NOAA Technical Memorandum NMFS-NWFSC-65

The 2003 Integrated Acoustic and Trawl Survey of Pacific Hake, *Merluccius productus*, in U.S. and Canadian Waters off the Pacific Coast

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The 2003 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 2003 integrated acoustic and trawl survey of Pacific hake was conducted by joint U.S. and Canadian science teams aboard the Canadian Coast Guard Ship (CCGS) *W.E. Ricker* from 29 June to 1 September 2003. This survey covered the west coast of North America from south of Monterey, California (36.1°N) to the Dixon Entrance area in Canada (51.4°N). A total of 115 line transects, generally oriented east-west and spaced at 10-nautical mile intervals, were completed. During the survey, aggregations of Pacific hake were found along the continental shelf break from just north of San Francisco Bay (38°N) to Queen Charlotte Sound (52°N). Peak concentrations of hake were observed north of Cape Mendocino, California (≈40.5°N), to Cape Blanco, Oregon (≈43°N), in the area spanning the U.S.-Canadian border off Cape Flattery and La Perouse Bank (≈48.5°N), and in Queen Charlotte Sound (≈51°N). Associated midwater and bottom trawl samples showed the majority of the coastal stock in 2003 was dominated by the 1999 year class (age 4). In tows south of 48°N, most fish were at an average size of 43–44 cm; larger hake were found farther north.

The coast-wide estimates of Pacific hake abundance totaled 3.35 billion fish weighing 1.84 million metric tons. Age and length distributions showed the population was dominated by age-4 fish. The 1999 year class contributed about 64% of the total coast-wide number and 60% of the total coast-wide biomass. The 1999 year class was prevalent across all regions, contributing 55%, 74%, 74%, 58%, and 33% to the total biomass for the Monterey, Eureka, South Columbia, Vancouver-North Columbia, and Canada statistical areas, respectively. The recruitment of the 1999 year class and the resulting increase in coast-wide biomass is significant. The 2003 biomass estimate of 1.84 million metric tons represents a 1.1 million metric ton or 250% increase over the biomass estimate made for 2001. The 2003 estimate ranks as the fifth largest coast-wide estimate in the time series and is the largest estimated population biomass of coastal Pacific hake since 1992.

Acknowledgments

We extend our sincere gratitude to Captains D. E. Wensley and S. Webb and their respective officers and crews for the successful completion of one of the largest survey efforts yet undertaken with the CCGS *W. E. Ricker*. Their devotion to and professional assistance to the Canadian and U.S. investigative personnel were outstanding throughout the cruise. We also want to thank all others who supported and helped make this a successful survey, notably the personnel from the NOAA FRAM Division, Canadian Coast Guard Regional Operations Centre, Pacific Region, and Fisheries and Oceans Canada Stock Assessment Division.

Introduction

Pacific hake (*Merluccius productus*), colloquially known as Pacific whiting, is a cod-like groundfish species distributed off the west coast of North America. This species is one of a dozen commercially valuable species of Merluccid hakes from the genus *Merluccius* distributed in both hemispheres of the Atlantic and Pacific Oceans (Alheit and Pitcher 1995). Worldwide, hake fisheries constitute nearly two million metric tons (mt) of catches annually (Alheit and Pitcher 1995). The coastal stock of Pacific hake is currently the most abundant groundfish population in the California Current system with recent annual harvests by U.S. and Canadian fishermen in excess of 200,000 mt (Helser et al. 2002). Smaller populations of Pacific hake occur in the 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 that Strait of Georgia and Puget Sound populations are genetically distinct from the coastal population (Utter 1971). The coastal stock differs from the inshore populations 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 Pacific hake stock typically ranges from Southern California to Queen Charlotte Sound (ca. 35°N–53°N latitude). Spawning generally occurs off south-central California during January–March; however, due to the difficulty of consistently locating major spawning concentrations, the specific spawning behavior of hake remains poorly understood (Saunders and McFarlane 1997). In the spring, adult Pacific hake migrate shoreward and to the north to feed along the continental shelf and slope from Northern California to Vancouver Island. In the summer, hake form extensive midwater aggregations that are distributed along the continental shelf break, with greatest densities located over bottom depths of 200–300 m (Dorn et al. 1994, Cooke et al. 1996).

Because of the economic and ecological value of coastal Pacific hake, acoustic surveys were established to assess the fish's distribution, abundance, and biology. These surveys were conducted triennially under the aegis of the Alaska Fisheries Science Center (AFSC) since 1977 and annually along the Canadian west coast since 1990 by the Pacific Biological Station (PBS). The AFSC and the PBS carried out joint triennial coast-wide surveys in 1995, 1998, and 2001. (Following the 2001 survey, the responsibility of the U.S. portion of the joint survey was transferred to the Fishery Resource Analysis and Monitoring [FRAM] Division at the Northwest Fisheries Science Center [NWFSC]). These acoustic surveys are a key data source for the joint Canada-U.S. Pacific hake stock assessments (e.g., Helser et al. 2002, Helser et al. 2004). The time series of survey estimates of abundance and age composition are used in age-structured assessment models to estimate Pacific hake abundance, which are used in population projections to provide international harvest advice.

Pacific hake stock assessments before 1993 added abundance estimates derived from the U.S. bottom trawl and the acoustic surveys. Bottom groundfish trawl surveys conducted in summer concurrent to the acoustic surveys allowed the assessment of the near-bottom component of the stock (Nelson and Dark 1985). Subsequent modeling efforts have treated each survey time series separately in evaluating trends in the population and have considered estimates from acoustic surveys since 1992 as the best estimates of total population biomass (Dorn 1996).

In this report, we document the operations and results of the coast-wide acoustic survey conducted during the summer of 2003, with the primary intent to provide the necessary age-specific abundance estimates of Pacific hake and related information for a subsequent stock assessment exercise (Helser et al. 2004).

Materials and Methods

The equipment and the techniques employed have evolved over the 26-year history of this acoustic survey (Saunders et al. 1992, Cooke et al. 1996, Wilson and Guttormsen 1997, Wilson et al. 2000, Guttormsen et al. 2003). Improvements in both, especially the rapid and continuous technological advances in echo sounding systems and acoustic data processing, have advanced the capabilities of the survey. It is this current state of operations that the NWFSC inherited from the AFSC with the transfer of survey responsibility. In order to preserve the continuity of the time series, the NWFSC made a concerted effort to conduct the 2003 survey in accord with all established procedures and methods. Overall consistency in technique was accomplished by conducting frequent joint briefings by NWFSC, AFSC, and PBS scientists as part of the planning process, by NWFSC scientists reviewing the AFSC hake acoustic survey field manual and using specific survey details of the U.S. portion of the survey, and by having the participation of an experienced AFSC scientist on the initial leg of the 2003 survey.

The 2003 acoustic survey was conducted by joint U.S. and Canadian science teams aboard the Canadian Coast Guard ship (CCGS) *W.E. Ricker* (science cruise number 2003-16) using this vessel for the entire survey. The CCGS *W.E. Ricker* is a 58-m stern trawler equipped for fishery oceanographic research and has been used in the past by those responsible for the Canadian portion of the acoustic Pacific hake surveys. Earlier coast-wide acoustic surveys included the NOAA ship Research Vessel (RV) *Miller Freeman*. Intervessel comparisons involving the RV *Miller Freeman* and the CCGS *W.E. Ricker* were conducted during previous joint acoustic surveys. To assess whether differences occur between the two vessels, comparisons were made of fish backscatter measured by each vessel running in tandem along several identical courses (Guttormsen et al. 2003). Some potential vessel effects were detected, but not to a consistent degree sufficient to warrant separate treatment.

As in past efforts, this survey was performed July–September, targeting aggregations of adult Pacific hake along the continental shelf and upper slope from central California to north of Queen Charlotte Sound. The cruise tracks were executed starting from the southern extent of the survey area. Pacific hake exhibit reciprocating north-south seasonal migrations along the west coast (Bailey et al. 1982), posing an obvious sampling issue for the survey during the height of their movements. By late summer, the fish have generally completed their northward spread along the coast and are fully available to the survey (Nelson and Dark 1985).

Acoustic Data Acquisition

All acoustic data were collected with a SIMRAD EK500 scientific echo sounding system (SIMRAD 1993). Both SIMRAD 38-kHz and 120-kHz split-beam transducers were used aboard the CCGS *W.E. Ricker*, with the 38-kHz echo sounder the primary source for the quantitative Pacific hake backscatter measurements. The transducers were located on a hydraulic ram that was extended 1.2 m below the keel to 5.2 m below the surface during acoustic data collection. Sample rates were typically 0.6 Hz (1.6-second ping intervals), but slowed to as low as 0.4 Hz

(2.5-second ping intervals) at greater water column depths. These system-determined rates were being controlled by EK500 sound propagation and internal processing constraints (i.e., EK500 operation setting of ping interval = 0.0 sec). Sampling ranges were set at 750 m for 38 kHz and 250 m for 120 kHz.

We logged all raw acoustic backscatter data (38-kHz and 120-kHz frequencies) using SonarData Echolog 500 software on computers equipped with external 400-GB hard drives and networked as a workgroup. The acoustic data files were stored in targeted directories and accrued to a maximum individual file size of 10 MB as a precaution to minimize any data loss in the event of a computer system failure. Data files collected between transects and off transect (i.e., during fishing operations) were stored in separate 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 (usually 7–9 transects), a third copy of the data files was archived to DVD media to ensure data safekeeping via redundancy.

Acoustic Survey Design and Operations

The Pacific hake population was surveyed along a series of parallel line transects that were generally oriented east-west and spaced at the established 10-nautical mile (nmi) interval (Figure 1), traversed sequentially in an alternating, or boustrophedonic, fashion. Logistically, the survey was conducted in four legs, designed to allow rotation of scientific and operations crews as well as time in port to allow ship fueling and provisioning.

We elected to use transects in 2003 identical to those covered in the 2001 survey, starting from south of Monterey Bay, California, and covering the area to the most northern extent at Dixon Entrance. Seafloor depth at the nearshore end of individual transects was typically 50 m. The offshore extent of individual transects typically ranged to depths of about 1500 m. Transects were extended deeper if Pacific hake aggregations were detected at or near the predetermined endpoints.

During acoustic data collection, the vessel’s speed was maintained at 4.6–5.1 m/sec (9–10 knots). Acoustic operations were run only during daylight hours (about 15 hours per day) when Pacific hake formed identifiable mesopelagic layers. Physical and biological oceanographic sampling operations were conducted at night. The past inclusion of coast-wide macrozooplankton collection was not attempted this year, because using a single vessel limited the amount of time we had to work with.

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 pre-determined — 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

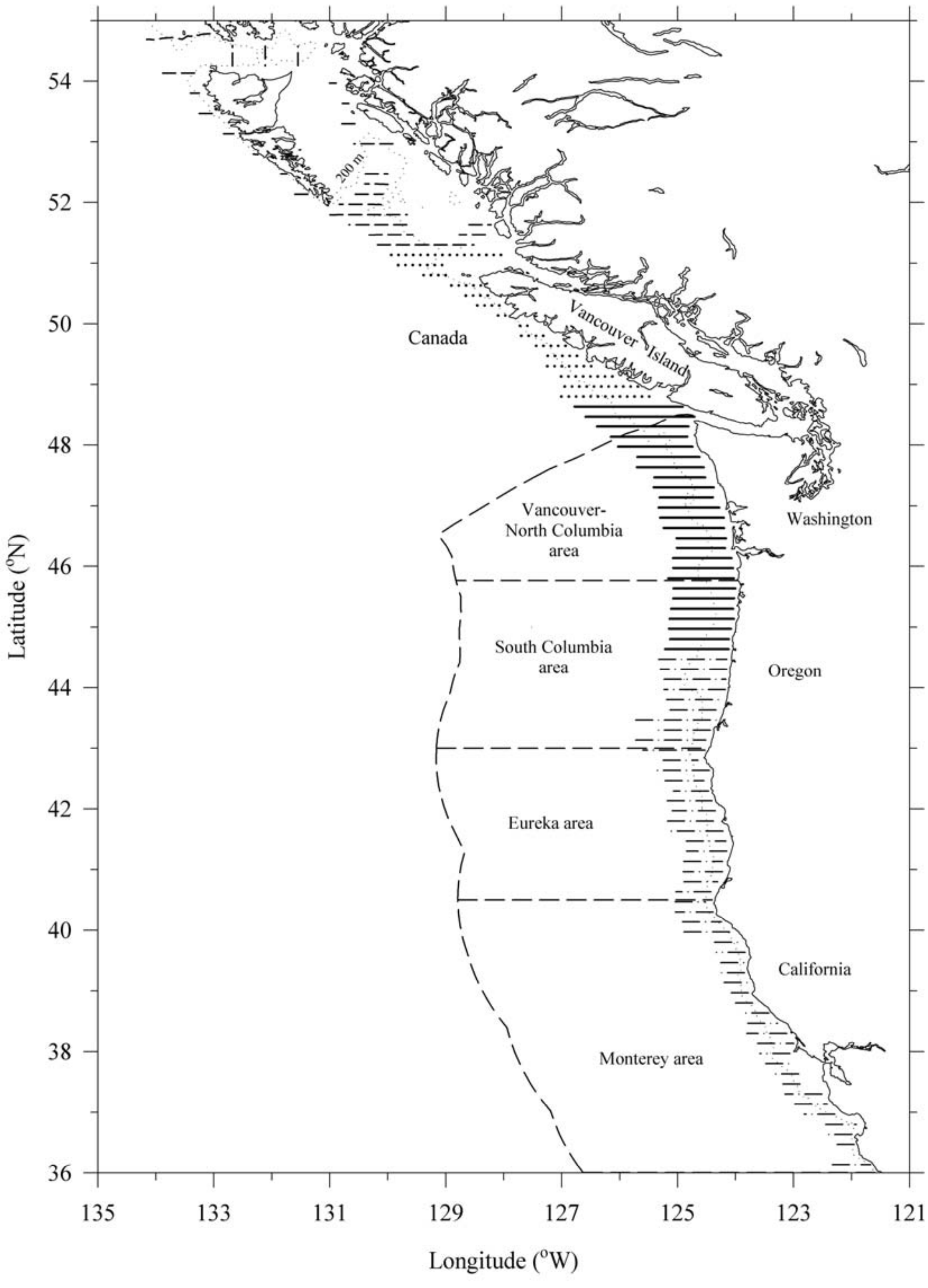

Figure 1. Survey track design used during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Different line types indicate the set of transects sounded during each individual leg of the cruise. International North Pacific Fisheries Commission (INPFC) statistical reporting areas and subareas as defined by Dorn (1996) are outlined for reference.

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 marginal areas of low fish density and putative aggregations of species other than Pacific hake, were also sampled. We paid particular attention to perform tows at several locations along any single, extensive, and continuous aggregation of Pacific hake, or within the same area where discrete, vertical backscattering layers appeared.

We used pelagic and bottom trawls to conduct sampling. Pelagic trawling was performed with a Polish rope trawl consistent with previous CCGS *W.E. Ricker* surveys. This net has a 20-m vertical opening, a 1-cm codend mesh, and is deployed with a pair of 5-m^2 USA JET (Model P) combination trawl doors (1,135 kg) and 80-m sweep wires with 300-kg chain weights. On- and near-bottom trawling was performed with a Poly-Yankee 36 research trawl modified with roller gear. This trawl net was constructed of 4-mm polyethylene twine and a codend with the same web and used a 2.5-cm liner. The hard-bottom ground line consisted of 43-cm wheels separated by 20-cm metal spacers that attached to 40-cm toggle chains. This design was a deliberate attempt to not fish hard on bottom (e.g., avoid flatfishes and other benthic fishes). The head rope was 18.3 m and produced vertical openings of 4–5 m at towing speed and was capable of being fished in a pelagic fashion just off bottom if required. This net also used the 5-m^2 USA JET (Model P) combination trawl doors. A Simrad FS3300 third-wire head-rope trawl sonar system was used to monitor and guide the fishing process for all tows. Underwater video observations were conducted on some of the trawls during the final leg of the survey to monitor net performance, catch composition, and species behavior in the net.

Upon retrieval, trawl catches were emptied from the codend into a below-deck hopper and sorted by species off a conveyor belt into baskets. Conventional catch sorting and enumeration procedures were employed to process all catches (Hughes 1976, Weir et al. 1978). However, slight procedural differences existed between U.S. and Canadian scientists that were related to data entry routines and established database requirements. Overall, all catches were sorted completely except for two exceptionally large hauls that were volumetrically estimated for total weight before being subsampled. Total numbers and weights were determined for all species. Aggregate weights were measured to the nearest 0.1 kg for the sorted portions of the catch using an electronic 60-kg capacity motion-compensating scale. Pacific hake were subsampled to determine length composition by sex, to collect otoliths for subsequent age determination, and to collect gonad condition and weight measurements. Fish lengths (fork length) were determined to the nearest centimeter using a polycorder measuring device — a combination of bar code reader and hand-held computer (Sigler 1994). We employed a 6-kg capacity motion-compensating scale to determine all weights of individual fish specimens to the nearest gram. Pacific hake maturity was determined by visual inspection of gonads and classified by either a 5-stage scale (ADP Code Book, 2003, RACE Division, AFSC, Seattle) or a 12-stage scale (PBS, Nanaimo, British Columbia)—the differences in the scaling techniques were inconsequential in that they accomplished an identical distinction between mature and immature individuals, which was the primary goal of this analysis, especially in a nonspawning time of year. Otoliths were preserved in either 50% ethanol or a 1/1 glycerine/freshwater solution with thymol at 0.3% for subsequent age determination.

In the portion of the survey in Canadian waters, Pacific hake stomach contents of individuals from 1 or 2 tubs from each haul were examined, prey items were identified to the lowest practicable taxon, and the volume of each prey item was estimated visually to the nearest 1 cc. The state of digestion was recorded for each prey item, and any identifiable Pacific herring (*Clupea pallasi*) remains were counted and measured.

Physical Oceanographic Data Collection

Physical oceanographic data were collected to contribute to ongoing investigations of the relationship of environmental covariates to the distribution of Pacific hake. Information was collected to describe ocean temperature, salinity, nutrient levels, and current velocity at the time of the survey.

Vertical profiles of salinity and temperature data were collected with a Sea-Bird Electronics, Inc. SEACAT SBE19 conductivity-temperature-depth (CTD) system during acoustic calibration operations and at locations along designated acoustic transects. CTD casts were made along an individual line each night after the cessation of acoustic data collection, usually along the last transect sounded. Cast sites were selected to collect as many observations along the transect as time permitted with the priority to measure at the deep and shallow ends of each line and the deep and shallow edges of the shelf-break (≈250 m contour). Surface nutrients were sampled at most cast locations, and salinity and nutrient samples were usually collected daily from one deep cast (500 m). Temperature and depth profile data were also collected during most trawl hauls by attaching a Sea-Bird temperature/pressure sensor (SBE-39) to the trawl head rope. Ocean current velocity profile data were obtained using an Acoustic Doppler Current Profiler (ADCP) system. ADCP data were not recorded off the coast of Vancouver Island due to a malfunction.

Acoustic Data Analysis

The range of strata considered for the analysis along each transect included depths from 11 m below the surface (≈6 m below the transducer) to 0.5 m above the detected bottom, or to a depth of 500 m when sea depths exceeded this value. In past 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 South Columbia International North Pacific Fisheries Commission (INPFC) statistical areas. 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 the southern areas to avoid including significant quantities of non-hake scatterers in the measured backscatter that would bias subsequent biomass estimates. To maintain consistency, we adopted this convention for 2003, because it has been applied since the 1992 survey (Wilson and Guttormsen 1997, Wilson et al. 2000, Guttormsen et al. 2003).

The first step in the analysis of the acoustic data entailed the identification and delineation of backscatter layers that were attributed to Pacific hake. Echograms of each entire transect were displayed and examined for aggregations of Pacific hake using SonarData Echoview V. 3.0 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 that there was a significant amount of backscatter from hake in the region plus other species that were partitioned quantitatively later, or "other," which indicated that there was no hake backscatter in the region. These classifications were guided by 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. A final post-survey review of the echograms, conducted by several of the participating Canadian and U.S. scientists, consisted of examining each echogram and refining the extent and classification of the regions. Each scientist also developed explicit documentation for these decisions. This process was followed by an exchange of assigned transects between U.S. and Canadian scientists to cross-check and validate the echograms and associated documentation in an effort to ensure consistency in the decisions among scientists.

Our acoustic estimates of fish abundance were derived from the 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. 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. Values of mean area backscatter from the EK500 echosounder, termed nautical area scattering coefficient (m^2/nmi^2) and denoted as s_A (MacLennan et al. 2002), were calculated along with related variables by the SonarData Echoview software.

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

$$\hat{N}_a = \left[\sum_i \frac{s_A}{4\pi\sigma_{bs}} P_i Q_{ia} A \right] \tag{1}$$

$$\hat{B}_a = \left[\sum_i \frac{s_A}{4\pi\sigma_{bs}} P_i \hat{W}_i Q_{ia} A \right] \tag{2}$$

where s_A is the measured mean area scattering attributed to Pacific hake, σ_{bs} is the expected backscattering cross section (m^2) for each particular interval (Appendix B), P_i is the proportion of hake at length class *i*, $\hat{W}_i$ is the predicted mean weight for length class *i* based on the composite weight-length relation for Pacific hake (regressed as $\hat{W} = 0.0037(length_{cm})^{3.144}$ from the 2003 samples), 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. 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 among Pacific hake and other species.

Pacific hake catches were pooled into analytical groups based on geographic proximity of hauls and on similarity in size compositions as guided by paired comparisons with the Kolmogorov-Smirnov test (Campbell 1974) (Appendix A). 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:

$$\sigma_{bs} = \sum_j f_{ij} 10^{\{[-68+20\log L_{ij}]/10\}} \tag{3}$$

for the frequency f of length L of the length class i in composite catch sample j. The Traynor (1996) relation of backscattering to fish size for Pacific hake, given as

$$TS_{dB} = 20\log L - 68 \tag{4}$$

where TS_{dB} is target strength in decibels and L is length in centimeters, assumes that backscattering cross section is proportional to the square of the fish length.

The estimates of age-specific biomass for individual cells were summed for each interval, transect, INPFC area or subarea (Dorn 1996), and ultimately a total coast-wide 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.

Acoustic System Calibration

The acoustic system was calibrated in the field before, during, and after the survey. The calibration procedure involved suspending copper spheres with known backscattering cross sections below the transducers and measuring the acoustic returns following standard procedures (Foote et al. 1987, MacLennan and Simmonds 1992, SIMRAD 1993). The vessel was anchored during each calibration. Sphere diameters were 60 and 23 mm for the 38- and 120-kHz transducers, respectively. Split-beam target strength and echo integration data were collected to calculate echo-sounder gain parameters and beam pattern as part of the evaluation of system performance. Signal-to-noise measurements were also collected periodically during the survey to monitor the system.

Results

The 2003 Pacific hake acoustic and trawl survey, initiated 29 June, was completed 1 September and covered the west coast from south of Monterey, California (36.1°N), to the Dixon Entrance area (51.4°N) with a total vessel track line of approximately 18,520 km (10,000 nmi). One hundred fifteen line transects, totaling 6,756 km (3,648 nmi) linear distance surveyed, and 106 trawl samples were completed (Figures 1, 2, 3, and 4).

Calibration

Multiple calibration sessions of the echo sounding systems were conducted. The first, carried out in Departure Bay, Nanaimo, British Columbia, on 24 June was not initially deemed definitive due to instability in the measured signal levels and generally poor signal returns, first thought to be caused by fish. As such, no adjustments were made to either of the transceivers and the system was operated for the first and second legs of the cruise using gain levels as measured the previous February (Table 1). A subsequent unsuccessful attempt at calibration was made in Monterey Bay on 30 June. The poor signal quality observed during these first two calibration attempts was thought to be a result of significant fish interference observed during the calibration sessions, given our assumption that the transducers had been cleaned at dockside in Nanaimo prior to departure. However, diver inspections of the transducers during a scheduled port call in Newport, Oregon, on 22 July found that the EK500 transducers were encrusted with a layer of barnacles, while other hull-mounted transducers and the ram-mounted ADCP unit were clean. The barnacles on the face of the EK500 transducers were identified as acorn barnacles, members of the genus *Chthamalus*. At this time, the EK500 transducers were cleaned for the remaining portion of the survey with the understanding that a calibration would be conducted at the earliest opportunity. On 6 August in Mayne Bay, in Barkley Sound, the 38-kHz unit was successfully calibrated and gain settings adjusted accordingly (Table 1). The beam pattern was also measured and indicated no significant change from manufacturer's settings. A fourth calibration was conducted 24 August in Prince Rupert, British Columbia, during an unscheduled crew change. Both transducers were successfully calibrated and results showed that the gain setting for the 38-kHz unit remained stable since the Mayne Bay measurement. The 120-kHz calibration results were within expected levels recorded during previous successful calibrations.

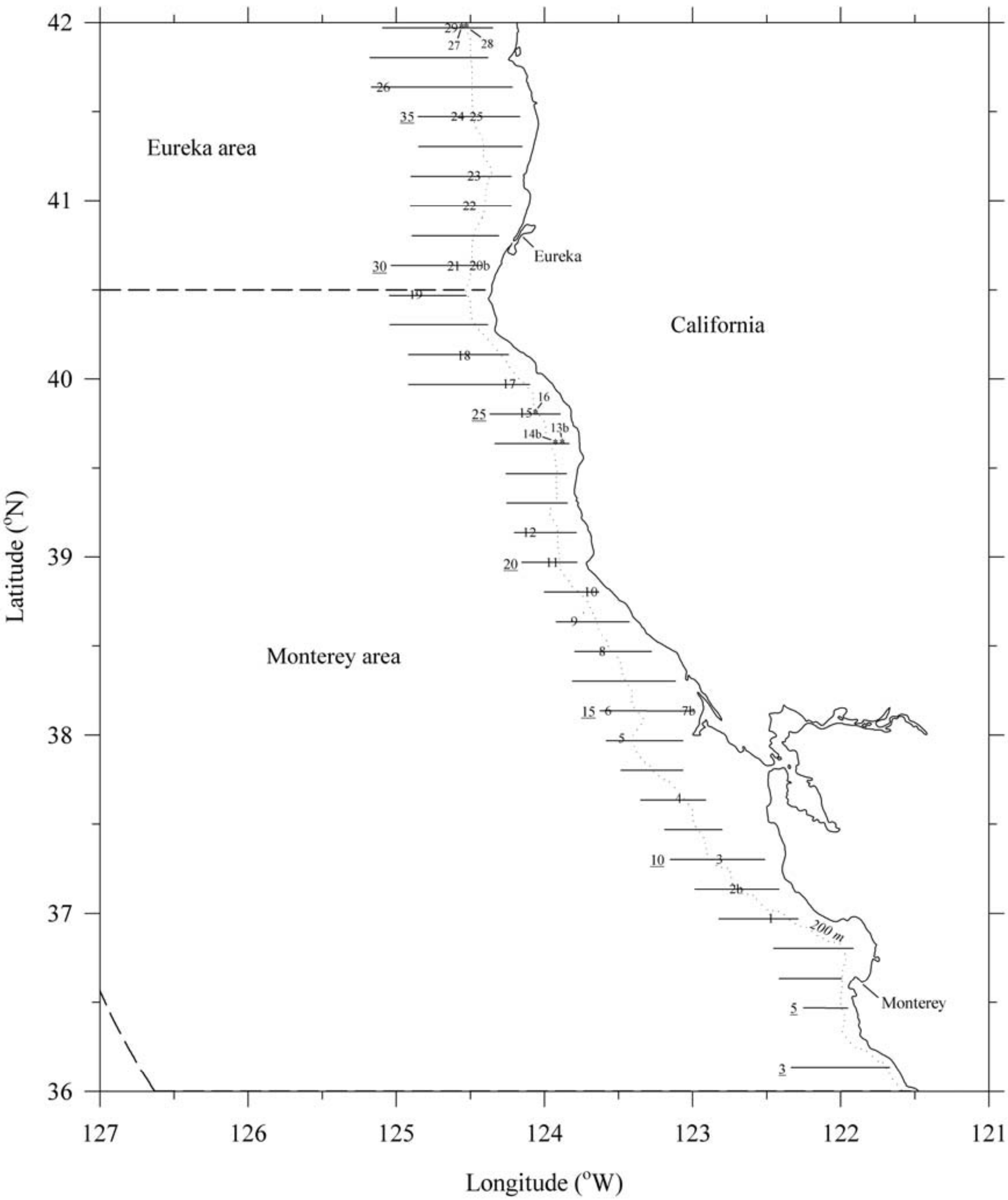

Figure 2. Details of acoustic transect lines and locations and haul sequence of midwater and bottom trawls (latter denoted with "b" suffix) during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Underscored numbers indicate transect sequence.

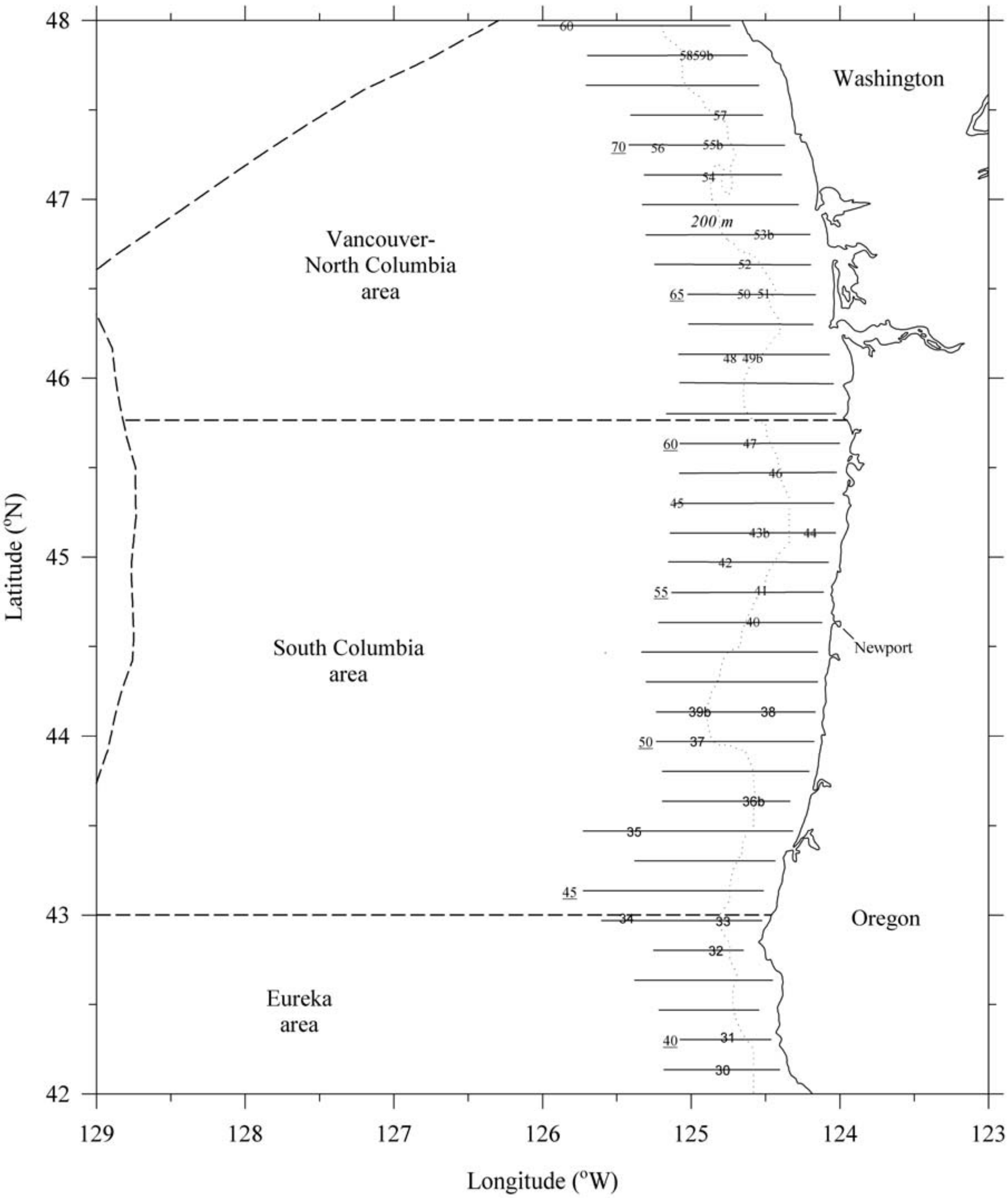

Figure 3. Details of acoustic transect lines and locations and haul sequence of midwater and bottom trawls (latter denoted with "b" suffix) during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Underscored numbers indicate transect sequence.

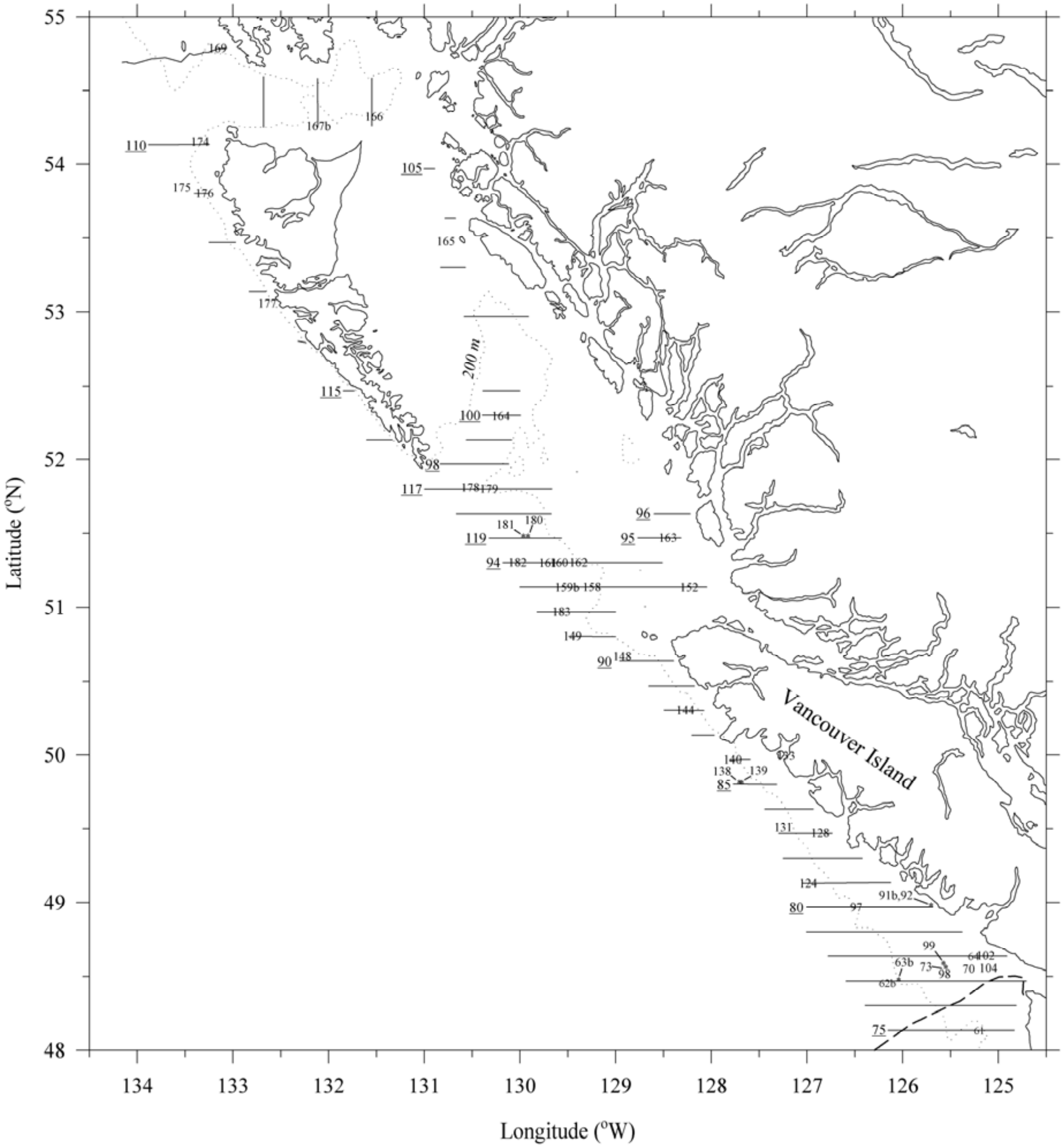

Figure 4. Details of acoustic transect lines and locations and haul sequence of midwater and bottom trawls (latter denoted with "b" suffix) during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Underscored numbers indicate transect sequence.

Table 1. Calibration sphere measurements performed as part of the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Range denotes target range, SV denotes volume backscattering, and TS denotes target strength.

Date	Location	Ambient water temperature (°C)	Freq. (kHz)	Range (m)	Sv Gain (dB)	TS Gain (dB)
05 Feb 2003[a]	Pat Bay		38	28.40	26.63	26.85
			120	25.70	25.21	25.35
25 Jun 2003	Depart. Bay	10.66	38	22.50	25.96	26.15
			120	–	–	–
05 Aug 2003	Mayne Bay	9.8	38	30.40	26.57	26.75
			120	–	–	–
25 Aug 2003	Prince Rupert	9.6	38	29.90	26.43	26.75
		10.2	120	18.63	25.78	25.75

[a] Results shown are from preceding calibration exercise.

To compensate for the signal loss due to biofouling by the barnacles, we used the calibration sphere backscatter cross section value obtained in Departure Bay to adjust the S_v transducer gain setting as per manufacturer's specifications. Taking advantage of the features of SonarData Echoview software, rather than the EK 500 software, the region to be echo integrated was restricted to immediately around the sphere to avoid interference from fish targets. The measured s_A values were grouped by 100-ping ensembles and compared for consistency. The measured s_A value for the calibration sphere with barnacle impedance was compared to the expected value, which is given by

$$s_A(theory) = \frac{4\pi r_0^2 \cdot \sigma_{bs} \cdot (1852)^2}{\psi \cdot r^2} \qquad (5)$$

where ψ is the equivalent two-way beam angle (provided by manufacturer), r_0 is the 1-m standard reference distance, σ_{bs} is the expected backscattering cross section of the sphere, and r is the range or distance the sphere is from the transducer. The correction in S_v transducer gain was

$$S_V(new) = S_V(original) + {}^{10\log(s_A(measured)/s_A(theory))}\!\big/_2 \qquad (6)$$

(SIMRAD 1993). In our case, the measured s_A value of 5,032.5 resulted in a new S_v transducer gain value of 25.96 dB as compared to the original value of 26.63 dB. The new S_v transducer gain value was used for subsequent data processing for the affected portion of the survey. This difference in gain (0.61 dB) translates to an increase in the measured backscatter and resultant biomass estimates from the barnacle-covered transducer by a factor of 32% ($10^{(2*0.61\ dB)/10}$ = 1.32). This signal loss was corrected for, but added uncertainty to that portion of the 2003 biomass estimate as a result of this correction. This correction also assumes that the barnacles did not affect the beam pattern.

Biological Sampling

A total of 88 midwater trawls and 18 bottom trawls were conducted during the course of the survey (Table 2, Figures 2, 3, and 4). Trawl durations ranged from 1 to 71 minutes (mean = 21 minutes) and catch weights ranged from 0.1 to 6,818.0 kg (mean = 883.4 kg). Pacific hake was the dominant fish species caught in midwater and bottom trawl hauls, accounting for roughly 79% and 73%, respectively, of catch composition by weight (Tables 3 and 4). Considering other species, most spiny dogfish (*Squalus acanthias*, 97%) were caught in a single tow (haul 10) in the Monterey INPFC area. Four species of rockfish (yellowmouth [*Sebastes reedi*], chilipepper [*S. goodei*], Pacific ocean perch [*S. alutus*], and yellowtail [*S. flavidus*]) together accounted for almost 8% of midwater catch by weight. Roughly 25% and 74% by weight of Pacific herring caught in midwater trawls were in the North Columbia INPFC area and Canada, respectively. In bottom trawls, five of the top seven bycatch species were rockfish, accounting for 12% of catch by weight. Arrowtooth flounder (*Atheresthes stomias*), Dover sole (*Microstomus pacificus*), and rex sole (*Glyptocephalus zachirus*) were the top three flatfish bycatch species. Walleye pollock (*Theragra chalcogramma*) were caught only in Canadian waters.

Oceanographic Sampling

We collected a total of 232 CTD temperature and salinity profiles at selected points along the line transects and at acoustic system calibration sites (Figure 5). Additional temperature profiles from SBE casts were collected at most trawl stations. From the CTD casts, sea surface temperatures were found to range from 9.1 to 18.1°C during the survey (Figure 5). The coolest surface temperatures (≈10°C) were encountered early in the survey in a restricted area off Point Arena, California (≈39°N). Temperatures increased with latitude to maximum values (≈19°C) in the offshore areas of central Oregon. Temperatures, generally warmer in the offshore areas as compared to near shore, ranged from 17 to 13°C for the northern areas off the U.S. coast. Sea surface temperatures ranged between only 13 and 15°C in waters off the Canadian coast.

Pacific Hake Distribution and Abundance Estimates

Aggregations of Pacific hake were detected along the continental shelf break from just north of San Francisco Bay (38°N) to Queen Charlotte Sound (52°N) (Figure 6). Peak concentrations of Pacific hake were observed in the following general areas: the area spanning north of Cape Mendocino, California (≈40.5°N), to Cape Blanco, Oregon (≈43°N), the area spanning the U.S.-Canadian border off Cape Flattery and La Perouse Bank (≈48.5°N), and in Queen Charlotte Sound (≈51°N). In one instance, hake were found in a single continuous shoal off the coast of Oregon along transect 44 (42.9°N) that extended to waters more than 2,500 m

Table 2. Trawl station and catch data summary from the 2003 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 (GMT)	Duration (min.)	Start position Latitude		Longitude		Depth (m) Gear[d]	Bottom	Temp. (°C) Gear[e]	Surface	Catch Pacific hake (kg)	Number	Other (kg)
1	mont	P	02 Jul	22:16	9	36	58.19	122	27.53	127	229	8.7	13.0	0.0	0	10.0
2	mont	Y	03 Jul	15:19	16	37	8.11	122	42.30	196	196	8.5	13.6	0.7	6	484.5
3	mont	P	03 Jul	21:04	22	37	18.05	122	48.32	113	161	8.8	13.5	217.6	1,012	1.5
4	mont	P	04 Jul	14:41	3	37	38.63	123	4.87	141	428	8.6	12.6	118.5	30,273	0.2
5	mont	P	05 Jul	1:48	4	37	58.84	123	28.01	317	410	7.0	10.6	78.7	1,318	380.6
6	mont	P	05 Jul	14:21	9	38	8.09	123	33.41	214	757	8.0	10.3	394.0	959	22.4
7	mont	Y	05 Jul	19:00	6	38	8.11	123	1.56	66	66	9.1	11.8	958.9	1,419	61.9
8	mont	P	06 Jul	14:40	3	38	28.11	123	35.84	142	205	8.3	9.3	123.4	333	981.5
9	mont	P	06 Jul	21:11	9	38	38.25	123	47.15	434	647	6.2	10.5	110.5	170	52.0
10	mont	P	07 Jul	2:06	7	38	48.12	123	40.51	55	90	8.9	9.5	49.8	71	5,404.2
11	mont	P	07 Jul	14:26	13	38	58.04	123	56.88	118	226	7.8	10.1	1,462.3	2,798	16.8
12	mont	P	07 Jul	19:13	33	39	8.17	124	5.34	270	715	7.1	9.7	595.5	1,243	15.3
13	mont	Y	08 Jul	16:01	3	39	38.06	123	52.63	116	116	8.0	10.5	0.4	27	5.2
14	mont	Y	08 Jul	16:34	20	39	38.00	123	55.38	147	147	7.7	10.0	19.3	140	111.9
15	mont	P	08 Jul	19:45	15	39	48.37	124	6.90	253	561	7.0	10.6	491.1	790	23.0
16	mont	P	08 Jul	20:48	9	39	47.99	124	3.44	158	190	7.6	10.7	232.1	633	357.9
17	mont	P	09 Jul	2:02	9	39	58.30	124	13.51	178	377	7.5	9.8	539.7	1,014	24.6
18	mont	P	09 Jul	19:55	6	40	7.69	124	31.90	110	714	8.2	9.4	4,081.0	8,344	2.7
19	mont	P	10 Jul	14:59	15	40	28.20	124	51.43	150	2,400	7.8	12.9	123.9	214	14.9
20	eur	Y	10 Jul	19:28	10	40	38.05	124	26.20	56	56	8.0	11.4	6.9	5	53.6
21	eur	P	10 Jul	20:54	12	40	37.81	124	35.90	255	588	7.0	13.3	2,496.4	5,270	21.8
22	eur	P	11 Jul	15:34	34	40	58.14	124	29.65	359	497	6.0	12.6	51.5	73	19.2
23	eur	P	12 Jul	19:59	23	41	8.17	124	27.76	267	662	6.5	12.3	2,817.0	5,167	1.1
24	eur	P	13 Jul	14:55	29	41	28.20	124	34.37	235	886	7.0	13.1	941.0	1,842	65.6
25	eur	P	13 Jul	17:12	8	41	28.18	124	26.81	93	136	7.8	13.0	540.2	1,007	14.6

Table 2. Trawl station and catch data summary from the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Continued.

Haul	INPFC	Gear		Time	Duration	Start position				Depth (m)		Temp. (°C)		Catch		
														Pacific hake		Other
no.[a]	area[b]	type[c]	Date	(GMT)	(min.)	Latitude		Longitude		Gear[d]	Bottom	Gear[e]	Surface	(kg)	Number	(kg)
26	eur	P	14 Jul	1:04	21	41	38.04	125	4.55	304	1,260	6.2	14.3	292.1	520	31.8
27	eur	P	14 Jul	18:18	1	41	58.05	124	33.46	96	156	7.9	12.6	24.7	47	22.0
28	eur	P	14 Jul	19:20	5	41	58.16	124	31.52	98	135	7.8	12.6	2,973.6	5,987	3.1
29	eur	P	14 Jul	21:19	21	41	58.02	124	37.82	252	477	6.8	12.8	931.2	1,765	13.7
30	eur	P	15 Jul	14:10	9	42	7.86	124	46.54	244	673	6.9	12.6	857.3	1,601	24.7
31	eur	P	16 Jul	1:47	17	42	18.79	124	44.48	275	528	6.5	12.5	1,362.5	2,806	6.8
32	eur	P	17 Jul	1:37	7	42	47.87	124	49.27	150	346	7.4	14.0	850.2	1,713	13.0
33	eur	P	17 Jul	14:37	6	42	57.73	124	46.36	115	156	7.3	12.8	4,276.5	8,304	159.2
34	eur	P	17 Jul	19:43	27	42	58.78	125	25.31	289	1,036	6.2	15.1	566.7	857	16.3
35	scol	P	18 Jul	22:30	7	43	27.75	125	22.30	412	1,473	5.8	17.6	928.7	1,803	4.9
36	scol	Y	19 Jul	18:49	20	43	38.12	124	34.77	240	240	6.7	15.5	989.2	1,970	192.2
37	scol	P	20 Jul	14:47	15	43	58.06	124	56.75	163	262	7.1	17.7	1,278.2	2,022	12.1
38	scol	P	20 Jul	21:29	13	44	8.06	124	28.15	85	114	7.0	13.1	1,089.1	1,918	6.5
39	scol	Y	21 Jul	1:18	10	44	8.06	124	56.48	204	204	7.0	18.1	1,888.8	3,635	247.8
40	scol	P	23 Jul	20:29	58	44	38.17	124	34.36	115	210	–	–	28.8	51	1.0
41	scol	P	24 Jul	14:21	27	44	48.61	124	31.07	128	203	7.4	13.0	0.0	0	15.0
42	scol	P	24 Jul	20:50	55	44	58.02	124	45.52	357	522	5.9	16.0	63.0	127	20.9
43	scol	Y	25 Jul	14:20	40	45	8.11	124	32.42	352	352	5.8	16.9	421.5	870	266.1
44	scol	P	25 Jul	16:44	31	45	8.04	124	11.24	93	138	7.2	11.5	0.5	1	6.9
45	scol	P	26 Jul	0:02	57	45	18.02	125	5.07	336	1,225	6.0	17.7	0.0	0	36.9
46	scol	P	26 Jul	14:00	60	45	28.00	124	25.21	207	254	6.7	15.9	2,410.1	4,622	0.4
47	scol	P	26 Jul	21:27	25	45	38.05	125	35.58	285	305	6.1	17.2	27.4	53	4.0
48	vannc	P	27 Jul	23:54	53	46	6.57	124	43.58	361	647	5.8	16.2	132.3	257	14.9
49	vannc	Y	28 Jul	1:57	22	46	6.61	124	35.24	150	150	–	–	252.4	472	17.5
50	vannc	P	28 Jul	23:28	50	46	28.12	124	38.06	297	863	6.2	14.8	65.6	120	12.4

Table 2. Trawl station and catch data summary from the 2003integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Continued.

Haul no.[a]	INPFC area[b]	Gear type[c]	Date	Time (GMT)	Duration (min.)	Start position Latitude		Longitude		Depth (m) Gear[d]	Bottom	Temp. (°C) Gear[e]	Surface	Catch Pacific hake (kg)	Number	Other (kg)
51	vannc	P	29 Jul	1:13	49	46	28.23	124	29.91	153	290	6.9	14.6	1,628.3	2,884	0.1
52	vannc	P	29 Jul	15:51	49	46	38.15	124	37.68	116	157	6.9	14.2	5,716.8	10,240	70.4
53	vannc	Y	29 Jul	23:55	22	46	48.12	124	30.73	94	94	6.7	14.3	1,583.3	2,799	38.0
54	vannc	P	30 Jul	19:49	55	47	7.26	124	52.27	111	150	7.1	15.3	0.0	0	273.7
55	vannc	Y	31 Jul	2:06	27	47	18.18	124	51.31	193	193	6.8	14.9	167.4	282	130.9
56	vannc	P	31 Jul	14:12	46	47	17.10	125	12.78	247	1,222	6.5	15.4	0.0	0	2.9
57	vannc	P	31 Jul	19:46	56	47	28.02	124	47.56	114	209	7.0	13.6	1,792.7	3,031	452.7
58	vannc	P	01 Aug	15:48	40	47	48.13	125	1.27	118	179	7.0	14.0	814.7	1,363	290.5
59	vannc	Y	01 Aug	17:20	40	47	48.09	124	55.26	109	109	7.0	14.3	610.5	853	167.3
60	vannc	P	02 Aug	1:01	71	47	58.02	125	49.52	473	1,133	5.1	15.3	2.5	4	29.8
61	vannc	P	02 Aug	16:52	42	48	7.97	125	10.97	114	276	6.7	13.1	1,133.9	1,735	11.3
62	can	Y	03 Aug	15:27	39	48	27.34	126	9.58	368	368	5.6	13.4	41.3	64	114.4
63	can	Y	03 Aug	16:44	44	48	28.16	126	2.66	185	185	6.6	13.7	310.9	441	213.9
64	can	P	04 Aug	1:58	26	48	38.11	125	14.54	65	104	7.3	10.5	2,775.7	3,314	205.8
70	can	P	06 Aug	19:35	15	48	32.99	125	18.53	68	111	6.9	12.8	0.0	0	5.6
73	can	P	06 Aug	22:32	3	48	32.85	125	32.73	77	122	6.8	11.8	453.4	687	11.3
91	can	Y	08 Aug	15:05	1	48	58.25	125	42.21	72	72	–	–	0.0	0	17.4
92	can	P	08 Aug	15:40	15	48	58.17	125	41.92	34	74	–	–	0.0	0	46.1
97	can	P	08 Aug	21:13	2	48	58.11	126	29.05	100	163	7.0	7.4	775.3	1,220	12.7
98	can	P	09 Aug	21:14	2	48	30.93	125	33.68	61	100	6.9	–	107.0	139	189.2
99	can	P	09 Aug	22:37	1	48	34.43	125	34.21	87	99	7.0	–	213.8	271	32.3
102	can	P	10 Aug	16:52	4	48	38.36	125	7.88	38	82	8.6	8.9	2,700.0	2,213	137.3
104	can	P	10 Aug	20:57	4	48	33.33	125	5.09	67	107	–	8.4	0.0	0	2,040.0
115	can	Y	12 Aug	17:55	15	48	46.46	125	24.70	96	96	7.6	–	750.6	848	271.1
124	can	P	13 Aug	21:40	13	49	7.82	126	57.67	350	600	5.9	14.6	4.4	6	17.8

Table 2. Trawl station and catch data summary from the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Continued.

Haul no.[a]	INPFC area[b]	Gear type[c]	Date	Time (GMT)	Duration (min.)	Start position Latitude		Longitude		Depth (m) Gear[d]	Bottom	Temp. (°C) Gear[e]	Surface	Catch Pacific hake (kg)	Number	Other (kg)
128	can	P	14 Aug	17:45	28	49	28.17	126	51.63	60	90	8.3	15.3	0.0	0	41.9
131	can	P	14 Aug	21:30	26	49	29.00	127	15.10	200	300	6.9	15.3	2.3	3	891.6
133	can	P	15 Aug	14:56	9	49	59.65	127	13.07	135	230	7.4	16.8	229.3	710	13.0
138	can	P	15 Aug	20:47	4	49	48.19	127	42.26	130	650	6.7	14.8	0.0	0	10.0
139	can	P	15 Aug	21:28	15	49	48.16	127	40.84	130	250	6.7	14.9	368.7	511	149.8
140	can	P	16 Aug	0:25	30	49	58.15	127	46.54	150	500	6.6	–	415.5	604	78.4
144	can	P	16 Aug	18:48	23	50	18.16	128	16.16	200	450	6.6	15.7	6,811.0	11,141	7.0
148	can	P	17 Aug	16:43	30	50	39.91	128	55.82	250	400	6.2	13.8	33.4	52	13.0
149	can	P	17 Aug	20:31	19	50	48.20	129	26.96	250	700	6.8	16.6	696.3	1,198	256.0
152	can	P	18 Aug	17:18	6	51	7.95	128	13.76	100	155	6.6	12.1	0.0	0	85.2
158	can	P	21 Aug	15:01	12	51	8.03	129	14.89	165	195	6.5	15.3	1,187.5	1,574	34.8
159	can	Y	21 Aug	17:14	17	51	7.94	129	30.48	280	280	5.7	15.1	98.3	–	281.6
160	can	P	22 Aug	1:07	20	51	18.14	129	35.44	185	225	6.0	15.6	2.7	4	0.6
161	can	P	22 Aug	2:25	9	51	18.11	129	42.31	194	230	5.9	15.6	412.7	593	3,670.3
162	can	P	22 Aug	14:42	3	51	18.26	129	23.18	160	260	6.0	14.0	315.4	457	4.1
163	can	P	22 Aug	20:58	9	51	28.12	128	27.21	130	190	6.1	15.0	2,081.5	2,651	11.3
164	can	P	23 Aug	23:31	22	52	17.62	130	11.87	460	490	4.8	14.6	0.0	0	21.4
165	can	P	24 Aug	21:52	46	53	28.57	130	46.37	130	162	6.3	13.1	0.0	0	12.7
166	can	P	26 Aug	14:58	6	54	19.30	131	31.48	72	167	7.3	12.7	0.0	0	399.1
167	can	Y	26 Aug	22:42	12	54	15.42	132	6.28	150	150	5.6	13.2	0.0	0	376.0
169	can	P	27 Aug	16:33	15	54	42.08	133	9.43	156	200	5.9	11.9	0.0	0	53.1
174	can	P	28 Aug	17:11	17	54	9.19	133	20.56	214	228	5.5	13.4	0.0	0	19.8
175	can	P	28 Aug	21:11	5	53	50.52	133	31.97	290	600	5.4	15.0	0.0	0	2.5
176	can	P	28 Aug	23:24	1	53	48.22	133	17.71	145	167	6.4	15.4	0.0	0	1.8
177	can	P	29 Aug	18:54	33	53	3.30	132	38.32	190	250	5.9	14.1	0.0	0	0.3

Table 2. Trawl station and catch data summary from the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. Continued.

Haul	INPFC	Gear		Time	Duration	Start position				Depth (m)		Temp. (°C)		Catch		
														Pacific hake		Other
no.[a]	area[b]	type[c]	Date	(GMT)	(min.)	Latitude		Longitude		Gear[d]	Bottom	Gear[e]	Surface	(kg)	Number	(kg)
178	can	P	30 Aug	21:17	19	51	48.62	130	31.06	220	275	5.5	15.6	0.0	0	0.1
179	can	P	30 Aug	23:41	36	51	48.13	130	19.33	190	227	5.6	15.6	0.0	0	16.0
180	can	P	31 Aug	23:06	17	51	28.01	129	54.79	215	250	5.9	14.1	159.7	218	118.0
181	can	P	01 Sep	0:55	30	51	28.03	129	57.71	315	350	5.7	14.4	222.7	281	29.2
182	can	P	01 Sep	18:21	19	51	18.25	130	1.39	300	325	6.0	15.6	88.4	119	4.8
183	can	P	02 Sep	0:54	3	50	58.06	129	33.83	200	240	6.4	15.7	60.1	82	33.0

[a] Not necessarily sequential. Haul operations for other sampling requirements not shown.
[b] mont = Monterey, eur = Eureka, scol = South Columbia, vannc = Vancouver - North Columbia, can = Canada.
[c] P = Polish rope midwater trawl, Y = Yankee 36 hard bottom trawl.
[d] Gear depths for midwater trawls were measured at the head rope.
[e] Gear temperatures were measured at the head rope.

Table 3. Catch by species from Polish rope midwater trawl hauls conducted by the CCGS *W. E. Ricker* during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. A total of 88 hauls were completed.

Common name	Scientific name	Weight (kg)	(%)	Numbers
Pacific hake	*Merluccius productus*	64,828.3	78.6	144,410
spiny dogfish	*Squalus acanthias*	5,501.0	6.7	8,163
yellowmouth rockfish	*Sebastes reedi*	3,335.5	4.0	–
Pacific herring	*Clupea pallasi*	2,780.3	3.4	–
chilipepper	*Sebastes goodei*	1,328.4	1.6	1,624
Pacific ocean perch	*Sebastes alutus*	1,025.9	1.2	–
yellowtail rockfish	*Sebastes flavidus*	821.6	1.0	–
walleye pollock	*Theragra chalcogramma*	508.5	0.6	–
Humboldt squid	*Dosidicus gigas*	364.3	0.4	67
lanternfish unidentified	Myctophidae	229.9	0.3	–
jack mackerel	*Trachurus symmetricus*	185.5	0.2	127
American shad	*Alosa sapidissima*	182.2	0.2	–
widow rockfish	*Sebastes entomelas*	179.8	0.2	–
arrowtooth flounder	*Atheresthes stomias*	173.2	0.2	–
California headlightfish	*Diaphus theta*	170.8	0.2	–
Chinook salmon	*Oncorhynchus tshawytscha*	162.5	0.2	–
eulachon	*Thaleichthys pacificus*	120.1	0.1	–
sockeye salmon	*Oncorhynchus nerka*	63.4	0.1	17
pink salmon	*Oncorhynchus gorbuscha*	62.1	0.1	33
redstripe rockfish	*Sebastes proriger*	51.2	0.1	–
jellyfish unidentified	Scyphozoa	47.3	0.1	–
rougheye rockfish	*Sebastes aleutianus*	40.8	<0.1	22
euphausiid unidentified	Euphausiacea	35.9	<0.1	–
silvergray rockfish	*Sebastes brevispinis*	28.5	<0.1	–
magistrate armhook squid	*Berryteuthis magister*	23.2	<0.1	–
whitebait smelt	*Allosmerus elongatus*	22.1	<0.1	–
sablefish	*Anoplopoma fimbria*	19.2	<0.1	8
shrimp unidentified	Decapoda	18.7	<0.1	–
squid unidentified	Teuthoidea	16.2	<0.1	–
California lanternfish	*Symbolophorus californiensis*	15.0	<0.1	7,405
cephalopod unidentified	Cephalopoda	14.9	<0.1	–
Pacific lamprey	*Lampetra tridentata*	13.0	<0.1	506
blue lanternfish	*Tarletonbeania crenularis*	12.0	<0.1	–
chum salmon	*Oncorhynchus keta*	12.0	<0.1	2
bocaccio	*Sebastes paucispinis*	11.1	<0.1	2

Table 3. Catch by species from Polish rope midwater trawl hauls conducted by the CCGS *W. E. Ricker* during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. A total of 88 hauls were completed. Continued.

Common name	Scientific name	Weight (kg)	(%)	Numbers
splitnose rockfish	*Sebastes diploproa*	10.4	<0.1	14
salps unidentified	Thaliacea	8.7	<0.1	–
coho salmon	*Oncorhynchus kisutch*	8.5	<0.1	6
California market squid	*Loligo opalescens*	6.0	<0.1	1,162
longnose skate	*Raja rhina*	5.5	<0.1	1
longfin dragonfish	*Tactostoma macropus*	5.3	<0.1	91
king-of-the-salmon	*Trachipterus altivelis*	4.5	<0.1	1
canary rockfish	*Sebastes pinniger*	4.4	<0.1	2
sergestid shrimp unidentified	Sergestidae	3.8	<0.1	12,412
boreopacific armhook squid	*Gonatopsis borealis*	3.8	<0.1	12
northern lampfish	*Stenobrachius leucopsarus*	3.6	<0.1	–
shortbelly rockfish	*Sebastes jordani*	3.6	<0.1	17
Pacific glass shrimp	*Pasiphaea pacifica*	3.1	<0.1	–
nail squid	*Onychoteuthis borealijaponicus*	2.9	<0.1	7
–	*Taonius pavo*	2.2	<0.1	179
roughscale sole	*Clidoderma asperrimum*	2.2	<0.1	2
shining loosejaw	*Aristostomias scintillans*	1.4	<0.1	52
bristlemouth unidentified	*Cyclothone* sp.	1.4	<0.1	2,055
ascidian unidentified	Ascidiacea	1.4	<0.1	–
Pacific viperfish	*Chauliodus macouni*	1.3	<0.1	–
–	*Octopoteuthis deletron*	1.0	<0.1	46
Pacific sardine	*Sardinops sagax*	0.8	<0.1	9
northern flashlightfish	*Protomyctophum thompsoni*	0.6	<0.1	–
greenstriped rockfish	*Sebastes elongatus*	0.4	<0.1	1
wheel jelly	*Atolla* sp.	0.4	<0.1	179
Dover sole	*Microstomus pacificus*	0.3	<0.1	4
northern anchovy	*Engraulis mordax*	0.3	<0.1	9
California flashlightfish	*Protomyctophum crockeri*	0.3	<0.1	196
popeye blacksmelt	*Bathylagus ochotensis*	0.3	<0.1	35
pasiphaeid shrimp unidentified	Pasiphaeidae	0.2	<0.1	119
ribbon barracudina	*Notolepsis risso*	0.2	<0.1	–
isopod unidentified	Isopoda	0.2	<0.1	–
northern smoothtongue	*Leuroglossus schmidti*	0.2	<0.1	–
river lamprey	*Lampetra ayresi*	0.2	<0.1	6

Table 3. Catch by species from Polish rope midwater trawl hauls conducted by the CCGS *W. E. Ricker* during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. A total of 88 hauls were completed. Continued.

Common name	**Scientific name**	**Weight (kg)**	**(%)**	**Numbers**
slender sole	*Lyopsetta exilis*	0.2	<0.1	2
chrysaora jellyfish	*Chrysaora* sp.	0.2	<0.1	1
flathead sole	*Hippoglossoides elassodon*	0.2	<0.1	1
slender barracudina	*Lestidiops ringens*	0.1	<0.1	5
rex sole	*Glyptocephalus zachirus*	0.1	<0.1	3
amphipod unidentified	Amphipoda	0.1	<0.1	–
bluethroat argentine	*Nansenia candida*	0.1	<0.1	–
northern pearleye	*Benthalbella dentata*	0.1	<0.1	–
Pacific sand lance	*Ammodytes hexapterus*	0.1	<0.1	1
robust blacksmelt	Bathylagus milleri	0.1	<0.1	–
snailfish unidentified	Liparidinae	0.1	<0.1	–
eel leptocephalus unidentified	Leptocephalus unident.	0.1	<0.1	2
fish larvae unidentified	Teleostei	<0.1	<0.1	12
flatfish larvae	Pleuronectiformes	<0.1	<0.1	5
cockeyed squid	*Histioteuthis heteropsis*	<0.1	<0.1	2
octopus unidentified	Octopoda	<0.1	<0.1	2
comb jelly unidentified	Ctenophora	<0.1	<0.1	1
fish unidentified	Teleostei	<0.1	<0.1	1
northern spearnose poacher	*Agonopsis vulsa*	<0.1	<0.1	1
ocean shrimp	*Pandalus jordani*	<0.1	<0.1	1

Table 4. Catch by species from Yankee 36 bottom trawl hauls conducted by the CCGS *W. E. Ricker* during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. A total of 18 hauls were completed.

Common name	**Scientific name**	**Weight (kg)**	**(%)**	**Numbers**
Pacific hake	*Merluccius productus*	8,100.3	72.7	13,831
splitnose rockfish	*Sebastes diploproa*	363.3	3.3	2,486
silvergray rockfish	*Sebastes brevispinis*	281.6	2.5	69
Pacific ocean perch	*Sebastes alutus*	271.8	2.4	28
chilipepper	*Sebastes goodei*	232.7	2.1	509
arrowtooth flounder	*Atheresthes stomias*	206.5	1.9	186
Dover sole	*Microstomus pacificus*	193.0	1.7	610
stripetail rockfish	*Sebastes saxicola*	192.6	1.7	1,761
walleye pollock	*Theragra chalcogramma*	178.9	1.6	513
rex sole	*Glyptocephalus zachirus*	127.7	1.1	977
canary rockfish	*Sebastes pinniger*	96.8	0.9	3
sablefish	*Anoplopoma fimbria*	84.9	0.8	45
sponge unidentified	Porifera	68.4	0.6	–
yellowtail rockfish	*Sebastes flavidus*	65.5	0.6	33
darkblotched rockfish	*Sebastes crameri*	62.7	0.6	158
shortspine thornyhead	*Sebastolobus alascanus*	49.6	0.4	348
spiny dogfish	*Squalus acanthias*	48.6	0.4	82
redbanded rockfish	*Sebastes babcocki*	36.6	0.3	26
English sole	*Parophrys vetulus*	35.1	0.3	102
eulachon	*Thaleichthys pacificus*	32.6	0.3	1,767
American shad	*Alosa sapidissima*	31.9	0.3	74
giant octopus	*Octopus dofleini*	29.0	0.3	1
Pacific halibut	*Hippoglossus stenolepis*	27.8	0.2	3
slender sole	*Lyopsetta exilis*	26.0	0.2	409
flathead sole	*Hippoglossoides elassodon*	23.4	0.2	47
rougheye rockfish	*Sebastes aleutianus*	22.4	0.2	38
Pacific sanddab	*Citharichthys sordidus*	21.7	0.2	181
white croaker	*Genyonemus lineatus*	18.6	0.2	176
yellowmouth rockfish	*Sebastes reedi*	16.8	0.2	1
spotted ratfish	*Hydrolagus colliei*	14.6	0.1	11
whitebait smelt	*Allosmerus elongatus*	14.6	0.1	3,177
Pacific cod	*Gadus macrocephalus*	13.5	0.1	8
petrale sole	*Eopsetta jordani*	12.9	0.1	23
greenstriped rockfish	*Sebastes elongatus*	10.3	0.1	42
jellyfish unidentified	Scyphozoa	9.4	0.1	9
lingcod	*Ophiodon elongatus*	8.6	0.1	4
octopus unidentified	Octopodidae	8.0	0.1	1
bocaccio	*Sebastes paucispinis*	8.0	0.1	2
sanddab unidentified	*Citharichthys* sp.	7.4	0.1	42

Table 4. Catch by species from Yankee 36 bottom trawl hauls conducted by the CCGS *W. E. Ricker* during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. A total of 18 hauls were completed. Continued.

Common name	Scientific name	Weight (kg)	(%)	Numbers
shortraker rockfish	*Sebastes borealis*	5.7	0.1	4
shortbelly rockfish	*Sebastes jordani*	5.7	0.1	72
northern anchovy	*Engraulis mordax*	5.6	0.1	91
sea cucumber unidentified	Holothuroidea	5.1	<0.1	56
ocean shrimp	*Pandalus jordani*	4.7	<0.1	838
longnose skate	*Raja rhina*	4.0	<0.1	1
rosethorn rockfish	*Sebastes helvomaculatus*	3.9	<0.1	12
Pacific herring	*Clupea pallasi*	3.9	<0.1	61
Pacific tomcod	*Microgadus proximus*	3.1	<0.1	22
Pandalus platyceros	*Pandalus platyceros*	2.9	<0.1	61
bigfin eelpout	*Lycodes cortezianus*	2.6	<0.1	17
widow rockfish	*Sebastes entomelas*	2.5	<0.1	2
sea anemone unidentified	Actiniaria	2.2	<0.1	9
snail unidentified	Gastropoda	2.2	<0.1	12
starfish unidentified	Asteroidea	2.2	<0.1	–
mud star	*Ctenodiscus crispatus*	2.2	<0.1	52
magistrate armhook squid	*Berryteuthis magister*	2.1	<0.1	3
sidestripe shrimp	*Pandalopsis dispar*	2.1	<0.1	21
Chinook salmon	*Oncorhynchus tshawytscha*	2.1	<0.1	2
black eelpout	*Lycodes diapterus*	2.0	<0.1	49
brittlestarfish unidentified	Ophiurida	2.0	<0.1	44
sharpchin rockfish	*Sebastes zacentrus*	1.9	<0.1	15
shrimp unidentified	Decapoda	1.9	<0.1	2
redstripe rockfish	*Sebastes proriger*	1.9	<0.1	4
Pacific argentine	*Argentina sialis*	1.4	<0.1	25
aurora rockfish	*Sebastes aurora*	1.4	<0.1	8
curlfin sole	*Pleuronichthys decurrens*	1.3	<0.1	3
Pacific pompano	*Peprilus simillimus*	1.1	<0.1	1
pink seaperch	*Zalembius rosaceus*	1.1	<0.1	2
Pacific lamprey	*Lampetra tridentata*	0.8	<0.1	29
clay pipe sponge	*Aphrocallistes vastus*	0.7	<0.1	–
rockfish unidentified	*Sebastes* sp.	0.6	<0.1	11
sea urchin unidentified	Echinacea	0.5	<0.1	7
dungeness crab	*Cancer magister*	0.5	<0.1	2
salmon unidentified	*Oncorhynchus* sp.	0.5	<0.1	2
threadfin sculpin	*Icelinus filamentosus*	0.5	<0.1	2
sand sole	*Psettichthys melanostictus*	0.3	<0.1	1
blackbelly eelpout	*Lycodes pacificus*	0.3	<0.1	13

Table 4. Catch by species from Yankee 36 bottom trawl hauls conducted by the CCGS *W. E. Ricker* during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast. A total of 18 hauls were completed. Continued.

Common name	**Scientific name**	**Weight (kg)**	**(%)**	**Numbers**
spotted cusk-eel	*Chilara taylori*	0.2	<0.1	5
California market squid	*Loligo opalescens*	0.2	<0.1	10
gorgonian coral unidentified	Gorgonacea	0.2	<0.1	–
cowcod	*Sebastes levis*	0.1	<0.1	1
salps unidentified	Thaliacea	0.1	<0.1	5
fish-eating starfish	*Stylasterias forreri*	0.1	<0.1	2
glass sponge unidentified	Hexactinellida	0.1	<0.1	1
California headlightfish	*Diaphus theta*	0.1	<0.1	3
lampshells unidentified	Brachiopoda	0.1	<0.1	–
big skate	*Raja binoculata*	0.1	<0.1	5
blackfin sculpin	*Malacocottus kincaidi*	0.1	<0.1	1
California sea cucumber	*Parastichopus californicus*	0.1	<0.1	1
hermit crab unidentified	Paguridae	0.1	<0.1	5
roughstem seawhip	*Stylatula gracile*	0.1	<0.1	3
smootheye poacher	*Xeneretmus leiops*	0.1	<0.1	2
basketstarfish unidentified	*Gorgonocephalus eucnemis*	0.1	<0.1	5
threaded sculpin	*Gymnocanthus pistilliger*	0.1	<0.1	1
fringed sculpin	*Icelinus fimbriatus*	0.1	<0.1	1
pasiphaeid shrimp unidentified	Pasiphaeidae	<0.1	<0.1	16
lanternfish unidentified	Myctophidae	<0.1	<0.1	14
sea pen unidentified	Pennatulacea	<0.1	<0.1	2
slender seawhips	*Stylatula* sp.	<0.1	<0.1	1
coral unidentified	Gorgonacea	<0.1	<0.1	–
pygmy rockfish	*Sebastes wilsoni*	<0.1	<0.1	1
blacktip poacher	*Xeneretmus latifrons*	<0.1	<0.1	1
bigeye poacher	*Bathyagonus pentacanthus*	<0.1	<0.1	1
Oregon triton	*Fusitriton oregonensis*	<0.1	<0.1	10
squid unidentified	Teuthoidea	<0.1	<0.1	1
isopod unidentified	Isopoda	<0.1	<0.1	6
crangonid shrimp unidentified	Crangonidae	<0.1	<0.1	2
sea whip unidentified	Virgularidae	<0.1	<0.1	1
northern spearnose poacher	*Agonopsis vulsa*	<0.1	<0.1	1

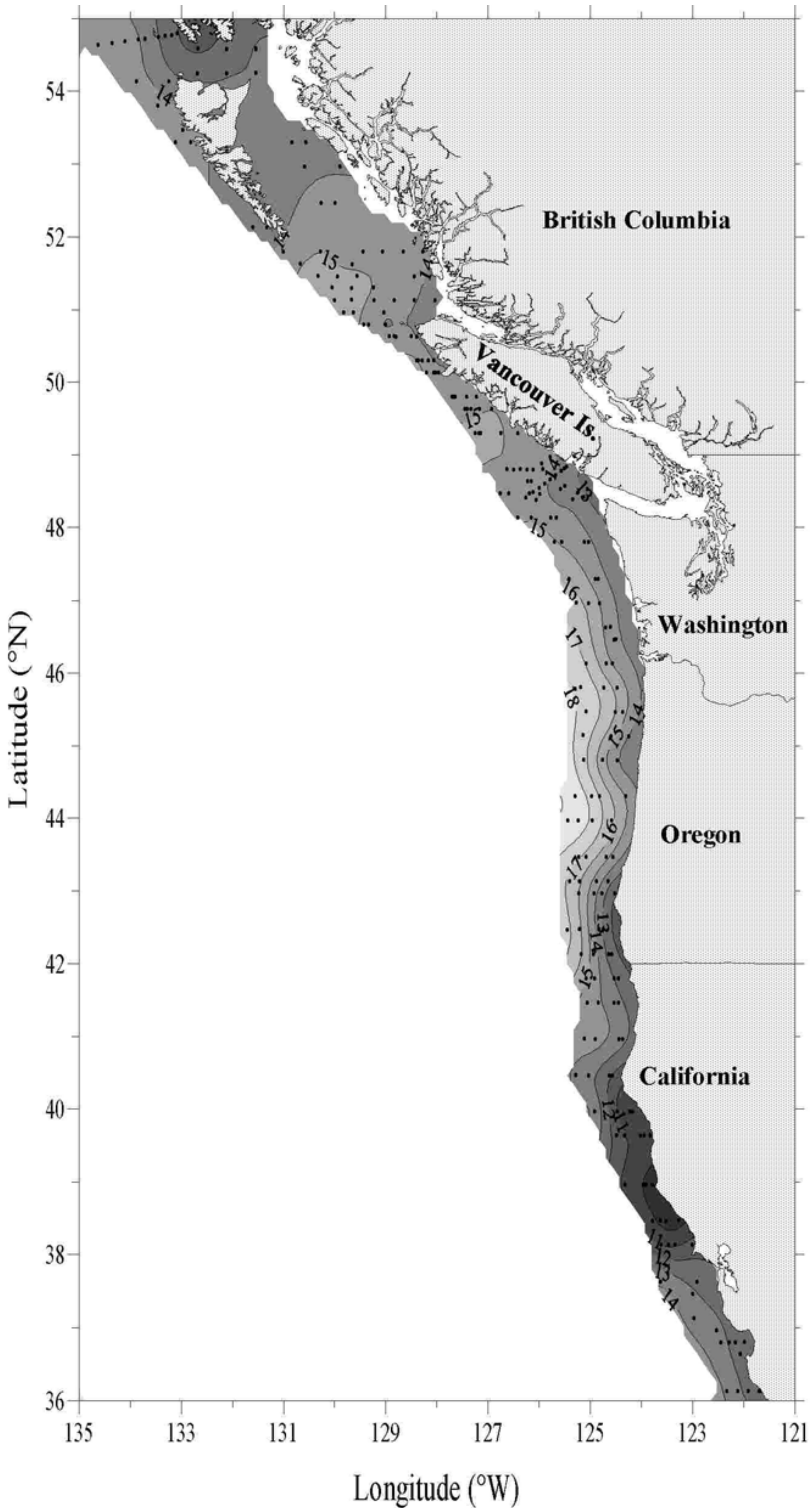

Figure 5. Surface temperature contours (°C) and locations (•) of temperature and salinity profile measurements taken during the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

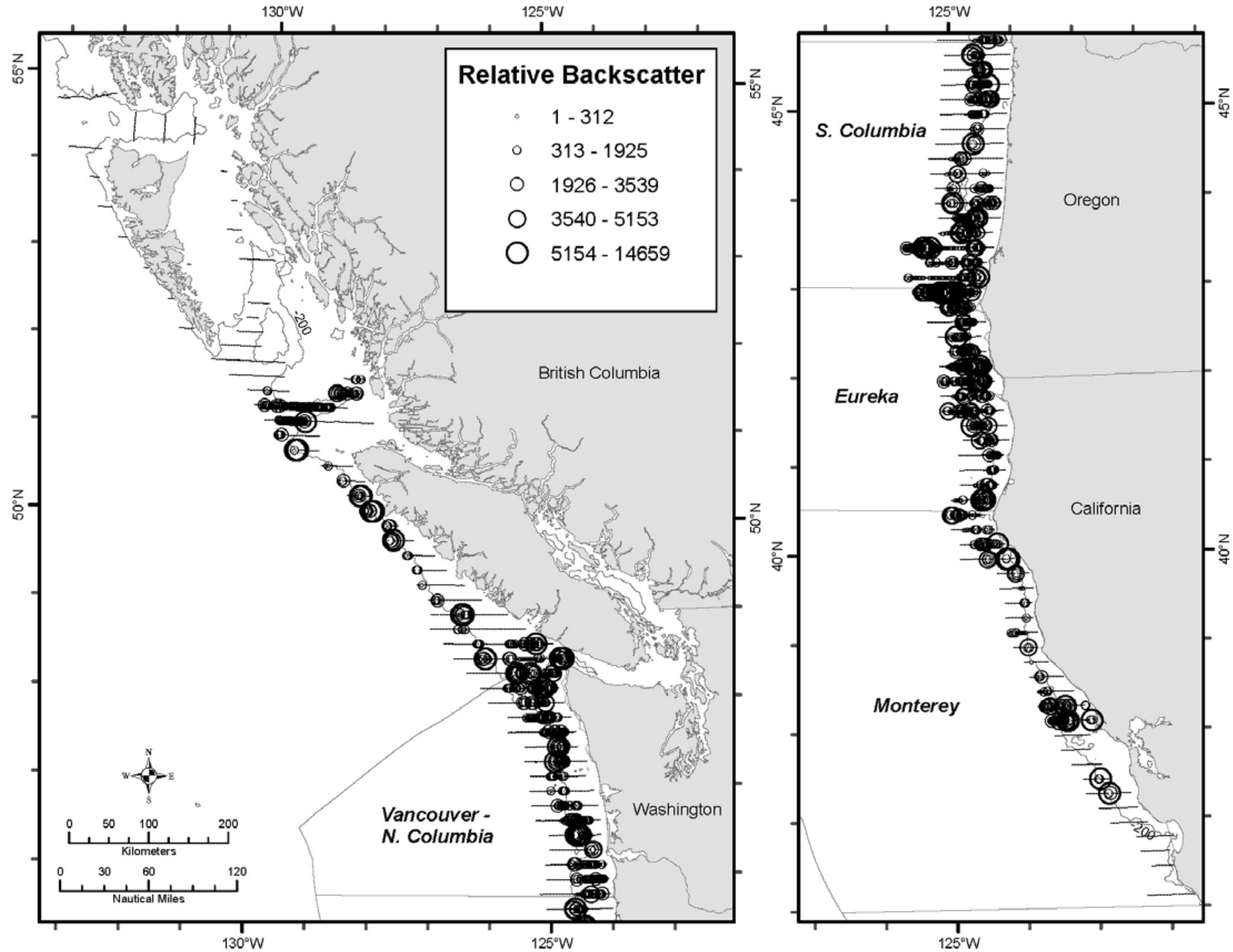

Figure 6. Acoustic area backscattering (s_A) attributed to Pacific hake along transects completed off the west coast of the United States and Canada during the joint 2003 integrated acoustic and trawl survey. Diameter of circles is proportional to measured values of backscatter. Isobaths are plotted at 50, 200, 700, and 1,500 m.

deep and 20 nmi farther offshore than seen previously in this area. By contrast, no hake were found north of transects 98 and 119 in Queen Charlotte Sound (52°N). Geographic details and abundance estimates of Pacific hake for each transect are listed in Appendix B.

As revealed by the associated midwater and bottom trawl samples, the majority of the coastal Pacific hake population comprised fish that were highly uniform in size distribution, averaging 44 cm (Figure 7). The exception was in the most southern (lower numbered) transects where smaller individuals were locally encountered. Larger Pacific hake were more prevalent farther north (Figure 7). Pacific hake specimens collected in the trawls ranged in age from 1 to 22 years (Figure 8). However, the size classes of Pacific hake that dominated the catches throughout their entire range represented members of the 1999 year class (age 4).

The coast-wide estimates of Pacific hake abundance totaled 3.35 billion fish weighing 1.84 million metric tons (Tables 5 and 6). As expected from the age and length distribution, the population was dominated by age-4 fish (Figure 9, Tables 5 and 6). The 1999 year class contributed about 64% of the total coast-wide number and 60% of the total coast-wide biomass. The 1999 year class was prevalent across all regions (Figure 9), contributing 55%, 74%, 74%, 58%, and 33% to the total biomass for the Monterey, Eureka, South Columbia, Vancouver-North Columbia, and Canada INPFC areas, respectively. The recruitment of the 1999 year class and the resulting increase in coast-wide biomass are significant: the 2003 biomass estimate of 1.84 million metric tons represents a 1.1 million metric ton or 250% increase over the biomass estimate made for 2001 (Figure 10). The 2003 estimate ranks as the fifth largest coast-wide estimate in the time series, and is the largest estimated population biomass of coastal Pacific hake since 1992.

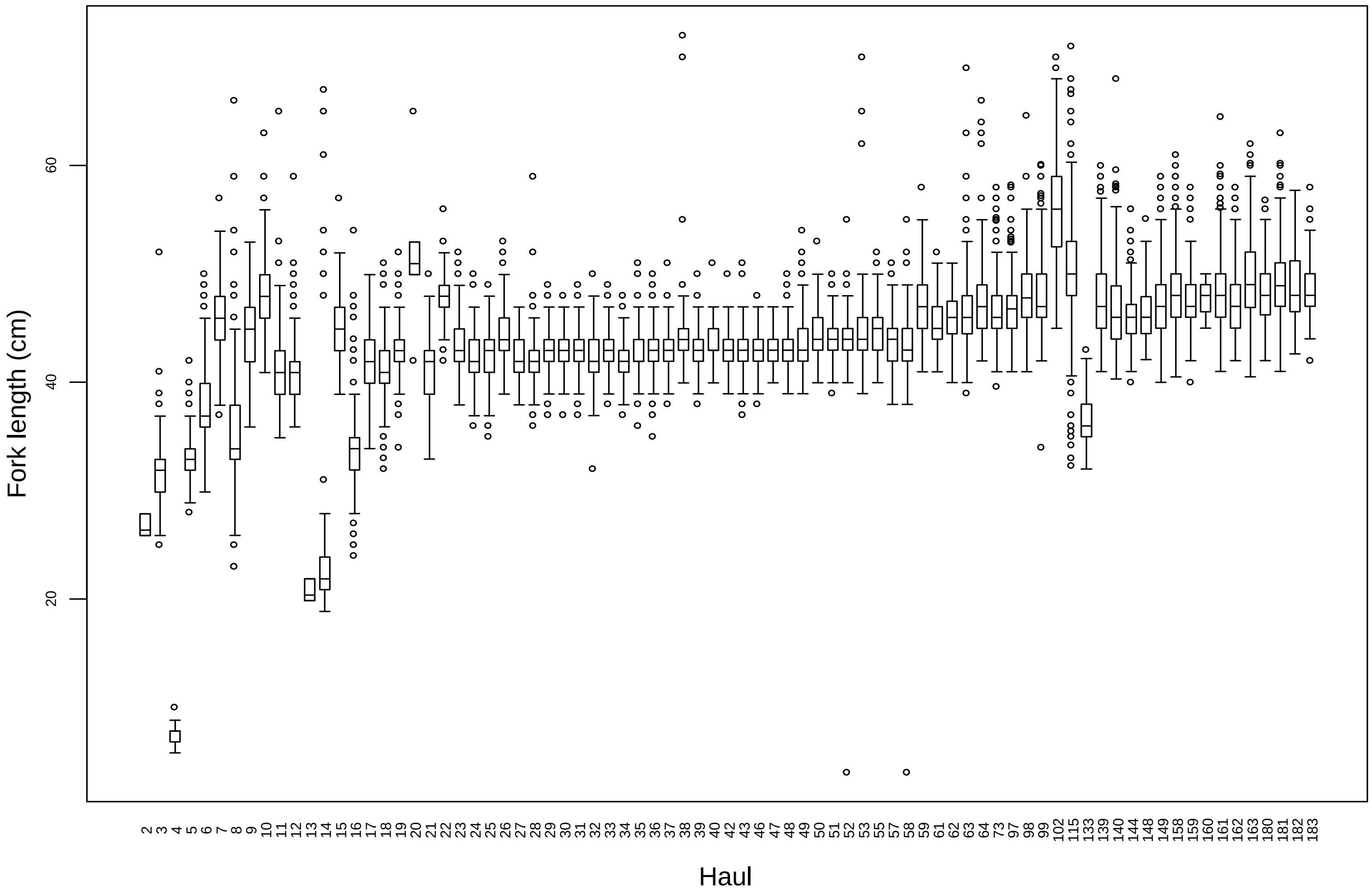

Figure 7. Box-and-whisker plot of the length-frequency distributions of Pacific hake for trawl tows conducted as part of the 2003 joint U.S. and Canada integrated acoustic and trawl survey. Length frequency distributions are shown in sequence and include only those tows that captured Pacific hake. The 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.

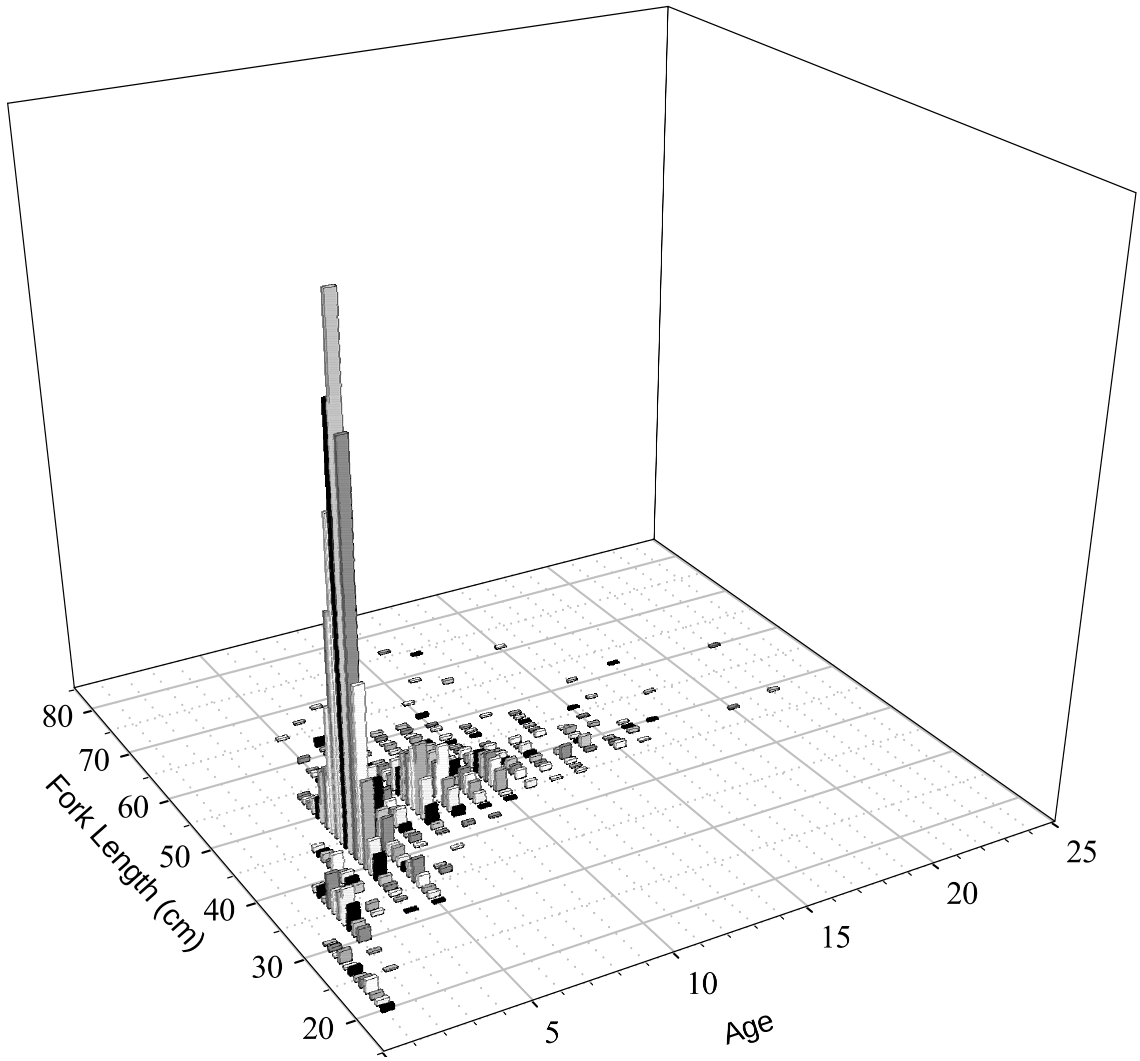

Figure 8. Age-length distribution of Pacific hake comparing INPFC areas from specimens collected during the 2003 joint U.S. and Canada integrated acoustic and trawl survey. Ages based on interpretation of otoliths.

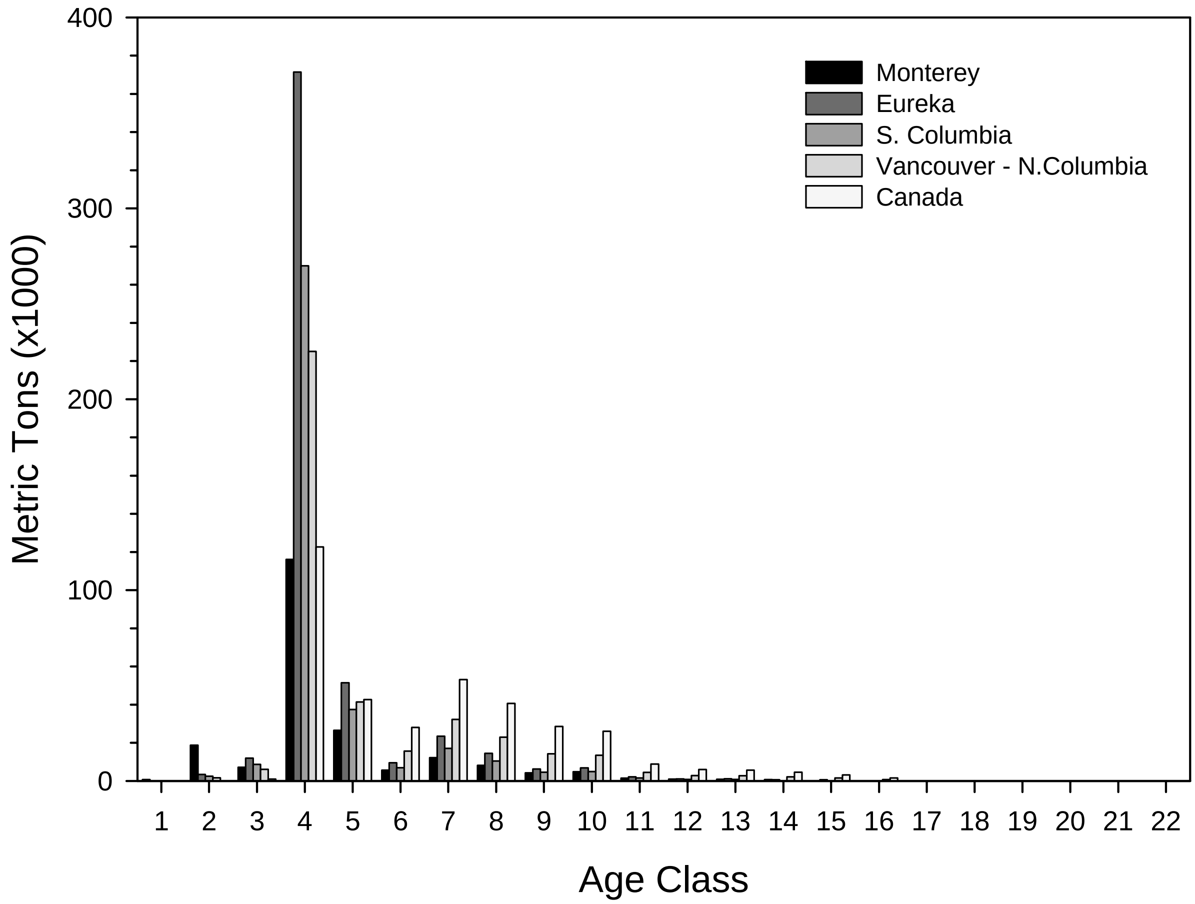

Figure 9. Estimated biomass (metric tons) of Pacific hake by age class comparing INPFC areas for the 2003 joint U.S. and Canada integrated acoustic and trawl survey.

Figure 10. Biomass estimates (millions of metric tons) of Pacific hake, 1977–2003. Estimates for 1977–1989 are adjusted as described in Dorn (1996) to account for changes in target strength model, depth, and geographic coverage. Biomass estimates since 1992 are based on the 20 log L–68 target strength relation used by Wilson and Guttormsen (1997). For consistency, biomass shown is for fish age 2 and older across time series.

Table 5. Estimated biomass (metric tons) of Pacific hake by age for each INPFC area for the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

	Geographic Area					
Age class	**Monterey**	**Eureka**	**South Columbia**	**Vancouver-North Columbia**	**Canada**	**Total**
1	724.1	0.0	0.0	0.0	0.0	724.1
2	18,733.3	3,416.8	2,483.0	1,657.5	81.9	26,372.5
3	7,172.2	11,972.4	8,700.4	6,069.8	949.0	34,863.8
4	116,066.1	371,389.2	269,892.2	225,118.5	122,548.7	1,105,014.7
5	26,587.3	51,432.6	37,376.6	41,339.4	42,664.7	199,400.6
6	5,705.7	9,544.6	6,936.1	15,649.8	28,086.7	65,922.9
7	12,156.7	23,492.0	17,071.9	32,201.1	53,158.3	138,080.1
8	8,252.4	14,490.5	10,530.4	22,949.7	40,594.0	96,817.0
9	4,295.9	6,282.1	4,565.2	14,276.1	28,536.7	57,956.1
10	4,831.5	6,844.6	4,974.0	13,538.5	25,995.7	56,184.4
11	1,475.7	2,084.9	1,515.1	4,511.5	8,898.4	18,485.5
12	949.4	1,068.6	776.6	2,858.3	5,940.9	11,593.9
13	910.7	1,150.2	835.8	2,802.9	5,702.8	11,402.4
14	687.9	611.5	444.4	2,101.7	4,577.8	8,423.3
15	487.8	577.7	419.8	1,509.2	3,120.5	6,115.0
16	250.4	252.0	183.1	744.2	1,578.3	3,008.0
17	37.6	42.2	30.6	139.5	302.1	552.1
18	16.8	32.0	23.3	148.5	337.0	557.6
19	0.0	0.0	0.0	0.0	0.0	0.0
20	56.0	57.5	41.8	127.7	253.7	536.8
21	0.0	0.0	0.0	0.0	0.0	0.0
22	41.9	46.4	33.7	155.9	338.3	616.2
Total	209,439.4	504,787.7	366,834.3	387,900.0	373,665.4	1,842,626.7

Table 6. Estimated numbers of Pacific hake by age for each INPFC area for the 2003 integrated acoustic and trawl survey of Pacific hake in U.S. and Canadian waters off the Pacific coast.

	Geographic Area					
Age class	**Monterey**	**Eureka**	**South Columbia**	**Vancouver-North Columbia**	**Canada**	**Total**
1	5,194,117	0	0	0	0	5,194,117
2	75,131,219	11,000,394	7,994,096	5,351,796	302,676	99,780,181
3	20,504,133	28,069,951	20,398,713	14,074,713	1,830,102	84,877,612
4	235,958,377	740,701,003	538,274,789	431,453,453	200,110,232	2,146,497,854
5	62,533,170	99,655,532	72,420,667	71,451,834	60,806,549	366,867,752
6	10,068,439	16,458,393	11,960,478	20,805,406	32,806,937	92,099,653
7	18,256,839	37,785,491	27,459,092	46,216,181	71,402,232	201,119,835
8	11,737,983	21,992,398	15,982,094	31,092,333	52,158,383	132,963,191
9	5,818,998	9,558,810	6,946,483	17,773,615	33,438,500	73,536,406
10	6,578,423	9,887,510	7,185,352	17,781,786	33,063,932	74,497,003
11	2,007,431	3,110,093	2,260,136	5,784,000	10,882,479	24,044,139
12	1,182,084	1,466,981	1,066,070	3,455,869	6,972,594	14,143,597
13	1,244,766	1,684,642	1,224,246	3,542,438	6,929,730	14,625,823
14	857,790	781,649	568,032	2,569,563	5,556,036	10,333,070
15	658,096	826,465	600,600	1,855,950	3,698,130	7,639,240
16	311,349	340,397	247,370	895,747	1,855,168	3,650,031
17	46,276	51,836	37,670	171,573	371,411	678,765
18	14,158	23,292	16,926	126,543	291,897	472,816
19	0	0	0	0	0	0
20	78,323	80,442	58,458	178,548	354,649	750,419
21	0	0	0	0	0	0
22	54,953	60,811	44,192	178,033	376,951	714,939
Total	458,236,924	983,536,090	714,745,463	674,759,380	523,208,587	3,354,486,444

Discussion

Our understanding of the level of abundance of Pacific hake was changed by this survey, with the 2003 estimate representing a reverse in the recent declining trend in coastal hake biomass. This result also supports the decision to advance the survey to a biennial regimen. Clearly, the increase from the 2001 estimated coast-wide biomass can be attributed almost entirely to recruitment of the 1999 year class. The unprecedented low estimate of Pacific hake in 2001 was the combined result of a nearly complete lack of hake being detected north of central Oregon (i.e., north of 44°N) and the predominance in the population (≈50% total biomass) of young fish of the 1999 year class (Guttormsen et al. 2003), which as age-2 fish were only partially recruited to the survey (Helser et al. 2002). In 2003 the Pacific hake population was again dominated by the 1999 year class, but was fully available to the survey and was distributed in more typical fashion along the coast (Figure 6). The 2001 and 2003 acoustic surveys were similar in that 80% and 86%, respectively, of the total hake biomass occurred south of 47°30'N (i.e., Monterey, Eureka, and Columbia INPFC areas). However, the biomass in Canadian waters changed dramatically from the last survey, as only about 10% of the biomass was observed in these waters in 2001, as compared to 33% in 2003.

In an initial attempt to address the uncertainty associated with the coast-wide Pacific hake biomass estimate, we analyzed the transect biomass data applying the technique of Jolly and Hampton (1990) to a post-survey stratification scheme. Transects were treated as sampling units. We stratified the line transects using a local regression (loess) smoothing technique, a generalization of running means, to guide the clustering of neighboring transects of similar values. 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. For each cluster, the mean and variance of the 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

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

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

where ($\bar{\hat{p}}$) is the mean estimated biomass density and (A) is the total represented area for each transect cluster. The coefficient of variation (CV), the measure of precision of the estimate, totaled 0.37 for the coast-wide Pacific hake biomass (Table 7). This level of precision does not include all error, but does provide some understanding of the expectation for the level of process error involved in the survey. It should be noted that the total biomass point estimate determined with the post-survey stratification technique was within 2% of the value calculated by the traditional summing method (Table 6).

Table 7. Biomass sampling error (CV) based on post-survey stratification of transects for the 2003 integrated acoustic and trawl survey of Pacific hake, where $\bar{\bar{p}}$ 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–H).

Transect clusters	**Strata statistics**				
	$\bar{\bar{p}}$	$Var(\bar{\bar{p}})$	A	$\hat{B}$	CV
A (3-14)	4.27	94.18	2,588.60	11,053	2.27
B (15-25)	37.61	3,138.26	2,462.14	92,612	1.49
C (26-33)	62.72	1,667.68	2,377.32	149,112	0.65
D (34-50)	98.93	4,496.43	6,607.18	653,647	0.68
E (51-68)	36.29	561.94	7,982.18	289,686	0.65
F (69-81)	49.60	739.25	6,759.29	335,230	0.55
G (82-98)	82.86	10,989.43	4,082.49	338,265	1.27
H (99-119)	0.27	1.58	3,623.92	993	4.58
Coast wide				1,870,601	0.37

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Appendix A

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

Group	Transects	Hauls	Mean length (cm)	Expected σ_{bs}
1	10, 11	3	33.0	1.743E-04
2	15,* 17	6	38.0	2.308E-04
3	15,* 16, 18, 19, 25	7, 9, 10, 15	46.0	3.374E-04
4	20-24, 26-72, 73,* 74,* 75*	11, 12, 17, 18, 19, 21, 23, 24, 25, 26, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 42, 43, 46, 47, 48, 49, 50, 51, 52, 53, 55, 57, 58	43.0	2.944E-04
5	73,* 74,* 75,* 76-96, 119	59, 61, 63, 64, 97, 139, 140, 144, 148, 149, 158, 161, 162, 163, 180, 181, 183	47.7	3.629E-04

* Denotes transects where subsections which 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 ($\hat{N}$) and biomass ($\hat{B}$) in metric tons.

Trans.	Start lat.	Start long.	End lat.	End long.	Length (nmi)	Area (nmi^2)	$\hat{N}$	$\hat{B}$ (mt)
3	36.1355	122.3333	36.1358	121.6705	32.1	321.19171	0	0.00
5	36.4688	122.2500	36.4683	121.9527	14.3	143.46654	0	0.00
6	36.6355	121.9950	36.6355	122.4140	20.2	201.7354	0	0.00
7	36.8022	122.4517	36.8022	121.9167	25.7	257.0275	0	0.00
8	36.9688	122.2878	36.9688	122.8223	25.6	256.22736	0	0.00
9	37.1355	122.9832	37.1355	122.4185	27.0	270.09476	0	0.00
10	37.3022	122.5128	37.3022	123.1490	30.4	303.62348	25,517,102	5,785.65
11	37.4688	123.1868	37.4688	122.8015	18.3	183.49983	22,591,351	5,122.28
12	37.6355	122.9117	37.6355	123.3500	20.8	208.27271	0	0.00
13	37.8022	123.4833	37.8022	123.0647	19.8	198.48112	0	0.00
14	37.9688	123.0647	37.9688	123.5826	24.5	244.97852	0	0.00
15	38.1355	123.6243	38.1353	122.9980	29.6	295.57123	144,654,741	54,303.79
16	38.3022	123.1167	38.3016	123.8118	32.7	327.28262	51,395,292	32,817.67
17	38.4688	123.7940	38.4688	123.2775	24.3	242.63517	6,176,719	2,189.54
18	38.6355	123.4282	38.6355	123.9200	23.1	230.51258	12,153,623	7,760.49
19	38.8022	124.0000	38.8022	123.6333	17.1	171.44914	329,466	210.38
20	38.9688	123.7813	38.9688	124.1520	17.3	172.91337	8,209,129	4,214.03
21	39.1355	124.2025	39.1355	123.7852	19.4	194.22414	6,224,147	3,195.05
22	39.3022	123.8450	39.3022	124.2537	19.0	189.73975	1,567,186	804.50
23	39.4688	124.2587	39.4688	123.8510	18.9	188.82398	3,411,710	1,751.35
24	39.6355	123.8333	39.6355	124.3333	23.1	231.03545	301,215	154.62
25	39.8022	124.3667	39.8022	123.8938	21.8	217.95517	10,526,222	6,721.35
26	39.9688	124.1000	39.9688	124.9167	37.6	375.53305	64,038,704	32,873.28
27	40.1355	124.9167	40.1355	124.2417	31.0	309.63147	45,843,170	23,532.87
28	40.3022	124.3833	40.3022	125.0427	30.2	301.70192	11,989,866	6,154.83
29	40.4688	125.0448	40.4688	124.5283	23.6	235.72122	43,682,665	22,423.82
30	40.6355	124.4247	40.6355	125.0333	27.7	277.14616	69,070,858	35,456.46
31	40.8022	124.8925	40.8022	124.3083	26.5	265.31811	27,827,735	14,284.93
32	40.9688	124.2250	40.9688	124.9032	30.7	307.23649	7,273,107	3,733.53
33	41.1355	124.9000	41.1355	124.2250	30.5	305.02816	17,106,659	8,781.43
34	41.3022	124.1500	41.3022	124.8475	31.4	314.39359	37,194,769	19,093.34
35	41.4688	124.8525	41.4688	124.1667	30.8	308.34355	48,673,672	24,985.89
36	41.6355	124.2167	41.6355	125.1670	42.6	426.14488	66,687,094	34,232.80
37	41.8022	125.1764	41.8022	124.3817	35.5	355.43839	41,924,398	21,521.23
38	41.9688	124.3500	41.9688	125.0932	33.2	331.53053	93,959,305	48,232.56

Table B-1. Individual transect coordinates (decimal degrees), length, corresponding area, and estimated Pacific hake population numbers ($\hat{N}$) and biomass ($\hat{B}$) in metric tons. Continued.

Trans.	Start lat.	Start long.	End lat.	End long.	Length (nmi)	Area (nmi^2)	$\hat{N}$	$\hat{B}$ (mt)
39	42.1355	125.1833	42.1355	124.4058	34.6	345.93788	107,344,332	55,103.54
40	42.3022	124.4645	42.3022	125.0733	27.0	270.17794	44,689,014	22,940.40
41	42.4688	125.2167	42.4688	124.5450	29.7	297.27082	21,884,886	11,234.28
42	42.6355	124.4542	42.6355	125.3788	40.8	408.15391	31,233,929	16,033.45
43	42.8022	125.2528	42.8022	124.6500	26.5	265.3808	76,229,648	39,131.30
44	42.9688	124.5250	42.9688	125.6025	47.3	473.05994	292,769,490	150,288.65
45	43.1355	125.7262	43.1355	124.5148	53.0	530.37415	65,126,944	33,431.84
46	43.3022	124.4363	43.3022	125.3780	41.1	411.19151	42,843,146	21,992.87
47	43.4688	125.7265	43.4688	124.3167	61.4	613.92534	132,380,850	67,955.66
48	43.6355	124.3367	43.6355	125.1933	37.2	372.00464	63,632,540	32,664.76
49	43.8022	125.1933	43.8022	124.2083	42.7	426.54483	70,977,550	36,435.23
50	43.9688	124.1750	43.9688	125.2340	45.7	457.30854	59,530,125	30,558.85
51	44.1355	125.2340	44.1355	124.1667	46.0	459.61186	24,485,666	12,569.31
52	44.3022	124.1500	44.3022	125.3022	49.5	494.74013	13,335,855	6,845.77
53	44.4688	125.3325	44.4688	124.1500	50.6	506.32163	15,007,392	7,703.82
54	44.6355	124.1203	44.6355	125.2202	47.0	469.57881	19,256,006	9,884.76
55	44.8022	125.1317	44.8037	124.1113	43.4	434.37818	7,097,776	3,643.54
56	44.9708	124.0777	44.9728	125.1530	45.6	456.4511	16,319,667	8,377.43
57	45.1357	125.1413	45.1375	124.0288	47.1	470.86857	70,201,624	36,036.88
58	45.3020	124.0403	45.3010	125.1153	45.4	453.67798	42,676,065	21,907.09
59	45.4692	125.0785	45.4730	124.0240	44.4	443.69895	42,044,139	21,582.71
60	45.6370	124.0017	45.6355	125.0750	45.0	450.29289	30,071,971	15,437.00
61	45.8027	125.1645	45.8032	124.0267	47.6	475.92979	37,369,779	19,183.19
62	45.9693	124.0443	45.9745	125.0767	43.1	430.50089	36,338,887	18,654.01
63	46.1358	125.0832	46.1338	124.0710	42.1	420.83853	36,395,842	18,683.24
64	46.3020	124.1812	46.3042	125.0175	34.7	346.66771	19,069,585	9,789.07
65	46.4693	125.0227	46.4672	124.1648	35.5	354.50532	68,389,245	35,106.55
66	46.6352	124.1970	46.6378	125.2453	43.2	431.88978	42,642,730	21,889.97
67	46.8022	125.3032	46.8040	124.2008	45.3	452.73485	25,211,384	12,941.86
68	46.9698	124.2792	46.9705	125.3282	42.9	429.48958	5,640,655	2,895.54
69	47.1362	125.3150	47.1375	124.3930	37.6	376.31504	13,741,092	7,053.77
70	47.3020	124.3732	47.3045	125.4180	42.5	425.11481	40,749,592	20,918.15
71	47.4708	125.4067	47.4710	124.5193	36.0	359.88344	35,111,929	18,024.17
72	47.6355	124.5453	47.6375	125.7055	46.9	469.05587	44,392,232	22,788.08
73	47.8028	125.6963	47.8037	124.6223	43.3	432.82996	46,578,549	26,617.63
74	47.9720	124.7393	47.9713	126.0313	51.9	518.99502	35,674,002	20,680.22
75	48.1353	126.1533	48.1365	124.8330	52.9	528.68768	68,657,799	47,915.97
76	48.3017	124.8128	48.3022	126.3930	63.1	630.68129	79,013,641	56,492.69
77	48.4687	126.5932	48.4687	124.7062	75.1	750.68203	83,632,775	59,795.30
78	48.6358	124.9095	48.6372	126.7808	74.2	741.98471	49,623,347	35,479.38
79	48.9695	125.6848	48.9693	127.0033	51.9	519.32693	4,235,921	3,028.57
80	48.8033	127.0070	48.8027	125.3800	64.3	642.97432	47,861,497	34,219.74

Table B-1. Individual transect coordinates (decimal degrees), length, corresponding area, and estimated Pacific hake population numbers ($\hat{N}$) and biomass ($\hat{B}$) in metric tons. Continued.

Trans.	Start lat.	Start long.	End lat.	End long.	Length (nmi)	Area (nmi^2)	$\hat{N}$	$\hat{B}$ (mt)
81	49.1355	126.1247	49.1305	127.0487	36.3	362.7593	5,100,271	3,646.55
82	49.3020	127.2502	49.3013	126.4222	32.4	323.95178	897,260	641.52
83	49.4695	126.7362	49.4692	127.2962	21.8	218.35136	5,427,540	3,880.55
84	49.6350	127.4422	49.6353	126.9353	19.7	196.95119	1,497,831	1,070.90
85	49.8007	127.3177	49.8040	127.7712	17.6	175.63196	22,229,563	15,893.56
86	49.9693	127.5923	49.9670	127.8120	8.5	84.787049	14,277,360	10,207.96
87	50.1367	127.9702	50.1350	128.2037	9.0	89.805425	49,555,458	35,430.85
88	50.3020	128.0762	50.3038	128.4952	16.1	160.58015	23,101,361	16,516.86
89	50.4683	128.6542	50.4708	128.1758	18.3	182.67815	6,667,730	4,767.25
90	50.6360	128.3947	50.6353	128.9592	21.5	214.82063	1,378,694	985.74
91	50.8022	129.0008	50.8040	129.4907	18.6	185.74441	47,169,382	33,724.88
92	50.9680	129.8230	50.9692	128.9998	31.1	311.03255	8,142,836	5,821.91
93	51.1358	128.0460	51.1357	130.0020	73.6	736.40742	34,328,419	24,543.92
94	51.3025	130.1800	51.3023	128.5133	62.5	625.20975	108,884,911	77,849.88
95	51.4687	128.3162	51.4692	128.7685	16.9	169.06594	43,902,886	31,389.42
96	51.6353	128.5988	51.6355	128.2195	14.1	141.26299	3,512,312	2,511.19
98	51.9688	130.1160	51.9695	130.8362	26.6	266.21082	0	0.00
99	52.1357	130.5632	52.1357	130.0847	17.6	176.22022	0	0.00
100	52.2993	129.9948	52.3022	130.3935	14.6	146.28467	0	0.00
101	52.4680	130.3890	52.4688	129.9993	14.2	142.43152	0	0.00
102	52.9688	129.9107	52.9687	130.5842	24.3	243.36946	0	0.00
103	53.3022	130.5683	53.3024	130.8305	9.4	94.035151	0	0.00
104	53.6355	130.6728	53.6355	130.7853	4.0	40.022105	0	0.00
105	53.9692	131.0047	53.9690	130.8900	4.0	40.469777	0	0.00
106	54.2583	131.5487	54.5833	131.5463	19.5	195.0017	0	0.00
107	54.5803	132.1162	54.2508	132.1128	19.8	197.70343	0	0.00
108	54.2497	132.6802	54.5923	132.6790	20.6	205.6004	0	0.00
109	54.7879	133.0642	54.6922	134.1595	38.4	383.69183	0	0.00
110	54.1328	133.8835	54.1358	133.2467	22.4	223.8746	0	0.00
111	53.8022	133.4052	53.8017	133.2500	5.5	54.983693	0	0.00
112	53.4695	133.2508	53.4702	132.9720	10.0	99.585449	0	0.00
113	53.1358	132.8313	53.1353	132.6565	6.3	62.932687	0	0.00
114	52.8022	132.3215	52.7930	132.2407	3.0	29.836006	0	0.00
115	52.4690	131.8490	52.4682	131.7335	4.2	42.220268	0	0.00
116	52.1352	131.6042	52.1350	131.3343	9.9	99.37458	0	0.00
117	51.7990	130.9983	51.8020	129.6670	49.4	493.98243	0	0.00
118	51.6348	129.6733	51.6358	130.6658	37.0	369.60612	0	0.00
119	51.4675	130.3218	51.4687	129.5655	28.3	282.6958	2,277,101	1,628.06

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