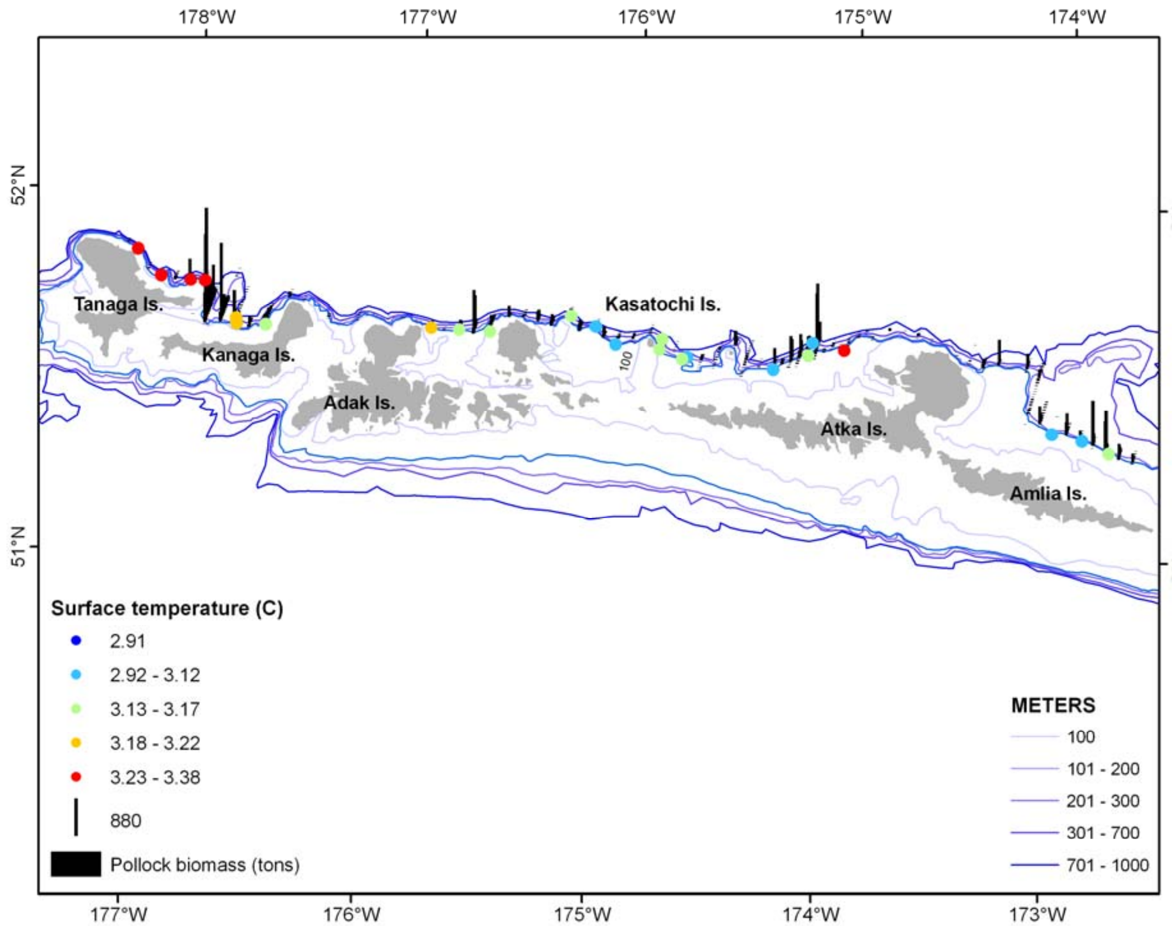


Figure 29. Surface temperature at CTD stations and acoustic estimates of pollock biomass from the *Oscar Dyson* cruise.

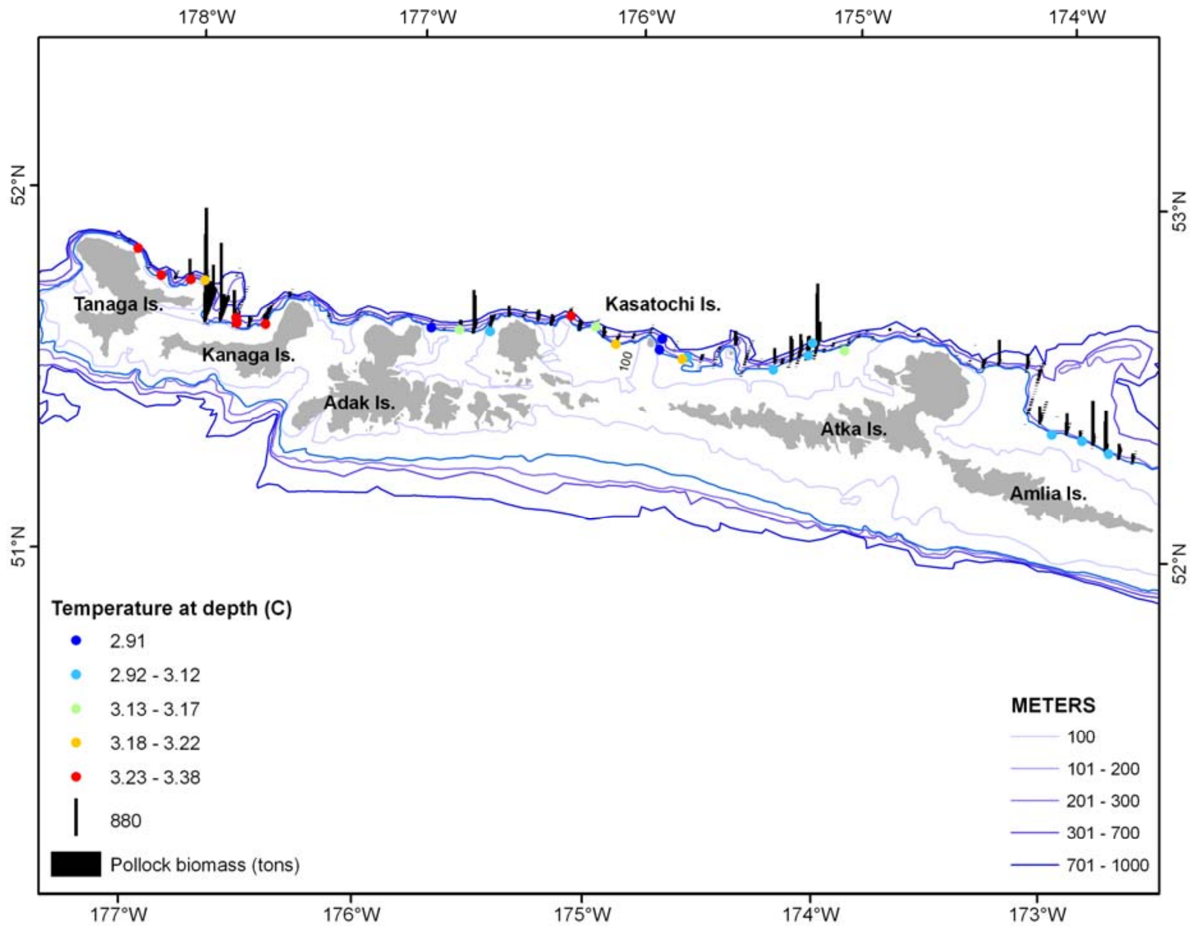


Figure 30. Temperature at maximum CTD cast depth (or 300 m for deeper casts) and acoustic estimates of pollock biomass from the *Oscar Dyson* cruise.

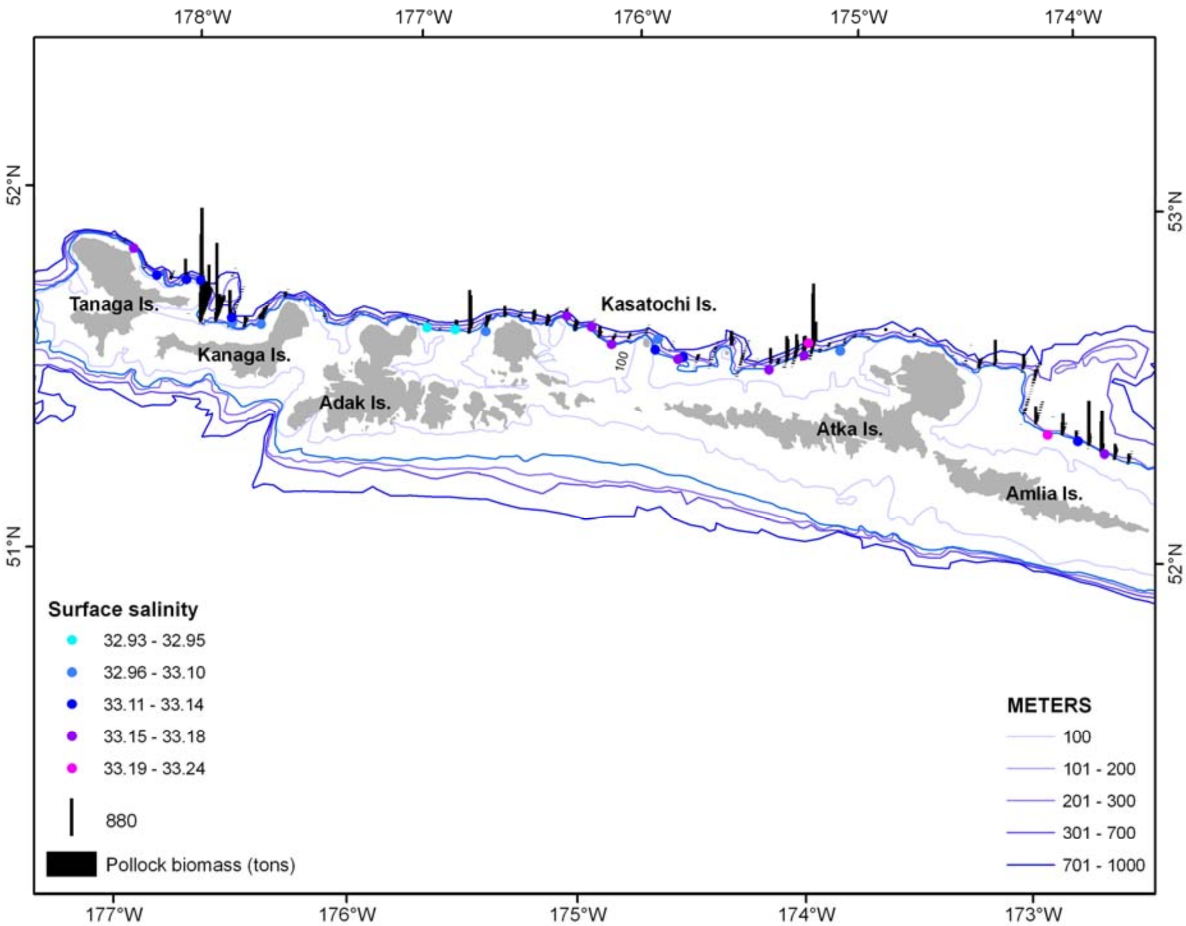


Figure 31. Surface salinity at CTD stations and acoustic estimates of pollock biomass from the *Oscar Dyson* cruise.

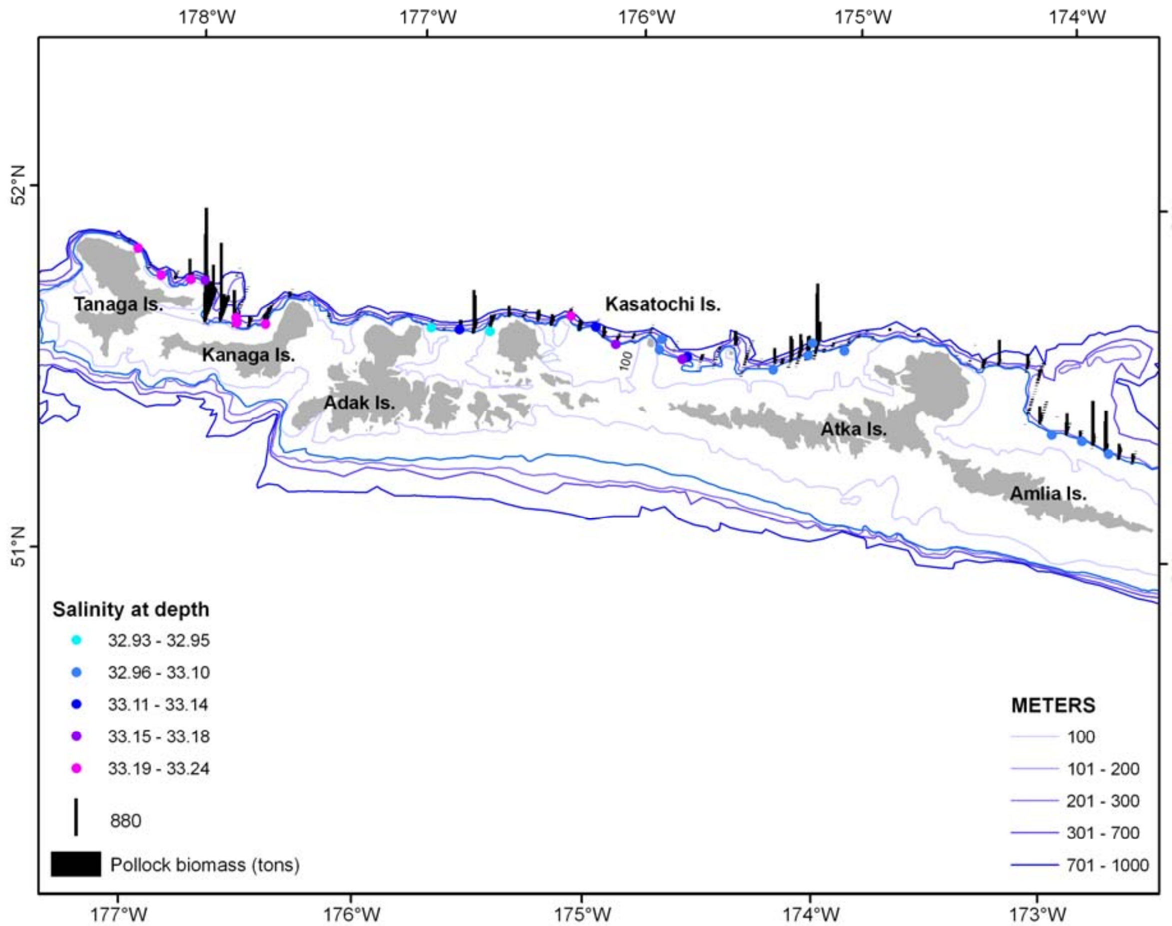


Figure 32. Salinity at maximum CTD cast depth (or 300 m for deeper casts) and acoustic estimates of pollock biomass from the *Oscar Dyson* cruise.

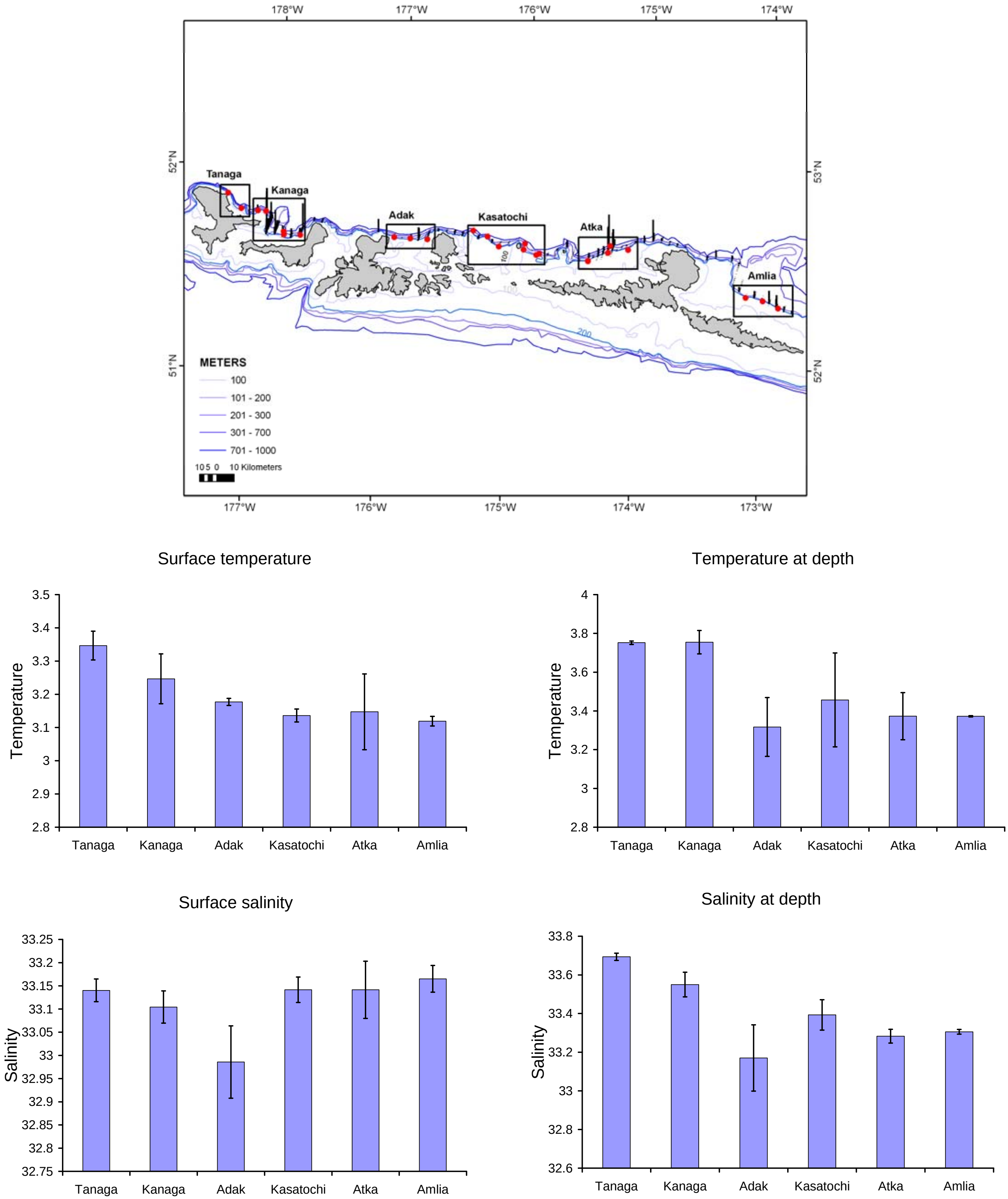


Figure 33. Mean (± stdev) temperature and salinity at the surface and at depth from CTD casts made in the six areas shown in the map at the top of the figure during the *Oscar Dyson* cruise.

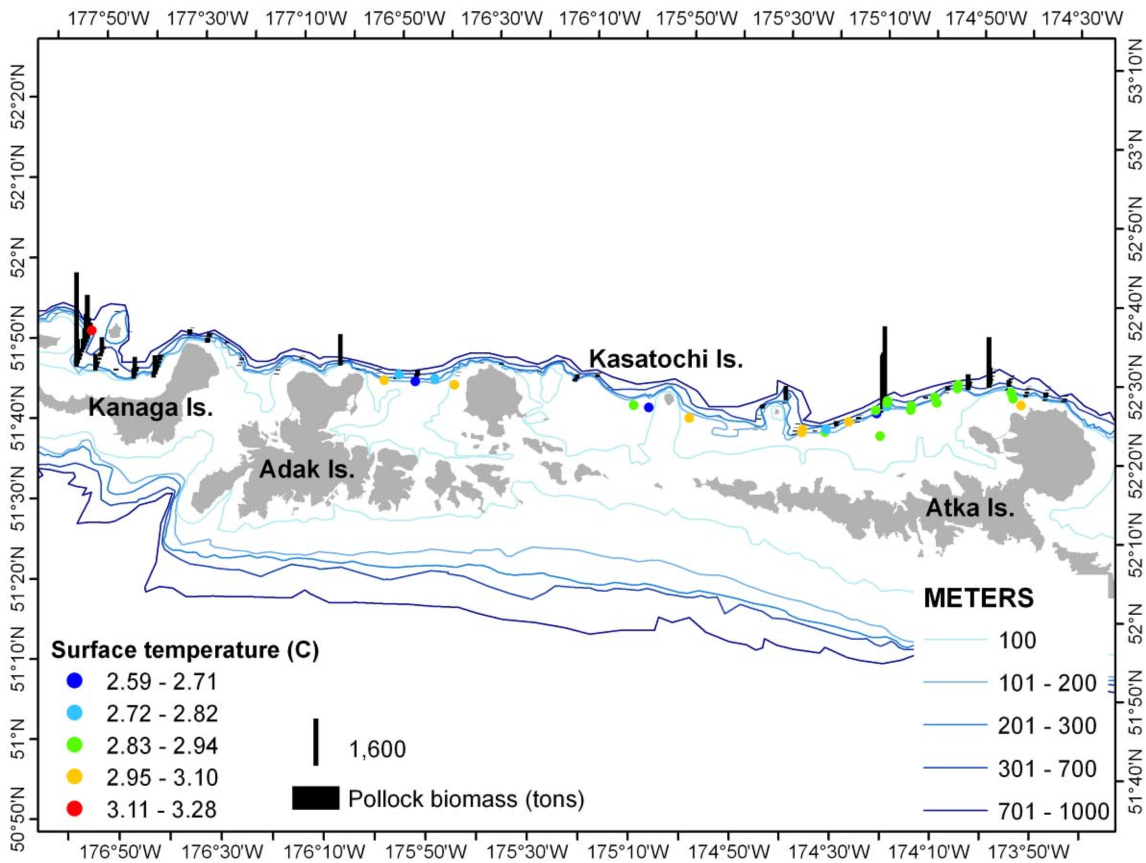


Figure 34. Surface temperature at CTD stations and acoustic estimates of pollock biomass from the *Muir Milach* cruise.

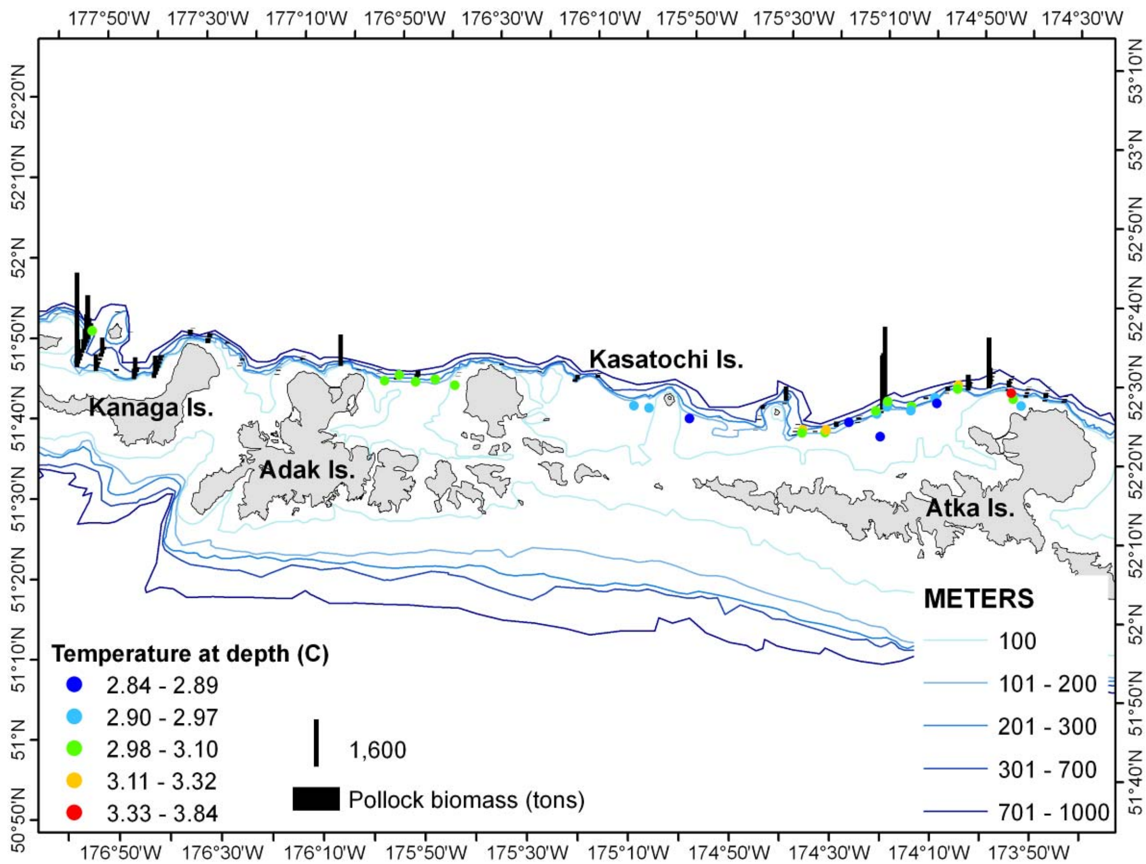


Figure 35. Temperature at maximum CTD cast depth and acoustic estimates of pollock biomass from the *Muir Milach* cruise.

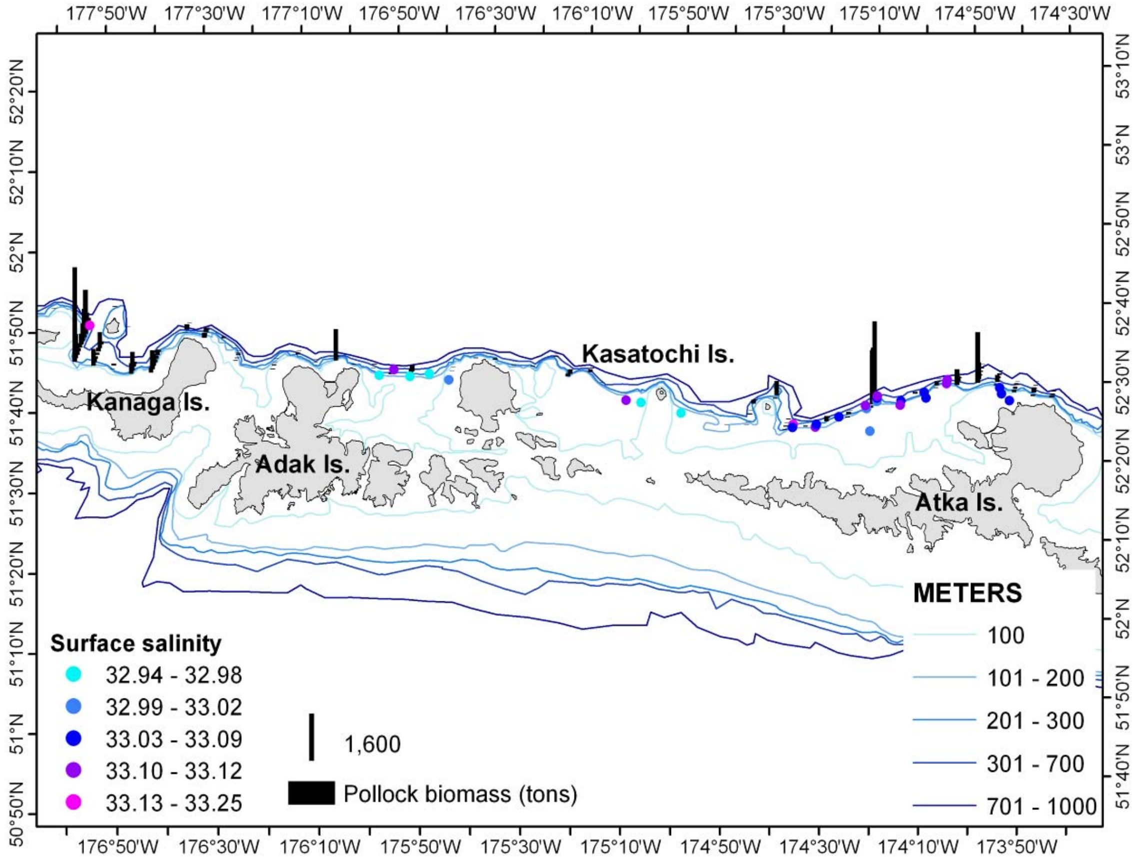


Figure 36. Surface salinity at CTD stations and acoustic estimates of pollock biomass from the *Muir Milach* cruise.

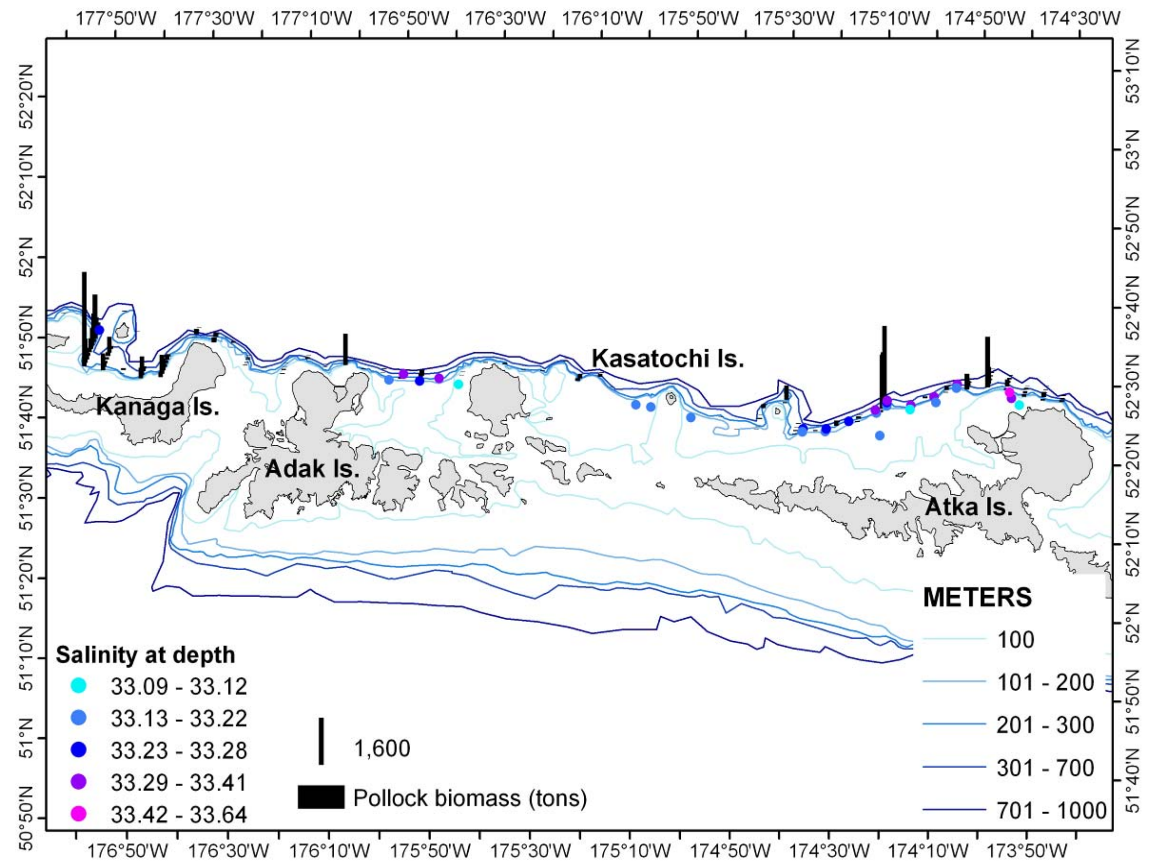


Figure 37. Salinity at maximum CTD cast depth and acoustic estimates of pollock biomass from the *Muir Milach* cruise.

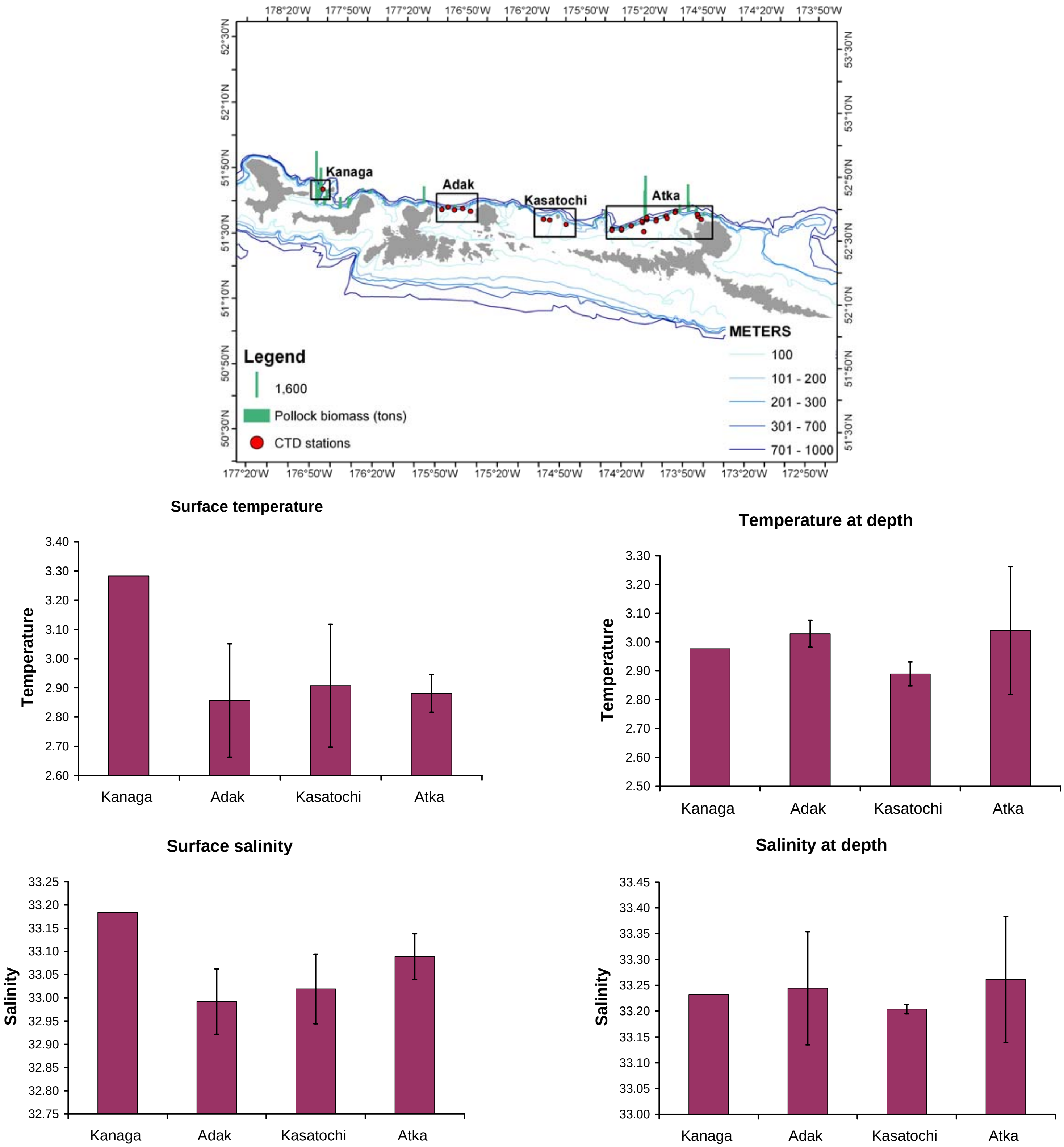


Figure 38. Mean (± stdev) temperature and salinity at the surface and at depth from CTD casts made in the four areas shown in the map at the top of the figure during the *Muir Milach* cruise.

Satellite-derived chlorophyll

Although the monthly composite from February 2008 provided the most cloud-free data, compared to the 8 day composites, there were still large areas with no satellite data during the *Oscar Dyson* survey (Fig. 39). Satellite data coverage was good in the eastern part of the survey area, near Atka Island and Kasatochi Island, but there were no data in the areas around Adak Island and Kanaga Island. Therefore we were not able to use the results of the *Oscar Dyson* survey to examine the hypotheses that pollock were more abundant where satellite-derived chlorophyll was high.

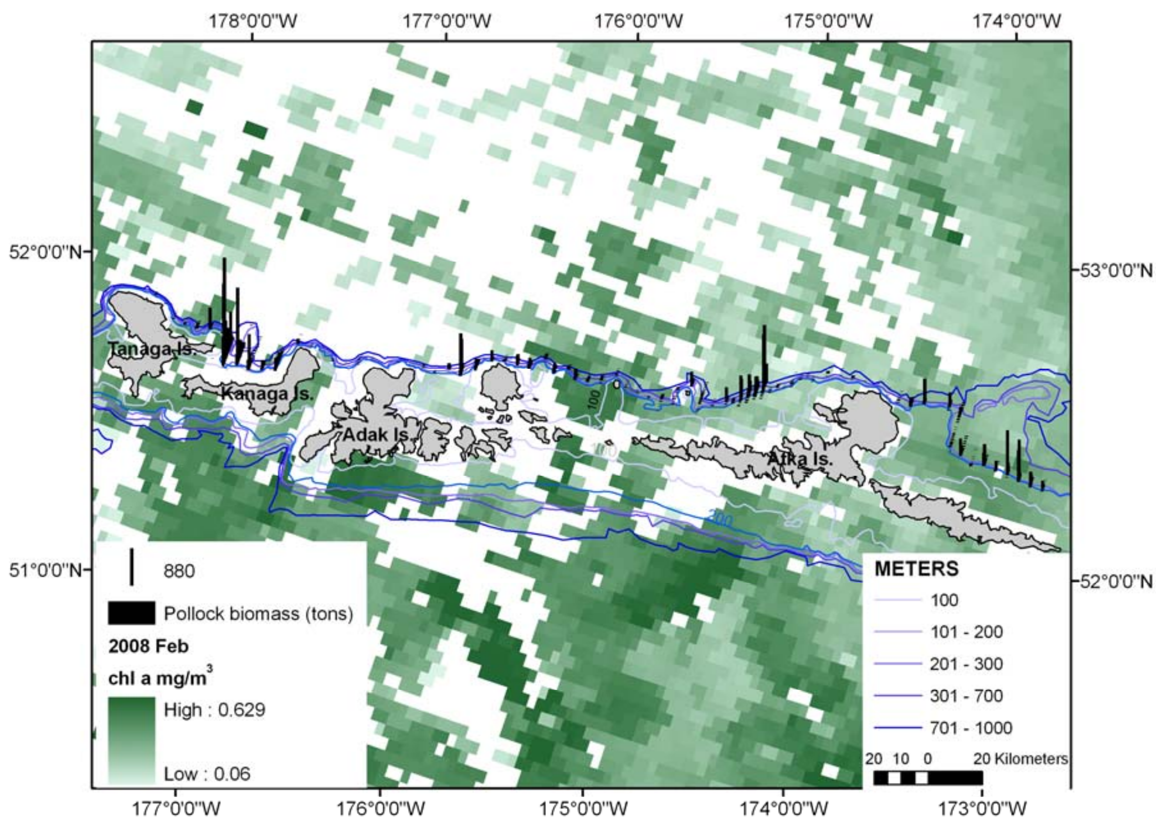


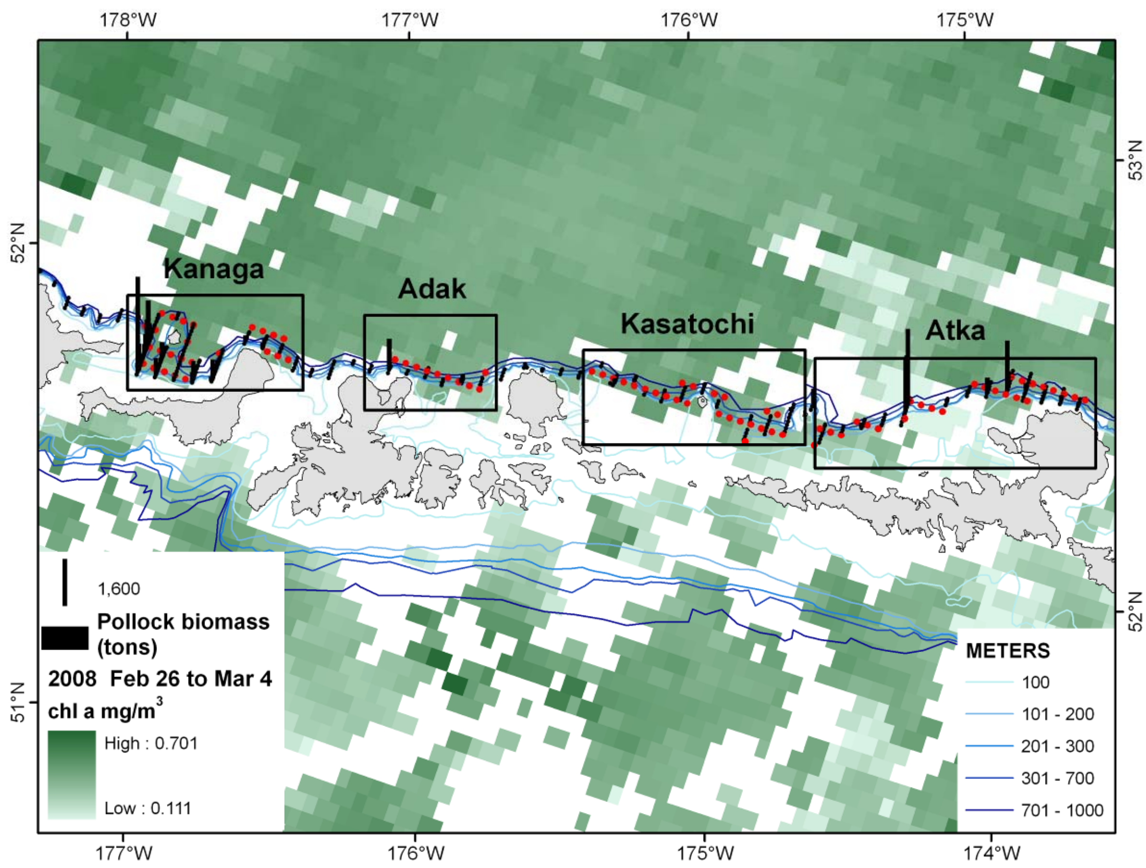
Figure 39. Satellite-derived chlorophyll-a density in February 2008 (1 month composite) the time of the *Oscar Dyson* survey. Black bars show the distribution of pollock biomass

Satellite chlorophyll data coverage was better in March 2008, the early March 8-day composite had little data loss due to cloud cover. Chlorophyll density was relatively uniform and low through most of the study area (Fig. 40a). Mean chlorophyll density was calculated from satellite data grid cells within each of the four areas examined for water column structure (Kanaga, Adak, Kasatochi and Atka). Mean chlorophyll biomass was lower in the Atka Island area than the other areas. One sample Kolmogorov-

Smirnoff Test of Composite Normality indicated that the chlorophyll data were not normally distributed. The non-parametric Kruskal-Wallis Rank Sum Test indicated that there were significant differences in chlorophyll biomass among areas (Kruskal-Wallis chi-square = 34.2, df=3, $p<0.001$). However, pollock biomass was high in the Atka Island area, so these data do not support our hypothesis that pollock were more abundant where satellite-derived chlorophyll was high.

It is useful to place the results of our winter time assessment of chlorophyll biomass in the context of the seasonal variability in ocean production. Chlorophyll biomass during March 2008 was lower overall and more uniformly distributed, compare to spring and summer, May-July (Fig. 41).

a.



b.

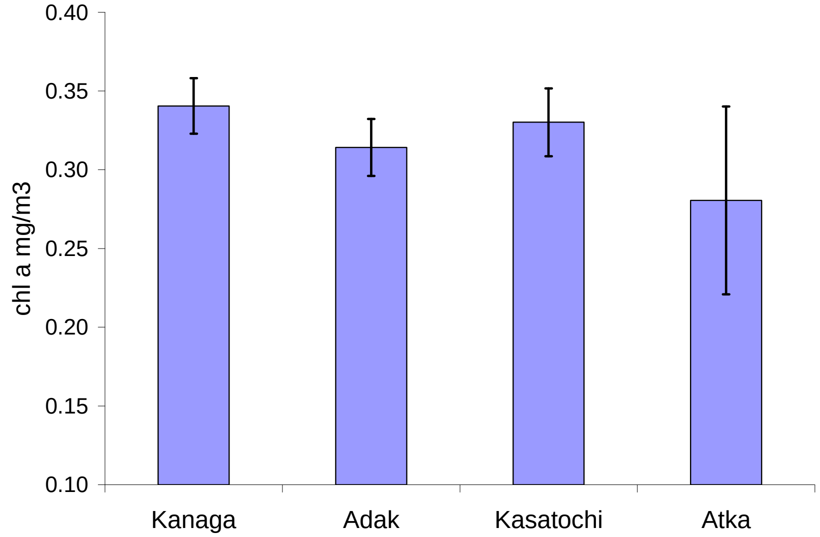


Figure 40. a. Chlorophyll a density in early March 2008 (8-day composite) the time of the *Muir Milach* survey. Red circles indicate grid cells selected for this analysis and boxes show areas over which mean chlorophyll was calculated. Black bars show the distribution of pollock biomass, b. mean chlorophyll a density by area (± standard deviation).

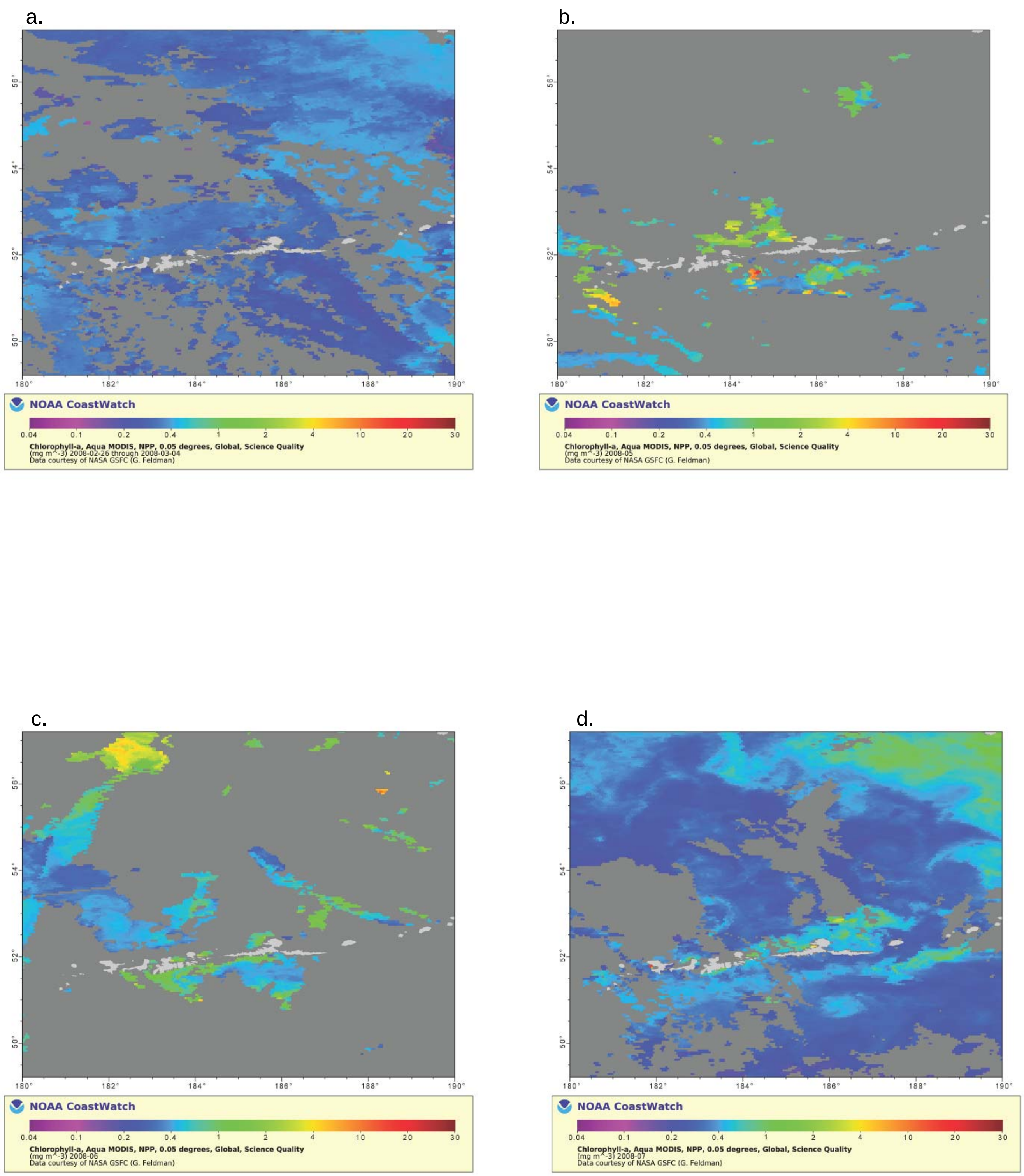


Figure 41. Monthly composite satellite maps of chlorophyll a in the central Aleutian Islands in 2008: a. March, b. May, c. June, and d. July

Hypotheses tested

Specific hypotheses that we explored were:

1) Sea lions are more abundant at haul-outs near areas where pollock are more abundant. Our data did not support this hypothesis. Atka mackerel dominated the diet at the greatest number of sites, and of the greatest number of sea lions. And these sites were found in areas where pollock abundance was observed to be relatively low (Kasatochi Island), or expected to be low (south side of the Aleutian Island chain).
2) Pollock are more abundant where the water column is mixed, surface temperatures are cold and satellite-derived chlorophyll is high. There was some support for this hypothesis. There were no consistent relationships between pollock abundance and water column structure; temperature and salinity at the surface and at depth; or chlorophyll biomass density. There was, however, a relationship between pollock abundance and surface salinity during the *Muir Milach* cruise.
3) Sea lions are more abundant at haul-outs near areas where pollock are aggregated for spawning compared to areas where pollock are not aggregated. Our data did not support this hypothesis. Because pollock spawning was correlated with abundance (i.e., there were more pre-spawning fish where pollock abundance was high), the conclusion under hypothesis 1 applies to this hypothesis also.
4) The proportion of spawning pollock is higher where the water column is mixed, surface temperatures are cold, currents are rapid and satellite-derived chlorophyll is high. Our data did not support this hypothesis. Because pollock spawning was correlated with abundance (i.e., there were more pre-spawning fish where pollock abundance was high), the conclusion under hypothesis 2 applies to this hypothesis also.
5) Pollock occur more frequently in the diets of sea lions at haul-outs where pollock are more abundant. Our data support this hypothesis. Pollock were more frequent in the diets of sea lions at sites near the three major aggregations of pollock (Kanaga, Adak and Atka) compare to sites away from these aggregations.
6) Sea lions are more abundant at haul-outs near areas where pollock distribution is predictable (at the temporal scale of months). Our data do not support this hypothesis. This is similar to hypotheses 1 and 3, in that pollock aggregate for spawning in predictable locations and times (in the central Aleutians in late winter), but haulouts nearby did not attract a disproportionately large number of Steller sea lions in the area.

We had originally proposed to build a multi-variate GAM to predict the abundance of sea lions or diet composition from oceanographic and pollock variables. However, there was only a relationship between sea lion diet composition and pollock abundance and limited support for a relationship between pollock and surface salinity. Furthermore, there were only nine sites at which diet data were collected which is not a sufficient size to justify a statistical model analysis.

Discussion

Pollock distribution

The Alaska Fisheries Science Center (AFSC) has conducted summer trawl surveys triennially from 1991 through 2000 and biennially from 2002 to 2006 in the Aleutian Islands region for waters between 50 and 500 meters depth. Although these surveys encounter pollock in the region of interest, the survey trawls are sparse, do not cover areas deeper than 500 m off the shelf break where pollock congregate, and are not specifically designed for surveying pollock. In addition, the AFSC trawl surveys are conducted in the summer when fish are spread out along the shelf for feeding. The distribution of adult pollock changes from summer to winter as the fish begin to form pre-spawning aggregations along shelf edge (Yanagimoto et al. 2002). The AFSC has conducted echo-integrated trawl surveys in the winter 400 km to the east of the study area in the region of Bogoslof Island biennially since 1988. The Bogoslof Island acoustic surveys reveal that although overall abundance in this region has decreased dramatically, pre-spawning aggregations of pollock have consistently been found in two specific locations (Honkalehto et al. 2005).

The 2006 through 2008 Aleutian Islands Cooperative Acoustic Survey Studies (AICASS) have been the only research conducted on winter pollock distribution and temporal stability in the Aleutian Islands west of 170° west longitude. The 2006 AICASS resulted in multiple acoustic surveys of the Atka (a.k.a. “Knoll”) aggregation, the abundance of pollock in this aggregation appeared to remain stable in the beginning of the survey period then decrease rapidly as both fishing occurred under the EFP and the proportion of spawning and spent pollock in the region increased (Barbeaux and Fraser 2009). The abundance and location of the Atka aggregation in 2006 was consistent with the 2007 and 2008 surveys. The 2007 AICASS surveyed the same region as the 2008 AICASS and, like the 2008 study, observed high densities of pollock consistent with the Kanaga, Adak, Kasatochi, Atka, and Amlia (a.k.a. “Atka Flats”) aggregations observed in the 2008 survey (Romain et al. in prep). The pollock maturity and length data collected during the three studies suggest that these were pre-spawning aggregations. The areas where these aggregations occurred in the studies were also areas with high pollock catches in the 1990's winter fisheries (Barbeaux et al. 2008). The three years of consistent AICASS results and a 20 year history of high catches suggest that the bathymetry and perhaps oceanographic conditions make these areas preferred habitat for forming pre-spawning aggregations. Further, the 2008 surveys show that the abundance and size composition of pollock in the region between 174° and 178° W longitude remains consistent from February through March, while the maturity stage progressed towards a higher proportion of pre-spawning and spawning fish. Although we cannot determine for certain given the available data that the two surveys observed the same population, the preponderance of evidence suggests this to be the case.

Sea lion distribution and diet

Sampling of Steller sea lion (SSL) diets at fine temporal and spatial scales, as we did in this study, can detect the consumption of ephemeral, patchy prey that can be missed in broad scale studies. We report a pollock percent frequency of occurrence (%FO, 26%) in scats collected in early April 2008 in the central Aleutian Islands that is almost 10 times that reported by Sinclair and Zeppelin (2002; 2.7%) for the entire Aleutians averaged during the winters (December-April) of 1990-98. This is almost certainly due to the focused sampling at haul-outs near (and when) pollock aggregate prior to spawning. We also analyzed almost twice the number of food habits samples (305) that Sinclair and Zeppelin (2002) used to characterize the winter Aleutian SSL diet (165), which could increase the likelihood of detecting prey species consumed less frequently. Subsequent analysis by NMML (unpublished) of an additional 196 winter-collected scats (1999-2005) in the central and western Aleutians increased the overall winter pollock %FO to 12%. However, in collections at two sites sampled in late March-early April 2002 (one near Adak Island on Silak, and one on Amlia Island), the pollock %FO averaged 38%. In our study, the %FO for pollock increases to 47% if only the 5 haul-outs sampled in the high pollock areas are considered. Therefore, when making conclusions about the relative importance of different prey species to sea lions, one must consider not only when and where the SSL diet samples were collected, but also the characteristics of the prey (e.g., aggregated prior to spawning) that will affect their availability to sea lions seasonally and spatially.

The %FO for rockfish spp. (Scorpaenidae) in our study (30%) was much higher than either the winter (4.2%) or summer (2.4%) values reported by Sinclair and Zeppelin (2002) for the Aleutian Islands as a whole. The higher %FO for rockfish spp. (probably Pacific ocean perch, POP) in our study may be the result of the same sampling scale issues discussed above for pollock. We observed POP in two main aggregations during our hydroacoustic surveys: one north of the chain from Adak Island to Great Sitkin Island, and a second on the slope north of Atka and Amlia Islands. Four SSL haulouts where we collected scat (Anagaksik, Salt, Atka/North Cape and Kasatochi) near the Atka and Amlia aggregations also have easy access to foraging areas north of the chain. These 4 haulouts also had the highest %FO for rockfish spp. encountered in our study. The haulout that had the lowest %FO for rockfish (0% on Kanaga/Ship Rock) was located about 40 mi W of the Adak rockfish aggregation, suggesting that SSL foraging ranges from this haulout were generally less than 40 mi.

The %FO for Pacific cod in our study (26%) was also higher than that reported for the Aleutians during winter by Sinclair and Zeppelin (2002; 17%) but quite similar when the additional samples collected in 1999-2005 are considered (27%). Pacific cod consumption by SSLs is higher in winter than summer (Sinclair and Zeppelin 2002; NMML unpublished), which is likely related to seasonal spawning aggregations increasing availability and predictability for SSL predation. Womble and Sigler (2006) and Sigler et al. (2009) came to similar conclusions in their studies of SSL diet and distribution in SE Alaska related to seasonally aggregated prey, such as Pacific herring and eulachon.

Atka mackerel was the most prevalent SSL prey species in our study, as it has been in both previous studies of SSL diets in the Aleutian Islands (Merrick et al. 1997; Sinclair and Zeppelin 2002). The %FO of Atka mackerel in winter from our study (53%) is slightly lower than the value reported by Sinclair and Zeppelin (2002; 65%), but quite similar when the additional samples collected in 1999-2005 are considered (55%). Atka mackerel was one of only three prey items (the other two being salmon sp. and Irish lord sp.) that occurred at each of the 10 haulouts sampled in our study, but at a higher overall %FO than either of the other two. The prevalence of Atka mackerel has generally been lower in winter than in summer (Sinclair and Zeppelin 2002; NMFS unpublished). Atka mackerel spawn and nest-guard in relatively nearshore areas in summer/fall, which would likely make them more susceptible to predation than in winter when they are more dispersed and offshore (McDermott et al. 2005).

Sinclair and Zeppelin (2002) found a similar relationship between Atka mackerel, walleye pollock and Pacific cod from their principal component analysis of SSL diet across the range of the western stock in Alaska throughout the year that we did in our study of the late winter, central Aleutian diet: separation between Atka mackerel (-) and pollock/cod (+) on PC1, and separation between pollock (-) and cod (+) on PC2. This suggests that the same general pattern of prey associations by site/region (but not necessarily magnitude) was revealed in their broad-scale study as we found in our fine-scale study.

This study and others (e.g., Merrick et al. 1997; Sinclair and Zeppelin 2002; Trites et al. 2007; McKenzie and Wynne 2008; NMML unpublished) have shown that Steller sea lions feed not only on schooling pelagic fishes, but also on demersal non-schooling fishes, such as Irish lord sp. (Cottidae), smooth lumpsuckers (*Aptocyclus ventricosus)* and flatfish (e.g., rock sole (*Lepidopsetta sp.*), and that the %FO of these species is generally higher in winter than in summer. For instance, for Irish lord sp., Sinclair and Zeppelin (2002) report %FO of 16% in winter and 4% in summer, while NMML (unpublished) reports %FO of 23% in winter (identical to the %FO reported here) and also 4% in summer. This may reflect the greater use of benthic foraging strategies by SSLs in winter than in summer to compensate for the generally more dispersed pelagic prey fields in winter. As a consequence, any factor that could further reduce the availability or predictability of pelagic prey patches could have a greater impact on Steller sea lion foraging efficiency in the Aleutians in winter than in summer.

Almost 90% of all SSLs counted in our study were juveniles or adult females, and many of the latter group likely had a dependent young born in one of the preceding several years (2005-2007). The high proportion of females and juvenile sea lions in the Aleutians in winter suggests that these age/sex classes largely remain in the same general area as the summer rookeries throughout the year. This does not imply that they remain near their breeding location, necessarily, but within the same general area. By contrast, the low number of males encountered in our study indicates that they over-winter in different areas, perhaps to reduce the local foraging intensity on relatively dispersed winter prey fields. Large numbers of adult males have been observed in the northern Bering Sea, on haulouts on St. Lawrence Island in the fall (G. Sheffield, ADFG, pers. comm.; NMML unpublished), and it is presumed that they move south with the ice during winter. Our observations support this general model regarding seasonal movement of different age/sex classes of SSLs in the area described by Calkins and Pitcher (1982).

The pollock consumed by Steller sea lions in this study were generally of commercial size, but could have been at the smaller end of the commercial range. While no pollock < 35 cm were encountered in either of our acoustic surveys, food habits collections provided evidence of Steller sea lion consumption of Pollock < 30 cm. Thus, juvenile pollock were not absent from the Aleutian Islands as suggested by the surveys, but appeared to be present in low numbers. Since most pollock consumed were > 30 cm, Steller sea lions apparently utilized aggregations that were distributed generally over deep water and located at between 100-400 m depth.

There was also considerable overlap between the sizes of Atka mackerel, Pacific cod and rockfish consumed by SSLs and caught by fisheries in the Aleutians. While SSLs counts in the central Aleutians (Kiska Island 177°E through Yunaska 171°W) continue to decline in the 2000s (Fritz et al. 2008), the region sampled in this study for food habits (Kanaga Island through Amlia Island) has been relatively stable for the last decade, and several of the rookeries produced more pups in 2005 than they did in the early 1990s (Kasatochi and Adak/Lake Point). Differences in population trends in portions of the western SSL range in AK must be considered when extrapolating results from this study to other areas.

About two-thirds of the SSLs counted in our survey were on haulouts within the high Atka mackerel area, while about one third were on haulouts in the high pollock areas. This suggests that the pollock spawning aggregations, while utilized extensively by those sea lions hauling out nearby, may not currently attract sea lions from throughout the surrounding area. Sigler et al. (2009) estimated that in SE Alaska, "…a standing biomass of 500 to 1700 t of prey in a nonbreeding area…, depending on species composition, can attract and sustain about 500 sea lions." In Kanaga Sound, we estimated a pollock biomass of 14,180 mt during the late March 2008 (*Muir Milach*) survey, and counted 243 SSLs at the haulouts in the Kanaga Sound area (on Kanaga and Tanaga Islands). Assuming that we counted only about 15% of the actual number of SSLs utilizing the area (haulout rate of adult females with a dependent young in winter; (Trites and Porter 2002), there were approximately 1,620 feeding in the Kanaga Sound area. Using the range of estimates from Sigler et al. (2009), the pollock aggregation could attract and sustain between 4,200 and 14,200 SSLs, far greater than the number estimated to be using the Kanaga Sound area from our survey. We estimate a slightly smaller difference at the Atka pollock aggregation, which had a hydroacoustic survey estimate of 12,217 mt of pollock that could sustain between 3,600 and 12,220 SSLs; we counted 349 SSLs during our aerial survey for an estimated 2,330 in the area. These results suggest that (1) the SSL attracted/prey biomass ratio estimated in SE Alaska may not apply in the Aleutians, or (2) that not all the pollock biomass we measured in the Kanaga Sound and Atka aggregations is available to SSLs. At the Adak aggregation (survey estimate of 2,251 mt of pollock could sustain between 660 and 2250 SSLs; 427 SSLs counted for an estimated 2,850 in the area), the numbers of SSLs sustained and SSLs estimated in the area were more similar.

We do not know the extent to which sea lions move between the food habits areas defined in this study, nor the time scales of such movement. Therefore, we can make no firm conclusions regarding the actual proportions of the overall SSL population in the area, nor the actual numbers that feed on the pollock pre-spawning aggregations identified in this study. The proportion estimated here could be considered a minimum based on the unknown rates of movement between food habits areas. We can conclude that sea lions that use haulouts near pollock spawning aggregations eat more pollock than those that haulout further away, and that pollock is the most common prey species at those haulouts. At other haulouts in the area surveyed, Atka mackerel was the most common prey species, which it is generally throughout the year for SSLs in the Aleutian Islands.

Oceanography

Oceanographic properties appeared to have little influence on the distribution and abundance of pollock biomass. Because pollock reproductive maturity was advanced in areas where they were aggregated, our results extend to the influence of oceanography on the proportion of spawning fish. Water column structure varied among stations, but there was no consistent difference in the degree of stratification (or mixing) among areas with high and low pollock biomass. Variations in water column structure could have been driven by variations in tide, winds and/or the location of the station relative to the shelf break (Ladd et al. 2005). Whatever the cause(s), pollock did not respond to differences in water column structure during our surveys, and thus our hypothesis that pollock would be more abundant in areas of greater mixing was not supported by our data.

Neither were there conclusive relationships between pollock biomass distribution and water properties (temperature and salinity) at the surface and at depth. So our results do not support the hypothesis that pollock are more abundant where surface temperatures are cold. However, there was a clear longitudinal trend in temperature at the surface and at depth, decreasing from the west to the east. Very few, if any, oceanographic surveys have been conducted in the winter in the Aleutian Islands. Spring and summer observations have shown the opposite trend of what we observed, a longitudinal cline in surface temperature increasing from west to east (Ladd et al. 2005). The spring/summer trend is likely driven by differences in source waters (Alaska Coastal Current versus Alaskan Stream), mixing depth, and Bering Sea influence. Further oceanographic surveys are needed to elucidate the mechanisms driving the winter trends we observed. Although there was no relationship between pollock biomass distribution and surface temperature, there was a suggestive relationship between pollock and surface salinity. Surface salinity was consistently higher in areas where pollock biomass was higher, and the difference was statistically significant during the *Muir Milach* cruise (but not during the *Oscar Dyson* cruise). Because salinity has been shown to be a tracer of nutrients in the Aleutian Islands (Mordy et al. 2005) these results suggest the hypothesis that areas of high pollock biomass are characterized by high surface nutrient concentrations which may in turn fuel greater primary and secondary production and thus provide improved foraging opportunities for pollock preparing to spawn. Given the variability among stations, greater wintertime sampling effort would be required to test this hypothesis.

Obtaining a sufficient amount of cloud-free satellite data to examine spatial patterns in chlorophyll-a biomass proved to be a challenge. Large portions of the study area were obscured by clouds during most of February. Satellite data coverage was better in March, but the images revealed that chlorophyll biomass was low in areas where pollock biomass was high (i.e., Atka Island). Thus, these results do not support the hypothesis that pollock biomass would be higher in areas with higher chlorophyll biomass. Comparing the March 2008 satellite images with images from spring and summer shows that chlorophyll biomass was much lower and more uniformly distributed in winter. Given the overall low ocean productivity in winter, perhaps it is not surprising that fish distribution is not related to chlorophyll biomass.

Feasibility of cooperative acoustic surveys

Multiple calibrations of the *Muir Milach's* acoustic system show no significant difference from 2006 through 2008 with a maximum difference among estimates of ±0.03 dB with a total variance among the four calibrations of 0.19 dB. For comparison, the maximum difference from a 38kHz ER-60 scientific echsosounder aboard the Norwegian research vessel *G.O. Sars* built in 2003 was ±0.1 dB for eight calibrations conducted between 2003 and 2008 with a variance among calibrations of 0.22 dB (Knudsen 2009). The target strength measurements from the *Muir Milach* calibrations were more or less constant with a jitter of 0.2 dB for the 2006 and 2007 calibrations and 0.9 dB for the more variable 2008 calibration. These results are well within the range of values observed from scientific acoustic systems (0.3 - 1.0 dB; Jech et al. 2005). From these results we can conclude that the 38kHz ES-60 acoustic system on board the *Muir Milach* is stable and scientifically reliable.

The mechanical noise produced by the vessel was kept to below a -80 dB threshold to a range of 500 m at 38 kHz by running the vessel at no more than 1,200 rpm. By monitoring the noise levels on the cross-transects we were able to ensure that vessel noise did not increase during the survey. One important point to note is that we conducted the noise test in shallow water (60 m), while the majority of pollock were observed at much deeper depths where noise reflection from the bottom would be expected to be less. It is therefore likely that we exceeded the 10:1 signal to noise ratio for these areas.

One issue of concern for acoustic fish surveys is the possible bias in biomass estimates due to fish migration within a study area (Simmonds and MacLennan 2005). At 1200 rpms the *Muir Milach* could travel between 4 and 8 nmi/h depending on sea conditions and when not conducting noise tests we were able to increase speed on cross-transects to reduce survey time. The 2008 *Muir Milach* survey required 570 nmi of travel to conduct 206 nmi of transects. The non-transect travel was composed of cross-transects, replicate transects, and travel to, from and during verification trawl hauls. The survey, including time when the vessel was not on transect, required 96.5 hours to complete, a little over four days. Given the results of the two surveys showing little change in the pollock distribution over a period of a month, there should be little to no bias in the biomass estimates due to fish migration over four days.

Another issue of concern for surveying pollock in the Aleutian Islands is the changing availability of pollock to acoustics between day and night. In the daytime pollock tend to settle onto bottom on the steep slope face of the shelf break making it difficult and at times impossible to observe them using acoustics; at night the pollock move away from the bottom and into the water column (Fig. 42). Although this hindered our ability to survey during the daytime, the issue was resolved by restricting all acoustic surveying to the nighttime hours. Any future acoustic surveys of pollock in this region should be restricted to nighttime surveys. In March and April this means acoustic surveys can only be conducted for 11 to 14 hours per 24.

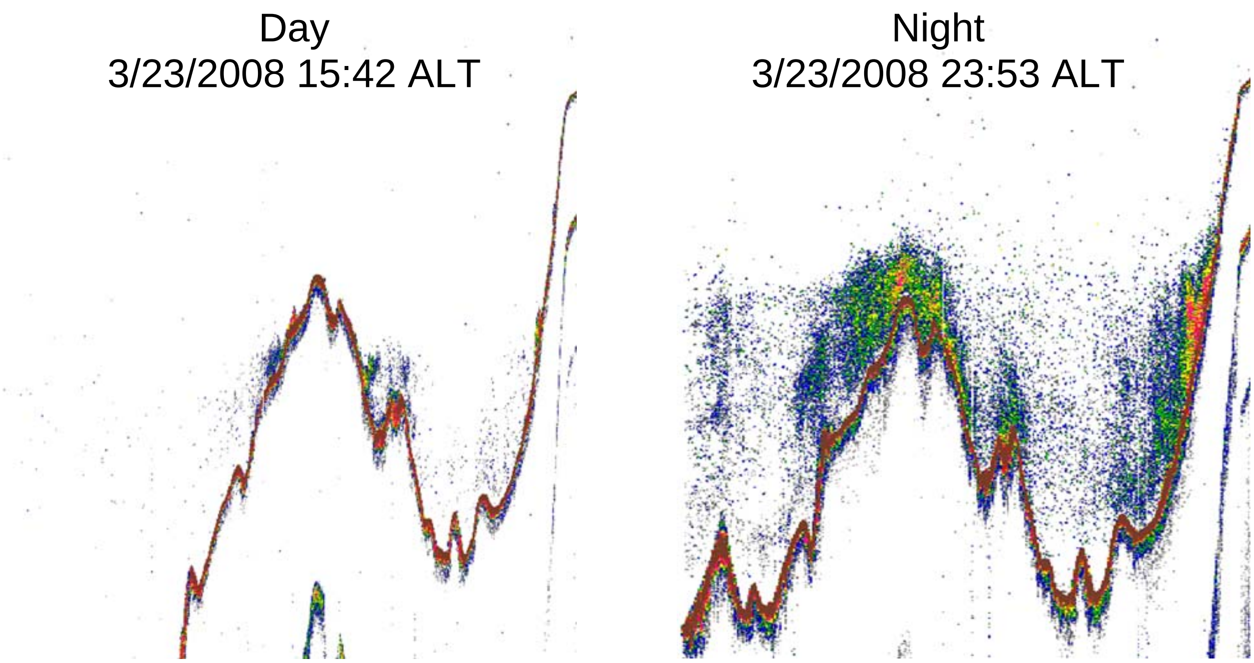


Figure 42. Echogram showing the change in pollock distribution and apparent abundance from day to night in the Tanaga aggregation from replicate transects conducted by the *Oscar Dyson* on 23 March 2008 (times shown are Alaska Local Time). The transects were surveyed 8 hours apart.

Five consistent pollock pre-spawning aggregations were observed in the 2007 and 2008 surveys. The Kanaga aggregation is located inside Barbarof Island north of Kanaga Island centered at 177.8° W longitude and is approximately 90 km from the port of Adak by boat. The Adak aggregation centered at 176.6° W longitude and is approximately 20 km from the port of Adak by boat. The Kasatochi aggregation is located on either side of Kasatochi Island between 175.6° W to 176 ° W longitude and starts approximately 90 km from the port of Adak. The Atka (a.k.a. "Knoll") aggregation is located north of Atka Island west of North Cape centered at 174.5° W longitude and is approximately 140 km from the port of Adak at its closest point. The Amlia (a.k.a. "Atka Flats") aggregation is located north of Amlia Island east of Nazan Bay centered at 173.5° W longitude approximately 200 km from the port of Adak. The locations of these aggregations are consistent with the areas of high pollock catch in the 1990's winter roe fisheries (Barbeaux et al. 2008) and the expectation is that should a pollock fishery develop in the Aleutian Islands once again, it would exploit these aggregations.

A conceptual model for investigating fisheries effects

Our primary research objective was to evaluate the feasibility of surveys for local-scale management of fisheries, with particular emphasis on the potential for competition between fishing and Steller sea lions for shared resources. Our second objective was the development of a conceptual model of local-scale fish ecology, as another way to investigate the potential impacts of fishing on prey availability for top trophic levels such as sea lions. Incorporating commercial fishing into such a conceptual model would then allow for the development of scenarios of potential fishing effects on prey availability. One important set of "parameters" in this conceptual model would address local-scale distribution and abundance of pollock, fish movement and spatial and temporal variability in pollock spawning. Our study provided information for all these parameters. We documented the distribution of wintertime aggregations of spawning pollock in the central Aleutian Islands, aggregations that were stable within the season and consistent between years. Large-scale movement of pollock between aggregations or into or out of the study area during the winter was not observed. Pollock reproductive maturity progressed from February to March, by March virtually all the pollock in the large aggregations were at an advanced maturity stage. These results suggest that one could "model" the wintertime distribution of pollock in the central Aleutians as a static distribution comprised primarily of spawning fish.

Another important component to the conceptual model we envision would be the response of pollock to oceanographic conditions. However, we found no consistent relationships between pollock distribution and abundance and the oceanographic variables we examined: water column structure; temperature and salinity at the surface and at depth; and chlorophyll biomass. These variables are typically indicators of spring and summer ocean productivity, so further study of variables that better represent wintertime oceanographic processes is in order.

A conceptual model that would form the basis of scenarios of the potential impacts of commercial fishing on sea lion foraging opportunities also would require information on the response of sea lions to variability in prey distribution (driven by natural or anthropogenic mechanisms). The diet composition of sea lions showed a response to spatial variability in pollock abundance, however the distribution of sea lion abundance did not. Instead, the distribution of sea lions appeared to be driven primarily by the distribution of Atka mackerel. Atka mackerel are dominant prey items for Steller sea lions during all seasons, whereas it appears that pollock are important prey primarily in the winter. This suggests that sea lion diets respond to small-scale, short-term distribution of prey, but that their distribution among haul-outs responds to the larger-scale, annual distribution of prey. Finally, information on the overlap in the sizes of fish exploited by the fishery and by sea lions is necessary to model fishing impacts. We found a high degree of overlap between the sizes of fish consumed by sea lions and the sizes taken in commercial fisheries.

Feasibility of a before-after-control-impact (BACI) experiment

Our final objective for this study was to provide information needed to evaluate whether a before-after-control-impact (BACI) experiment of the effects of commercial fishing could be designed for the central Aleutian Islands. A BACI design allows for the comparison of sea lion prey fields before and after commercial fishing in fished and unfished areas. The results of previous BACI experiments in Alaska vary by species. A BACI experiment on Pacific cod at Cape Sarichef in the eastern Bering Sea showed no localized depletion at the temporal scale of weeks, despite heavy commercial trawling (Conners and Munro 2008). One possible explanation for the apparent lack of fishery impact was the high rate of cod movement observed during the study (from tagging data). High movement of cod could result in dispersion or displacement of a local depletion. Ancillary data on reproductive maturity of cod collected during the BACI experiments indicated that the movement may have been related to spawning. Another BACI experiment on walleye pollock off the east coast of Kodiak Island in the Gulf of Alaska, showed interannual variability in the response of pollock to commercial trawling. During one of the three years experiments were conducted there was a significant decline of pollock biomass in the fished area. However, during the other two years there was no evidence of a fishery response (Chris Wilson, AFSC, pers. com.; Wilson et al. 2003). An ancillary result of these field studies was that the distribution of pollock was tightly linked to water mass properties in the study area (Hollowed et al. 2007; Logerwell et al. 2007).

For a BACI experiment to be conducted on pollock in the central Aleutian Islands it is necessary that sufficiently similar fished and unfished areas can be designated. We identified a number of distinct pollock aggregations which would be suitable to serve as either the fished "experimental" site or the unfished "control" site. For example, the two aggregations at Atka and Amlia were of similar size (in terms of total tons of pollock) and were located over similar bathymetric terrain. A successful BACI experiment also requires that there is no movement of fish between sites during the course of the experiment. We found no statistically significant difference in pollock distribution from February to March. Because the BACI experiments we are envisioning are intended to examine the potential disruption or depletion of sea lion prey, it is desirable that the study be conducted in an area used by foraging Steller sea lions. The results of the sea lion diet analysis confirm that sea lions located on haulouts near pollock aggregations were feeding primarily on pollock. The greatest challenge to designing a BACI experiment in the central Aleutians at this time is that the overall low biomass of pollock would make it unattractive for commercial fishers. In fact, the 2006 cooperative survey vessel was fully compensated for their costs with the value of the fish caught, but in 2008 the expectation was that pollock biomass would be too low to support the survey and the vessel was chartered using funds from NPRB (and the NOAA Cooperative Research Program). Previous BACI experiments on sea lion prey have relied on the usual commercial fishing activity to provide the experimental treatment. Without sufficient commercial fishing, a vessel would need to be chartered to fish in the experimental site which would make the study much more expensive.

Conclusions

The primary objective of our project was to investigate whether cooperative biomass surveys can be an effective way to manage fisheries at the local scales that are important to predators such as Steller sea lions. Multiple calibrations of the acoustic system on the fishing vessel used for the cooperative survey indicated that the system was scientifically reliable. In addition, the survey was conducted in a sufficiently brief span of time that there was likely little bias in the biomass estimates due to fish migration. The greatest challenge to the effective implementation of cooperative biomass surveys (and other cooperative research such as BACI experiments) in the central Aleutians at this time is that the overall low biomass of pollock would make such surveys unattractive for commercial fishers. However, if/when strong pollock year classes recruit to the Aleutian Islands then our results suggest that cooperative surveys can be an effective way to obtain local-scale information on the biomass distribution of pollock.

Our study design and data analyses were also directed by the following conceptual model: Geographic patterns in Steller sea lion haul-out and diet composition are directly related to pollock distribution/abundance; and indirectly related to water depth, water column structure, and satellite-derived chlorophyll. The diet composition of sea lions showed a response to spatial variability in pollock abundance (a functional response), however the distribution of sea lion abundance did not (a numerical response). The distribution of sea lions may primarily reflect the distribution of Atka mackerel. Atka mackerel are dominant prey items for Steller sea lions during all seasons, whereas it appears that pollock (and Pacific cod, along with a suite of demersal species) are important prey primarily in the winter. This suggests that sea lion diets respond to small-scale, short-term distribution of prey. Seasonal diet changes reflect differences in availability due to seasonal differences in spawning and aggregating of various prey species. The fact that we did not observe a numerical response of sea lions to spatial variability in pollock abundance may be related to the low overall biomass of pollock in the Aleutian Islands, compared to the past (Fig. 43). Of course Steller sea lion numbers are also much lower than they were in the past. Trends in Steller sea lion populations are determined by aerial surveys during the breeding season, when the majority of sea lions are hauled out on terrestrial rookeries and other sites. The Steller sea lion population in the central Aleutian Islands region declined approximately 33% overall between 1991 and 2008 (Fig. 44). Most of this decline occurred between 1991 and 1995, which was followed by a period of stability through 2004, and another decline through 2008. The area surveyed (in winter) during this study is essentially the center of the central Aleutian Islands region, and declined less overall (only about 22% since 1991), though it had a similar pattern of relative abundance. Further research is needed to evaluate whether the abundance of pollock we observed would be expected to elicit a numerical response from a local population of sea lions of the size currently occupying the study area.

To assess the indirect, environmental effects on sea lions, we examined a suite of oceanographic properties that are indicators of ocean production. There were no consistent relationships between oceanography and the distribution and abundance of pollock biomass, and thus the availability of Steller sea lion prey. However, the processes underlying these oceanographic indicators, such as mixing cold, nutrient rich waters to the surface, may only be relevant during the spring and summer when light levels are sufficient for chlorophyll growth and subsequent food chain productivity to take place. If oceanographic processes are important for driving the distribution and abundance of pollock in the Aleutian Islands during winter, they were not well represented by the variables we examined and a new conceptual model needs to be developed that takes into account whatever other processes are important during this season.

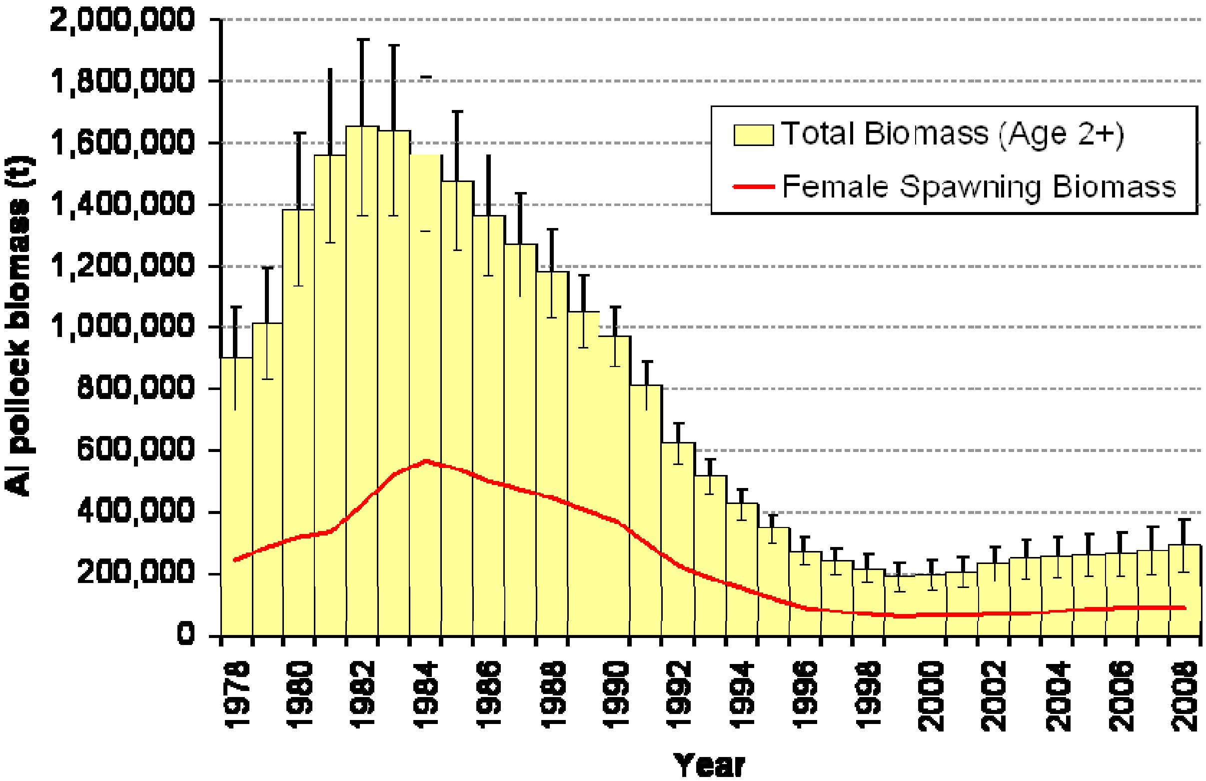


Figure 43. Reference model estimates of Aleutian Islands walleye pollock biomass with approximate lower and upper 95% confidence bounds for age 2+ biomass. Also shown (red line) are the female spawning stock biomass estimates. Data from the most recent Aleutian Islands walleye pollock stock assessment (Barbeaux et al. 2009)

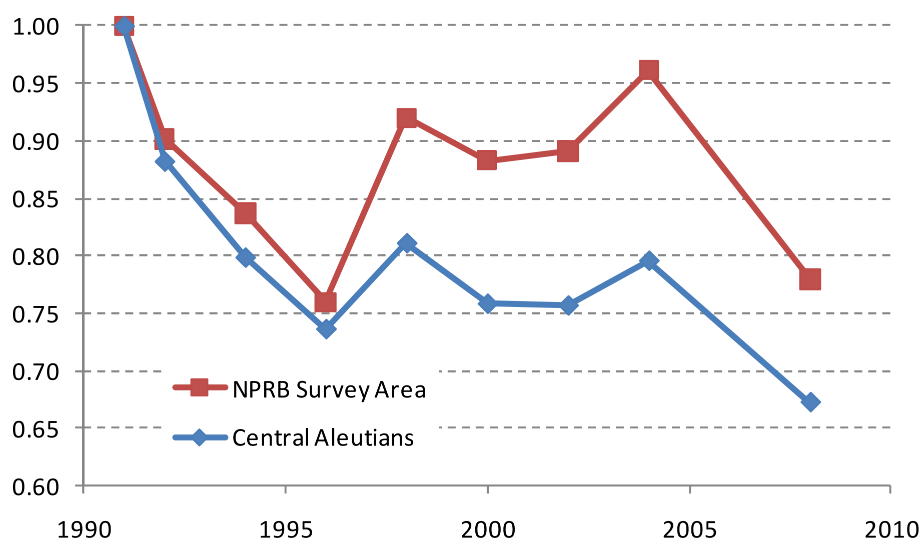


Figure 44. Trend in counts of adult and juvenile Steller sea lions from 1991 (base year set to 1) through 2008 in the area surveyed during this study (NPRB Study area 172-180°W) and in the central Aleutian Island region as a whole (169.5°W – 177°E). Counts from aerial photographs taken during surveys conducted during the summer breeding season (June-early July).

Publications

Progress Reports (July 2008, January 2009, June 2009)

Final Report (December 2009)

Outreach

Reporting period	Specific dates	Outreach Activities
12/31/07 – 7/1/08	1/19/08	▪ Poster presentation at AKMSS, S. Barbeaux
	7/1/08	▪ Progress Report submitted
7/1/08 – 12/31/08	1/15/09	▪ Progress Report submitted
	1/19/09	▪ Poster presentation at AKMSS, E. Logerwell
	2/2/09	▪ Poster presentation to North Pacific Fishery Management Council
	5/5/09	▪ Oral presentation to Marine Stewardship Council
1/1/09 – 7/1/09	6/17/09	▪ Progress Report submitted
	9/10/09	▪ Oral presentation at the Museum of the Aleutians in Dutch Harbor (also transmitted via local public radio and TV), S. Barbeaux
	12/18/09	▪ Final Report
	1/18/10	▪ Oral presentations at AKMSS, Barbeaux and Logerwell

Acknowledgements

We would like to express our appreciate for the hard work and dedication of the science and vessel crew of the *Oscar Dyson*, Capt. Paul Tate and crew of the *Norseman*, Nicholas Toth, Douglas MacIntyre and Kevin Rooteveel of NOAA's Aircraft Operations Center, and the Captain and crew of the *Muir Milach*. We also could not have completed this study without the assistance and efforts of Kathryn Sweeney and Sara Finneseth of AFSC National Marine Mammal Laboratory, and Olav Ormseth of AFSC Resource Ecology and Fishery Management. Steller sea lion research was done under authority of NMFS MMPA Research Permit 782-1889 issued to AFSC NMML. The NOAA Cooperative Research Fund provided partial financial support for the *Muir Milach* survey. NOAA AFSC and NMML provided salary support for project P.I.s.

Literature Cited

Barbeaux, S., Ianelli, J. and Brown, E. 2005. Stock assessment of Aleutian Islands region pollock. North Pacific Fishery Management Council, Anchorage.

Barbeaux, S., Ianelli, J., Gaichas, S. and Wilkins, M. 2008. Stock assessment of Aleutian Islands region pollock. North Pacific Fishery Management Council, Anchorage.

Barbeaux, S.J. and Fraser, D. 2009. Aleutian Islands cooperative acoustic survey study for 2006. NOAA Technical Memorandum NMFS-AFSC-198. Alaska Fisheries Science Center, 7600 Sand Point Way, Seattle, WA 98107 91.

Calkins, D. and Pitcher, K. 1982. Population assessment, ecology and trophic relationships of Steller sea lions in the Gulf of Alaska. Final Report 17, U.S. Department of Commerce, Washington, D.C., USA.

Conners, M.E. and Munro, P. 2008. Effects of commercial fishing on local abundance of Pacific cod (*Gadus macrocephalus*) in the Bering Sea. Fishery Bulletin 106: 281-292.

Foote, K.G. 1985. Rather-high-frequency sound scattering by swimbladdered fish. The Journal of the Acoustical Society of America 78: 688-700.

Fritz, L.W. and Stinchcomb, C. 2005. Aerial, ship, and land-based surveys of Steller sea lion (*Eumetopias jubatus*) in the western stock in Alaska, June and July 2003 and 2004. NOAA Technical Memorandum NMFS-AFSC-153: 56 pp.

Fritz, L.W., Lynn, M., Kunisch, E. and Sweeney, K. 2008. Aerial, ship, and land-based surveys of Steller sea lions (Eumetopias jubatus) in Alaska, June and July 2005-2007. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-183 70.

Fu, G., Baith, K.S. and Mcclain, C.R. 1998. SeaDAS: The SeaWiFS data analysis system. The 4th Pacific Ocean Remote Sensing Conference, pp. 73-79, Qingdao, China.

Gordon, H.R. and Wang, M. 1994. Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: a preliminary algorithm. Appl. Opt. 33: 443-452.

Hollowed, A.B., Wilson, C.D., Stabeno, P.J. and Salo, S.A. 2007. Effect of ocean conditions on the cross-shelf distribution of walleye pollock (*Theragra chalcogramma*) and capelin (*Mallotus villosus*). Fisheries Oceanography 16: 142-154.

Honkalehto, T., Mckelvey, D.R. and Williamson, N.J. 2005. Results of the March 2005 echo integration-trawl survey of walleye pollock (*Theragra chalcogramma*) conducted in the southeastern Aleutian basin near Bogoslof Island, cruise MF2005-03. AFSC Processed Report 2005-05.

Jech, J.M., Foote, K.G., Chu, D. and Hufnagle, L.C., Jr. 2005. Comparing two 38-kHz scientific echosounders. ICES Journal of Marine Science 62: 1168-1179.

Kieth, G.J., Tyan, T.E. and Kloser, R.J. 2005. ES60Adjust.jar Java Software utility to remove a systematic error in Simrad ES60 data.

Knudsen, H.P. 2009. Long-term evaluation of scientific-echosounder performance. ICES Journal of Marine Science 66: 1335-1340.

Kumagai, S., Rosen, D.A.S. and Trites, A.W. 2006. Body mass and composition repsonses to short-term low energy intake are seasonally dependent in Steller sea lions (*Eumetopias jubatus*). Journal of Comparative Biochemistry and Physiology B 197: 589-598.

Ladd, C., Hunt, J.G.L., Mordy, C.W., Salo, S.A. and Stabeno, P.J. 2005. Marine environment of the eastern and central Aleutian Islands. Fisheries Oceanography 14 (Suppl. 1): 39-54.

Logerwell, E.A., Stabeno, P.J., Wilson, C.D. and Hollowed, A.B. 2007. The effect of oceanographic variability and interspecific competition on juvenile pollock (*Theragra chalcogramma*) and capelin (*Mallotus villosus*) distributions on the Gulf of Alaska shelf. Deep Sea Research II 54: 2849-2868.

Loughlin, T.R. 1998. The Steller sea lion: a declining species. Biosphere Conservation 1: 91-98.

Lowe, S., Ianelli, J., Wilkins, M., Aydin, K., Lauth, R. and Spies, I. 2008. Stock assessment of Bering Sea/Aleutian Islands Atka mackerel. North Pacific Fishery Management Council 1119-1198.

MacLennan, D.N., Fernandes, P.G. and Dalen, J. 2002. A consistent approach to definitions and symbols in fisheries acoustics. Journal of Marine Science 59: 365-369.

McDermott, S.F., Fritz, L.W. and Haist, V. 2005. Estimating movement and abundance of Atka mackerel (*Pleurogrammus monopterygius*) with tag-release-recapture data. Fisheries Oceanography 14 (Supl. 1): 113-130.

McKenzie, J. and Wynne, K. 2008. Spatial and temporal variation in the diet of Steller sea lions in the Kodiak Archipelago, 1999 to 2005. Marine Ecology Progress Series 360: 265-283.

Merrick, R.L., Chumbley, M.K. and Byrd, G.V. 1997. Diet diversity of Steller sea lions (Eumetopias jubatus) and their population decline in Alaska: a potential relationship Canadian Journal of Aquatic and Fisheries Sciences 54: 1342-1348.

Merrick, R.L. and Loughlin, T.R. 1997. Foraging behavior of adult female and young-of-the-year Steller sea lions in Alaskan waters. Canadian Journal of Zoology 75: 776-786.

Mordy, C.W., Stabeno, P.J., Ladd, C., Zeeman, S., Wisegarver, D.P. and Hunt, J.G.L. 2005. Nutrients and primary production along the eastern Aleutian Islands Archipelago. Fisheries Oceanography 14 (Suppl. 1): 55-76.

N.M.F.S. 2000. Section 7 consultation of the authorization of the Bering Sea and Aleutian Islands groundfish fishery under the BSAI FMP and the authorization of the Gulf of Alaska groundfish fishery under the GOA FMP. Office of Protected Resources NMFS.

National Research Council 2003. Decline of the Steller Sea Lion in Alaskan Waters: Untangling Food Webs and Fishing Nets. The National Academies Press, Washington, D.C.

O'Driscoll, R.L. and Macaulay, G.J. 2005. Using fish-processing time to carry out acoustic surveys from commercial vessels. ICES Journal of Marine Science 62: 295-305.

O'Reilly, J.E. 2000. Ocean color chlorophyll a algorithms for SeaWiFS, OC2, and OC4: Version 4. *In* S.B. Hooker and E.R. Firestone (Editors), SeaWiFS Postlaunch Technical Report Series, pp. 9-23. Greenbelt, Maryland: NASA, Goddard Space Flight Center.

Petigas, P. 1993. Geostatistics for fish stock assessments: a review and an acoustic application. ICES Journal of Marine Science 50: 285-298.

Romain, S., Barbeaux, S. and Logerwell, E.A. in prep. 2007 Aleutian Islands Cooperative Survey Study. Alaska Fisheries Science Center Processed Report. Alaska Fisheries Science Center 7600 Sand Point Way, Seattle, WA 98107.

Sease, J.L. and York, A.E. 2003. Seasonal distribution of Steller's sea lions at rookeries and haulout sites in Alaska. Marine Mammal Science 19: 745-763.

Shettle, E.P. and Fenn, R.W. 1979. Models for the Aerosols for the Lower Atmosphere and the Effects of Humidity Variations on Their Optical Properties. AFGL-TR-79-0214 Environmental Research Papers No. 676.

Sigler, M.F., Tollit, D.J., Vollenweider, J.J., Thedinga, J.F., Csepp, D.J., Womble, J.N., Wong, M.A., Rehberg, M.J. and Trites, A.W. 2009. Steller sea lion foraging response to seasonal changes in prey availability. Marine Ecology Progress Series 388: 243-261.

Simmonds, J. and MacLennan, D.N. 2005. Fisheries Acoustics: Theory and Practice. Blackwell Science, Oxford.

Sinclair, E.H. and Zeppelin, T.K. 2002. Seasonal and spatial differences in diet in the western stock of Steller sea lions (*Eumetopias jubatus*). Journal of Mammology 83: 973-990.

Spencer, P.D. and Ianelli, J. 2008. NPFMC Bering Sea and Aleutian Islands SAFE: BSAI Pacific Ocean Perch. North Pacific Fishery Management Council 917-972.

Syrjala, S.E. 1996. A statistical test for a difference between the spatial distributions of two populations. Ecology 77: 75-80.

Thompson, G.G., Ianelli, J., Lauth, R., Gaichas, S. and Aydin, K. 2008. Assessment of the Pacific cod stock in ther eastern Bering Sea and Aleutian Islands area. *In* S. The Plan Team for the Groundfish Fisheries of the Bering and I. Aleutian (Editors), Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. Anchorage, AK: North Pacific Fishery Management Council.

Traynor, J. 1996. Target-strength measurements of walleye pollock (*Theragra chalcogramma*) and Pacific whiting (*Merluccius productus*). Journal of Marine Science 53: 253-258.

Trites, A.W. and Porter, B.T. 2002. Attendance patterns of Steller sea lions (*Eumetopias jubatus*) and their young during winter. Journal of Zoology (London) 256: 547-556.

Trites, A.W., Calkins, D. and Winship, A.J. 2007. Diets of Steller sea lions (*Eumetopias jubatus*) in Southeast Alaska, 1993-1999. Fishery Bulletin 105: 234-248.

Williamson, N.J. and Traynor, J.J. 1996. Application of a one-dimensional geostatistical procedure to fisheries acoustic surveys of Alaskan pollock. ICES Journal of Marine Science 53: 423-428.

Wilson, C.D., Hollowed, A.B., Shima, M., Walline, P. and Stienessen, S. 2003. Interactions between commercial fishing and walleye pollock. Alaska Fisheries Research Bulletin 10: 61-77.

Womble, J.N. and Sigler, M.F. 2006. Temporal variation in Steller sea lion diet at a seasonal haul-out in Southeast Alaska. *In* Alaska Sea Grant College Program (Editor), Sea Lions of the World, pp. 141-154.

Wynne, K. and Foy, R.J. 2002. Is it food now? Gulf Apex Predator-prey study. *In* D.P. Demaster and S. Atkinson (Editors), Steller sea lion decline: Is it food II, pp. 49-52: University of Alaska Sea Grant.

Yanagimoto, T., Nishimura, A., Mito, K., Takao, Y. and Williamson, N.J. 2002. Interannual changes of biological properties of walleye pollock Theragra chalcogramma in the Central Bering Sea. Progress in Oceanography 55: 195-208.

Zeppelin, T.K., Tollit, D.J., Call, K.A., Orchard, T.J. and Gudmundson, C.J. 2004. Sizes of walleye pollock (*Theragra chalcogramma*) and Atka mackerel (*Pleurogrammus monopterygius*) consumed by the western stock of Steller sea lions (*Eumetopias jubatus*) in Alaska from 1998 to 2000. Fishery Bulletin 102: 509-521.