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The 2005 Integrated Acoustic and Trawl Survey of Pacific Hake, *Merluccius productus,*

in U.S. and Canadian Waters off the Pacific Coast

August 2008

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The 2005 Integrated Acoustic and Trawl Survey of Pacific Hake, *Merluccius productus,* in U.S. and Canadian Waters off the Pacific Coast

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Executive Summary

The 2005 Integrated Acoustic and Trawl Survey of Pacific hake (*Merluccius productus*) was conducted by joint U.S. and Canadian science teams aboard the NOAA research vessel *Miller Freeman* from 20 June to 19 August 2005, covering the Pacific coast from north of Point Piedras Blancas, California (lat 35.7°N), to the Dixon Entrance area in Canada (ca. lat 54.5°N). The survey completed 105 line transects, generally oriented east-west and spaced at intervals of 10 nautical miles.

During the survey, aggregations of Pacific hake were found along the continental shelf break from Monterey Bay (lat 37°N) to the Dixon Entrance area. Peak concentrations of Pacific hake were observed near Point Arena, California (ca. lat 39°N); between Eureka, California (ca. lat 41°N), and Cape Blanco, Oregon (ca. lat 43°N); off Heceta Head, Oregon (ca. lat 44°N); and in Queen Charlotte Sound, Canada (ca. lat 52°N). Associated midwater and bottom trawl samples showed that the majority of the coastal stock in 2005 was dominated by the 1999 year class (age 6), with most fish at an average size of 43 cm in tows north of lat 40°N and smaller hake (average size = 35 cm) found further south.

The coast-wide estimates of Pacific hake abundance totaled 2.518 billion fish weighing 1.265 million metric tons. Age and length distributions showed that age-6 hake were the largest component of the population. The 1999 year class contributed about 48% of the total coast-wide number and 55% of the total coast-wide biomass. The 2003 year class, which contributed about 24% and 13% of the total coast-wide number and biomass, respectively, was more prevalent in the southern regions of the survey. Age-2 hake accounted for 68% and 26% of the total biomass for the Monterey and Eureka International North Pacific Fisheries Commission (INPFC) statistical areas, respectively. The 1999 year class was more prevalent further north, contributing 46%, 65%, 64%, and 63% to the total biomass for the Eureka, South Columbia, and Vancouver-North Columbia INPFC areas, and Canada, respectively.

The 2005 biomass estimate of 1.265 million metric tons represents a decrease of 577,000 metric tons, or 31% from the biomass estimate made for 2003. However, the 2005 estimate is still 528,000 metric tons greater than the 2001 biomass estimate, which was the smallest since coast-wide acoustic surveys began in 1977.

Acknowledgments

We extend our sincere gratitude to Captain Michael Gallagher and the officers and crew of the NOAA research vessel *Miller Freeman* for the successful completion of one of the most challenging survey efforts yet undertaken over the 28-year history of this survey. Their devotion to the science program and professional assistance to Canadian and U.S. investigative personnel were outstanding throughout the cruise. We also thank personnel from the Northwest Fisheries Science Center Fishery Resource Analysis and Monitoring Division and the Stock Assessment Division of Fisheries and Oceans Canada for their support and help in making this a successful survey.

Introduction

Pacific hake (*Merluccius productus*), colloquially also known as Pacific whiting, is a gadoid species distributed off the west coast (Pacific coast) of North America. This species is one of about a dozen commercially valuable species of hakes from the genus *Merluccius* distributed in both hemispheres of the Atlantic and Pacific oceans (Alheit and Pitcher 1995). Worldwide, hake fisheries constitute between 1 million and 2 million mt of catches annually (Alheit and Pitcher 1995; data obtainable from the Web site of the United Nations Food and Agriculture Organization at http://www.fao.org/fishery/statistics/programme/3,1,1/en).

The coastal stock of Pacific hake is currently the most abundant groundfish population in the California Current Large Marine Ecosystem. Recent annual harvests total in excess of 300,000 mt by U.S. and Canadian fisheries (Helser et al. 2006) at an annual value of about $22 million (U.S.) in the United States and $14 million (U.S.) in Canada (Magnuson-Stevens Act 2008). Smaller populations of Pacific hake occur in major inlets of the north Pacific Ocean, including the Strait of Georgia (Kieser et al. 1998), Puget Sound, and the Gulf of California. Electrophoretic studies indicate the Strait of Georgia and Puget Sound populations are genetically distinct from the coastal population (Utter 1971). The coastal stock differs from the inshore populations (which are excluded from integrated acoustic and trawl surveys) by exhibiting larger body size, a pronounced seasonal migratory behavior, and patterns of normally low recruitment punctuated by infrequent but extremely large year classes.

The coastal stock of Pacific hake is generally distributed from Southern California to Hecate Strait (ca. lat 36°N–53°N), though these fish have been found as far south as Baja California and north to southeast Alaska (Alverson and Larkins 1969, Dark et al. 1980, Bailey et al. 1982, Saunders and McFarlane 1997, Wilson et al. 2000). Spawning aggregations occur within the general area off southcentral California during January–March. However, due to the difficulty of locating major offshore spawning concentrations, the specific behavior of spawning Pacific hake remains poorly understood (Saunders and McFarlane 1997). In spring, adult Pacific hake begin to migrate to the north and onshore along the continental shelf and slope. During summer, Pacific hake form extensive midwater aggregations that are distributed along the length of the continental shelf break from California to British Columbia, with greatest densities located over bottom depths of 200–300 m (Dorn et al. 1994, Cooke et al. 1996). The extent of their annual migrations is influenced by oceanographic conditions and is related to size because larger (older) Pacific hake migrate further north than smaller fish (Dorn 1995, Agostini et al. 2008).

Because of the economic and ecological value of coastal Pacific hake, integrated acoustic and trawl surveys have been used to assess the distribution, abundance, and biology of hake along the Pacific coasts of the United States and Canada. The Pacific Biological Station (PBS) of the Department of Fisheries and Oceans Canada has conducted annual surveys along the Canadian west coast since 1990. From 1977 to 2001, the Alaska Fisheries Science Center (AFSC) conducted triennial surveys in U.S. waters. The triennial surveys in 1995, 1998, and 2001 were jointly carried out by AFSC and PBS. Following 2001, the responsibility for the U.S.

portion of the survey was transferred to the Fishery Resource Analysis and Monitoring (FRAM) Division of NOAA's Northwest Fisheries Science Center. Since the transfer, the survey frequency was increased to biennial, with joint acoustic surveys conducted by FRAM and PBS in 2003 and 2005.

These acoustic surveys are a key data source for joint Canada-U.S. Pacific hake stock assessments (e.g., Helser et al. 2006). Biomass estimates, length, and age-at-length compositions are used along with fishery-dependent data in integrated statistical age-length structured assessment models to estimate Pacific hake abundance. Estimates of stock size from the assessment models are used in population projections to provide international harvest advice.

This report documents the operations and results of the acoustic survey conducted jointly by U.S. and Canadian scientists aboard the NOAA research vessel (RV) *Miller Freeman* during the summer of 2005. This survey marks the eleventh coast-wide survey effort over the period from 1977 to 2005.

Materials and Methods

The goal of the joint U.S.-Canadian survey for Pacific hake is to "determine the distribution, biomass, and length-at-age composition of the exploitable portion of the (hake) population" (Nelson and Dark 1985) in support of analysis and management of the stock. The current survey design is based on knowledge of the biology of the fish and historical distribution of the stock, past survey coverage, statistical considerations, and logistical constraints. The sampling design includes these assumptions: 1) the survey area encompasses the entire range of the recruited stock, 2) the stock is available to survey techniques at the time of the survey, and 3) the spatial distribution of Pacific hake is quasi-stationary.

The 2005 survey was jointly conducted by U.S. and Canadian science teams aboard the RV *Miller Freeman* (science cruise number 2005–09). The RV *Miller Freeman*, a 66-m stern trawler equipped for fishery oceanographic research, was used for the entire survey. This vessel has been employed in earlier coast-wide acoustic surveys.

Acoustic System Calibration

The acoustic system was calibrated in the field before, during, and after the survey. The calibration procedure involved anchoring the vessel, suspending one or more metal spheres with known backscattering cross sections below the transducer(s), then measuring the acoustic returns following standard procedures (Foote et al. 1987, Simrad 1993, Simmonds and MacLennan 2005). A 38.1-mm tungsten carbide sphere was used for the 38-kHz, 120-kHz, and 200-kHz transducers, and a 64-mm copper sphere was used for the 18-kHz transducer. Split-beam target strength and echo integration data were collected to calculate echo sounder gain parameters as part of the evaluation of system performance. On-axis (Simmonds and MacLennan 2005) or beam model (Simrad 2004) measurements or both were taken, depending on time and weather constraints. Signal-to-noise measurements were also collected periodically during the survey to monitor the system. The water depths at the calibration locations were greater than 50 m to avoid echo contamination from seafloor reverberation.

Acoustic Survey Design and Operations

To meet the goals of the survey, the Pacific hake population was surveyed along a series of parallel line transects that were oriented generally east-west, spaced at a nominal 10-nautical mile (nmi) interval (Figure 1), and traversed sequentially in alternating directions. Sea depth at the nearshore end of individual transects was typically 50 m; offshore extent of individual transects was typically at a depth of 1,500 m, although transects in Hecate Strait (ca. lat 53°N) and Dixon Entrance (ca. lat 54.5°N) did not reach depths that great. By established protocol, transects were extended further seaward if Pacific hake aggregations were detected at or near the predetermined endpoints. This was required to locate the boundaries of the population and to

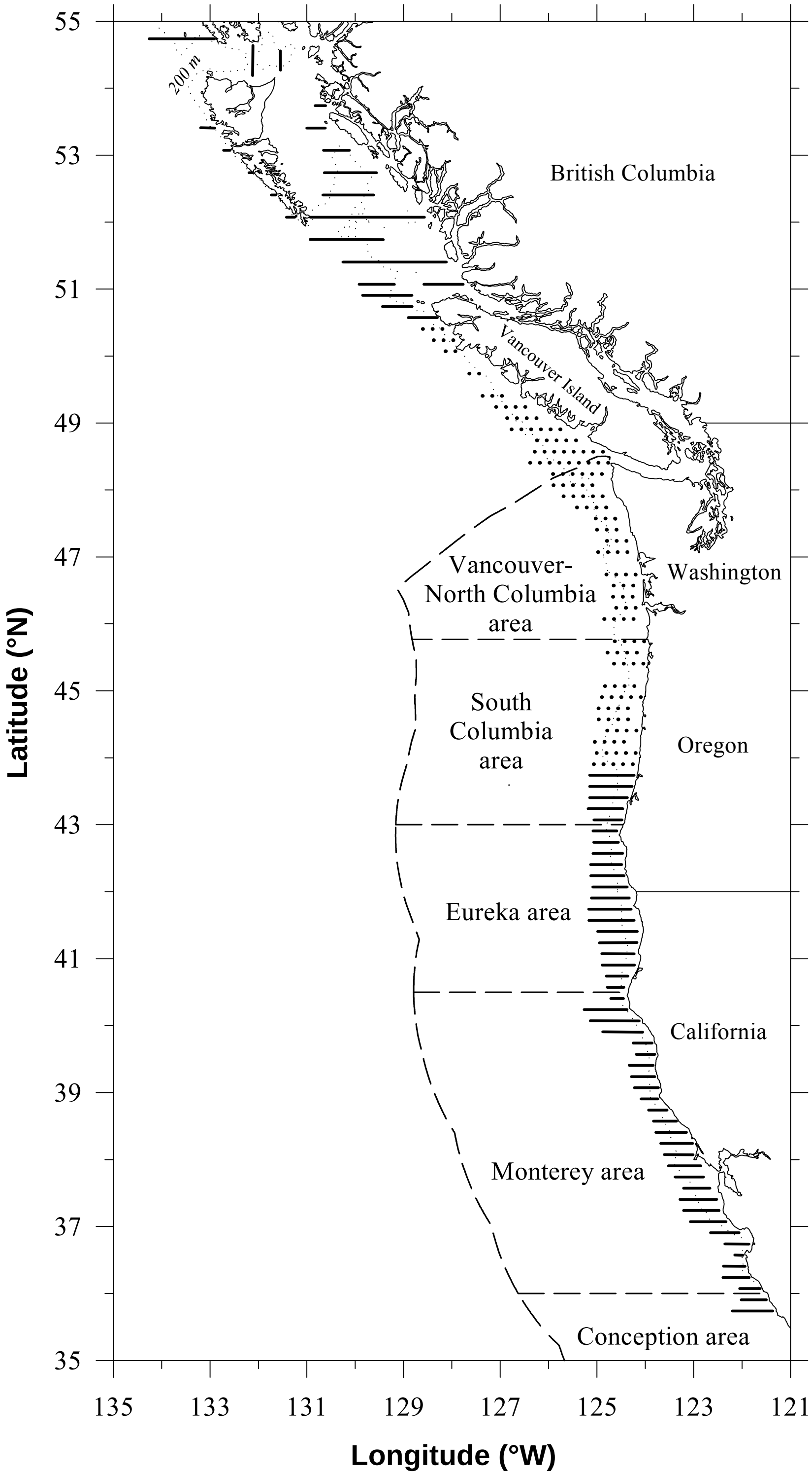

Figure 1. Survey track design used during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Transects marked by dotted lines were out of order, from north to south. International North Pacific Fisheries Commission (INPFC) statistical reporting areas and subareas as defined by Dorn (1996) are outlined for reference.

ensure that the assumption of complete survey coverage was met. Conversely, some transects were truncated at their offshore end if the ship had passed at least 1 nmi beyond detected aggregations of Pacific hake; such a decision considered the advantages of using limited ship time more efficiently by proceeding to the next transect.

Geographical coverage in 2005 was similar to that in the 2003 survey, although the 2005 survey began about 24 nmi further south, just north of Point Piedras Blancas, California (lat 35.7°N). The latitude of the first transect had been randomly selected previously between lat 35°40′N and lat 35°50′N. Subsequent transects were planned for sampling in an established fashion (Fleischer et al. 2005), proceeding north toward the Dixon Entrance area while targeting aggregations of Pacific hake along the continental shelf and upper slope. However, technical mishaps occurred that ultimately resulted in the collection of compromised data between transects 50 through 89 (roughly the area from Heceta Head, Oregon [ca. lat 44°N], to north Vancouver Island, British Columbia).

Time constraints did not allow for the RV *Miller Freeman* to transit south to resurvey these transects in a northerly direction. Instead, transects 50 through 89 were resurveyed in a southerly direction, out of normal order, after a reliable transducer had been installed and the northern extent of the survey area was completed. The decision to complete the survey in an unorthodox manner took into consideration the potential for sampling bias due to fish movements (e.g., surveying fish that had been previously observed). Because Pacific hake movements are believed to be minimal in summer (Nelson and Dark 1985), we agreed that a potential sampling bias would be less problematic than the alternative of not completing the survey. However, surveying transects 50 through 89 out of order did result in a time gap of about 38 days between transects 49 and 50.

As in past efforts, the 2005 survey was performed June through August. Logistically, the survey was conducted in discrete operational segments or legs, with time in port between each to permit rotation of both scientific and operations crew as well as to allow ship fueling, provisioning, and, for at least this survey, installation of replacement transducers.

Vessel speed was maintained at 5.6–6.1 m/sec (11–12 knots) during acoustic sounding along each transect, resulting in an acoustic sample volume coverage of nearly 100% for a fish layer at a depth of about 50 m. Acoustic operations were run only during daylight hours (i.e., from sunrise to sunset, about 15 hours per day) when Pacific hake formed distinct and identifiable midwater or mesopelagic layers. Physical oceanographic sampling was conducted at day and at night.

Acoustic Data Acquisition

All acoustic data were collected with a Simrad EK60 scientific echo sounder coupled with the ER60 software system (Simrad 2004). Simrad 18-kHz, 38-kHz, 120-kHz, and 200-kHz split-beam transducers were initially aboard the RV *Miller Freeman*. These transducers were mounted on the bottom of the vessel's centerboard which, when fully extended, held the transducers 9 m below the water surface. On 28 June, the ship's centerboard instrument pod, with all four transducers, was lost at sea between transects 26 and 27. A replacement 38-kHz transducer was custom mounted to the centerboard on 2 July and deployed in the fashion described above. This arrangement was acceptable because acoustic data collected at 38 kHz have been and continue to be the sole source for quantitative Pacific hake backscatter measurements. The transducers operating at different frequencies were intended for exploratory work. As the survey progressed past 12 July, we noticed a gradual failure of the replacement transducer that resulted in its eventual loss. Direct observation determined that chafing and subsequent cutting of the transducer cable caused it to fail. On 31 July, a second replacement 38-kHz transducer was installed with a design to minimize cable chafing. This transducer operated successfully throughout the remainder of the survey.

We logged raw acoustic backscatter (ER 60) and SonarData Echolog 500 data files; the latter used for live viewing in EchoView. Event log markers and other marks, including initial judgments of Pacific hake backscattering layers, were made on the live-viewed files. The acoustic data and event files were stored in targeted directories. Upon completion of each transect, the full collection of acoustic data files were immediately copied to a second hard drive. When sufficient backup data were accumulated, a third copy of the data files was archived to DVD media to ensure redundant data safekeeping.

Fishing Operations and Biological Sampling

Trawl samples were used to classify the observed backscatter layers to species and size composition and to collect specimens of Pacific hake and other organisms. The number and locations of trawl sets were not predetermined—other than an allowance for an expected total number of tows for each area based on past surveys—but were dependent on the occurrence and pattern of backscattering layers observed at the time of the survey. Our goal was to obtain catches that were representative of the species composition and the size distribution of organisms detected acoustically in as many areas as was feasible within the constraints of vessel logistics and time. As such, coverage by trawling was not systematic but adaptive, and individual tows did not require a standardized effort. Distinct layers of intense backscatter that were indicative of high densities of Pacific hake were the highest priority for trawl sample assignments, but other types of backscattering features, both in terms of areas of low fish density and putative aggregations of species other than Pacific hake, were also sampled. We also were attentive to perform tows at several locations along any single, extensive, and continuous aggregation of Pacific hake, or within the same area where vertically discrete backscattering layers appeared.

We used pelagic and bottom trawls to conduct fish sampling. Pelagic trawling was performed with an Aleutian wing 24/20 trawl (AWT). This net had a 20-m vertical opening and a headrope and footrope of 101.8 m each. Mesh sizes tapered from 320.0 cm in the forward section of the net to 10.0 cm in the codend; a 3.2-cm codend liner was used. The AWT was deployed with a pair of 4-m^2 "Fishbuster" trawl doors (884.5 kg), 82.3-m legs, and 226.8 kg or 113.4 kg chain weights on each side. For one haul, the chain weights were removed in order to target shallow water fish sign as registered acoustically. Trawling on bottom was performed with a poly Nor'eastern trawl 89/121 (PNE). This net had a 10-m vertical opening, a headrope of 27.1 m, and a footrope of 36.6 m. Mesh size was 12.7 cm in the intermediate section and a 3.2-cm codend liner was used. The PNE also used the 4-m^2 "Fishbuster" trawl doors. A WESMAR TCS 770 third-wire sonar system for the trawl headrope or Furuno wireless net sounder system were used to monitor and guide the fishing process for all tows.

Upon retrieval, trawl catches were emptied from the codend onto a sorting table and sorted by species into baskets. We used conventional catch sorting and enumeration procedures to process all catches (Hughes 1976, Weir et al. 1978). All catches were sorted completely except for two large hauls that were volumetrically estimated for total weight before being subsampled. Total numbers and weights were determined for all species, although invertebrates such as jellyfish, salps, and euphausiids often were not counted. Aggregate weights were measured to the nearest 0.1 kg for the sorted portions of the catch using an electronic, 60-kg capacity motion-compensated scale.

Pacific hake were subsampled to determine length composition by sex, to collect otoliths for subsequent age determination, and to collect individual weight measurements and gonad condition. (Pacific hake were sampled completely from a trawl catch when just a small number were caught, i.e., fewer than roughly 300 to 400.) Fish lengths (fork length) were determined to the nearest centimeter using a Scantrol fish meter board. We employed a 6-kg capacity motion-compensated scale to determine all weights of individual fish specimens to the nearest 10 grams. Pacific hake maturity was determined by visual inspection of gonads and classified by a five-stage scale, according to the ADP Code Book 2003 (AFSC, Resource Assessment and Conservation Engineering Division, Seattle, Washington). Otoliths were preserved in 50% ethanol for subsequent age determination.

Additional Physical and Biological Data Collection

Other types of data were collected but not directly related to or used in the current hake biomass or abundance estimation. These data included Pacific hake stomach samples, conductivity-temperature-depth profiles, expendable bathythermograph profiles, trawl temperature and pressure profiles, and current data recorded with an Acoustic Doppler Current Profiler system.

Acoustic Data Analysis

The first step in the analysis of the acoustic data was to identify and delineate the backscatter layers that were attributed to Pacific hake. Echograms of each transect were displayed and examined for aggregations of Pacific hake using SonarData EchoView v.3.30 software. Display settings reflected the echo sounder calibration settings at the time of acoustic data acquisition. On each display, continuous backscattering layers were demarked and classified as either “hake,” which indicated all backscatter in the region was considered hake; “hake mix,” which indicated there was a significant amount of backscatter from hake in the region plus other species that were partitioned quantitatively later; or “other,” which indicated there was no hake backscatter in the region. These classifications were guided by visual interpretation of the echo traces and the species compositions observed in the associated trawl catches.

Initial scrutiny of echograms took place at sea, usually immediately upon completion of a given transect. This process was followed by an exchange of assigned transects between scientists to cross-check and validate the echograms and associated documentation in an effort to ensure consistency in the decisions among scientists. A final postsurvey review of the echograms, conducted by several of the participating Canadian and U.S. scientists, consisted of the perusal of each echogram and refinement of the extent and classification of the regions. Each scientist also developed explicit documentation for these decisions.

We derived our acoustic estimates of fish abundance from application of echo integration theory, where the range-compensated measure of calibrated volume backscattering is assumed to be directly proportional to fish density (Burczynski 1979, Foote 1983). Calculations of the echo integral (mean volume backscattering strength) were made over a specific volume in the vertical direction of a depth stratum in a defined region and averaged in the horizontal direction along each transect. The range of strata considered for the analysis along each transect included depths from 14 m below the surface (approximately 5 m below the extended transducer) to 0.5 m above the detected bottom, or to a maximum depth of 500 m when sea depths exceeded this value. In our application, the integrator output was averaged for the hake backscatter regions within "cells" defined by 10-m vertical depth strata along 0.5-nmi horizontal intervals. The vertical depth strata were summed to produce the s_A for an interval (a column of cells from 14 m below the surface to 0.5 m above the bottom). Values of mean area backscatter from the EK60 echo sounder, termed the nautical area scattering coefficient (m^2/nmi^2) and denoted here as s_A (MacLennan et al. 2002), were calculated along with related variables by the SonarData EchoView software.

Pacific hake catches were pooled into analytical groups (Appendix A) based on geographic proximity of hauls and on similarity in size compositions as guided by paired comparisons with the Kolmogorov-Smirnov test (Campbell 1974). We assigned equal weight to each haul, taking no account of differences in the total catch. The composite length-frequency distributions were used for characterizing the hake distributions along each particular transect and were the basis for predicting the expected backscattering cross section (σ_{bs}) for Pacific hake based on the relation suggested by Traynor (1996) as

$$\sigma_{bs} = \sum_i f_{ij} \sigma_{bs}^{ij} \tag{1}$$

with a linear regression relation between the backscatter cross section and the length square in linear scale

$$\sigma_{bs}^{ij} = 1.58489 \cdot 10^{-7} L_{ij}^2 \tag{2}$$

for the frequency f of length class i in composite catch sample j. Equation 2 is the linear form of the regression relation in the logarithmic form given by Traynor (1996)

$$TS_{dB} = 10 \log_{10} \sigma_{bs} = 20 \log L - 68 \tag{3}$$

where TS_{dB} is target strength in decibels and L is length in centimeters.

Equation 2 was combined with the length-frequency weightings from each catch, f_{ij} in Equation 1, to calculate the final σ_{bs} for each hake analytical group.

The age-specific population number ($\hat{N}_a$) and biomass ($\hat{B}_a$) estimates of Pacific hake (Appendix B) were derived from the measured mean area backscattering (s_A) for each cell within each echo integration interval and were derived as

$$\hat{N}_a = \left[\sum_i \frac{s_A}{4\pi\sigma_{bs}} P_i Q_{ia} A \right] \tag{4}$$

and

$$\hat{B}_a = \left[\sum_i \frac{s_A}{4\pi\sigma_{bs}} P_i \hat{W}_i Q_{ia} A \right] \tag{5}$$

where σ_{bs} is the expected backscattering cross section (m^2) for each particular interval, P_i is the proportion of hake at length class i, $\hat{W}_i$ is the mean weight for length class i, Q_{ia} is the proportion of age class a for length interval i derived from the age-length key, and A is the applied linear areal interpolation (typically 0.5 nmi by 10.0 nmi, or 5 nmi^2) for each echo integration interval (Appendix B). For 2005 we changed the method of calculating $\hat{W}_i$ from always using a weight-length model to using the data directly when possible. This was done by averaging all weights for each length class i when the sample size was six or greater. Only when this sample size was fewer than six was $\hat{W}_i$ derived from the weight-length model $\hat{W} = 0.0036(length_{cm})^{3.143}$. For regions we classified as a mixture of species, the s_A attributed to hake was apportioned from total s_A based on the biomass catch proportion of acoustically detectable species (i.e., not including bladderless or bottom dwelling fish). This direct ratio or "slider" method assumes equal trawl catchability and identical backscattering properties between Pacific hake and other species.

The estimates of age-specific biomass for individual cells were summed over each interval, transect, International North Pacific Fisheries Commission (INPFC) area, or subarea (Dorn 1996) and ultimately coast-wide to obtain a total estimate. This technique of linear interpolation at each cell area and subsequent summing to desired area does not allow for propagation of error in the estimates of abundance.

One of the important issues in data analysis is the determination of the threshold value of the volume backscattering strength (Sv) to exclude echoes from non-hake weak scattering targets. In previous surveys, relatively high levels of backscattering attributed to unidentified organisms other than Pacific hake were encountered throughout much of the water column in the Monterey, Eureka, and Columbia INPFC statistical areas. As a result, an acoustic volume backscattering threshold value of −58.5 dB was applied to the backscattering data in these regions, whereas −69 dB was used for all other areas. The higher threshold was used in these southern areas to avoid including significant quantities of non-hake scatterers in the measured backscatter that would bias subsequent biomass estimates. However, initial analysis of threshold effects on the 2005 backscattering data indicated the application of the higher threshold appeared unnecessary in 2005. The 2005 acoustic-based estimates were derived entirely on the application of a uniform −69-dB threshold, and not by the historic convention of a dual −58.5/−69-dB threshold that been applied since the 1992 survey (Wilson and Guttormsen 1997, Wilson et al. 2000, Guttormsen et al. 2003).

As presented previously (Fleischer et al. 2005) as an initial attempt to address the uncertainty associated with the coast-wide Pacific hake biomass estimate in 2003, we analyzed the 2005 transect biomass data applying the technique of Jolly and Hampton (1990) to a postsurvey stratification scheme. Again, transects were treated as sampling units. We stratified the line transects using a local regression smoothing technique (loess), a generalization of running means, to guide the clustering of neighboring transects with similar biomass densities. The biomass estimates for the individual transects were plotted in geographic sequence and the modes revealed from the loess plot were used to cluster the individual transects into similar groups. This clustering, based on similar transect biomass densities—not similar Pacific hake lengths—is different from the hake "analytical groups" referred to earlier in this subsection. For each cluster, the mean and variance of the Pacific hake biomass density (mt/nmi^2) and the corresponding total area (nmi^2) were calculated. Subsequently, the total biomass ($\hat{B}$) and variance ($Var(\hat{B})$) were estimated as

$$\hat{B} = \sum (\bar{\hat{p}} \cdot A) \tag{6}$$

and

$$Var(\hat{B}) = \sum \; (Var(\bar{\hat{p}}) \cdot A^2) \tag{7}$$

where ($\bar{\hat{p}}$) is the mean estimated biomass density and (A) is the total represented area for each transect cluster.

Results and Discussion

The 2005 Pacific hake acoustic and trawl survey was initiated 20 June and completed 19 August. It covered the west coast from north of Point Piedras Blancas, California, to the Dixon Entrance area, Canada, then back south to the central Oregon area (lat 43.7°N) with a total vessel track line of approximately 24,050 km (12,986 nmi), consisting of 153 line transects, covering 5,658 km (3,055 nmi) linear distance (Figure 1).

Acoustic System Calibration

Four calibrations of the acoustic system were conducted (Table 1), but only for the first did the RV *Miller Freeman* have its full complement of four transducers. After the centerboard instrument pod was lost at sea with all four transducers, calibrations were done only for the replacement 38-kHz transducers. Only at Elliott Bay on 15 June were on-axis and beam-model calibrations performed; for the next three calibrations, only on-axis measurements were taken. Calibration results were within expected levels based on factory settings and results from previous calibrations.

Table 1. Calibration sphere measurements performed before and in association with the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

Date	Location	Ambient water temperature (°C)	Freq. (kHz)	Range (m)	Sv gain (dB)	TS gain (dB)
15 June 2005	Elliott Bay, WA	11.2	18	28.4	22.26	22.91
		11.2	38	19.8	24.28	24.83
		11.3	120	23.5	26.92	26.76
		11.3	200	22.7	26.88	26.67
2 July 2005	West of Humboldt Bay, CA	8.4	38	25.0	23.97	24.57
31 July 2005	Quatsino Inlet, B.C.	10.1	38	24.0	24.57	25.14
21 Aug. 2005	Elliott Bay, WA	13.2	38	23.2	24.68	25.15

Biological Sampling

A total of 61 midwater trawls and 2 bottom trawls were conducted during the course of the survey (Table 2, Figures 2 through 4). Trawl durations ranged from 0.1 to 75.1 minutes (mean = 12.8 minutes) and catch weights ranged from 0.0 to 4,129.1 kg (mean = 797.3 kg). Pacific hake was the dominant fish species caught in both midwater and bottom trawl hauls, accounting for roughly 87% and 56%, respectively, of catch composition by weight (Table 3 and Table 4). The top five non-hake species caught in midwater trawl hauls, totaling almost 10% by weight, were rockfish: splitnose (*Sebastes diploproa*), yellowtail (*S. flavidus*), widow (*S. entomelas*), yellowmouth (*S. reedi*), and Pacific ocean perch (*S. alutus*). All splitnose rockfish were caught in a single tow (haul 4) in the Monterey INPFC area; all yellowmouth rockfish and Pacific ocean perch were caught off Canada. Sizable numbers of Pacific herring (*Clupea pallasii pallasii*) and lanternfish (Myctophidae) were caught throughout the survey area. In the two completed bottom trawls, Pacific hake and spiny dogfish (*Squalus acanthias*) accounted for nearly 94% of catch composition by weight.

A total of 259 stomachs were collected from 42 hauls from Pacific hake whose fork length ranged from 25 cm to 80 cm. Six stomachs were empty. Analysis showed that euphausiids were the most commonly occurring prey item, followed by fish. In general, consumption of fish prey, both by frequency and by weight, increased as hake became larger. For smaller hake, euphausiids were a more important dietary component. This shift from a diet of primarily euphausiids to primarily fish occurred gradually when hake were around 44 cm to 48 cm; only hake larger than 49 cm ate almost exclusively fish. Regional differences in diet composition were also observed. In the Eureka INPFC area and in Canada, the diet was dominated by euphausiids. In the South Columbia and Vancouver-North Columbia areas, the diet was mostly fish; however, this difference may be confounded by the tendency of larger hake to occur further north.

Table 2. Trawl station and catch data summary from the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

Haul no.[a]	INPFC area[b]	Gear type[c]	Date	Time (PDT)	Duration (min.)	Start position Latitude		Start position Longitude		Depth (m) Gear[d]	Depth (m) Bottom	Temp (°C) Gear[e]	Temp (°C) Surface	Catch Pacific hake (kg)	Catch Pacific hake No.	Catch Other (kg)
2	Mont	A	21 Jun	17:43	30.2	36	23.77	121	58.24	102	117	9.0	11.5	0.0	0	6.7
3	Mont	A	22 Jun	8:38	10.5	36	44.32	121	59.15	209	654	8.2	12.6	263.0	1,417	54.3
4	Mont	A	22 Jun	18:30	2.5	37	4.28	122	39.76	176	202	8.6	14.1	459.9	2,154	1,708.6
5	Mont	A	23 Jun	14:28	25.0	37	14.48	122	49.78	188	242	8.5	13.5	0.0	0	49.9
6	Mont	A	24 Jun	7:33	14.9	37	24.31	122	53.84	194	359	8.4	13.8	13.5	51	4.9
7	Mont	P	25 Jun	12:03	10.4	38	14.31	123	20.98	132	132	8.5	13.3	15.1	23	14.2
8	Mont	A	26 Jun	8:20	2.1	38	43.72	123	37.39	88	90	8.4	10.8	6.7	9	101.1
9	Mont	A	26 Jun	10:14	10.7	38	43.97	123	47.98	189	224	8.7	11.8	3,269.8	12,578	17.3
10	Mont	A	26 Jun	17:08	20.1	38	43.90	123	50.67	277	419	7.9	12.7	297.1	771	45.9
11	Mont	A	27 Jun	11:05	75.1	39	14.80	124	4.62	392	590	–	11.7	280.7	692	18.7
12	Eur	A	3 Jul	19:04	12.1	40	34.29	124	40.99	265	352	7.6	12.2	253.3	746	418.1
13	Eur	A	4 Jul	7:52	6.4	40	43.84	124	39.14	128	870	8.3	12.7	1,198.6	2,090	0.0
14	Eur	A	4 Jul	10:44	2.3	40	43.54	124	28.79	123	128	8.0	12.3	863.7	1,616	108.7
15	Eur	A	4 Jul	19:36	2.1	41	3.85	124	27.49	113	554	7.9	12.3	2,036.3	6,219	1.1
16	Eur	A	5 Jul	18:17	2.8	41	34.34	125	1.59	106	1,260	9.2	10.8	537.5	942	0.0
17	Eur	A	6 Jul	12:53	0.1	41	54.04	124	40.55	161	631	7.7	11.3	320.4	913	0.0
19	Eur	A	7 Jul	18:57	11.3	42	44.47	124	42.26	166	182	7.4	13.1	527.7	985	0.3
20	SCol	A	8 Jul	13:44	20.4	43	13.96	124	44.50	273	285	6.8	16.5	137.0	257	3.8
21	SCol	A	8 Jul	20:10	15.3	43	24.11	124	43.55	361	485	6.5	16.5	65.0	117	11.1
22	SCol	A	12 Jul	8:58	14.8	43	33.53	124	36.40	237	249	7.2	16.9	1,103.3	3,213	0.0
23	SCol	A	13 Jul	7:57	19.1	44	4.88	124	57.56	272	351	7.1	17.0	1,181.0	2,213	2.0
24	SCol	A	13 Jul	19:59	1.7	44	23.92	124	49.43	306	385	6.8	17.4	1,357.3	2,511	0.6
25	Scol	A	14 Jul	18:13	35.6	44	43.93	124	44.54	345	380	6.3	16.5	721.4	1,370	15.3
26	SCol	A	15 Jul	13:29	14.7	45	4.06	124	22.08	235	240	6.7	16.0	183.5	331	12.4
27	SCol	A	15 Jul	17:07	10.2	45	5.08	124	47.88	489	594	5.5	16.6	7.0	13	13.0
28	SCol	P	16 Jul	12:16	3.1	45	24.73	124	10.60	126	126	7.2	16.7	118.2	214	90.1
29	SCol	A	17 Jul	10:56	17.3	45	44.62	124	39.22	226	227	6.7	17.2	5.3	9	74.9
30	VanNC	A	17 Jul	18:07	10.3	45	54.40	124	45.34	373	394	6.0	17.4	379.0	710	11.2
31	VanNC	A	18 Jul	9:49	7.8	46	3.79	124	17.23	100	107	7.0	15.6	2,139.8	3,757	0.1
32	VanNC	A	19 Jul	16:23	27.9	46	53.72	124	29.83	79	82	7.7	14.9	1,151.2	2,082	15.9
33	VanNC	A	20 Jul	12:00	17.8	47	14.02	124	54.21	350	576	6.1	15.0	119.5	227	0.3
34	VanNC	A	20 Jul	21:15	1.2	47	33.97	124	54.79	57	145	8.7	15.1	0.0	0	0.0
35	VanNC	A	21 Jul	19:18	25.1	47	54.16	125	19.21	297	512	–	15.8	0.0	0	0.8
36	VanNC	A	22 Jul	10:51	8.1	48	4.51	125	39.07	328	364	5.7	15.2	0.5	1	1.6

Table 2 continued. Trawl station and catch data summary from the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

Haul no.[a]	INPFC area[b]	Gear type[c]	Date	Time (PDT)	Duration (min.)	Start position Latitude		Start position Longitude		Depth (m) Gear[d]	Depth (m) Bottom	Temp (°C) Gear[e]	Temp (°C) Surface	Catch Pacific hake (kg)	Catch Pacific hake No.	Catch Other (kg)
37	VanNC	A	22 Jul	14:03	30.2	48	4.30	125	7.65	125	137	6.9	14.2	1.6	3	15.4
38	Can	A	25 Jul	14:36	4.9	48	24.17	125	53.21	160	181	6.7	15.9	0.0	0	260.4
39	Can	A	26 Jul	8:08	23.6	48	33.74	125	21.29	119	138	7.2	11.5	3,572.1	6,135	557.0
40	Can	A	26 Jul	16:18	3.2	48	44.30	126	11.33	141	148	6.8	15.0	1,807.4	3,992	47.0
41	Can	A	27 Jul	13:36	1.1	49	4.02	126	38.83	134	142	6.7	13.7	2,575.2	4,475	9.7
42	Can	A	27 Jul	18:14	2.1	49	14.14	126	26.95	71	80	8.4	12.7	16.9	14	58.0
43	Can	A	28 Jul	13:42	19.8	49	44.10	127	28.52	123	141	6.3	11.2	0.9	1	594.1
44	Can	A	29 Jul	9:19	0.7	50	14.32	128	5.71	135	143	6.7	12.8	2,018.9	3,430	148.8
45	Can	A	1 Aug	8:02	11.9	50	34.31	128	39.41	204	206	6.2	13.3	2.1	3	91.4
46	Can	A	1 Aug	9:22	31.0	50	34.02	128	40.63	346	555	5.6	13.3	133.6	238	50.1
47	Can	A	1 Aug	14:32	15.5	50	44.31	129	13.85	172	209	6.7	13.4	0.0	0	622.5
48	Can	A	2 Aug	10:35	21.2	50	58.86	129	39.16	213	306	6.0	15.1	0.0	0	517.4
49	Can	A	2 Aug	21:03	10.1	51	44.00	130	42.95	405	547	5.3	16.2	177.0	323	8.7
50	Can	A	4 Aug	11:11	2.6	51	24.16	128	34.02	177	197	5.9	15.9	1,907.6	3,321	68.5
51	Can	A	5 Aug	7:12	8.8	52	4.29	130	51.76	209	213	5.4	15.0	548.4	889	17.3
52	Can	A	6 Aug	12:25	5.6	53	4.40	130	30.48	152	166	6.6	16.0	2,202.8	3,182	38.1
53	Can	A	6 Aug	21:10	11.7	53	44.30	130	45.05	116	137	7.2	15.8	333.0	516	10.2
54	Can	A	7 Aug	10:30	8.0	54	15.80	132	7.06	142	157	7.0	14.5	424.9	580	23.4
55	Can	A	8 Aug	10:10	4.2	53	3.19	132	35.50	178	200	6.2	15.4	0.0	0	2.2
56	Can	A	9 Aug	15:12	20.7	49	24.16	127	14.48	227	256	6.4	15.1	0.0	0	470.2
57	Can	A	11 Aug	11:24	7.9	48	44.32	125	50.81	85	98	8.0	14.1	0.0	0	149.9
58	Can	A	12 Aug	8:56	5.5	48	24.30	125	43.59	130	136	6.8	12.5	1,099.0	1,497	22.1
59	VanNC	A	13 Aug	11:22	3.2	47	54.31	125	7.03	149	150	3.9	13.7	3,090.1	5,395	6.3
60	VanNC	A	14 Aug	9:46	17.1	47	14.32	124	28.36	41	54	–	11.4	663.5	1,103	9.1
61	VanNC	A	15 Aug	18:06	4.4	46	14.21	124	24.31	126	180	7.1	12.5	380.1	637	2.5
62	SCol	A	16 Aug	12:40	7.6	45	44.30	124	12.53	108	113	7.1	12.5	160.6	254	0.1
63	SCol	A	16 Aug	17:41	12.6	45	34.35	124	34.00	265	395	7.0	14.1	1,110.3	1,977	4.8
64	SCol	A	18 Aug	15:55	4.7	44	13.79	124	56.72	186	228	7.5	12.4	1,842.6	3,787	41.5
65	SCol	A	19 Aug	14:05	15.3	43	54.34	124	16.98	96	102	7.9	10.3	501.0	776	2.2

[a] Hauls 1 and 18 were aborted because of equipment failure.
[b] Mont = Monterey, Eur = Eureka, SCol = South Columbia, VanNC = Vancouver-North Columbia, Can = Canada.
[c] A = Aleutian wing midwater trawl, P = poly Nor'eastern bottom trawl.
[d] Gear depths were measured at the head rope.
[e] Gear temperatures were measured at the head rope.

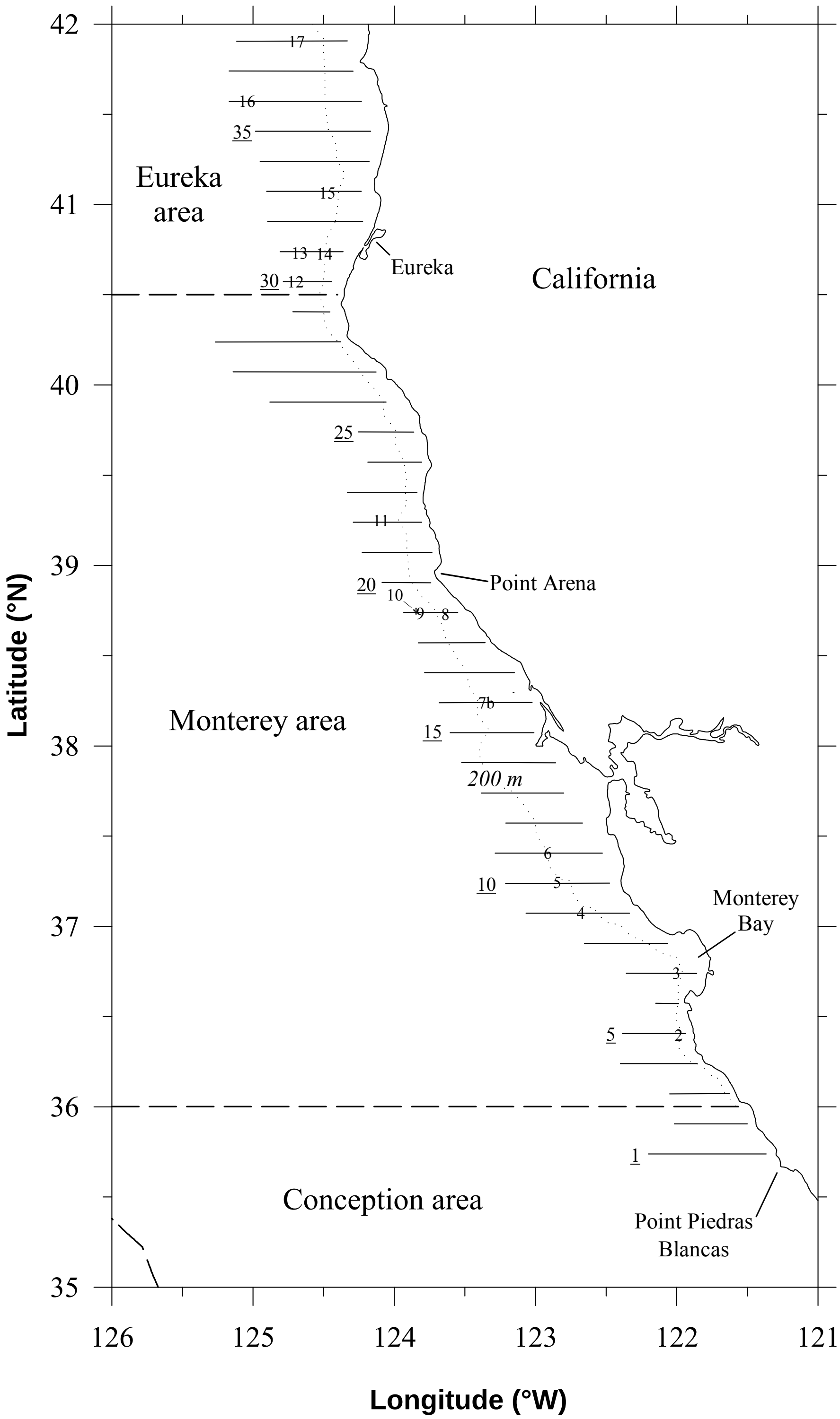

Figure 2. Details of southern acoustic transect lines and locations and haul sequence of midwater and bottom trawls (latter denoted with "b" suffix) during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Underscored numbers indicate transect sequence.

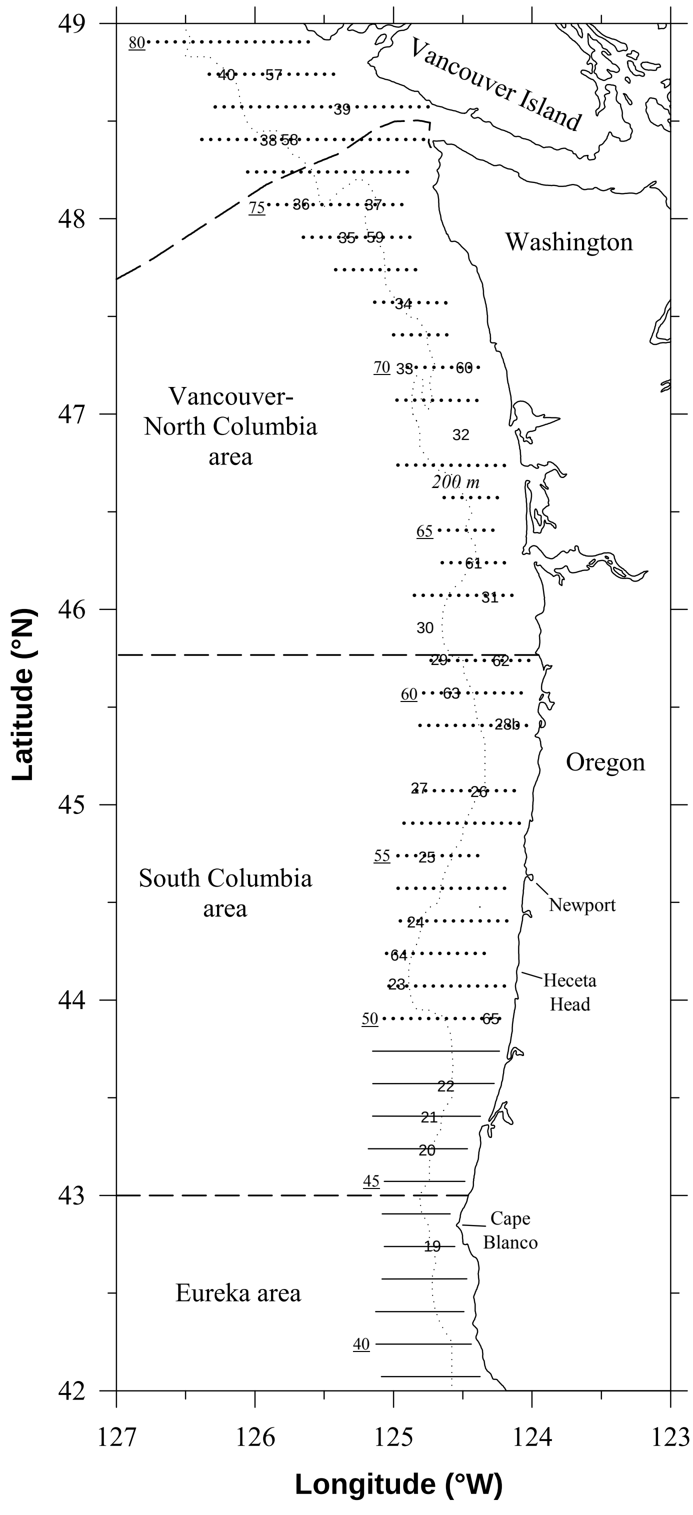

Figure 3. Details of central acoustic transect lines and locations and haul sequence of midwater and bottom trawls (latter denoted with "b" suffix) during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Transects marked by dotted lines were surveyed from north to south, while transects with solid lines were surveyed south to north. Underscored numbers indicate transect sequence.

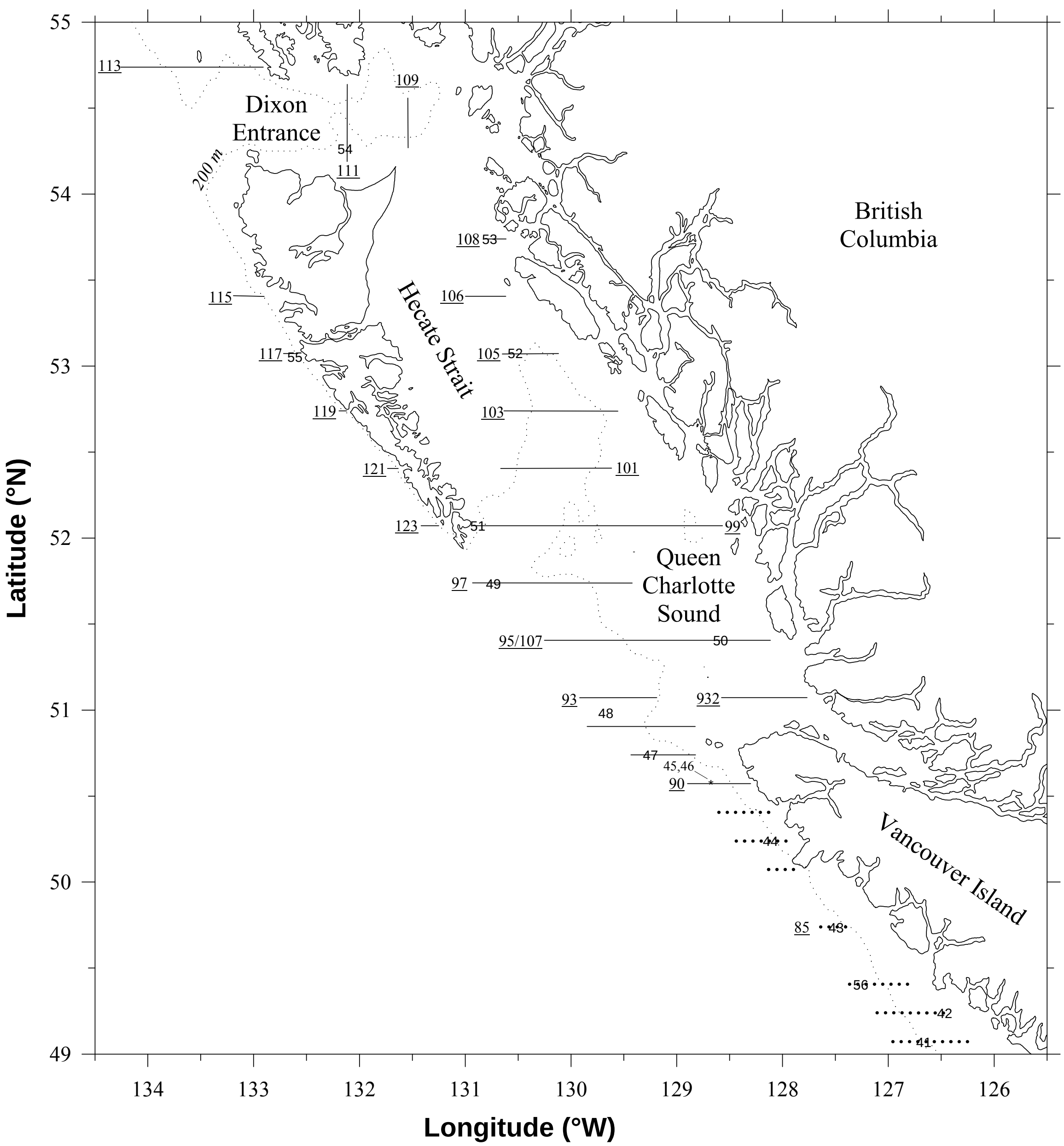

Figure 4. Details of northern acoustic transect lines and locations and haul sequence of midwater trawls during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Transects marked by dotted lines were surveyed out of order, from north to south. Underscored numbers indicate transect sequence.

Table 3. Catch by species from Aleutian wing midwater trawl hauls conducted by the RV *Miller Freeman* during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

Common name	**Scientific name**	**Weight (kg)**	**(%)**	**Numbers**
Pacific hake	*Merluccius productus*	43,447.4	86.9	90,522
Splitnose rockfish	*Sebastes diploproa*	1,628.2	3.3	4,738
Yellowtail rockfish	*S. flavidus*	1,350.0	2.7	896
Widow rockfish	*S. entomelas*	851.9	1.7	710
Yellowmouth rockfish	*S. reedi*	567.9	1.1	425
Pacific ocean perch	*S. alutus*	564.4	1.1	494
Spiny dogfish	*Squalus acanthias*	517.6	1.0	132
Chilipepper	*Sebastes goodei*	240.6	0.5	385
Pacific herring	*Clupea pallasii pallasii*	229.1	0.5	3,756
Chinook salmon	*Oncorhynchus tshawytscha*	109.0	0.2	46
Redstripe rockfish	*Sebastes proriger*	104.4	0.2	218
Jellyfish unident.	Scyphozoa	91.6	0.2	–
Lanternfish unident.	Myctophidae	34.5	0.1	4,246
Rougheye rockfish	*Sebastes aleutianus*	32.9	0.1	22
Big squid	*Moroteuthis robusta*	32.6	0.1	2
Silvergray rockfish	*Sebastes brevispinus*	29.9	0.1	11
Bocaccio	*S. paucispinis*	23.0	<0.1	5
Humboldt squid	*Disidicus gigas*	15.0	<0.1	3
Ocean sunfish	*Mola mola*	14.0	<0.1	1
King-of-the-salmon	*Trachipterus altivelis*	13.6	<0.1	2
Canary rockfish	*Sebastes pinniger*	13.5	<0.1	5
Arrowtooth flounder	*Atheresthes stomias*	13.1	<0.1	6
Darkblotched rockfish	*Sebastes crameri*	8.7	<0.1	20
Shortbelly rockfish	*S. jordani*	7.3	<0.1	40
Black rockfish	*S. melanops*	7.0	<0.1	4
Lingcod	*Ophiodon elongatus*	6.5	<0.1	1
California market squid	*Loligo opalescens*	5.3	<0.1	198
Magistrate armhook squid	*Berryteuthis magister*	5.3	<0.1	10
Salps unident.	Thaliacea	5.2	<0.1	31
American shad	*Alosa sapidissima*	4.6	<0.1	15
Pacific sardine	*Sardinops sagax*	3.9	<0.1	48
Pacific pomfret	*Brama japonica*	3.5	<0.1	5
Pacific electric ray	*Torpedo californica*	2.2	<0.1	1
Longnose lancetfish	*Alepisaurus ferox*	2.0	<0.1	1
Pacific cod	*Gadus macrocephalus*	1.8	<0.1	1
Brown cat shark	*Apristurus brunneus*	1.4	<0.1	2
Squid unident.	Teuthoidea	1.2	<0.1	162
California headlightfish	*Diaphus theta*	1.0	<0.1	273
Eulachon	*Thaleichthys pacificus*	0.9	<0.1	33
Shrimp unident.	Decapoda	0.6	<0.1	364
Scaleless dragonfish unident.	Melanostomiidae	0.4	<0.1	84
Cockeyed squid	*Histeoteuthis heteropsis*	0.3	<0.1	4
Pacific lamprey	*Lampetra tridentata*	0.3	<0.1	2
Pacific viperfish	*Chauliodus macouni*	0.2	<0.1	37
Northern anchovy	*Engraulis mordax*	0.2	<0.1	6
Shiny loosejaw	*Aristostomias scintillans*	0.1	<0.1	1

Table 3 continued. Catch by species from Aleutian wing midwater trawl hauls conducted by the RV *Miller Freeman* during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

Common name	Scientific name	Weight (kg)	(%)	Numbers
Sergestid shrimp unident.	Sergestidae	0.1	<0.1	59
Ragfish	*Icosteus aenigmaticus*	0.1	<0.1	1
Armhook squid unident.	*Gonatus* sp.	0.1	<0.1	12
Hatchetfish unident.	Sternoptychidae	0.1	<0.1	2
Ribbon barracudina	*Arctozenus risso*	0.1	<0.1	2
Slender barracudina	*Lestidiops ringens*	0.1	<0.1	3
Viperfish unident.	Chauliodontidae	0.1	<0.1	2
Blacksmelt unident.	*Bathylagus* sp.	<0.1	<0.1	1
Eastern Pacific bobtail squid	*Rossia pacifica*	<0.1	<0.1	8
Longfin dragonfish	*Tactostoma macropus*	<0.1	<0.1	1
Medusafish	*Icichthys lockingtoni*	<0.1	<0.1	1
Euphausiid unident.	Euphausiacea	<0.1	<0.1	–
Isopod unident.	Isopoda	<0.1	<0.1	2
Pandalid shrimp unident.	Pandalidae	<0.1	<0.1	4

Table 4. Catch by species from poly Nor'eastern bottom trawl hauls conducted by the RV *Miller Freeman* during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

Common name	Scientific name	Weight (kg)	(%)	Numbers
Pacific hake	*Merluccius productus*	133.3	56.1	237
Spiny dogfish	*Squalus acanthias*	89.8	37.8	370
Soupfin shark	*Galeorhinus galeus*	9.9	4.2	1
Longnose skate	*Raja rhina*	4.2	1.8	1
Dover sole	*Microstomus pacificus*	0.3	0.1	2
Salps unident.	Thaliacea	0.1	<0.1	–
Sea pen unident.	Pennatulacea	<0.1	<0.1	1

Pacific Hake Distribution and Abundance Estimates

Aggregations of Pacific hake were detected along the continental shelf break from Monterey Bay (lat 37°N) to the Dixon Entrance area (Figures 5 through 7). Peak concentrations of Pacific hake were observed in the following general areas: near Point Arena, California (ca. lat 39°N); the area spanning from Eureka, California (ca. lat 41°N), to Cape Blanco, Oregon (ca. lat 43°N); off Heceta Head; and Queen Charlotte Sound. Less concentrated yet persistent aggregations of Pacific hake were observed in the area between north of the Columbia River mouth (ca. lat 46°N) and La Perouse Bank, Canada (ca. lat 48.5°N).

The overall coast-wide length-frequency distribution of Pacific hake shows a bimodal distribution (Figure 8). However, as revealed by the associated midwater and bottom trawl samples, the majority of the coastal Pacific hake population was composed of fish from the 1999 year class that were quite uniform in size distribution, averaging 43 cm. South of lat 43°N, however, smaller individuals from the 2003 year class were encountered (average = 35 cm). Larger Pacific hake were more prevalent further north (Figure 9). Pacific hake specimens collected in the trawls ranged in age from 1 to 18 years, although the 1999 year class (age 6) was the dominant age (Figure 10 and Figure 11). Age-2 Pacific hake (2003 year class) were also quite prevalent.

The coast-wide estimates of Pacific hake abundance totaled 2.518 billion fish weighing 1.265 million metric tons (Table 5 and Table 6). Most of the observed biomass (40% of survey total) was in Canadian waters, followed by 26% in the Eureka INPFC area. As expected from the age and length distribution, the overall population was dominated by age-6 fish (Figure 11, Table 5 and Table 6). The 1999 year class contributed about 48% of the total coast-wide number and 55% of the total coast-wide biomass. Prevalent primarily north of the Monterey INPFC area, this year class contributed 46%, 65%, 64%, and 63% to the total biomass for the Eureka, South Columbia, and Vancouver-North Columbia areas and Canada, respectively. The 2003 year class also was relatively strong, contributing 24% and 13% of coast-wide numbers and biomass, respectively. In the Monterey INPFC area, age-2 Pacific hake were almost nine times more numerous than age-6 fish and contributed four times the biomass (68% of area biomass versus 17%). In the Eureka INPFC area, numbers of age-2 Pacific hake were slightly more than over 11% greater than those of age-6 fish even though the age-6 biomass was 78% greater. In all other INPFC areas, age-6 Pacific hake were markedly more numerous than age-2 fish and had higher biomasses.

The 2005 biomass estimate of 1.265 million metric tons represents a decrease of 577,000 tons or 31% from the biomass estimate made for 2003 (Figure 12). However, the 2005 estimate is still 528,000 metric tons greater than the biomass estimate made for 2001, which was the smallest since coast-wide acoustic surveys began in 1977.

Fleischer et al. (2005) noted a dramatic increase in the biomass of Pacific hake in Canadian waters from 2001 to 2003. This trend continued in 2005; Pacific hake biomass in Canada was approximately 37% larger than that observed in 2003. The increase appears to be a reflection of a northward shift of the dominant 1999 year class as it matured; age-4 fish that were most prevalent in the Eureka INPFC area in 2003 became the age-6 fish that were most dominant in Canadian waters in 2005.

The coefficient of variation (CV)—the measure of precision of the estimate—totaled 0.31 for the coast-wide Pacific hake biomass (Table 7). This estimate of precision is strictly exploratory, but does provide some understanding of the minimum expectation for the level of process error involved in the survey. By comparison, the same analysis for the 2003 biomass estimates yielded a CV of 0.37 (Fleischer et al. 2005). It should be noted that the total 2005 biomass point estimate determined with the postsurvey stratification technique was greater, but within 7% of the value calculated by the traditional linear summing method (Table 6).

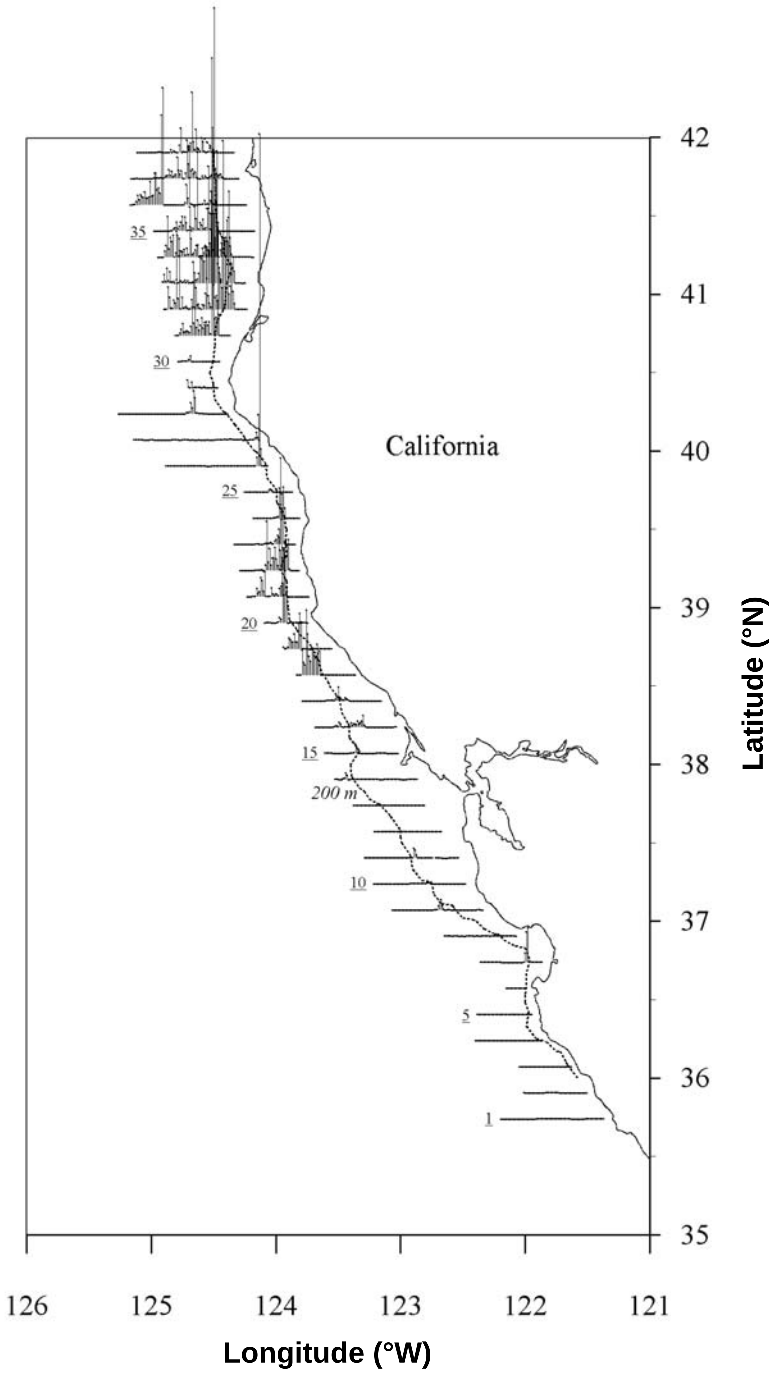

Figure 5. Acoustic area backscattering (s_A) attributed to Pacific hake along southern transects completed during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Height of lines is proportional to measured values of backscatter. Underscored numbers indicate transect sequence.

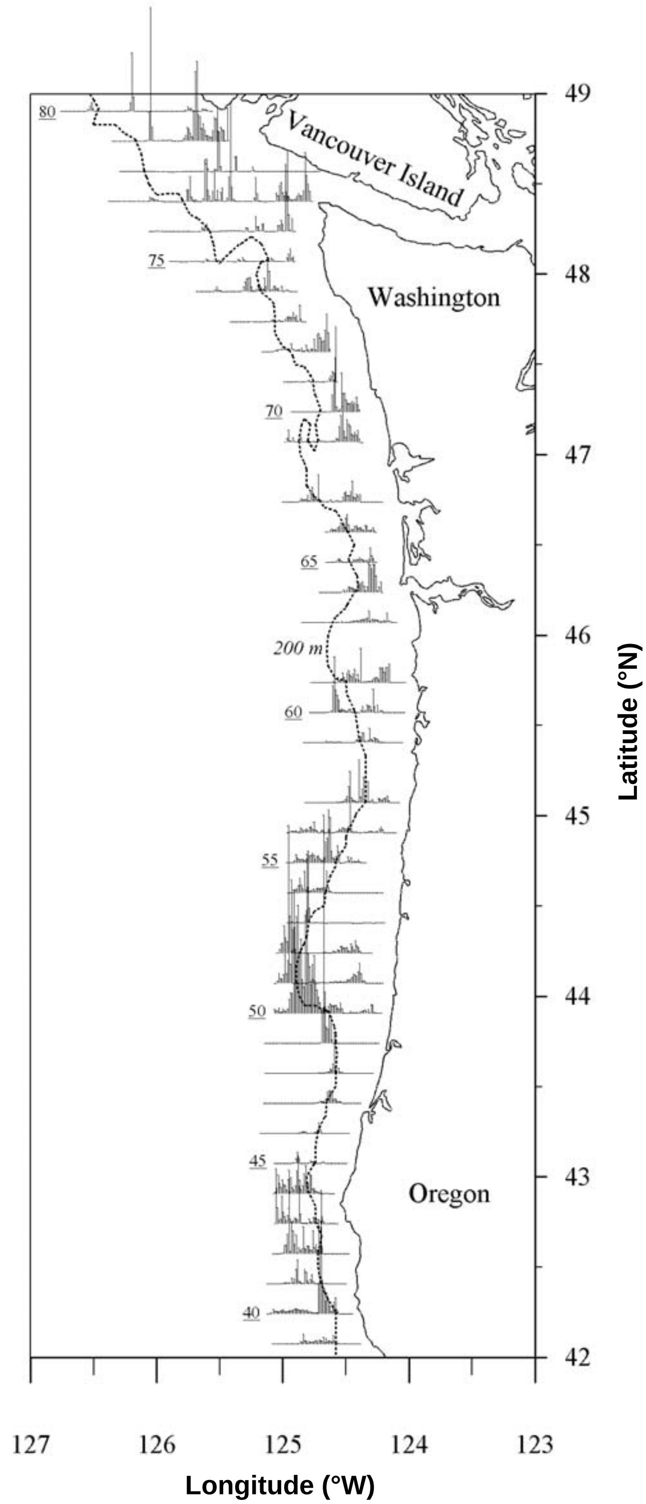

Figure 6. Acoustic area backscattering (s_A) attributed to Pacific hake along central transects completed during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Height of lines is proportional to measured values of backscatter. Underscored numbers indicate transect numbering sequence.

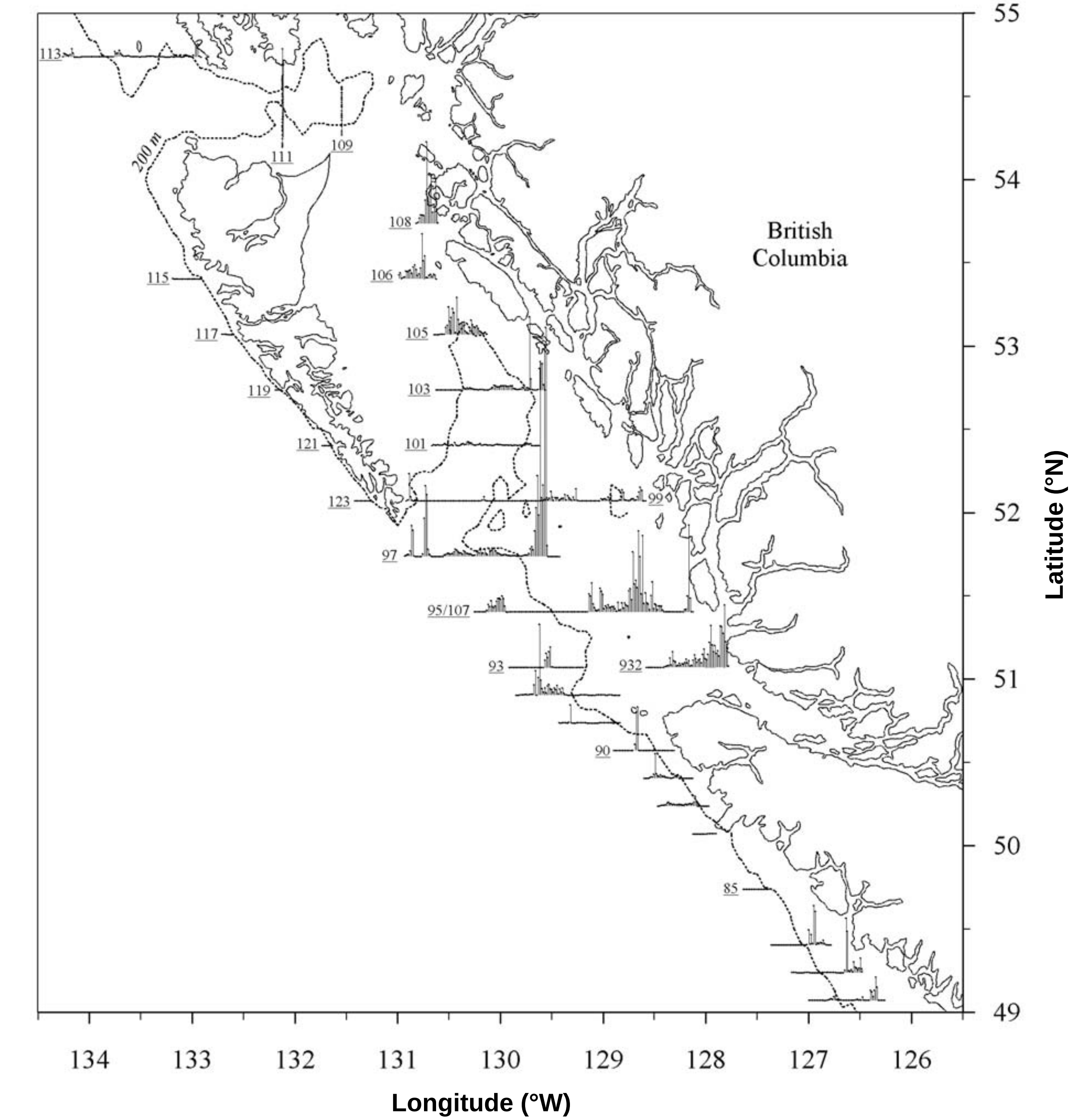

Figure 7. Acoustic area backscattering (s_A) attributed to Pacific hake along northern transects completed during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Height of lines is proportional to measured values of backscatter. Underscored numbers indicate transect numbering sequence.

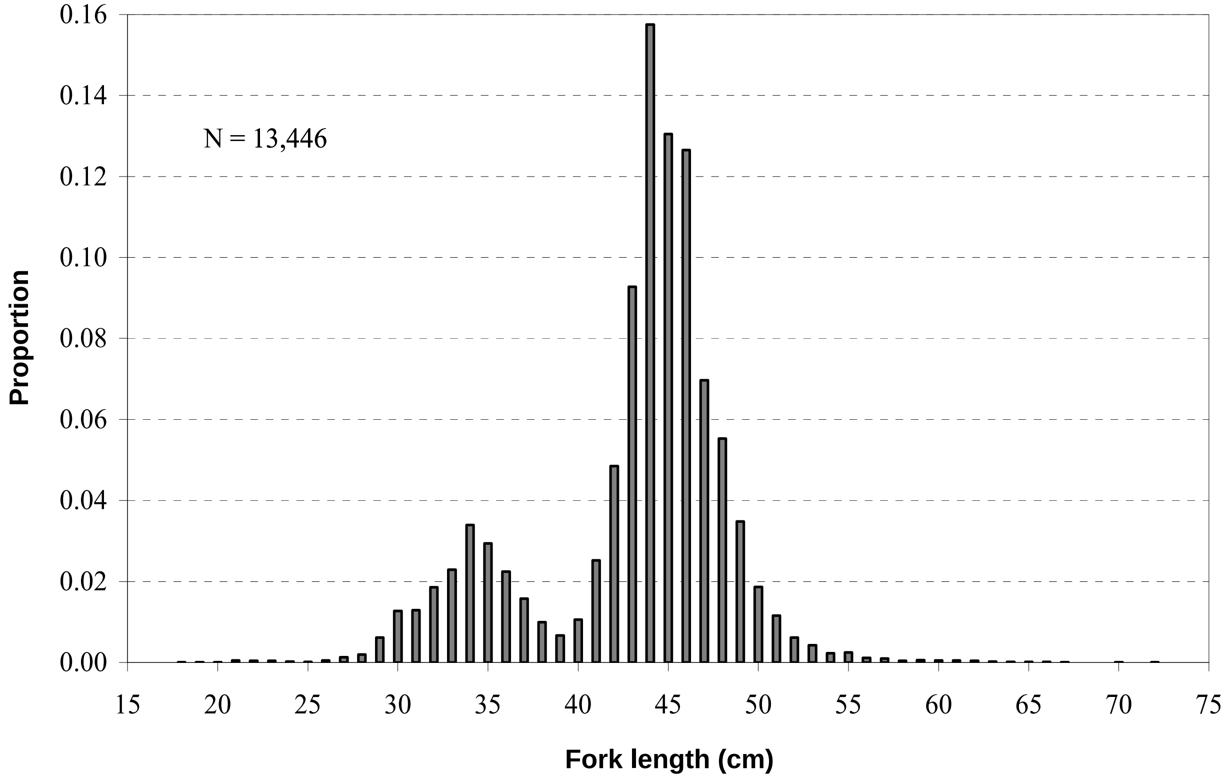

Figure 8. Coast-wide length-frequency distribution of Pacific hake from specimens collected during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

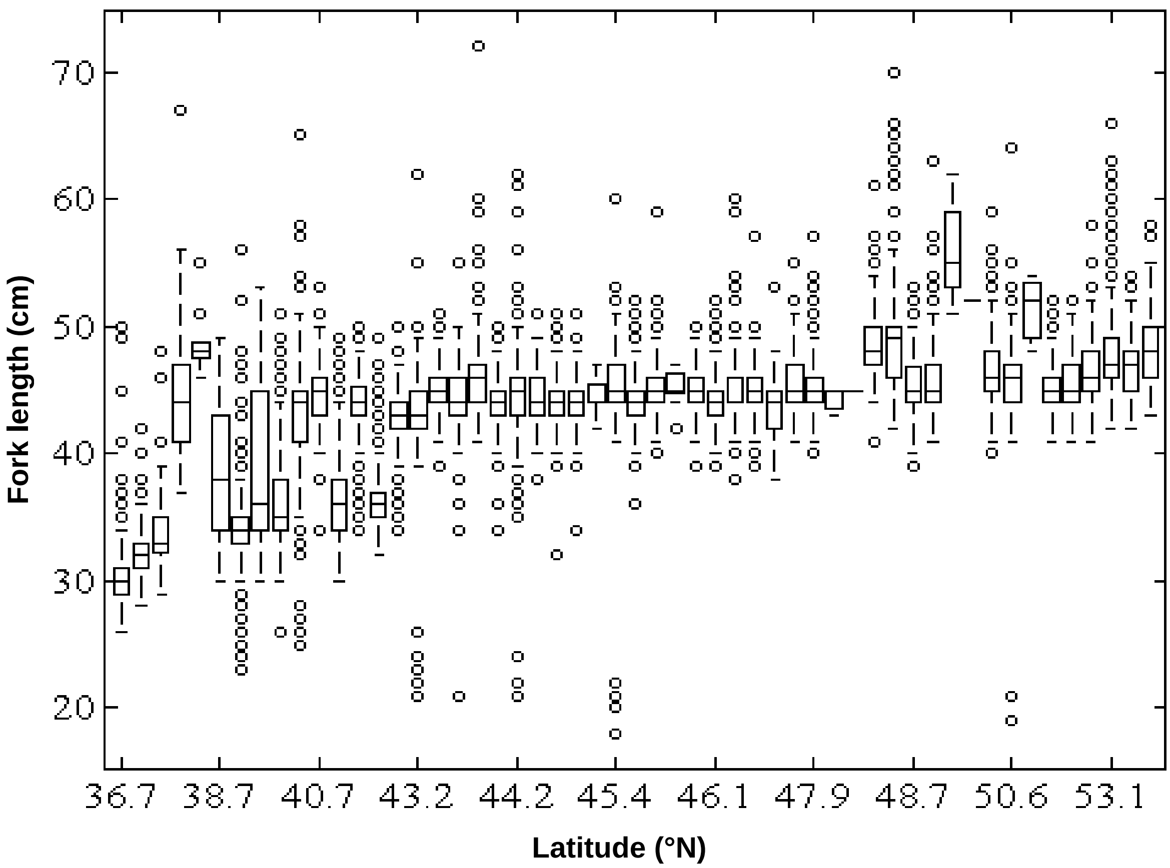

Figure 9. Box-and-whisker plot of the length-frequency distributions of Pacific hake for trawl tows conducted as part of the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. The central box indicates the range of fish lengths in the upper and lower quartiles, with the median represented by the horizontal line in the box. The whiskers extend to 1.5 times the interquartile range, or approximately the 1 and 99 percentiles, and outliers are shown as open circles for each haul.

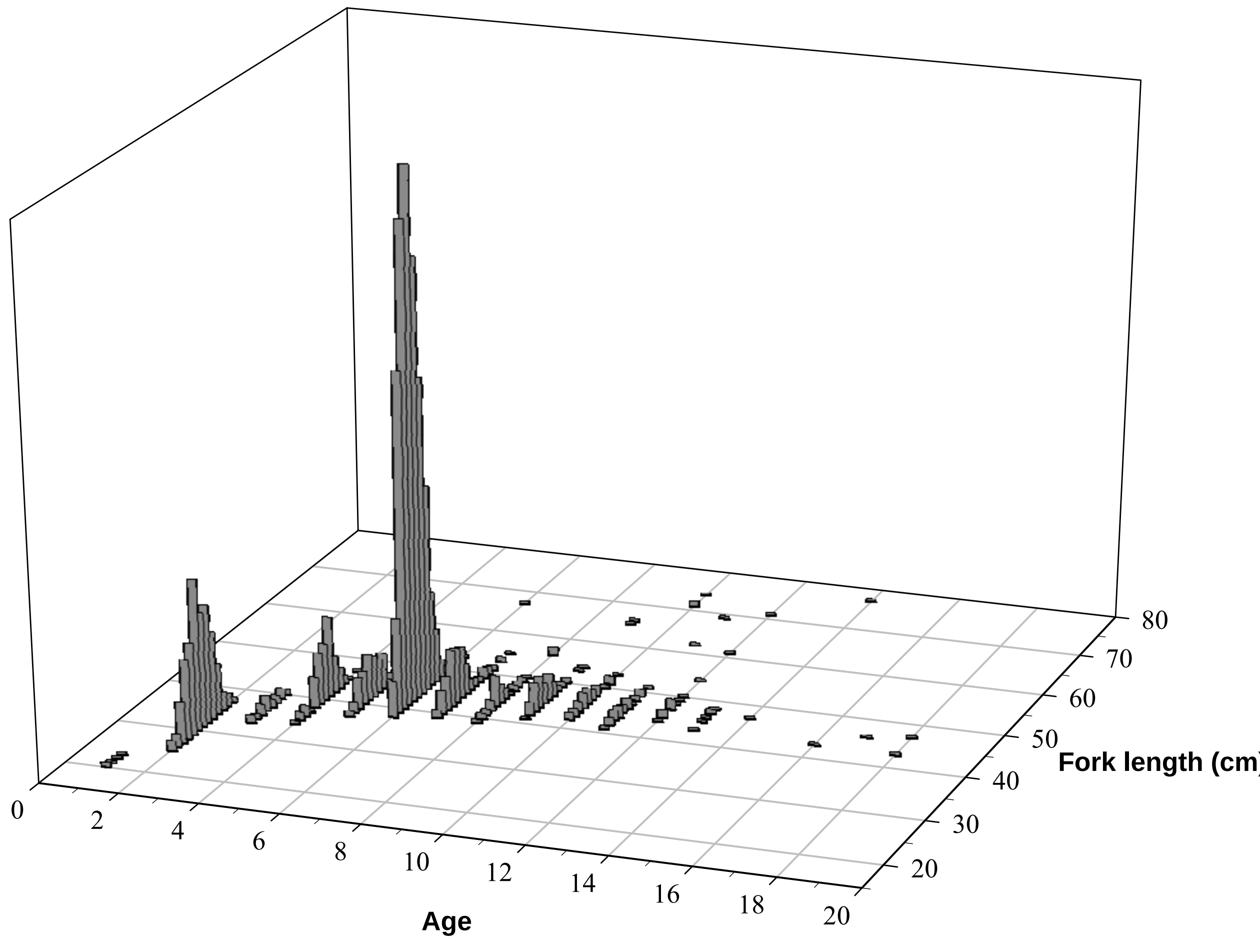

Figure 10. Age-length distribution of Pacific hake from specimens collected during the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Ages are based on interpretation of otoliths.

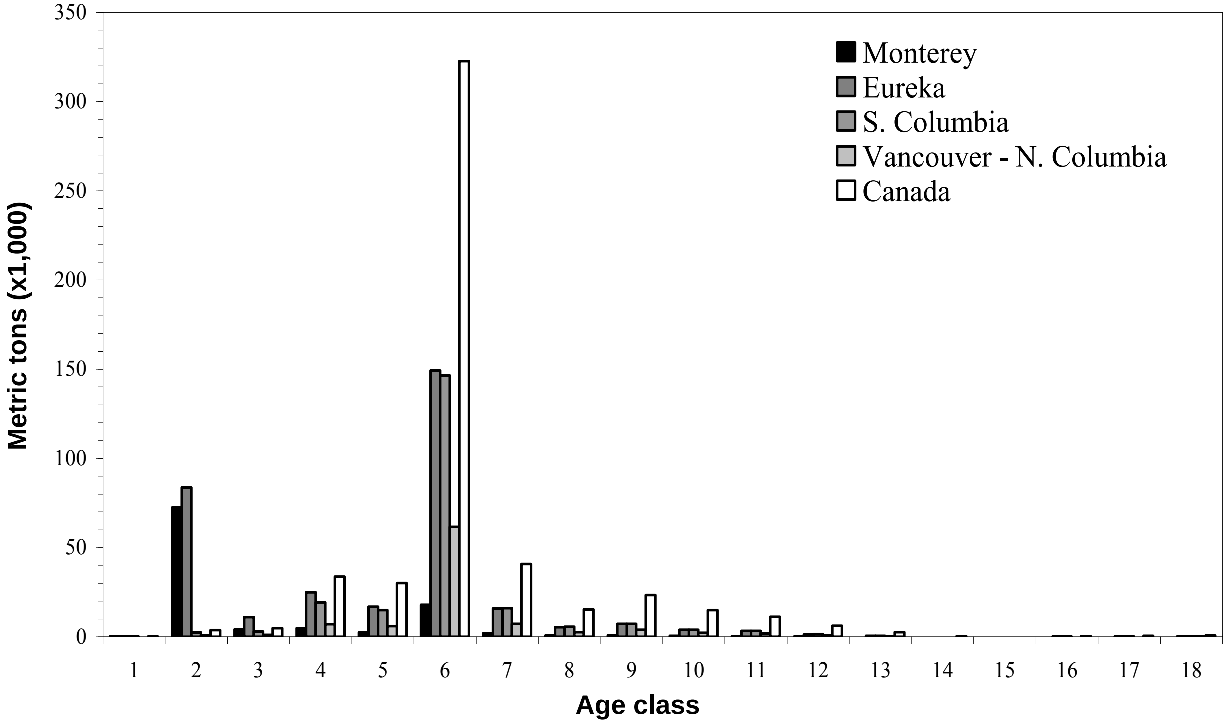

Figure 11. Estimated biomass (mt) of Pacific hake by age class comparing INPFC areas and Canada for the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

Table 5. Estimated biomass (mt) of Pacific hake by age for each INPFC area and Canada for the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. (Sums shown in the Total row and Total column reflect rounding.)

	Geographic area					
Age class	**Monterey**	**Eureka**	**South Columbia**	**Vancouver-North Columbia**	**Canada**	**Total**
1	340.0	109.1	114.9	39.8	173.3	777.1
2	72,535.0	83,641.7	2,497.4	865.7	3,777.1	163,316.9
3	4,162.9	11,024.1	3,088.1	1,085.3	4,808.0	24,168.5
4	4,870.3	24,895.9	19,228.1	7,175.0	33,797.5	89,966.8
5	2,469.6	16,910.7	14,944.2	5,996.9	30,156.8	70,478.1
6	17,886.7	149,243.6	146,521.5	61,703.4	322,571.0	697,926.1
7	1,980.0	15,990.3	16,174.6	7,370.3	40,778.9	82,294.0
8	664.7	5,449.3	5,605.1	2,676.4	15,262.8	29,658.4
9	965.5	7,237.9	7,267.9	3,863.6	23,429.7	42,764.5
10	530.5	3,896.1	3,887.1	2,323.9	14,913.6	25,551.2
11	401.5	3,332.8	3,463.2	1,846.3	11,212.7	20,256.5
12	149.2	1,352.4	1,502.2	944.8	6,195.6	10,144.1
13	84.4	629.0	610.4	398.3	2,650.5	4,372.6
14	4.9	65.3	71.4	58.0	415.6	615.1
15	0.0	0.0	0.0	0.0	0.0	0.0
16	22.0	145.6	149.1	63.3	333.2	713.2
17	16.6	135.9	113.6	73.7	489.1	828.8
18	26.9	210.8	220.5	121.3	748.8	1,328.3
Total	107,110.6	324,270.4	225,459.2	96,605.9	511,714.1	1,265,160.2

Table 6. Estimated numbers of Pacific hake by age for each INPFC area and Canada for the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. (Sums shown in the Total row and Total column reflect rounding.)

	Geographic area					
Age class	**Monterey**	**Eureka**	**South Columbia**	**Vancouver-North Columbia**	**Canada**	**Total**
1	3,034,134	1,320,216	1,505,708	521,203	2,270,413	8,651,674
2	285,322,633	295,484,673	7,366,066	2,552,703	11,134,175	601,860,251
3	11,223,210	28,801,214	7,229,372	2,537,393	11,224,200	61,015,390
4	11,073,329	52,088,654	37,927,556	14,051,062	65,724,152	180,864,753
5	4,951,977	32,221,044	27,746,287	10,932,507	54,125,897	129,977,712
6	31,797,203	265,069,373	258,987,367	106,662,746	547,939,638	1,210,456,326
7	3,184,948	26,634,937	26,730,794	11,789,998	63,780,920	132,121,596
8	1,071,582	8,607,158	8,722,678	4,043,281	22,626,373	45,071,071
9	1,420,214	10,763,522	10,750,520	5,577,846	33,387,919	61,900,022
10	738,268	5,476,921	5,410,923	3,157,998	20,048,356	34,832,466
11	599,172	4,797,012	4,886,703	2,552,593	15,335,372	28,170,852
12	199,975	1,587,640	1,711,536	1,101,996	7,295,318	11,896,465
13	122,665	899,114	875,278	555,718	3,658,265	6,111,040
14	6,430	86,107	94,187	76,534	548,490	811,748
15	0	0	0	0	0	0
16	36,943	244,232	250,051	106,223	559,012	1,196,460
17	23,070	188,589	157,585	102,220	678,702	1,150,167
18	43,373	330,339	344,238	182,756	1,107,502	2,008,208
Total	354,849,125	734,600,744	400,696,849	166,504,777	861,444,703	2,518,096,197

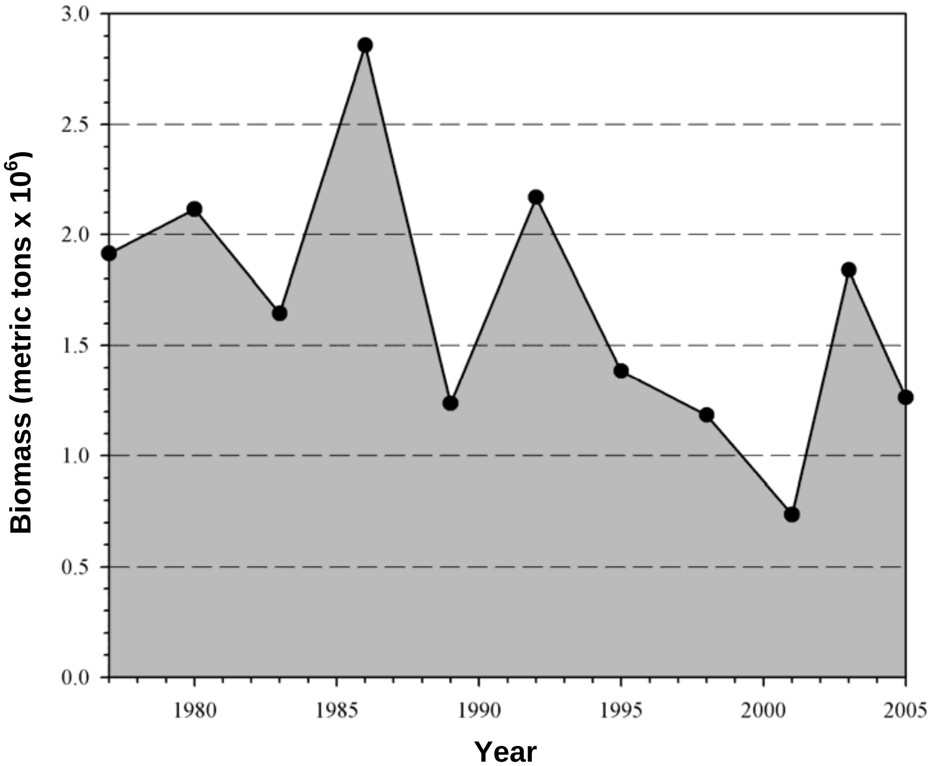

Figure 12. Biomass estimates (millions of mt) of Pacific hake, 1977–2005. Estimates for 1977–1989 are adjusted as described in Dorn (1996) and updated in Helser et al. (2004) to account for changes in target strength model, depth, and geographic coverage. Biomass estimates since 1992 are based on a target strength relation of 20 log L-68 used by Wilson and Guttormsen (1997). For consistence, biomass shown is for fish age 2 and older across time series.

Table 7. Biomass sampling error (CV) based on post-survey stratification of transects for the 2005 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. $\bar{\hat{p}}$ is the mean biomass density (mt/nmi^2), A is the total represented area for each transect cluster (nmi^2), and $\hat{B}$ is the estimated biomass (mt). Transect groups used in stratification are shown in parentheses for each transect cluster (A–J).

Transect clusters	**Strata statistics**				
	$\bar{\hat{p}}$	$Var(\bar{\hat{p}})$	A	$\hat{B}$	CV
A (1–13)	1.39	8.02	3,541.92	4,923	2.04
B (14–29)	27.16	551.31	4,179.11	113,489	0.86
C (30–39)	80.19	3,325.77	3,162.02	253,565	0.72
D (40–48)	37.83	761.28	2,586.64	97,865	0.73
E (49–65)	42.98	1,262.15	5,408.69	232,440	0.83
F (66–73)	27.99	122.60	1,904.76	53,318	0.40
G (74–91)	16.39	207.22	5,399.85	88,515	0.88
H (92–101)	35.88	1,158.90	5,446.85	195,422	0.95
I (103–113)	69.27	2,628.95	4,449.29	308,211	0.74
J (115–123)	0.00	0.00	554.27	0	0.00
Coast wide				1,347,748	0.31

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Appendix A

Table A-1. Analytical groups of transects, hauls, and composite mean length and expected mean backscattering cross-sectional values (σ_{bs}) for pooled hauls used to characterize Pacific hake along corresponding transects.

Group	**Transects**	**Hauls**	**Mean length (cm)**	**Expected σ_{bs}**
1	7	3	30.6	1.493E-04
2	9, 10	4	31.9	1.618E-04
3	11, 14*, 15, 16*, 17*, 18*, 19*, 20*, 21*, 22*, 23*, 24*, 26*	6, 9	34.2	1.878E-04
4	14*, 16*, 17*, 18*, 19*, 20*, 21*, 22*, 23*, 24*, 25*, 26*, 27–30, 33, 34, 38, 39, 40*, 41, 42*, 43*	10, 11, 12, 15, 17	37.5	2.264E-04
5	16*, 17*, 31, 32, 35, 36, 37, 40*, 42*, 43*, 44–57, 59–61, 63–67, 69–75, 77*, 79, 80*, 81–83, 89–91, 92*, 93, 95, 97, 99*, 101*, 103, 107, 113*	7, 13, 14, 16, 19–26, 28, 30–33, 40, 41, 46, 49, 50, 59–65	44.6	3.175E-04
6	76, 77*, 78, 80*, 88, 92*, 99*, 101*, 105, 106, 108, 109, 111, 113*	39, 44, 51–54, 58	47.6	3.598E-04

*Denotes transects where subsections were assigned to different groups owing to differences in Pacific hake size or distribution patterns.

Appendix B

Table B-1. Individual transect coordinates (decimal degrees), length, corresponding area, and estimated Pacific hake population numbers (*N*) and biomass (*B*) in metric tons.

Transect	Start latitude	Start longitude	End latitude	End longitude	Length (nmi)	Area (nmi^2)	*N*	*B* (mt)
1	35.7384	122.2001	35.7387	121.3658	40.6	406.3	0	0.00
2	35.9052	121.4997	35.9055	122.0162	25.1	251.0	0	0.00
3	36.0716	122.0504	36.0724	121.6263	20.6	205.7	0	0.00
4	36.2390	121.8550	36.2390	122.3988	26.3	263.1	0	0.00
5	36.4060	122.3837	36.4055	121.9384	21.5	215.0	0	0.00
6	36.5718	121.9861	36.5733	122.1499	7.9	78.9	0	0.00
7	36.7392	122.3567	36.7385	121.8587	23.9	239.5	12,915,797	2,436.82
8	36.9053	122.0666	36.9056	122.6535	28.2	281.6	0	0.00
9	37.0722	123.0668	37.0723	122.3337	35.1	350.9	6,651,681	1,411.89
10	37.2385	123.2121	37.2389	122.4752	35.2	352.0	1,496,624	317.67
11	37.4055	122.5256	37.4060	123.2857	36.2	362.3	3,960,851	1,075.62
12	37.5723	123.2112	37.5721	122.6670	25.9	258.8	0	0.00
13	37.7387	122.7998	37.7389	123.3830	27.7	276.7	0	0.00
14	37.9069	123.5225	37.9061	122.8569	31.5	315.1	2,977,308	887.92
15	38.0731	123.6040	38.0722	123.0120	28.0	279.6	2,030,381	551.38
16	38.2401	123.0247	38.2389	123.6822	31.0	309.8	10,118,041	4,149.38
17	38.4059	123.7851	38.4052	123.1507	29.8	298.3	6,266,162	2,057.09
18	38.5722	123.3556	38.5715	123.8303	22.3	222.7	44,957,424	14,750.14
19	38.7386	123.9339	38.7391	123.5504	17.9	179.5	30,734,710	9,102.08
20	38.9044	123.7419	38.9052	124.0864	16.1	160.9	20,763,158	5,988.89
21	39.0721	123.7330	39.0720	124.2269	23.0	230.1	41,061,868	12,408.88
22	39.2389	124.2906	39.2390	123.8059	22.5	225.3	53,315,927	16,437.92
23	39.4059	123.8383	39.4061	124.3326	22.9	229.2	28,518,947	8,395.53
24	39.5717	124.1872	39.5721	123.8062	17.6	176.2	17,580,738	5,283.50
25	39.7397	124.2535	39.7387	123.8612	18.1	181.0	1,873,973	671.14
26	39.9050	124.0572	39.9056	124.8822	38.0	379.7	49,824,282	14,093.19
27	40.0714	124.1276	40.0723	125.1407	46.5	465.2	5,555,844	1,989.76
28	40.2385	125.2668	40.2394	124.3787	40.7	406.8	12,315,419	4,410.63
29	40.4046	124.4552	40.4053	124.7177	12.0	119.9	1,929,990	691.20
30	40.5721	124.7860	40.5722	124.4423	15.7	156.7	3,261,891	1,168.21
31	40.7385	124.8076	40.7389	124.3617	20.3	202.7	53,717,956	30,225.36
32	40.9055	124.2244	40.9055	124.8952	30.4	304.2	78,143,925	43,969.07

Table B-1 continued. Individual transect coordinates (decimal degrees), length, corresponding area, and estimated Pacific hake population numbers (*N*) and biomass (*B*) in metric tons.

Transect	Start latitude	Start longitude	End latitude	End longitude	Length (nmi)	Area (nmi^2)	*N*	*B* (mt)
33	41.0730	124.9037	41.0722	124.2333	30.3	303.2	152,541,913	54,631.18
34	41.2388	124.1769	41.2386	124.9494	34.9	348.5	91,576,257	32,797.01
35	41.4053	124.9836	41.4055	124.1674	36.7	367.3	51,156,253	28,783.98
36	41.5717	124.2325	41.5712	125.1685	42.0	420.1	50,729,475	28,543.84
37	41.7398	125.1699	41.7389	124.2923	39.3	392.9	25,206,612	14,182.95
38	41.9062	124.3332	41.9056	125.1158	34.9	349.5	25,306,073	9,063.09
39	42.0726	125.0874	42.0720	124.3759	31.7	316.9	16,092,929	5,763.50
40	42.2388	124.4384	42.2391	125.1266	30.6	305.7	65,228,803	24,199.08
41	42.4051	125.1297	42.4054	124.4917	28.3	282.6	19,165,427	6,863.88
42	42.5732	124.4703	42.5719	125.0824	27.0	270.5	40,781,214	15,399.34
43	42.7386	125.0666	42.7386	124.5574	22.4	224.4	30,873,837	11,339.50
44	42.9053	124.5913	42.9055	125.0821	21.6	215.7	30,818,181	17,340.40
45	43.0720	125.0659	43.0721	124.4839	25.5	255.1	5,171,960	2,910.10
46	43.2385	124.4660	43.2390	125.1817	31.3	312.9	5,232,623	2,944.23
47	43.4057	125.1509	43.4054	124.3728	33.9	339.2	8,798,122	4,950.42
48	43.5729	124.2740	43.5722	125.1493	38.0	380.5	9,337,007	5,253.63
49	43.7386	125.1511	43.7387	124.2346	39.7	397.3	30,205,084	16,995.43
50	43.9056	125.0670	43.9055	124.2175	36.7	367.2	104,112,067	58,580.51
51	44.0716	124.2000	44.0720	125.0680	37.4	374.2	23,578,710	13,266.98
52	44.2388	125.0500	44.2389	124.2856	32.9	328.6	31,056,062	17,474.25
53	44.4055	124.1826	44.4056	124.9657	33.6	335.7	7,597,660	4,274.96
54	44.5723	124.9669	44.5715	124.1960	33.0	329.5	13,994,596	7,874.31
55	44.7389	124.9683	44.7392	124.3304	27.2	271.8	34,807,318	19,584.96
56	44.9051	124.0913	44.9054	124.9662	37.2	371.8	28,763,561	16,184.33
57	45.0719	124.8332	45.0721	124.0672	32.5	486.9	27,886,829	15,691.02
59	45.4053	124.0410	45.4059	124.8339	33.4	501.1	15,034,938	8,459.68
60	45.5724	124.7830	45.5718	124.0272	31.7	317.5	26,694,685	15,020.24
61	45.7386	124.0246	45.7390	124.7775	31.5	472.9	28,425,628	15,994.19
63	46.0722	124.8496	46.0723	124.0939	31.5	471.9	6,400,814	3,601.53
64	46.2387	124.1993	46.2391	124.7083	21.1	211.2	18,792,449	10,573.91
65	46.4051	124.6670	46.4051	124.2535	17.1	171.1	4,120,831	2,318.66
66	46.5718	124.2501	46.5727	124.6663	17.2	171.7	11,626,372	6,541.78
67	46.7364	124.2003	46.7384	124.9999	32.9	493.2	22,210,834	12,497.32
69	47.0715	124.9755	47.0686	124.3651	24.9	374.2	23,752,837	13,364.96
70	47.2392	124.3884	47.2383	124.9328	22.2	221.8	16,441,046	9,250.85
71	47.4054	124.9997	47.4050	124.5617	17.8	177.9	5,284,343	2,973.33
72	47.5691	124.6226	47.5723	125.1673	22.1	220.5	11,605,317	6,529.94
73	47.7387	125.4173	47.7386	124.8086	24.6	245.6	3,810,774	2,144.20

Table B-1 continued. Individual transect coordinates (decimal degrees), length, corresponding area, and estimated Pacific hake population numbers (*N*) and biomass (*B*) in metric tons.

Transect	Start latitude	Start longitude	End latitude	End longitude	Length (nmi)	Area (nmi^2)	*N*	*B* (mt)
74	47.9052	124.8826	47.9056	125.6904	32.5	324.9	11,423,507	6,427.64
75	48.0722	125.9007	48.0712	124.9000	40.1	401.2	3,232,662	1,818.91
76	48.2390	124.8991	48.2389	126.0580	46.3	463.1	14,260,256	9,520.90
77	48.4056	126.3834	48.4056	124.7586	64.7	647.2	34,050,948	22,638.02
78	48.5722	126.2871	48.5725	124.7003	63.0	630.0	8,318,128	5,553.62
79	48.7396	125.4327	48.7389	126.3508	36.3	363.3	38,595,949	21,716.70
80	48.9056	126.7676	48.9057	125.5587	47.7	476.7	6,595,121	3,808.36
81	49.0725	126.2505	49.0717	126.9985	29.4	294.0	7,243,344	4,075.60
82	49.2384	126.4788	49.2397	127.1663	26.9	269.3	11,265,347	6,338.65
83	49.4056	127.3667	49.4056	126.7688	23.3	350.1	12,744,203	7,170.75
85	49.7390	127.6393	49.7388	127.3834	9.9	198.4	0	0.00
87	50.0726	128.1321	50.0723	127.8879	9.4	141.1	0	0.00
88	50.2381	127.9669	50.2386	128.4752	19.5	195.1	4,259,619	2,843.95
89	50.4052	128.6012	50.4054	128.1166	18.5	185.3	4,640,638	2,611.14
90	50.5722	128.3006	50.5723	128.8994	22.8	228.2	6,463,166	3,636.62
91	50.7392	129.4337	50.7389	128.8229	23.2	231.9	1,382,582	777.93
92	50.9052	128.8250	50.9047	129.8471	38.7	386.7	15,962,953	10,338.26
93	51.0718	129.9172	51.0724	129.1896	27.4	411.5	7,674,136	4,317.99
932	51.0725	127.7687	51.0725	128.5774	30.5	457.3	66,324,505	37,318.66
95	51.4056	129.4997	51.4055	130.2511	28.1	562.4	18,767,581	10,559.91
97	51.7398	130.9300	51.7390	129.4202	56.1	1,121.9	210,770,782	118,593.93
99	52.0720	130.9252	52.0723	128.5678	86.9	1,738.9	30,416,137	17,693.83
101	52.4056	129.6162	52.4054	130.6654	38.4	768.1	7,854,682	4,572.87
103	52.7385	129.5554	52.7396	130.6341	39.2	783.7	37,304,255	20,989.90
105	53.0705	130.6497	53.0722	130.1169	19.2	384.1	39,315,456	26,249.08
106	53.4054	130.6160	53.4053	130.9979	13.7	273.2	28,198,692	18,826.94
107	51.4058	128.1154	51.4056	129.4996	51.8	1,036.2	136,380,092	76,736.68
108	53.7390	130.6122	53.7388	130.8256	7.6	151.5	42,987,179	28,700.51
109	54.5582	131.5426	54.2689	131.5404	17.4	347.2	19,425,786	12,969.68
111	54.1889	132.1167	54.6382	132.1142	27.0	539.1	64,699,527	43,196.82
113	54.7386	132.9083	54.7386	134.2571	46.7	934.4	13,346,628	8,519.60
115	53.4090	133.1921	53.4046	132.9002	10.4	208.9	0	0.00
117	53.0728	132.7174	53.0720	132.5837	4.8	96.4	0	0.00
119	52.7390	132.1935	52.7390	132.1216	2.6	52.2	0	0.00
121	52.4055	131.7341	52.4055	131.6337	3.7	73.5	0	0.00
123	52.0723	131.4171	52.0721	131.2500	6.2	123.2	0	0.00

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