West Coast Aerial Sardine Survey

Sampling Results in 2010

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Introduction

Advisory bodies of the Pacific Fishery Management Council (PFMC), including the Coastal Pelagic Species Advisory Subpanel (CPSAS), Coastal Pelagic Species Management Team (CPSMT) and the Scientific and Statistical Committee (SSC), have recommended that additional fishery-independent indices of abundance be developed for the assessment of Pacific Sardine. Aerial survey methods have been used previously in S. Africa to assess sardine stock abundance (Misund et al. 2003), and Hill et al. (2007) described how aerial survey indices were developed from spotter pilot logs and a contracted line transect survey conducted in 2004 and 2005 for sardine in Southern California.

To meet the stated need for a credible comparative index, a coastwide aerial survey was developed by a consortium formed by the West Coast sardine industry and was conducted in the summer of 2009 as part of an Exempted Fishery Permit (EFP) granted by the National Marine Fisheries Service (NMFS). Results from the 2009 aerial sardine survey were incorporated into the sardine stock assessment model used to set harvests for the 2010 fishing year (Hill et al 2009). The survey was expanded further in scope and conducted again in 2010. This paper reports the results of the aerial sardine survey in 2010.

The aerial survey incorporates effort from both northern and southern industry components; the Northwest Sardine Survey (NWSS), and California Wetfish Producers Association (CWPA), respectively. The survey conducted in 2010 follows the same basic approach that was used in 2009 (Jagielo et al 2009). It incorporates methods that were initially developed through pilot study work conducted in the northwest in 2008 (Wespestad et al. 2008) and were subsequently reviewed at Stock Assessment Review (STAR) panels in May and September of 2009.

The survey employs a two-part approach, involving 1) quantitative photographs collected on planned, randomly sampled aerial transects to estimate sardine school surface areas, and 2) fishing vessels operating at sea to capture a sample of photographed and measured schools to determine the relationship between sardine school biomass and school surface area.

Materials and Methods

I. Survey Design

A two-stage survey sampling design was employed. Stage 1 consisted of aerial transect sampling to estimate the surface area (and ultimately the biomass) of individual sardine schools from quantitative aerial photogrammetry; Stage 2 involved at-sea sampling to quantify the relationship between individual school surface area and biomass. Sampling was coordinated on a coastwise basis. Pilots from both NWSS and CWPA participated in coast wide transects. Vessels from NWSS conducted point sets in the north, and vessels from CWPA conducted point sets in the south. Logistical details of the survey are provided in an Operational Plan document which is included as Appendix I of the of the 2010 EFP Application (Thon and Pleschner-Steele, 2010).

Stage 1: Aerial Transect Survey

Logistics

The aerial survey employs the belt transect method using systematic random sampling, with each transect comprising a single sampling unit (Elzinga et al. 2001). Three alternative fixed starting points five miles apart were established, and from these points, three SETs of transects were delineated for the survey in each study region (north and south). The order of conducting the three replicate SETs was chosen by randomly picking one SET at a time without replacement. The first SET chosen in 2010 was SET C, followed by SET A, and finally SET B. The starting and ending positions for these transects are given in the Operational Plan.

Survey transects were conducted in an east-west orientation, generally parallel to the gradient of sardine schools distributed along the coast. To fully encompass the expected westward (offshore) extent of the sardine school distribution, transects originated three miles from the shoreline and extended westward for 35 miles. Additionally, the segment from the coastline to the transect east end (3 miles offshore) was also photo-documented for future evaluation. The spatial coverage of the survey design extended from the Canadian border in the north to the southern California Bight area in the south. Transects were parallel and spaced 15 nautical miles apart. For each SET, a total of 66 transects were planned for the 2010 survey with 26 off Washington and Oregon, and 40 off California. Three replicate SETS, or 198 transects in total were planned. Six pilots participated in the 2010 survey; four operated single engine airplanes, and two operated twin engine airplanes (Table 1).

A transect SET was conducted as follows. Survey pilots within each region operated as a coordinated team. The prevailing conceptual model of west coast sardine movement holds that fish tend to move in a northward direction during summer. A "leap-frog" approach was taken such that southward progress was continually maintained. This approach enabled relatively rapid southward progress in order to avoid double counting of sardine schools, which were presumably travelling northward during the survey time period. It was acceptable to skip transects or portions of transects if conditions required it (e.g. if better weather was available to the south of an area), but transects could not be "made up" once skipped during the sampling of a transect SET.

Once begun, the goal was to cover the full number of transects in a SET within a region in as few days as possible. Transects were flown at the nominal survey altitude of 4,000 ft, and could be flown starting at either the east end or the west end. At the beginning of each potential survey day, the survey pilots conferred by telephone to jointly determine if conditions could permit safe and successful surveying that day. Factors taken into consideration included sea condition, the presence of cloud or fog cover, and other relevant factors as determined by the survey pilots. The goal was to conduct sampling on days when prevailing conditions could permit clear visibility of sardine schools on the ocean surface from an altitude of 4000 ft.

Data Collection and Reduction

Each of the six survey planes was equipped with the same Aerial Imaging Solutions photogrammetric aerial digital camera mounting system and data acquisition system as used in the 2008 and 2009 work (see Operational Plan). This integrated system was used to acquire digital images and to log transect data. The system recorded altitude, GPS position, and spotter observations, which were directly linked to the time stamped quantitative digital imagery. At the nominal survey altitude of 4000 feet, the approximate transect width-swept by the camera with a 24 mm lens was 1829 m (1.13 mi). Digital images were collected with 60% overlap to ensure seamless photogrammetric coverage.

A Transect Flight Log Form was kept during the sampling of each transect for the purpose of documenting the observations of the pilot and/or onboard observers. Key notations included observations of school species identification and documentation of any special conditions that could have an influence on interpreting transect photographs.

In order to provide ground truth information and a cross comparison between survey aircraft, digital imagery of certain objects of known size (e.g. airplane hangars, baseball field diamonds, and football fields) was collected at a series of altitudes ranging from 500 ft. to 4000 ft. The observed vs. actual sizes of the objects were subsequently compared to evaluate photogrammetric error.

Five analysts performed the tasks of locating and measuring sardine schools on the aerial transect digital photographs collected in 2010. The procedure for analyzing transects was as follows: 1) two analysts independently conducted a preliminary examination of all photographs on a transect and made note of the presence or absence of schools on each photograph, 2) a third analyst examined the findings of the first two analysts and resolved which pictures would be used for sardine school measurements, and 3) transect school measurement assignments were made using the photographs selected for analysis on the transect.

Digital images were analyzed to determine the number, size, and shape of sardine schools on each transect. Adobe *Photoshop Lightroom 3.0* software was used to bring the sardine schools into clear resolution and measurements of sardine school size (m^2) and shape (circularity) were made using Adobe *Photoshop CS5-Extended*. Transect width was determined from the digital images using the basic photogrammetric relationship:

$$\frac{I}{F} = \frac{GCS}{A}$$

and solving for *GCS*:

$$GCS = \frac{I}{F}A$$

where *I* = Image width of the camera sensor (e.g. 36 mm), *F* = the focal length of the camera lens (e.g. 24mm), *A* = altitude, and *GCS* = “ground cover to the side” or width of the field of view of the digital image. Transect width was obtained by taking the average of *GCS* for all images collected. Transect length was obtained from the distance between start and stop endpoints using the GPS data logged by the data acquisition system.

Stage 2: At-Sea Point Set Sampling

Logistics

Point sets were the means used to determine the relationship between individual school surface area (as documented with quantitative aerial photographs, described above) and the biomass of individual fish schools. Empirical measurements of biomass were obtained by conducting research hauls or "point sets" at sea. Four purse seine vessels participated in the survey in the north (Astoria - NWSS), and eight in the south (Monterey and S. California - CWPA) (Table 2).

For the purposes of the aerial survey, a point set was defined as a sardine school first identified by a survey pilot and subsequently captured in its entirety by a survey purse seine vessel. Pilots were instructed to first identify schools for point sets at an altitude of 4,000 ft -- which was also the nominal altitude specified for survey transects. The protocol for conducting point sets, and the specific criteria used for determining the acceptability of point sets for analysis of the school area-biomass relationship are given in the Operational Plan.

For fully captured schools, the 1) total weight of the school, 2) numbers per unit weight, and 3) species composition was determined, based on biological sampling of the point set hauls. Additionally, school height information was recorded from vessel sonar and down-sounder equipment.

The point set sampling design was based on school size, with the goals of 1) obtaining a range of sizes representative of schools photographed on the transects and 2) keeping within a size range consistent with the safe operation of the vessels participating in the survey. Thus, point sets were generally not attempted for schools larger than approximately 130 mt. Point set sampling was distributed between the northern and southern areas, with 2100 mt available for point sets for each area. A total of n = 54 schools were planned for the north, and 54 for the south.

Biological Sampling

Fish were collected at processing plants upon landing. Fishermen participating in the survey were instructed to keep the point set hauls in separate holds upon capture so the tonnage of each aerially photographed and measured haul could be determined separately upon landing. Samples were collected from the unsorted catch while being pumped from the vessels. Fish were taken systematically at the start, middle, and end of each delivery as it was pumped. The three samples were then combined and a random subsample of fish was taken from the pooled sample. Length, weight, sex, and maturity data were collected for each sampled fish. Sardine weights were taken using an electronic scale accurate to 0.5 gm; sardine lengths were taken using a millimeter length strip provided attached to a measuring board. Standard length was determined by measuring from sardine snout to the last vertebrae. Sardine maturity was documented by referencing maturity codes (female- 4 point scale, male- 3 point scale) supplied by Beverly Macewicz NMFS, SWFSC (Table 3).

II. Analytical Methods

Total Biomass

Estimation of total sardine biomass for the survey area was accomplished in a 3 step process, and required 1) measurements of individual school surface area on sampled transects, 2) estimation of individual school biomass (from measured school surface area and estimated school density), and 3) transect sampling design theory for estimation of a population total. The calculations described below were implemented using the R statistical programming language. The R programs used for the analysis are included as Appendix I.

Individual school surface area (a_i) was measured on the photo-documented transects using the measurement tool feature of *Adobe Photoshop*, and employed the photogrammetric relationships described above. Individual school density (d_i) is specific to school size and was determined from the empirical relationship between surface area and biomass obtained from Stage 2 (point set) sampling (described below). Individual school biomass (b_i) was estimated as the product of school density and surface area ($b_i = d_i a_i$). The sum of individual school biomass (b_u) was then determined for each transect (u). The mean sampled biomass for the study area ($\bar{b}$) was computed as

$$\bar{b} = \sum_{u=1}^{n} b_u \;\; / n \;\; ,$$

where n = the number of transects sampled. Total biomass for the study area $(\hat{B})$ was estimated using the unbiased estimator for a population total (Stehman and Salzer 2000),

$$\hat{B} = N\bar{b} \;\; ,$$

where N = the total number of transects that could possibly be sampled in the survey area without overlap. In 2010, three replicate sets of transects (SET A, SET B, and SET C) were completed and thus three estimates of $\hat{B}$ were calculated: $\hat{B}_A$, $\hat{B}_B$, and $\hat{B}_C$, respectively. The point estimate of total biomass for the study area ($\hat{B}_T$) was obtained by averaging these three estimates of biomass.

Individual School Biomass

The biomass of individual schools observed on the transects (b_i) was calculated using 1) measurements of school surface area, and 2) the relationship between school surface area and biomass, obtained from point sets. The three parameter Michaelis-Menten (MM) model assuming log-normal error was used to describe the sardine surface area– density relationship

d_i = (yint * cc + asymp * a_i) / (cc + a_i)

where

d_i = school density (mt/m^2)
a_i = school area (m^2)
yint = y intercept
asymp = asymptote as x -> infinity
asymp/cc = slope at the origin .

As noted above, individual school biomass (b_i) was then estimated as the product of school density and surface area ($b_i = d_i a_i$).

Total Biomass Coefficient of Variation (CV) for the 2010 Survey

The CV of the total biomass estimate was obtained by employing a bootstrapping procedure implemented with the R statistical programming language (Appendix I). The intent of the procedure was to propagate error from the point of school density estimation forward -- to the ultimate goal of total biomass estimation from the three replicate sets of transect data. The steps of the procedure were:

1) The MM model was fit to the point set data.
2) A variance-covariance matrix was derived for the MM model fit to the data, using the R library "MSBVAR" .
3) A matrix of simulated MM parameters was derived from the MSBVAR output, using the R function "rmultnorm".
4) For n = 100,000 bootstraps:
   a. One realization of the MM parameters was selected from the matrix of simulated parameters.
   b. The predicted MM curve was calculated.
   c. Total biomass for the study area was estimated for each of the three replicate transect sets.
   d. The three replicate estimates of total biomass were sampled with replacement.
   e. The mean of the sampled replicates was calculated, and stored as the bootstrap estimate of biomass.
5) The standard error (SE) was calculated from the stored bootstrap estimates of biomass (4e).
6) CV was calculated as CV = SE/$\hat{B}_T$.

Total Biomass Coefficient of Variation (CV) for the 2009 Survey

The 2009 survey did not collect replicate sets of transect data for analysis. Thus, the CV for the 2009 estimate of biomass was based on between-transect variability (see Appendix I – *bootsard3.r*). The steps were:

1) The MM model was fit to the point set data.
2) A variance-covariance matrix was derived for the MM model fit to the data, using the R library "MSBVAR" .
3) A matrix of simulated MM parameters was derived from the MSBVAR output, using the R function "rmultnorm".
4) For n = 100,000 bootstraps:
   a. One realization of the MM parameters was selected from the matrix of simulated parameters.
   b. The predicted MM curve was calculated.
   c. Biomass was estimated for the transects.
   d. The transects were randomly sampled with replacement.
   e. Total biomass for the study area was calculated from the sampled transects and stored as the bootstrap estimate of biomass.
5) The standard error (SE) was calculated from the stored bootstrap estimates of biomass (4e).
6) CV was calculated as CV = SE/$\hat{B}$.

Survey Results

Photogrammetric Evaluation
To evaluate photogrammetric error, a cross-comparison of the camera systems employed on the survey aircraft was conducted by analyzing photographs of known-size objects. Measurements of airplane hangars (or football fields) with known area (m^2) were obtained from photographs taken at altitudes ranging from 918 to 4482 ft. Average deviance ranged from 3.0% to 11.4% for five of the six camera systems employed in the study (area measurement data were not available for SP6) (Table 12).

In 2010, every transect photograph was examined by two photo analysts for the presence of sardine schools. The photo analysts worked independently during this phase of photograph analysis. A summary of the rate of agreement between photo analysts independently engaged in the activity of finding fish schools on photographs is given in Table 13. For the 22,878 photographs examined on the three replicate transect SETs, the average percent agreement per transect ranged from 97.0 to 98.5%.

Stage 1: Aerial Transect Survey

Transect sampling in 2010 was conducted from August 13th through September 9th and was successful in obtaining three replicate SETs, for a total of 182 transects sampled (Table 4). Three transects were not sampled on SET A (37, 48, and 49), seven on SET B (27, 28, 30, 31, 32, 33, and 34), and six on SET C (23, 32, 40, 41, 56, and 59). Transect detail data are presented in Tables 5a- 5f. Sardine schools were observed on 18 of 63 transects sampled for SET A, 13 of 59 sampled on SET B, and 20 of 60 sampled on SET C (Tables 5a-5f). The observed average biomass per transect was 200.0 mt for SET A, 96.9 for SET B, and 160.6 for SET C. The total number of transects possible (N) was 883 for SET A, 896 for SET B, and 945 for SET C. Fewer schools per transect were seen in 2010, compared with 2009 (Table 4). Schools sampled in 2010 tended to be smaller in size, on average, when compared with those sampled in 2009 (Figure 1), and schools observed in the south were smaller on average compared to schools in the north

(Figure 2). Maps showing the locations of sardine schools observed on transects in 2010 are given in Figure 11.

Stage 2: At-Sea Point Set Sampling

At-sea sampling in 2010 resulted in the landing of 71 point sets between August 9th and September 14th, which included 37 from the north (2,065 mt), and 34 from the south (1,248 mt). A summary of point sets landed by size is given in Table 14. Point set data detail is summarized in Table 6 for the north, and Table 7 for the south. Point set species composition averaged 99.5% sardine in the north, and 98.3% sardine in the south. Pacific mackerel was the predominant bycatch species. Point set locations are plotted in Figure 3 (north) and Figure 4 (south). Point set sampling was not successful in the Monterey area in 2010. Histograms of size frequency and maturity stage for all point sets landed in 2010 are given in Figures 9 and 10, respectively. Maps of point set locations, shown with respect to the location of sardine schools observed on transects in 2010, are given in Figure 12.

Area-Biomass Analysis
In 2010, 24 of 37 point sets qualified for the area-biomass analysis in the north (Table 8), and 17 of 34 point sets qualified in the south (Table 9). Specific reasons for not using point sets in the analysis are summarized in Table 6 (north) and Table 7 (south). Fits of the MM model to the data are shown in Figures 5 and 6.

Two likelihood ratio tests were conducted (Table 10). The first test evaluated pooling the new 2010 data from the north with the data collected previously in the north and used in the 2009 analysis (Table 10, top); the null hypothesis of no difference between model fits to the separate vs. pooled data was not rejected (P = 0.189). The second test evaluated pooling the new 2010 data from the south with all of the data from the north (Table 10, bottom); the null hypothesis was rejected at the 0.05 level of significance (P = 0.029). It is noteworthy that 1) fitting the model to the pooled data from the north resulted in the asymptote parameter becoming bound at the lower limit (0.001), and 2) fitting the model to the new 2010 data from the south resulted in the cc parameter becoming bound at the lower limit (100). It was concluded that the best model for the area-biomass analysis is the coastwide (all data pooled) model. Pooling data for this model was not rejected at the P = 0.01 level of significance, and fitting the model to the data did not result in any bound parameters.

Estimation of quantities for input to the sardine stock assessment

Total Biomass
Estimates of total biomass and associated CVs are summarized in Tables 11 and 11a. The point estimate for the coast wide survey in 2010 was 138,379 mt (CV = 0.30); this analysis used the coastwide pooled point set data (filename = *cdata2010nsp*).

Total biomass was also calculated separately using the point set data from each region; filenames *cdata2010np* (north) and *cdata2010s* (south), respectively. Analysis of the northern region yielded a point estimate of 105,738 mt, (CV = 0.44) with the asymptote bound at 0.001, and a point estimate of 108,851 (CV = 0.40) with the asymptote bound at 0.005. Analysis of the southern region resulted in 27,695 mt (CV = 0.72).

Total biomass was also re-calculated for 2009 using the transect data from that year with the updated point set data (Table 11). Using the pooled point set data from the north, total biomass was 794,159 mt (CV = 2.08) with the asymptote bound at 0.001, and 1,247,250 mt (CV = 1.12) when the asymptote was bound at 0.005. A third run using the coast wide pooled point set data resulted in 2,000,618 mt (CV = 0.66). By comparison, the biomass estimate using only the point set data from the 2009 analysis yielded a biomass estimate of 1,236,911 mt (CV = 1.12).

Weighted length composition

Vectors of weighted length frequency were also derived for input to the sardine stock assessment model. The raw length frequency data were weighted by the landed point set weights. Separate vectors were computed for the north, south, and coast as a whole. Length distributions differed noticeably with larger fish predominating in the north, as compared to the south (Figure 8).

Discussion

In 2010, we were successful in coordinating industry resources on a coast wide basis to achieve a second synoptic West Coast sardine survey. The results were strikingly different in 2010 compared to 2009.

Factors that can contribute to make the survey a minimum estimate of biomass were enumerated by the May 2009 STAR Panel and include incomplete detection due to: 1) schools too deep, 2) schools lost in glare, 3) marginal cloud cover – reduced visibility, 4) sea state, and 5) weather that is consistently prohibitive to sampling (limiting to full area coverage during the survey time window).

Weather again negatively impacted survey results in 2010. In the limited time available for the survey, we completed three replicate transect SETs, however, it was often not possible to sample during optimal conditions for sardine observation. As a result, sampling often occurred under sub-optimal conditions.

Monterey point sets in 2010 – Observations by Doyle Hanan

A question raised by this year's aerial survey is the presence of sardines in the aerial transects from the Monterey area but absence of point sets for determining the ratio of school surface area to school biomass. A primary objective of the 2010 summer survey was to accomplish, to the degree possible, three complete replicates of the aerial transects in order to establish a defensible CV. Although dense and persistent marine layer plagued the project in California during the entire month of August and early September, by chartering four pilots we were able to deploy planes strategically to capitalize on the few clear days available to fly, and three complete sets of 40 transects were flown successfully. During the few days that the marine layer lifted sufficiently to allow visibility from the air, the area around Monterey Bay was scouted (low altitude flights to look for sardine schools) by airplane and by fishing vessels participating in other fisheries and traversing to and from those fishing grounds. Specifically we were in communication several times each day with both the pilot(s) and with the fishing vessels participating in the market squid fishery, which was active just north of Monterey Bay, and they reported no sardines visible. We also scouted the area up to the Farallon Islands with airplanes, as well as, areas to the south of Monterey Bay. Apparently those schools visible in the enhanced transect photographs were not visible to or seen by our pilots or fishermen in fishing vessels using various sonar gears. We did observe sardines in the northeast corner of Monterey Bay in shallow water, but we followed the guidelines recommended by the SSC and CPSMT and did not attempt to capture schools from this area as it was very close to shore within the three mile exclusion zone. Resulting from the inability to conduct point sets in Monterey Bay during the survey period, August to September 14, we were required to return 861 metric tons of the EFP set aside to the fall directed fishery. As EFP fish are sold at cost to cover research expenses, the inability to capture point sets in Monterey caused a significant budget shortfall in the California portion of the survey. Ironically, sardines became visible in the Bay both to pilots and fishermen after the fall directed fishery was closed for the year on September 23.

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Table 1. Pilot and aircraft information for the aerial sardine survey in 2010.

Region	Pilot ID	Pilot Name	Aircraft ID	Aircraft Type
North	Survey Pilot No.1 (SP1)	Frank Foode	N700AM	Cessna 336 Skymaster (twin engine)
North	Survey Pilot No.2 (SP2)	Merrill Danne	N18ZF	Piper Super Cub
South	Survey Pilot No.3 (SP3)	Eric Waxman	N2950A	Piper Seminole (twin engine)
South	Survey Pilot No.4 (SP4)	Allen Hewitt	N5210Y	Cessna 182 Turbo
South	Survey Pilot No.5 (SP5)	Geno Zandona	N735U	Cessna 182
South	Survey Pilot No.6 (SP6)	Devin Reed	N172JP	Cessna 172

Table 2 . Identification and gear configuration of participating vessels in 2010.

Vessel Name	Skipper	Owner	USGS/OR Reg#	CPS/Sardine Permit #	Length	GRT	Holds	Capacity (Tons)
Astoria								
Pacific Pursuit	Keith Omey	Pacific Pursuit, LLC	OR873ABY	30920	73'	86	4	80
Lauren L. Kapp	Ryan Kapp	Daryll Kapp	OR072ACX	57008	72'	74	4	60
Pacific Knight	Mike Hull	Dulcich, Inc.	OR155ABZ	57011	62'	53	4	50
Pacific Raider	Nick Jerkovich	Nick Jerkovich	972638	57010	58'	75	2	55
Monterey								
Sea Wave	Andy Russo	Sea Wave Corp-Sal Tringali	D951443	10	78'	206.9	2	75
King Philip	Anthony Russo	Sea Wave Corp-Sal Tringali	D1061827	9	79'	156.9	6	125
El Dorado	Frank Aliotti	Aliotti Brothers, Inc.	D690849	32	56'	54.9	3	40
Aliotti Bros.	Dominic Aliotti	Joseph D. Aliotti	D685870	48	67.6'	107	3	80
Southern CA								
Eileen	Nick Jurlin	South Sound Fisheries, Inc.	D252749	38	79.4'	119.9	2	85
Trionfo	Neil Guglielmo	Aniello Guglielmo	D625449	45	63.8'	79.2	3	60
Endurance	Vince Lauro	Vincent Lauro	D613302	35	49'	42	3	40
Maria T	Robert Terzoli	Vito Terzoli	D509632	25	57.3'	68.1	3	65

Table 3. Sardine maturity codes. Source: Beverly Macewicz NMFS, SWFSC.

Female maturity codes	Male maturity codes
1. Clearly immature- ovary is very small; no oocytes present	1. Clearly immature- testis is very small thin, knifed-shaped with flat edge
2. Intermediate- individual oocytes not visible but ovary is not clearly immature; includes maturing and regressed ovaries	2. Intermediate- no milt evident and is not a clear immature; includes maturing or regressed testis
3. Active- yolked oocytes visible; any size or amount as long as you can see them with the unaided eye in ovaries	3. Active- milt is present; either oozing from pore, in the duct, or when testis is cut with knife.
4. Hydrated oocytes present; yolked oocytes may be present	

Table 4. Transect summary results, 2009 and 2010.

Coastwide		No. of Transects Sampled	No. of Schools	Avg. School Area (m2)	Total School Area (m2)	Total School Biomass (mt)
2009		41	1,033	9,853	10,178,228	85,371
2010	Rep A	63	642	775	497,841	12,597
	Rep B	59	230	1,198	275,467	5,719
	Rep C	60	618	572	353,198	9,633
	2010 Total	182	1,490	756	1,126,506	27,949

North		No. of Transects Sampled	No. of Schools	Avg. School Area (m2)	Total School Area (m2)	Total School Biomass (mt)
2010	Rep A	26	504	868	437,607	10,698
	Rep B	26	177	1,348	238,645	4,818
	Rep C	25	281	902	253,482	6,235
	2010 Total	77	962	966	929,734	21,752

South		No. of Transects Sampled	No. of Schools	Avg. School Area (m2)	Total School Area (m2)	Total School Biomass (mt)
2010	Rep A	37	138	436	60,234	1,899
	Rep B	33	53	695	36,822	901
	Rep C	35	337	296	99,716	3,398
	2010 Total	105	528	373	196,772	6,198

Table 5a. Transect detail, 2010 – SET A (north).

Transect	No. of Schools	Area (m^2)	Biomass (mt)	Date	Pilot	Start Dec. Longitude	Start Dec. Latitude	End Dec. Longitude	End Dec. Latitude	Transect Avg. Width (m)	Transect Length (km)
1	14	5706.5	207.4	8/22/2010	SP1	-124.7162	48.3327	-125.4720	48.3341	1822.8	55.8
2	36	26176.3	738.1	8/22/2010	SP1	-125.4842	48.0824	-124.7358	48.0847	1830.9	55.6
3	13	7728.8	241.0	8/23/2010	SP1	-124.5352	47.8329	-125.2817	47.8336	1806.6	55.7
4	36	27976.6	708.7	8/23/2010	SP1	-125.1432	47.5832	-124.3985	47.5845	1791.2	55.8
5	98	53222.7	1572.6	8/23/2010	SP1	-124.3320	47.3357	-125.0750	47.3345	1794.0	56.0
6	39	8239.3	355.2	8/23/2010	SP1	-124.9523	47.0825	-124.2160	47.0829	1792.7	55.7
7	2	450.8	20.7	8/23/2010	SP1	-124.1499	46.8333	-124.8818	46.8337	1800.0	55.6
8	11	3508.4	139.5	8/23/2010	SP1	-124.8472	46.5831	-124.1164	46.5823	1809.2	55.8
9	111	176658.4	3540.5	8/23/2010	SP1	-124.8269	46.3343	-124.1003	46.3340	1801.6	55.7
10	19	33378.6	668.9	8/23/2010	SP1	-123.9831	46.0822	-124.7022	46.0843	1792.0	55.4
11	46	37345.9	886.2	8/23/2010	SP1	-124.7071	45.8341	-123.9956	45.8344	1795.3	55.1
12	75	55153.8	1548.7	8/23/2010	SP1	-123.9795	45.5844	-124.6962	45.5841	1783.2	55.7
13	1	836.7	24.1	8/23/2010	SP1	-124.7218	45.3334	-124.0159	45.3381	1779.6	55.1
14	1	378.7	15.0	8/24/2010	SP1	-124.7577	45.0837	-124.0475	45.0825	1822.0	55.7
15	0	0.0	0.0	8/24/2010	SP1	-124.1132	44.8349	-124.8231	44.8336	1814.5	55.9
16	2	845.3	31.5	8/24/2010	SP1	-124.8156	44.5821	-124.1115	44.5831	1821.0	55.7
17	0	0.0	0.0	8/24/2010	SP1	-124.1645	44.3347	-124.8614	44.3342	1822.1	55.4
18	0	0.0	0.0	8/24/2010	SP1	-124.8803	44.0838	-124.1772	44.0822	1824.6	56.1
19	0	0.0	0.0	8/24/2010	SP1	-124.2123	43.8342	-124.9057	43.8327	1820.8	55.6
20	0	0.0	0.0	8/24/2010	SP1	-124.9572	43.5837	-124.2613	43.5832	1822.4	56.0
21	0	0.0	0.0	8/24/2010	SP1	-124.4276	43.3338	-125.1171	43.3339	1805.2	55.7
22	0	0.0	0.0	8/24/2010	SP1	-125.1636	43.0843	-124.4779	43.0833	1816.1	55.6
23	0	0.0	0.0	8/24/2010	SP1	-124.5965	42.8348	-125.2769	42.8335	1840.0	55.4
24	0	0.0	0.0	8/24/2010	SP1	-125.1270	42.5840	-124.4457	42.5868	1826.6	55.7
25	0	0.0	0.0	8/24/2010	SP1	-124.4771	42.3334	-125.1544	42.3334	1812.9	55.6
26	0	0.0	0.0	8/24/2010	SP1	-125.0203	42.0849	-124.3417	42.0837	1819.2	56.0

Table 5b. Transect detail, 2010 – SET A (south).

Transect	No. of Schools	Area (m^2)	Biomass (mt)	Date	Pilot	Start Dec. Longitude	Start Dec. Latitude	End Dec. Longitude	End Dec. Latitude	Transect Avg. Width (m)	Transect Length (km)
27	0	0.0	0.0	8/24/2010	SP5	-124.2600	41.8347	-124.9327	41.8348	1989.3	55.7
28	0	0.0	0.0	8/24/2010	SP5	-124.8153	41.5823	-124.1422	41.5838	2006.9	55.9
29	0	0.0	0.0	8/24/2010	SP5	-124.1060	41.3391	-124.7814	41.3342	2459.3	56.3
30	0	0.0	0.0	8/24/2010	SP5	-124.8563	41.0881	-124.1915	41.0838	2010.1	55.7
31	0	0.0	0.0	8/24/2010	SP5	-124.2380	40.8349	-124.8908	40.8373	1847.6	54.9
32	0	0.0	0.0	8/24/2010	SP5	-125.0314	40.5868	-124.3861	40.5828	2000.0	54.5
33	0	0.0	0.0	8/25/2010	SP5	-124.3771	40.3319	-124.4514	40.3404	2053.2	6.4
34	0	0.0	0.0	8/25/2010	SP5	-124.5937	40.0828	-124.1042	40.0831	1882.6	41.6
35	0	0.0	0.0	8/25/2010	SP5	-123.8948	39.8333	-124.4937	39.8403	1958.5	51.1
36	0	0.0	0.0	8/25/2010	SP5	-124.4461	39.5791	-123.8001	39.5772	1963.1	55.3
37	Not Sampled										
38	0	0.0	0.0	8/24/2010	SP4	-123.7268	39.0861	-124.3726	39.0806	1901.5	55.7
39	0	0.0	0.0	8/24/2010	SP4	-124.2881	38.8261	-123.6428	38.8329	1920.2	55.9
40	5	1854.2	72.3	8/24/2010	SP4	-123.3941	38.5823	-124.0354	38.5795	1932.8	55.7
41	0	0.0	0.0	8/24/2010	SP4	-123.7544	38.3344	-123.1060	38.3328	1904.7	56.5
42	0	0.0	0.0	8/25/2010	SP4	-122.9920	38.0853	-123.6324	38.0853	1903.8	56.0
43	0	0.0	0.0	8/25/2010	SP4	-123.1811	37.8349	-122.5432	37.8331	1909.1	56.0
44	0	0.0	0.0	8/25/2010	SP4	-122.5385	37.5878	-123.1757	37.5886	1923.5	56.1
45	5	885.9	43.4	8/25/2010	SP4	-123.0570	37.3357	-122.4236	37.3323	1919.4	56.0
46	0	0.0	0.0	8/25/2010	SP4	-122.3089	37.0832	-122.9390	37.0868	1883.6	55.9
47	0	0.0	0.0	8/25/2010	SP4	-122.4545	36.8352	-122.2702	36.8360	1887.2	16.4
48	Not Sampled										
49	Not Sampled (No GPS data)										
50	0	0.0	0.0	8/24/2010	SP3	-122.2803	36.0828	-121.6514	36.0844	1829.4	56.5
51	0	0.0	0.0	8/24/2010	SP3	-121.4344	35.8317	-122.0610	35.8335	1832.8	56.4
52	0	0.0	0.0	8/24/2010	SP3	-121.8243	35.5798	-121.1551	35.5849	1837.7	60.5
53	0	0.0	0.0	8/24/2010	SP3	-120.9194	35.3345	-121.5384	35.3308	1791.5	56.1
54	0	0.0	0.0	8/24/2010	SP3	-121.2712	35.0842	-120.6525	35.0826	1878.8	56.3
55	0	0.0	0.0	8/24/2010	SP3	-120.6492	34.8360	-121.2660	34.8344	1800.9	56.3
56	0	0.0	0.0	8/24/2010	SP3	-121.3030	34.5828	-120.7460	34.5840	1861.4	51.0
57	128	57493.8	1783.6	8/29/2010	SP6	-119.4397	34.3321	-120.0521	34.3370	1848.4	56.2
58	0	0.0	0.0	8/29/2010	SP6	-120.3533	34.3338	-120.6295	34.3273	1839.2	25.4
59	0	0.0	0.0	8/29/2010	SP6	-119.6809	34.0816	-119.0732	34.0825	1862.9	55.9
60	0	0.0	0.0	8/29/2010	SP6	-120.5783	34.0850	-119.9835	34.0842	1875.2	54.7
61	0	0.0	0.0	8/30/2010	SP3	-119.0455	33.8343	-118.4404	33.8336	1741.4	55.9
62	0	0.0	0.0	8/30/2010	SP3	-119.9538	33.8314	-119.3441	33.8344	1813.6	56.3
63	0	0.0	0.0	8/30/2010	SP3	-117.8736	33.5802	-118.4776	33.5829	1875.0	55.9
64	0	0.0	0.0	8/30/2010	SP3	-118.7785	33.5808	-119.3816	33.5843	1815.7	55.8
65	0	0.0	0.0	8/30/2010	SP3	-118.1393	33.3348	-117.5385	33.3343	1834.0	55.8
66	0	0.0	0.0	8/30/2010	SP3	-119.0440	33.3320	-118.4423	33.3333	1846.4	55.9

Table 5c. Transect detail, 2010 – SET B (north).

Transect	No. of Schools	Area (m^2)	Biomass (mt)	Date	Pilot	Start Dec. Longitude	Start Dec. Latitude	End Dec. Longitude	End Dec. Latitude	Transect Avg. Width (m)	Transect Length (km)
1	0	0.0	0.0	8/28/2010	SP1	-124.7513	48.2514	-125.5041	48.2508	1784.8	55.7
2	0	0.0	0.0	8/28/2010	SP1	-125.4712	47.9979	-124.7180	48.0014	1795.9	56.0
3	0	0.0	0.0	9/2/2010	SP1	-124.4648	47.7504	-125.2193	47.7511	1832.4	56.4
4	23	8200.7	286.2	9/2/2010	SP1	-125.1312	47.5015	-124.3826	47.5015	1840.6	56.2
5	16	9077.7	269.4	9/2/2010	SP1	-124.2666	47.2510	-125.0064	47.2506	1829.1	55.8
6	51	124146.5	2095.1	9/2/2010	SP1	-124.9532	47.0013	-124.2143	46.9949	1819.2	56.0
7	35	43608.9	893.3	9/2/2010	SP1	-124.1478	46.7508	-124.8687	46.7500	1822.2	54.9
8	33	38619.3	859.7	9/2/2010	SP1	-124.8255	46.4999	-124.0978	46.4950	1801.9	55.7
9	5	6977.6	150.7	9/2/2010	SP1	-124.0815	46.2506	-124.8084	46.2515	1796.9	55.9
10	0	0.0	0.0	9/2/2010	SP1	-124.7085	46.0001	-123.9809	45.9999	1789.4	56.2
11	0	0.0	0.0	9/2/2010	SP1	-123.9951	45.7491	-124.7182	45.7510	1796.5	56.1
12	0	0.0	0.0	9/2/2010	SP1	-124.7208	45.4991	-123.9943	45.4984	1793.6	56.6
13	0	0.0	0.0	9/3/2010	SP1	-123.9973	45.2528	-124.5284	45.2506	1804.6	41.5
14	6	3156.8	107.1	9/3/2010	SP1	-124.7755	44.9972	-124.0623	45.0002	1817.2	56.0
15	8	4857.7	156.8	9/3/2010	SP1	-124.0980	44.7515	-124.4985	44.7493	1811.6	31.6
16	0	0.0	0.0	9/3/2010	SP1	-124.8196	44.4981	-124.1140	44.4981	1832.6	55.9
17	0	0.0	0.0	9/3/2010	SP1	-124.1442	44.2518	-124.8481	44.2497	1820.7	56.0
18	0	0.0	0.0	9/3/2010	SP1	-124.8823	43.9994	-124.1776	44.0008	1820.2	56.3
19	0	0.0	0.0	9/4/2010	SP1	-124.2279	43.7516	-124.9245	43.7503	1831.7	55.9
20	0	0.0	0.0	9/4/2010	SP1	-125.0061	43.4999	-124.3133	43.4994	1835.3	55.8
21	0	0.0	0.0	9/4/2010	SP1	-124.4427	43.2509	-125.1367	43.2499	1844.6	56.2
22	0	0.0	0.0	9/4/2010	SP1	-125.2030	43.0005	-124.5097	43.0008	1836.9	56.3
23	0	0.0	0.0	9/4/2010	SP1	-124.5606	42.7499	-125.2496	42.7499	1834.7	56.2
24	0	0.0	0.0	9/4/2010	SP1	-125.1466	42.5002	-124.4582	42.5016	1834.0	56.4
25	0	0.0	0.0	9/4/2010	SP1	-124.4438	42.2506	-125.1260	42.2501	1829.0	56.1
26	0	0.0	0.0	9/4/2010	SP1	-124.9218	42.0005	-124.2443	42.0005	1822.4	55.9

Table 5d. Transect detail, 2010 – SET B (south).

Transect	No. of Schools	Area (m^2)	Biomass (mt)	Date	Pilot	Start Dec. Longitude	Start Dec. Latitude	End Dec. Longitude	End Dec. Latitude	Transect Avg. Width (m)	Transect Length (km)
27	Not Sampled (No GPS data)			8/31/2010	SP3						
28	Not Sampled (No GPS data)			8/31/2010	SP3						
29	0	0.0	0.0	8/31/2010	SP3	-124.1416	41.2517	-124.4802	41.2470	1882.7	28.3
30	Not Sampled (No GPS data)			8/31/2010	SP3						
31	Not Sampled (No GPS data)			8/31/2010	SP3						
32	Not Sampled (No GPS data)			8/31/2010	SP3						
33	Not Sampled (No GPS data)			8/31/2010	SP3						
34	Not Sampled (No GPS data)			8/31/2010	SP3						
35	0	0.0	0.0	9/1/2010	SP3	-123.8597	39.7539	-124.5077	39.7495	1885.0	55.4
36	0	0.0	0.0	9/1/2010	SP3	-124.4518	39.5044	-123.8294	39.4927	1858.2	53.4
37	0	0.0	0.0	9/2/2010	SP3	-123.8258	39.2512	-124.4756	39.2504	1861.1	55.9
38	0	0.0	0.0	9/2/2010	SP3	-124.3721	39.0092	-123.7237	39.0003	1865.5	56.0
39	0	0.0	0.0	9/2/2010	SP3	-123.5565	38.7511	-124.2046	38.7495	1872.3	56.2
40	0	0.0	0.0	9/2/2010	SP3	-123.8849	38.5046	-123.2389	38.5000	1879.0	56.2
41	0	0.0	0.0	9/2/2010	SP3	-122.9905	38.2492	-123.6048	38.2488	1892.7	53.6
42	0	0.0	0.0	9/2/2010	SP3	-123.6457	38.0045	-123.0388	38.0011	1910.2	53.1
43	0	0.0	0.0	9/6/2010	SP3	-123.1607	37.7545	-122.5237	37.7508	1847.4	56.0
44	0	0.0	0.0	9/6/2010	SP3	-122.4882	37.5006	-123.1263	37.5004	1878.5	56.2
45	0	0.0	0.0	9/6/2010	SP3	-123.0578	37.2676	-122.4240	37.2511	1890.5	56.1
46	47	33142.3	784.5	9/6/2010	SP5	-122.2045	36.9874	-122.8383	36.9984	1803.3	56.3
47	0	0.0	0.0	9/6/2010	SP5	-122.4698	36.7505	-121.8362	36.7424	1873.6	56.4
48	0	0.0	0.0	9/6/2010	SP5	-121.9580	36.4977	-122.5739	36.4977	1878.8	55.0
49	0	0.0	0.0	9/6/2010	SP5	-122.4319	36.2484	-121.9224	36.2448	1814.2	45.7
50	0	0.0	0.0	9/6/2010	SP5	-121.7549	35.9943	-122.0724	35.9999	1895.6	28.5
51	0	0.0	0.0	9/9/2010	SP3	-121.7089	35.7464	-121.3584	35.7507	1802.8	31.6
52	0	0.0	0.0	9/9/2010	SP3	-121.0980	35.4961	-121.5557	35.4984	1876.5	41.4
53	0	0.0	0.0	9/9/2010	SP3	-121.2910	35.2530	-120.9206	35.2514	1798.8	33.6
54	0	0.0	0.0	9/9/2010	SP3	-120.6746	34.9932	-121.1157	34.9948	1806.3	40.2
55	2	890.7	33.1	9/9/2010	SP3	-120.9747	34.7507	-120.6626	34.7510	1839.2	28.5
56	0	0.0	0.0	9/9/2010	SP3	-121.1321	34.4988	-120.6405	34.4995	1821.5	45.0
57	1	735.5	22.4	9/9/2010	SP3	-119.9141	34.2501	-119.3046	34.2491	1785.8	56.0
58	0	0.0	0.0	9/9/2010	SP3	-120.8258	34.2532	-120.2165	34.2486	1794.1	56.0
59	0	0.0	0.0	9/9/2010	SP3	-118.8561	33.9976	-119.4626	33.9997	1850.5	55.9
60	0	0.0	0.0	9/9/2010	SP3	-119.7659	34.0006	-120.3702	34.0003	1830.6	55.7
61	2	871.5	31.0	9/9/2010	SP3	-119.0595	33.7503	-118.4537	33.7508	1797.7	56.0
62	0	0.0	0.0	9/9/2010	SP3	-119.9691	33.7507	-119.3635	33.7487	1846.5	56.0
63	0	0.0	0.0	9/9/2010	SP3	-117.7862	33.5004	-118.3942	33.5004	1851.5	56.3
64	0	0.0	0.0	9/9/2010	SP3	-118.6939	33.4985	-119.2976	33.4980	1833.3	55.9
65	1	1181.9	29.6	9/9/2010	SP3	-118.0722	33.2499	-117.4712	33.2508	1855.3	55.9
66	0	0.0	0.0	9/9/2010	SP3	-118.9734	33.2473	-118.3716	33.2509	1844.0	55.9

Table 5e. Transect detail, 2010 – SET C (north).

Transect	No. of Schools	Area (m^2)	Biomass (mt)	Date	Pilot	Start Dec. Longitude	Start Dec. Latitude	End Dec. Longitude	End Dec. Latitude	Transect Avg. Width (m)	Transect Length (km)
1	1	1194.3	29.7	8/13/2010	SP1	-124.7678	48.1683	-125.5197	48.1674	55.7	1899.5
2	26	39514.0	836.9	8/13/2010	SP1	-124.6660	47.9131	-125.4135	47.9156	55.7	1883.8
3	84	73401.7	1833.0	8/13/2010	SP1	-125.1616	47.6674	-124.4182	47.6663	55.6	1894.1
4	30	17194.1	507.3	8/13/2010	SP1	-124.3685	47.4153	-125.1081	47.4148	55.6	1888.9
5	44	15374.0	591.1	8/13/2010	SP1	-124.9724	47.1662	-124.2325	47.1650	55.9	1872.6
6	16	3605.8	158.0	8/13/2010	SP1	-124.1822	46.9168	-124.9160	46.9177	55.7	1888.2
7	0	0.0	0.0	8/13/2010	SP1	-124.8406	46.6679	-124.1148	46.6665	55.3	1857.3
8	7	6326.1	171.5	8/19/2010	SP1	-124.0978	46.4182	-124.8265	46.4153	55.8	1800.5
9	0	0.0	0.0	8/19/2010	SP1	-124.7412	46.1661	-124.0155	46.1668	55.8	1806.0
10	1	175.8	8.9	8/19/2010	SP1	-124.0128	45.9166	-124.7364	45.9161	55.9	1816.5
11	5	4052.2	107.8	8/20/2010	SP1	-123.9657	45.6679	-124.6831	45.6679	55.7	1802.1
12	50	74188.2	1570.8	8/20/2010	SP1	-124.7123	45.4165	-123.9973	45.4169	55.8	1813.4
13	9	13046.5	276.8	8/20/2010	SP1	-124.0141	45.1678	-124.7253	45.1686	55.7	1831.5
14	0	0.0	0.0	8/20/2010	SP1	-124.7695	44.9147	-124.0621	44.9157	55.7	1828.0
15	0	0.0	0.0	8/20/2010	SP1	-124.0969	44.6668	-124.8003	44.6676	55.6	1833.7
16	0	0.0	0.0	8/20/2010	SP1	-124.8236	44.4204	-124.1294	44.4159	55.1	1810.0
17	0	0.0	0.0	8/20/2010	SP1	-124.1606	44.1678	-124.8629	44.1688	56.0	1827.2
18	0	0.0	0.0	8/20/2010	SP1	-124.8929	43.9173	-124.1936	43.9159	56.0	1816.4
19	0	0.0	0.0	8/20/2010	SP1	-124.2479	43.6667	-124.9403	43.6692	55.7	1819.6
20	0	0.0	0.0	8/20/2010	SP1	-125.0545	43.4165	-124.3606	43.4184	56.0	1826.7
21	0	0.0	0.0	8/20/2010	SP1	-124.4600	43.1686	-125.1490	43.1638	55.8	1822.8
22	0	0.0	0.0	8/20/2010	SP1	-125.2454	42.9152	-124.5627	42.9146	55.6	1794.5
23	Not Sampled										
24	8	5409.1	143.5	8/22/2010	SP5	-124.4628	42.4170	-125.0160	42.4111	45.4	1965.7
25	0	0.0	0.0	8/22/2010	SP5	-125.0904	42.1664	-124.4101	42.1673	56.0	1909.1
26	0	0.0	0.0	8/22/2010	SP5	-124.2301	41.9171	-124.8615	41.9095	52.2	1879.8

Table 5f. Transect detail, 2010 – SET C (south).

Transect	No. of Schools	Area (m^2)	Biomass (mt)	Date	Pilot	Start Dec. Longitude	Start Dec. Latitude	End Dec. Longitude	End Dec. Latitude	Transect Avg. Width (m)	Transect Length (km)
27	0	0.0	0.0	8/22/2010	SP5	-124.8363	41.6735	-124.1600	41.6630	56.1	1921.4
28	0	0.0	0.0	8/22/2010	SP5	-124.0922	41.4193	-124.7642	41.4163	56.0	1826.7
29	0	0.0	0.0	8/22/2010	SP5	-124.7951	41.1686	-124.1725	41.1204	52.4	1823.0
30	0	0.0	0.0	8/22/2010	SP5	-124.1725	40.9196	-124.7212	40.9167	46.1	1941.8
31	0	0.0	0.0	8/22/2010	SP5	-124.7597	40.6691	-124.3256	40.6687	36.6	1844.7
32	Not Sampled										
33	0	0.0	0.0	8/23/2010	SP5	-124.2426	40.1669	-124.7294	40.1670	41.3	1950.9
34	0	0.0	0.0	8/23/2010	SP5	-124.6165	39.9298	-123.9577	39.9068	56.2	1826.6
35	0	0.0	0.0	8/23/2010	SP5	-123.8245	39.6671	-124.3395	39.6685	44.0	1942.8
36	0	0.0	0.0	8/23/2010	SP5	-124.3809	39.4194	-123.8406	39.4195	46.4	1834.5
37	0	0.0	0.0	8/23/2010	SP5	-123.7801	39.1647	-124.3114	39.1662	45.8	1902.9
38	0	0.0	0.0	8/23/2010	SP5	-124.2689	38.9207	-123.7401	38.9123	45.7	1950.0
39	0	0.0	0.0	8/23/2010	SP5	-123.4748	38.6624	-123.8826	38.6700	35.4	1539.3
40	Not Sampled										
41	Not Sampled										
42	3	3688.7	88.4	8/22/2010	SP3	-122.7565	37.9148	-123.3992	37.9194	56.3	1886.3
43	0	0.0	0.0	8/22/2010	SP3	-123.1619	37.6563	-122.5262	37.6679	55.9	1850.5
44	0	0.0	0.0	8/22/2010	SP3	-122.4594	37.4140	-123.0920	37.4151	55.8	1847.0
45	0	0.0	0.0	8/22/2010	SP3	-123.0386	37.1656	-122.4055	37.1669	56.1	1849.6
46	201	54185.8	1885.6	8/23/2010	SP4	-121.8914	36.9150	-122.5207	36.9085	55.9	1876.6
47	3	9220.5	163.4	8/23/2010	SP4	-122.4863	36.6597	-121.8563	36.6685	56.2	1870.5
48	0	0.0	0.0	8/23/2010	SP4	-121.9259	36.4088	-122.5466	36.4131	55.5	1875.3
49	24	1163.0	69.7	8/23/2010	SP4	-122.3150	36.1648	-121.6960	36.1686	55.5	1878.4
50	0	0.0	0.0	8/23/2010	SP4	-121.4898	35.9146	-122.1117	35.9176	56.0	1870.0
51	0	0.0	0.0	8/23/2010	SP4	-121.9471	35.6850	-121.3202	35.6636	56.6	1859.7
52	0	0.0	0.0	8/23/2010	SP4	-120.9070	35.4186	-121.5218	35.4159	55.7	1932.3
53	0	0.0	0.0	8/23/2010	SP4	-121.4219	35.1608	-120.8076	35.1624	55.8	1835.0
54	0	0.0	0.0	8/23/2010	SP4	-120.7067	34.9099	-121.3236	34.9117	56.2	1893.8
55	0	0.0	0.0	8/23/2010	SP3	-120.7229	34.6704	-121.2698	34.6667	50.0	1812.1
56	Not Sampled										
57	0	0.0	0.0	8/22/2010	SP6	-119.2694	34.1642	-119.8822	34.1798	56.4	1879.0
58	0	0.0	0.0	8/22/2010	SP6	-120.1807	34.1765	-120.7906	34.1666	56.1	1912.3
59	Not Sampled									17.9	1806.4
60	0	0.0	0.0	8/22/2010	SP6	-119.9869	33.9164	-119.3794	33.9148	14.6	546.0
61	27	14007.8	444.3	8/23/2010	SP3	-118.6439	33.6674	-118.0369	33.6685	56.0	1883.6
62	0	0.0	0.0	8/23/2010	SP3	-119.5534	33.6685	-118.9474	33.6614	56.1	1859.0
63	38	6760.1	319.5	8/23/2010	SP3	-117.6560	33.4152	-118.2569	33.4091	56.1	1830.0
64	0	0.0	0.0	8/23/2010	SP3	-118.5570	33.4105	-119.1608	33.4174	55.7	1831.6
65	17	6546.3	232.9	8/23/2010	SP6	-117.4074	33.1603	-118.0068	33.1729	56.0	1844.0
66	24	4143.9	194.1	8/23/2010	SP6	-118.3069	33.1681	-118.9040	33.1624	55.8	1891.1

Table 6. Point set data detail for the north in 2010.

Point Set No.	Date	Vessel	Additional Vessel Utilized	Fish Ticket No.	Survey Pilot	Dec. Latitude	Dec. Longitude	Total Sardine (lbs)	Total Pacific Mackerel (lbs)	Total Landed Wt. (lbs)	% Sardine	Area (m²)	Status
1	8/20/2010	Pacific Pursuit		4925269	SP2	46.5919	-124.4220	177,270	1405	178,675	99.2%	1867.5	Acceptable - Measured
2	8/20/2010	Lauren L Kapp		4925270	SP2	46.5788	-124.4133	168,281	207	168,488	99.9%	1987.6	Acceptable - Measured
3	8/21/2010	Pacific Pursuit		4925271	SP2	46.3801	-124.3364	155,218	1761	156,979	98.9%	2774.0	Flown at 1000 feet
4	8/21/2010	Pacific Knight		4925273	SP2	46.3522	-124.3502	113,295	363	113,658	99.7%	2135.8	Acceptable - Measured
5	8/21/2010	Lauren L Kapp		4925272	SP2	46.3580	-124.3366	70,069	241	70,310	99.7%	1840.5	Acceptable - Measured
6	8/21/2010	Lauren L Kapp		4925272	SP2	46.3393	-124.2927	61,603	385	61,988	99.4%	N/A	No approach photograph
7	8/22/2010	Pacific Pursuit	Lauren L Kapp	4925274	SP2	46.1269	-124.3272	249,646	1025	250,671	99.6%	2674.6	Acceptable - Measured
8	8/22/2010	Pacific Knight		4925276	SP2	46.1544	-124.4091	88,517	856	89,373	99.0%	N/A	Percent captured
9	8/22/2010	Lauren L Kapp		4925275	SP2	46.1704	-124.4191	35,950	659	36,609	98.2%	N/A	Not visible: clouds
10	8/23/2010	Pacific Pursuit		4925277	SP2	46.1452	-124.3410	132,025	3636	135,661	97.3%	2676.3	Acceptable - Measured
11	8/23/2010	Lauren L Kapp		4925278	SP2	46.1512	-124.3525	112,674	389	113,063	99.7%	2087.9	Acceptable - Measured
12	8/23/2010	Pacific Pursuit	Pacific Knight	4925277, 4925279	SP2	46.1481	-124.3432	132,317	1548	133,865	98.8%	1876.3	Acceptable - Measured
13	8/24/2010	Pacific Pursuit		4925280	SP2	46.1954	-124.5371	105,027	1958	106,985	98.2%	3660.7	Acceptable - Measured
14	8/24/2010	Lauren L Kapp		4925281	SP2	46.1888	-124.5485	101,036	491	101,527	99.5%	2570.5	Acceptable - Measured
15	8/26/2010	Pacific Pursuit		4925282	SP2	46.3584	-124.4748	115,460	245	115,705	99.8%	N/A	School not visible: mixed haul
16	8/26/2010	Lauren L Kapp		4925283	SP2	46.3672	-124.4742	166,046	209	166,255	99.9%	3892.2	Acceptable - Measured
17	8/26/2010	Pacific Knight		4925284	SP2	46.3026	-124.4822	85,619	1063	86,682	98.8%	2792.2	Acceptable - Measured
18	8/26/2010	Pacific Pursuit		4925282	SP2	46.2956	-124.4544	61,654	245	61,899	99.6%	1389.0	Measured: mixed haul
19	8/27/2010	Pacific Pursuit	Lauren L Kapp	4925285, 4925286	SP2	46.3205	-124.5086	307,174	197	307,371	99.9%	3167.2	Acceptable - Measured
20	8/27/2010	Pacific Knight		4925287	SP2	46.3061	-124.5076	72,201	28	72,229	100.0%	775.2	Acceptable - Measured
21	8/29/2010	Pacific Pursuit		4925288	SP2	46.6722	-124.4356	177,995	1301	179,296	99.3%	817.7	Acceptable - Measured
22	8/29/2010	Pacific Knight	Lauren L Kapp	4925290, 4925289	SP2	46.6776	-124.4353	180,429	269	180,698	99.9%	2044.2	Acceptable - Measured
23	8/29/2010	Lauren L Kapp		4925289	SP2	46.6637	-124.3964	70,528	0	70,528	100.0%	1112.9	Acceptable - Measured
24	8/30/2010	Pacific Knight		4925293	SP2	46.4264	-124.3645	99,123	165	99,288	99.8%	N/A	Not visible: clouds
25	8/30/2010	Lauren L Kapp		4925292	SP2	46.4980	-124.5095	167,643	87	167,730	99.9%	1764.6	Acceptable - Measured
26	8/30/2010	Pacific Pursuit		4925291	SP2	46.5232	-124.5292	88,814	116	88,930	99.9%	1792.1	Acceptable - Measured
27	8/30/2010	Pacific Pursuit		4925291	SP2	46.5201	-124.4582	68,459	246	68,705	99.6%	1528.7	Acceptable - Measured
28	9/1/2010	Lauren L Kapp		4925295	SP2	46.4363	-124.4109	118,491	87	118,578	99.9%	953.4	Acceptable - Measured
29	9/1/2010	Pacific Pursuit		4925294	SP2	46.4575	-124.3985	149,643	91	149,734	99.9%	1672.5	Acceptable - Measured
30	9/1/2010	Pacific Knight		4925296	SP2	46.4323	-124.4201	73,121	158	73,279	99.8%	1635.6	Acceptable - Measured
31	9/2/2010	Pacific Pursuit		4925297	SP2	46.6157	-124.2861	149,551	356	149,907	99.8%	7461.5	Acceptable - Measured
32	9/2/2010	Lauren L Kapp		4925298	SP2	46.6318	-124.2652	96,225	257	96,482	99.7%	N/A	Unable to determine school
33	9/4/2010	Pacific Pursuit		4925299	SP2	46.6111	-124.3237	91,829	205	92,034	99.8%	N/A	Unable to determine school
34	9/4/2010	Lauren L Kapp	Pacific Knight	4925300, 4925301	SP2	46.5819	-124.3235	213,613	229	213,842	99.9%	3470.3	Acceptable - Measured
35	9/6/2010	Lauren L Kapp		4925303	SP2	45.9297	-124.3302	77,336	100	77,436	99.9%	1870.1	Flown at 1000 feet
36	9/6/2010	Pacific Pursuit		4925302	SP2	45.9384	-124.3021	79,195	177	79,372	99.8%	1514.6	Flown at 1000 feet
37	9/14/2010	Pacific Knight	Lauren L Kapp	4925305, 4925304	SP2	46.4835	-124.4683	118,645	240	118,885	99.8%	N/A	No photos available

Table 7. Point set data detail for the south in 2010.

Point Set No.	Date	Vessel	Additional Vessel Utilized	Fish Ticket No.	Survey Pilot	Dec. Latitude	Dec. Longitude	Total Sardine (lbs)	Total Pacific Mackerel (lbs)	Other Species (lbs)	Total Landed Wt. (lbs)	% Sardine
1	8/9/2010	Eileen		W324597	SP6	34.2440	-119.3109	10,692	0	0	10,692	100.0%
2	8/12/2010	Trionfo		W317881	SP6	33.9667	-119.5833	88,584	0	0	88,584	100.0%
3	8/12/2010	Eileen		W325559	SP6	33.9668	-119.5833	56,750	0	0	56,750	100.0%
4	8/16/2010	Trionfo		W318964	SP6	34.1510	-119.5274	84,962	0	0	84,962	100.0%
5	8/17/2010	Maria T		W319004	SP6	33.3333	-118.4833	24,010	3222	0	27,232	88.2%
6	8/17/2010	Eileen		W325565	SP6	33.3167	-118.4500	22,286	2824	0	25,110	88.8%
7	8/18/2010	Maria T		W319007	SP6	33.4167	-118.6167	14,832	4	0	14,836	100.0%
8	8/18/2010	Eileen		W325567	SP6	33.4168	-118.5334	33,868	1338	0	35,206	96.2%
9	8/18/2010	Eileen		W325566	SP6	33.4333	-118.5668	32,986	5747	0	38,733	85.2%
10	8/18/2010	Maria T		W319006	SP6	33.4333	-118.5667	39,502	5387	0	44,889	88.0%
11	8/19/2010	Eileen		W325569	SP6	33.4627	-118.5958	6,269	0	0	6,269	100.0%
12	8/19/2010	Eileen		W325570	SP6	33.4621	-118.5995	21,198	0	0	21,198	100.0%
13	8/22/2010	Eileen		W325572	SP6	33.4178	-118.5056	32,747	0	0	32,747	100.0%
14	8/23/2010	Maria T		W319013	SP6	33.6708	-118.0711	23,675	0	0	23,675	100.0%
15	8/23/2010	Eileen		W325573	SP6	33.6912	-118.0577	44,162	0	0	44,162	100.0%
16	8/31/2010	Eileen		W317887	SP6	33.9846	-119.5952	129,430	0	0	129,430	100.0%
17	8/31/2010	Maria T		W318989	SP6	33.9802	-119.6465	96,899	0	0	96,899	100.0%
18	8/31/2010	Eileen	Maria T	W317885 W317886	SP6	33.9633	-119.6979	69,061	0	0	69,061	100.0%
19	9/1/2010	Eileen		W317890	SP6	34.0158	-119.5326	148,612	0	0	148,612	100.0%
20	9/1/2010	Maria T		W318993	SP6	34.0175	-119.5367	99,282	0	0	99,282	100.0%
21	9/7/2010	Eileen		W317892	SP6	34.0005	-119.5333	157,431	0	0	157,431	100.0%
22	9/8/2010	Eileen		W317893	SP6	34.0145	-119.5358	85,594	0	0	85,594	100.0%
23	9/8/2010	Maria T		W319000	SP6	34.0180	-119.5357	52,797	0	0	52,797	100.0%
24	9/9/2010	Eileen		W317894	SP6	34.0288	-119.6072	169,215	0	0	169,215	100.0%
25	9/9/2010	Maria T		W319126	SP6	34.0123	-119.5113	103,223	0	0	103,223	100.0%
26	9/10/2010	Maria T		W319127	SP6	34.0251	-119.6088	123,644	0	0	123,644	100.0%
27	9/10/2010	Eileen		W317895	SP6	34.0275	-119.6086	187,164	0	0	187,164	100.0%
28	9/12/2010	Maria T		W319128	SP6	34.0136	-119.5346	111,389	0	0	111,389	100.0%
29	9/12/2010	Eileen		W317896	SP6	34.0159	-119.5288	186,454	0	0	186,454	100.0%
30	9/13/2010	Eileen		W317898	SP6	34.0188	-119.5350	44,504	800	0	45,304	98.2%
31	9/13/2010	Maria T		W319132	SP6	34.0127	-119.5353	89,237	901	0	90,138	99.0%
32	9/13/2010	Eileen		W317898	SP6	34.0168	-119.5380	141,510	1000	0	142,510	99.3%
33	9/14/2010	Eileen		W320403	SP6	34.0167	-119.5317	162,478	0	66	162,544	100.0%
34	9/14/2010	Maria T		W319134	SP6	34.0167	-119.5167	35,040	715	0	35,755	98.0%

Table 8. Point set data from the 2010 survey used for the area-biomass analysis (north).

Point Set No.	Sardine wt (mt)	Area (m^2)	Density (mt/m^2)
1	80.4	1867.5	0.0431
2	76.3	1987.6	0.0384
4	51.4	2135.8	0.0241
5	31.8	1840.5	0.0173
7	113.2	2674.6	0.0423
10	59.9	2676.3	0.0224
11	51.1	2087.9	0.0245
12	60.0	1876.3	0.0320
13	47.6	3660.7	0.0130
14	45.8	2570.5	0.0178
16	75.3	3892.2	0.0194
17	38.8	2792.2	0.0139
19	139.3	3167.2	0.0440
20	32.7	775.2	0.0422
21	80.7	817.7	0.0987
22	81.8	2044.2	0.0400
23	32.0	1112.9	0.0287
25	76.0	1764.6	0.0431
26	40.3	1792.1	0.0225
27	31.1	1528.7	0.0203
28	53.7	953.4	0.0564
30	33.2	1635.6	0.0203
31	67.8	7461.5	0.0091
34	96.9	3470.3	0.0279

Table 9. Point set data from the 2010 survey used for the area-biomass analysis (south).

Point Set No.	Sardine wt (mt)	Area (m^2)	Density (mt/m^2)
1	4.8	546.0	0.0089
5	10.9	2033.3	0.0054
8	15.4	311.8	0.0493
9	15.0	1482.4	0.0101
10	17.9	127.6	0.1404
11	2.8	620.1	0.0046
12	9.6	799.6	0.0120
13	14.9	455.1	0.0326
14	10.7	2133.6	0.0050
15	20.0	2187.1	0.0092
16	58.7	2488.0	0.0236
17	44.0	673.2	0.0653
18	31.3	2144.3	0.0146
25	46.8	1787.1	0.0262
26	56.1	1828.9	0.0307
30	20.2	618.2	0.0327
31	40.5	1147.7	0.0353

Table 10. Likelihood ratio tests for MM model fits to the point set data.

Comparision of data from the north used in the 2009 analysis with the new 2010 data from the north:

Model Data	Data File Name	Model Name	Log Likelihood	df
(north 2008;2009 pooled)	cdata	mmfit	-28.26	33
(north 2010)	cdata2010n	mmfita	-11.46	21
(north 2008;2009;2010 pooled)	cdata2010np	mmfitb	-44.50	57
		LLcombined	-44.50	57
		LLseparate	-39.73	54

(LLseparate - LLcombined) =	4.76996845	
Chi Sq (df=3) P =	0.189	->Fail to reject H_o at 0.05 significance level.

Comparision of all data from the north (pooled) with the new 2010 data from the south:

Model Data	Data File Name	Model Name	Log Likelihood	df
(north 2008;2009;2010 pooled)	cdata2010np	mmfitb	-44.50	57
(south 2010)	cdata2010s	mmfitc	-19.75	14
(all data pooled)	cdata2010nsp	mmfitd	-73.28	74
		LLcombined	-73.28	74
		LLseparate	-64.24	71

(LLseparate - LLcombined) =	9.03413383	
Chi Sq (df=3) P =	0.029	->Reject H_o at 0.05 significance level.

Table 11. Estimates of total biomass and CV from the 2010 aerial sardine survey.

Region	Point Set Data File	Biomass Estimate (mt)		CV	Area-Biomass Calibration Parameters		
					asymp	yint	cc
Coastwide	cdata2010nsp	Total	138,379	0.30	0.0119	0.0707	338.0
		Rep A	176,561				
		Rep B	86,850				
		Rep C	151,726				
North (asymp = 0.001)	cdata2010np	Total	105,738	0.44	0.001 (bound)	0.0435	2375.5
		Rep A	157,749				
		Rep B	62,314				
		Rep C	97,150				
North (asymp = 0.005)	cdata2010np	Total	108,851	0.40	0.005 (bound)	0.0464	1649.4
		Rep A	161,448				
		Rep B	66,656				
		Rep C	98,450				
South	cdata2010s	Total	27,695	0.72	0.0061	0.1392	100.0 (bound)
		Rep A	21,511				
		Rep B	10,767				
		Rep C	50,806				
2009 (asymp = 0.001)	cdata2010np		794,159	2.08	0.001 (bound)	0.0435	2375.5
2009 (asymp = 0.005)	cdata2010np		1,247,250	1.12	0.005 (bound)	0.0464	1649.4
2009	cdata2010nsp		2,000,618	0.66	0.0119	0.0707	338.0
2009	cdata (2009)		1,236,911	1.12	0.0057	0.0455	1187.5

Table 11a. Estimates of total biomass and CV from the 2010 aerial sardine survey – Runs conducted at the STAR Panel meeting, 10-5-2010.

Region	Point Set Data File	Biomass Estimate (mt)		CV	Area-Biomass Calibration Parameters		
					asymp	yint	cc
Runs conducted at the STAR panel meeting 10-5-2010							
North	cdata2010n	Total	173,390	0.42	0.0057	0.2020	257.5
		Rep A	263,331				
		Rep B	100,626				
		Rep C	156,214				
South	cdata2010s	Total	27,695	0.56	0.0061	0.1392	100.0 (bound)
		Rep A	21,511				
		Rep B	10,767				
		Rep C	50,806				

Table 12. Results from the analysis of photographs of known-size objects, collected to evaluate photogrammetric error.

Pilot	No. of Photographs Analyzed	No. of Measurements Made	Average % Deviance	Min Altitude (ft)	Max Altitude (ft)
SP1	10	195	4.8%	1017	4022
SP2	12	240	7.5%	918	4026
SP3	2	40	11.4%	1423	1430
SP4	17	200	5.7%	1066	4482
SP5	11	55	3.0%	1086	4307
SP6			data not available		

Table 13. Rate of agreement between photo analysts engaged in the activity of finding fish schools on photographs (results from blind comparisons of independent measurements).

Transect Replicate	No. of Photographs	Average % Agreement (per transect)	Min. % Agreement (per transect)	Max. % Agreement (per transect)
SET A	7647	98.2%	86.8%	100.0%
SET B	7774	98.5%	88.9%	100.0%
SET C	7457	97.0%	76.4%	100.0%

Table 14. Summary of point sets landed in 2010, by size category.

Weight (mt)	No. Planned	North	South
3.8	8	0	1
10.6	8	0	3
17.0	8	1	6
26.5	8	0	6
51.9	8	19	9
70.5	8	7	4
82.1	8	7	3
95.0	0	0	2
115.0	0	2	0
140.0	0	1	0
	56	37	34

Figure 1. Histograms of school surface area (m^2) from 2009 and 2010 transect sampling.

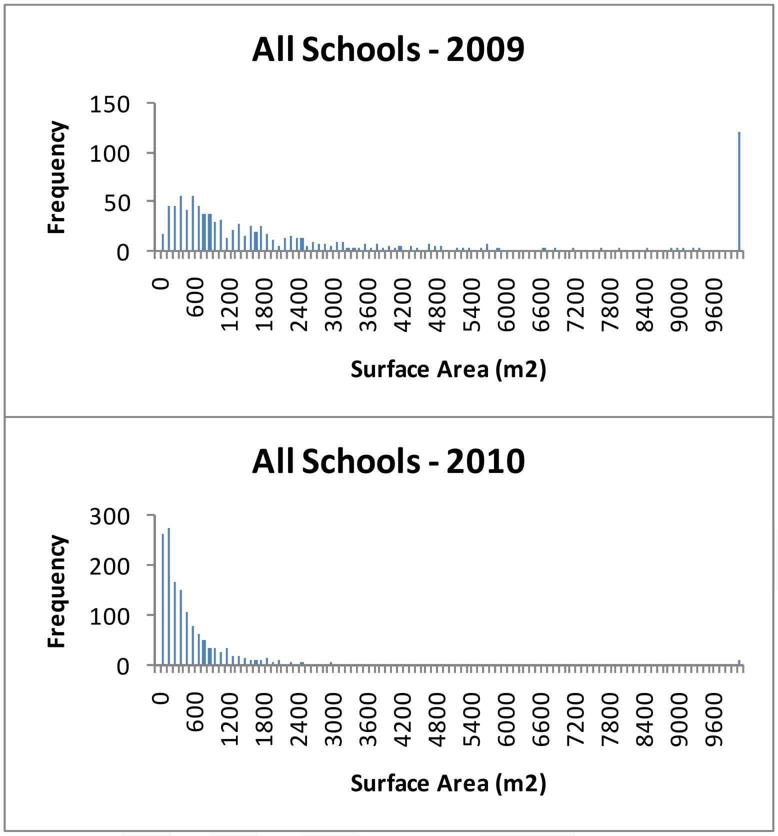


Figure 2. Histograms of school surface area (m^2) from transect sampling in 2010.

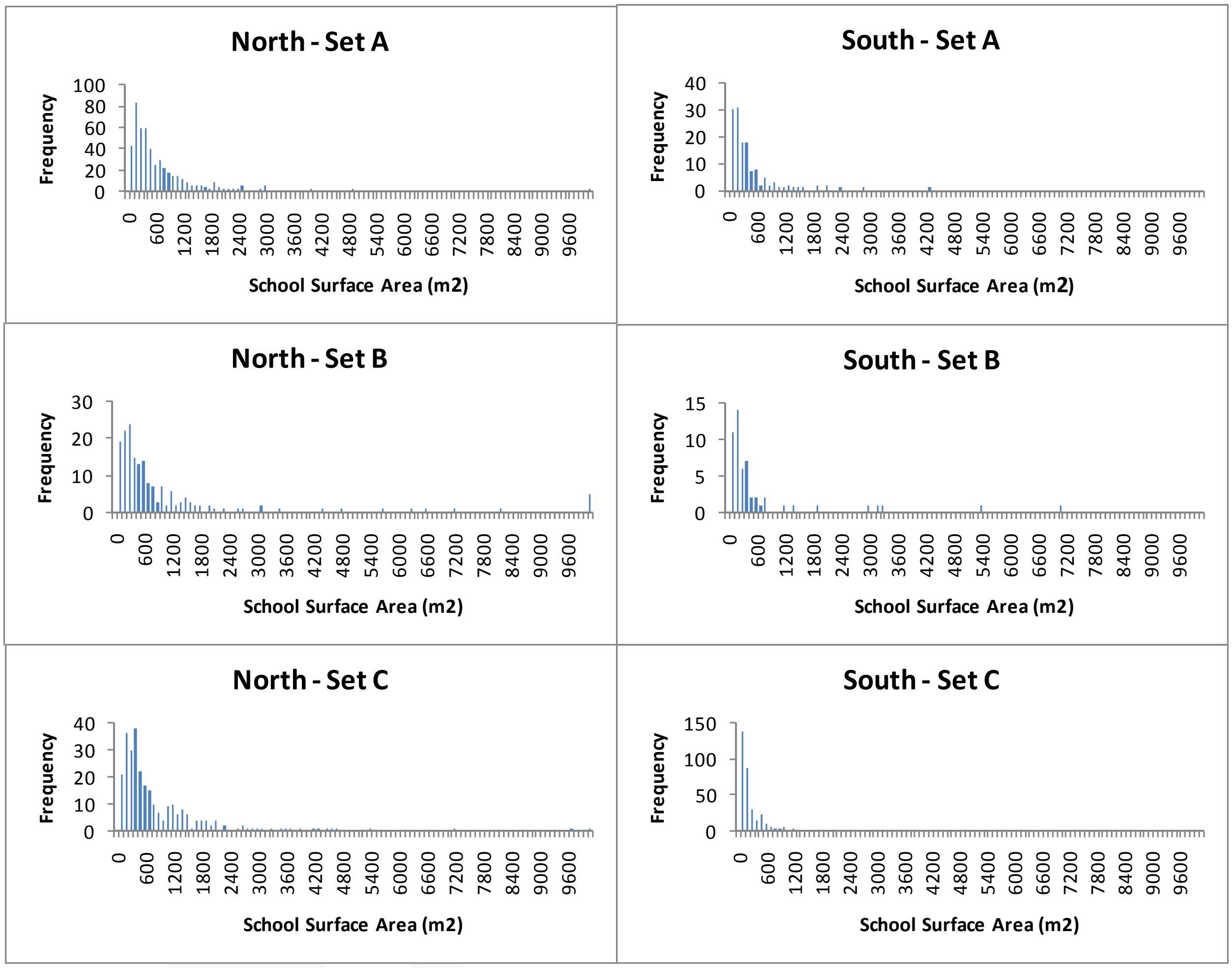


Figure 3. Location of point sets conducted in 2010 (north).

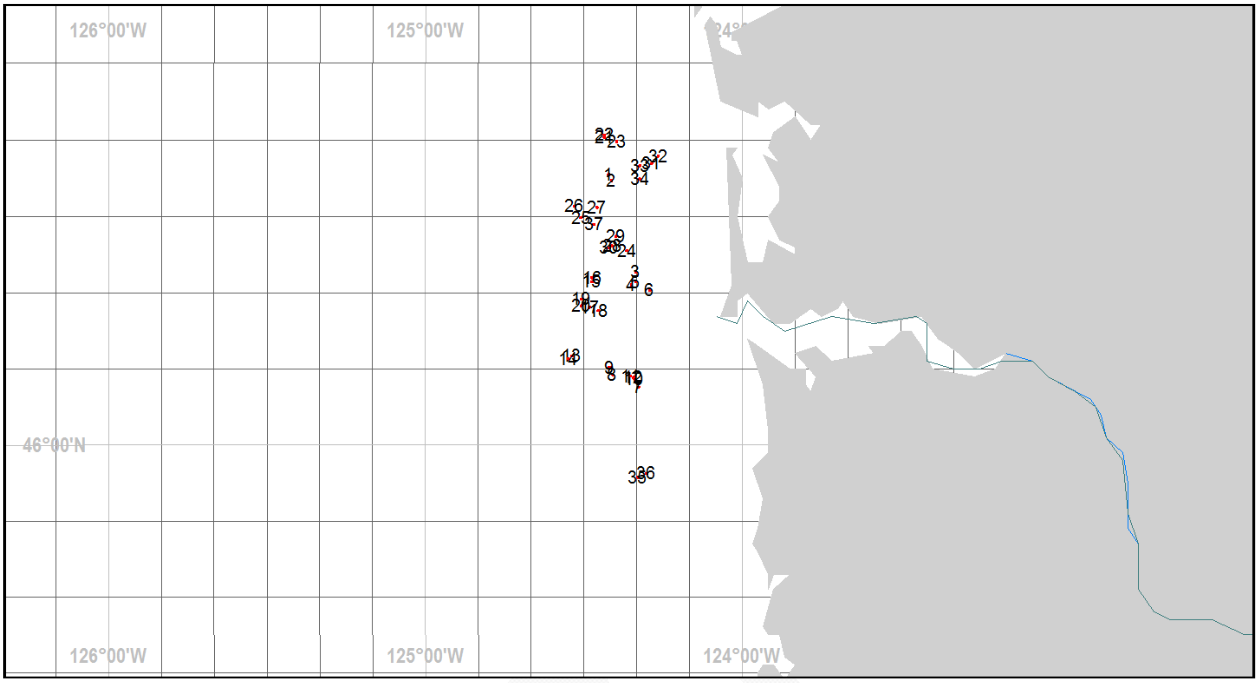


Figure 4. Location of point sets conducted in 2010 (south).

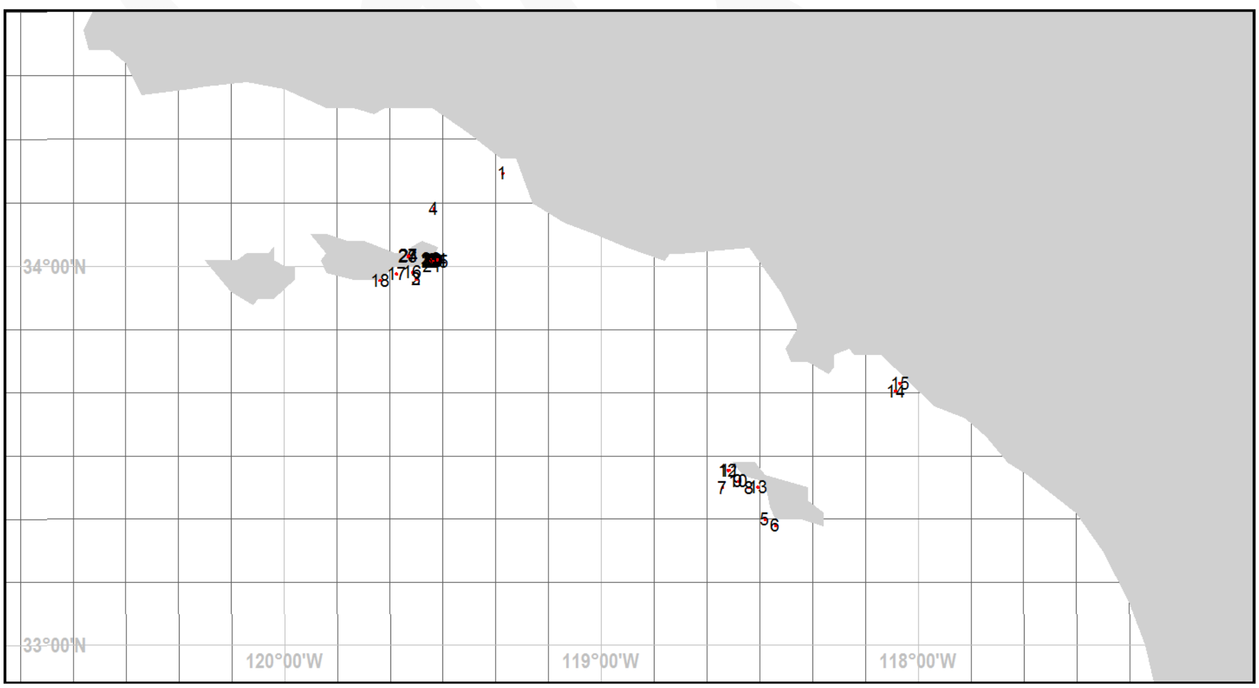


Figure 5. Plot of point set data used in the 2009 analysis (filename = cdata: blue points – solid line) and point set data from the north in 2010 (filename = cdata2010n: green points – dashed line). Likelihood ratio test P = 0.189; reject H_0 at the 0.05 significance level. Pooled data filename = cdata2010np.

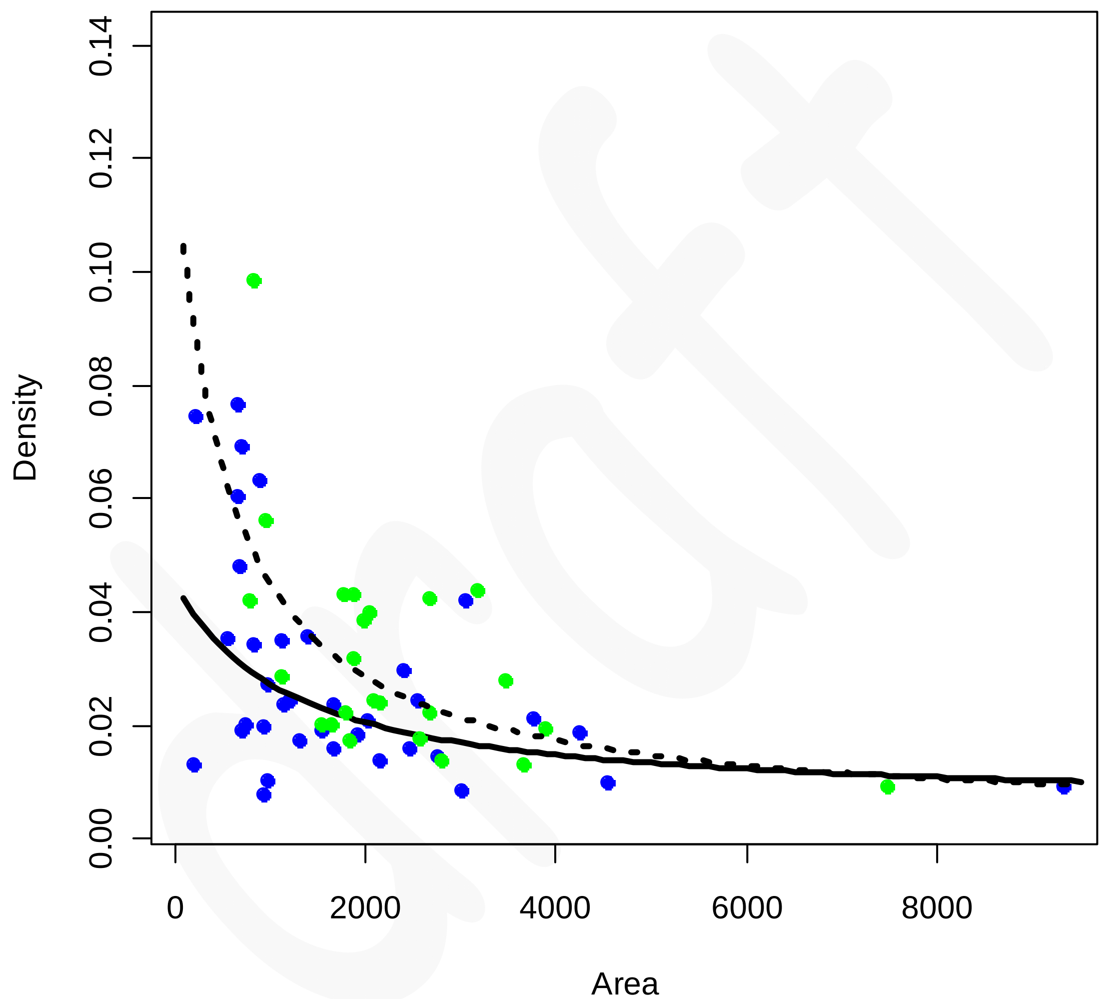


Figure 6. Plot of the pooled data from the north (filename = cdata2010np: blue points – solid line), and the new data from the south in 2010 (filename = cdata2010s: green points – dashed line). Likelihood ratio test P = 0.029; fail to reject H_0 at the 0.05 significance level.

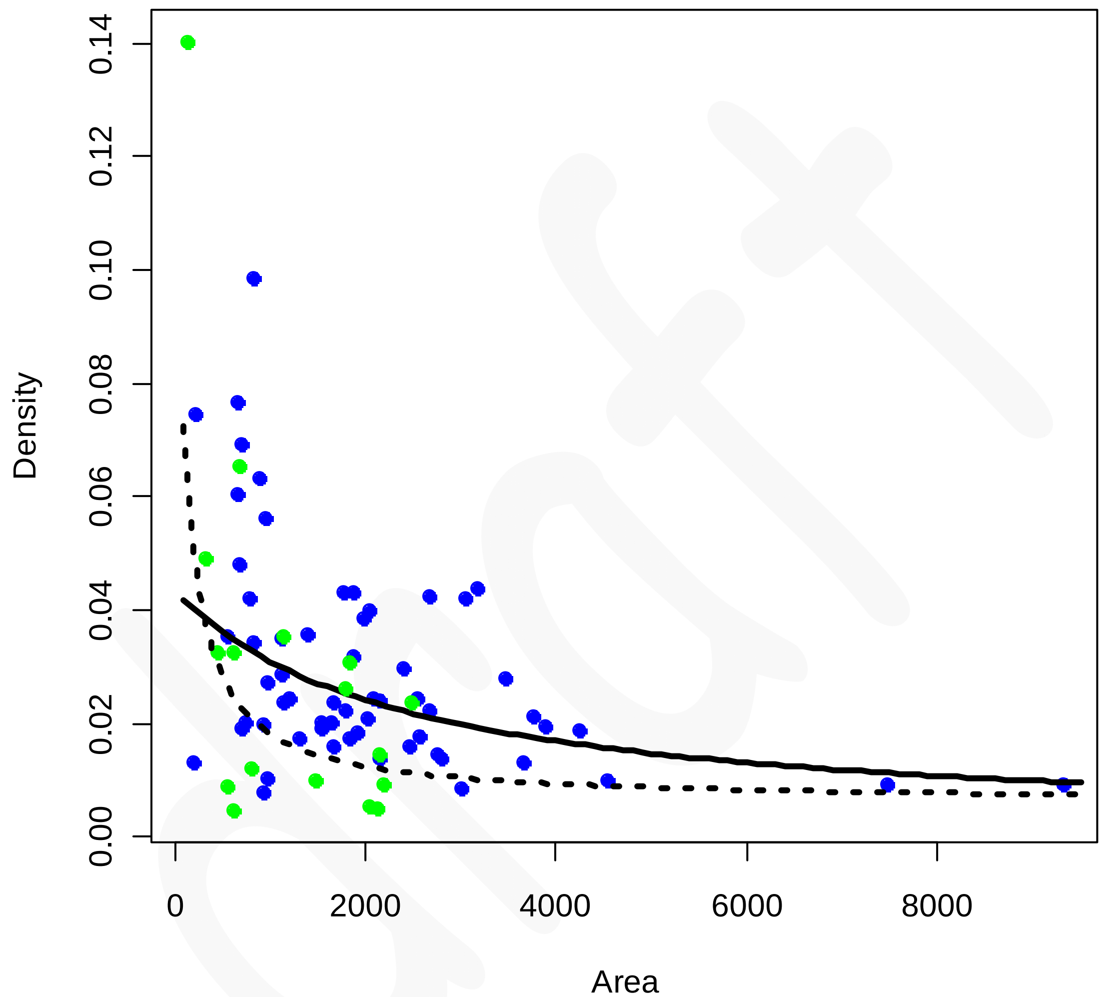


Figure 7. Plot of all data pooled (filename = cdata2010nsp).

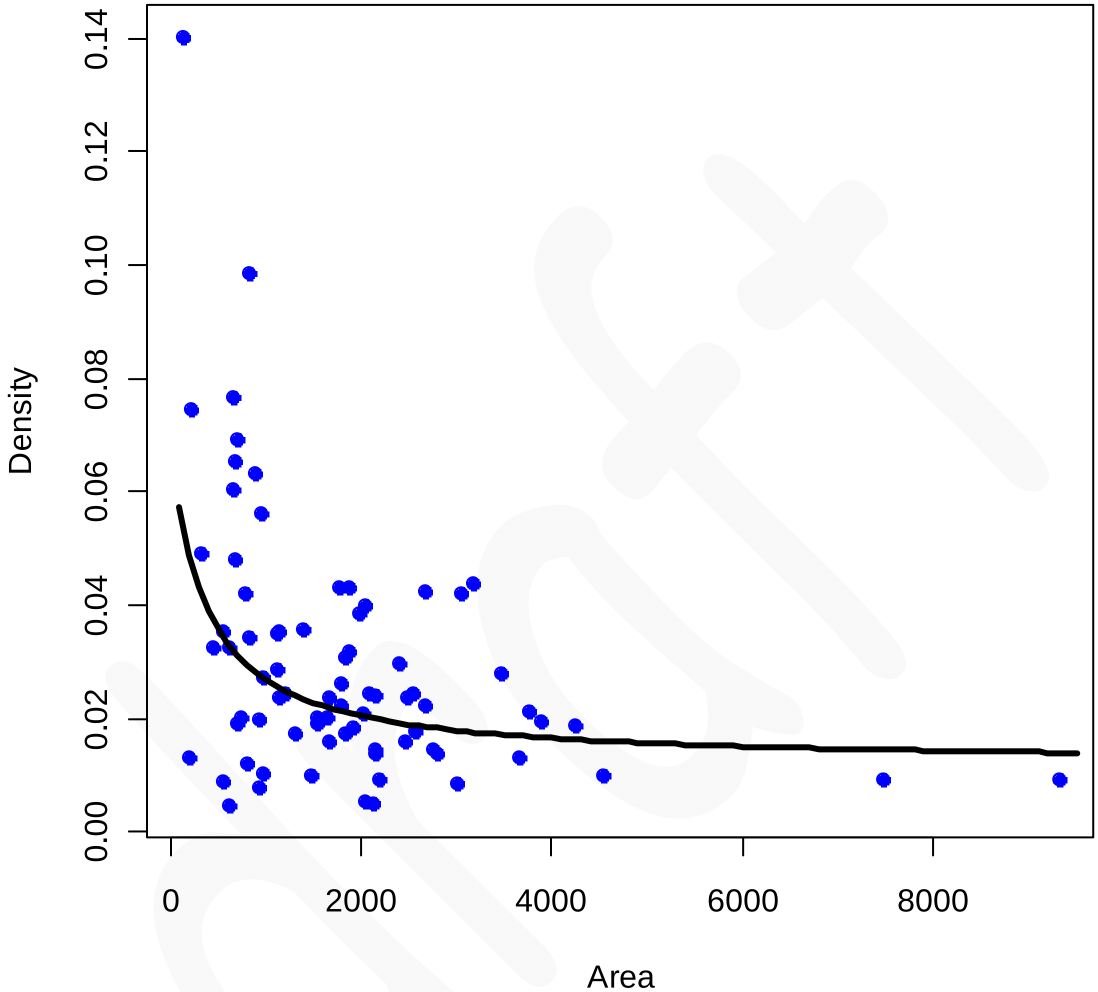
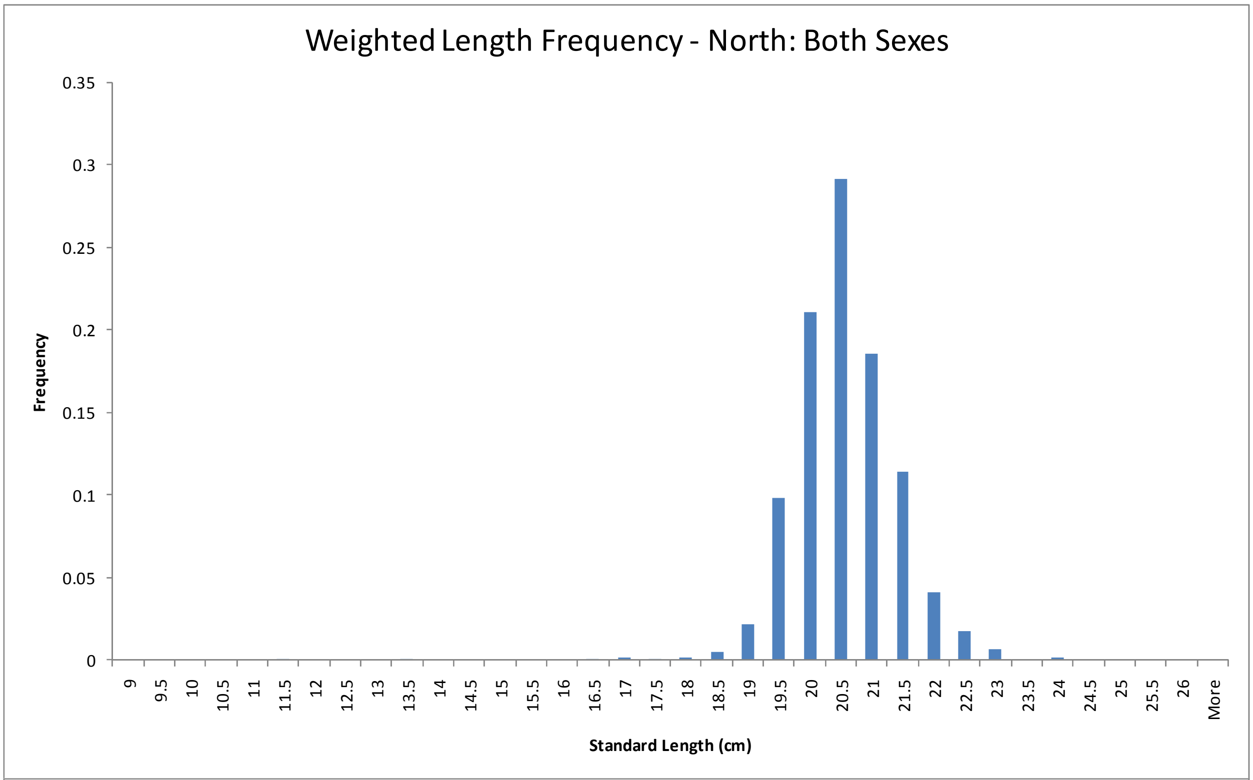


Figure 8. Weighted length frequencies from point sets used in the area-biomass analysis in 2010.



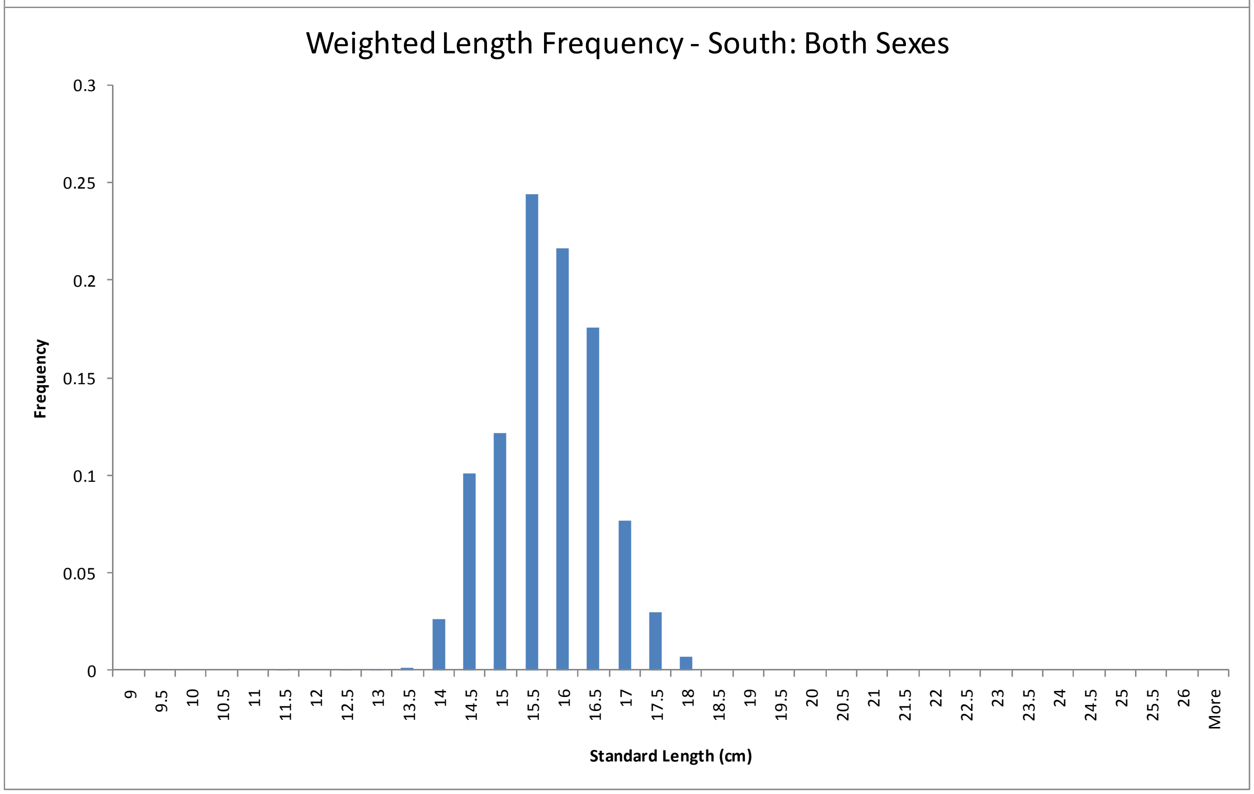


Figure 9. Histograms of length frequency for all point sets landed in 2010.

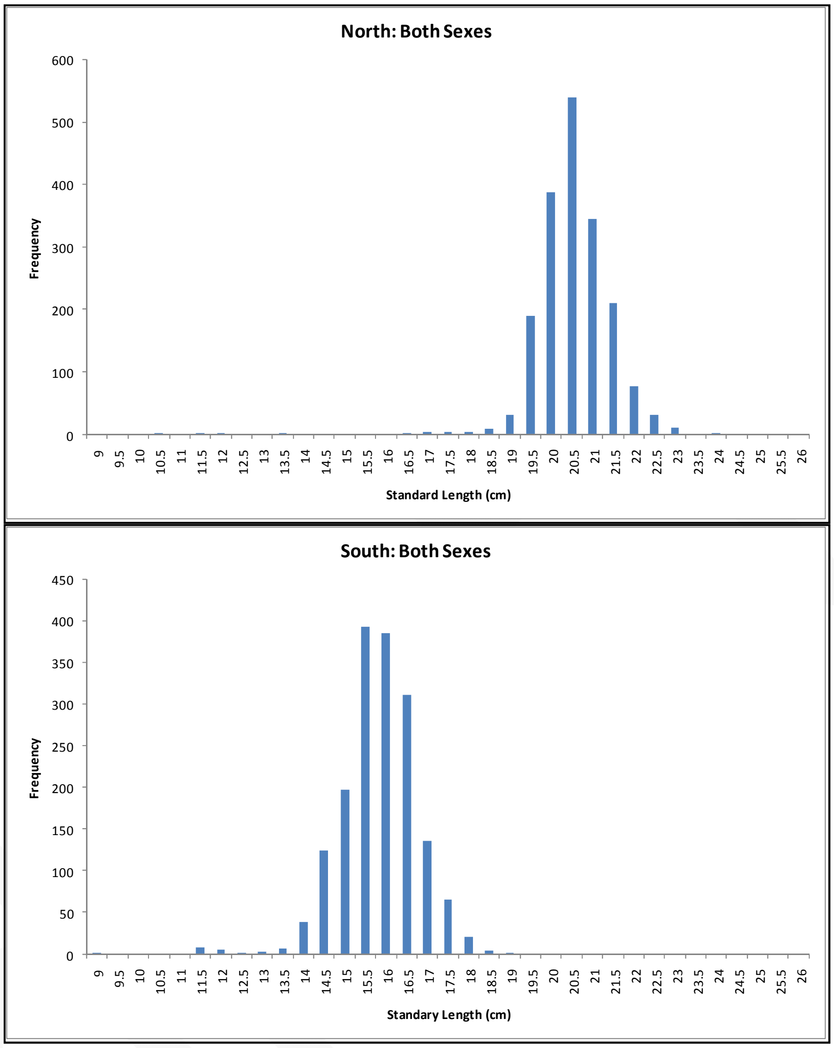
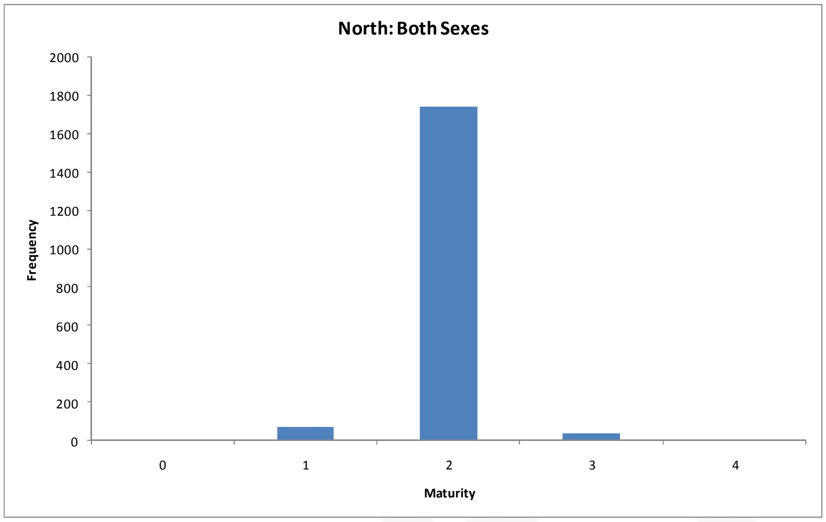


Figure 10. Histograms of maturity stage for all point sets landed in 2010.



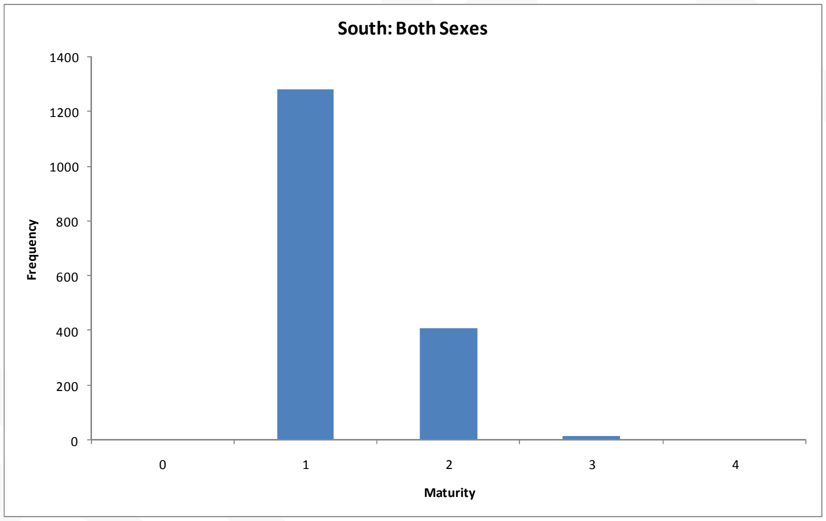


Figure 11. Maps showing the locations of sardine schools observed on transects in 2010. Top (north); bottom (south).

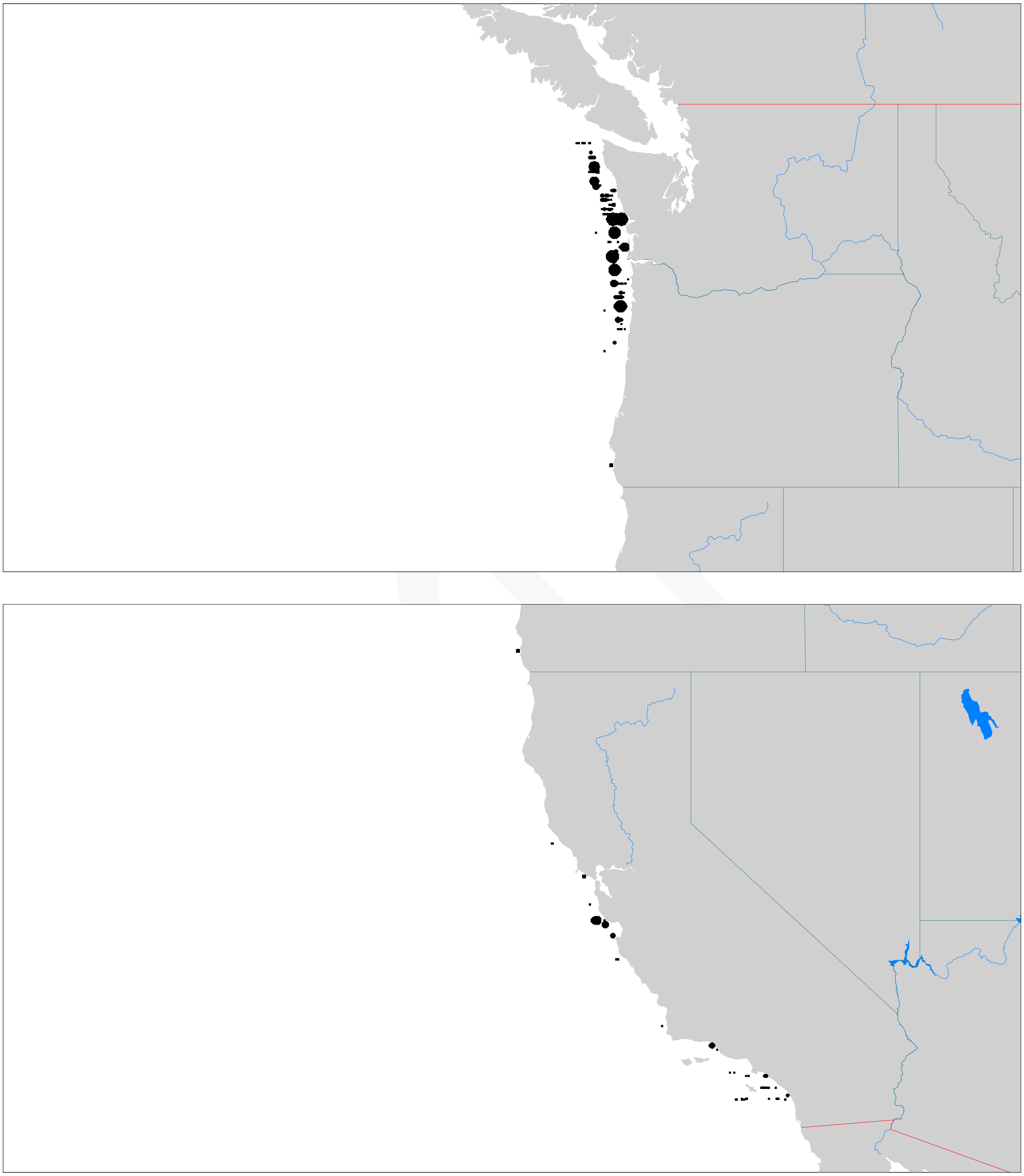
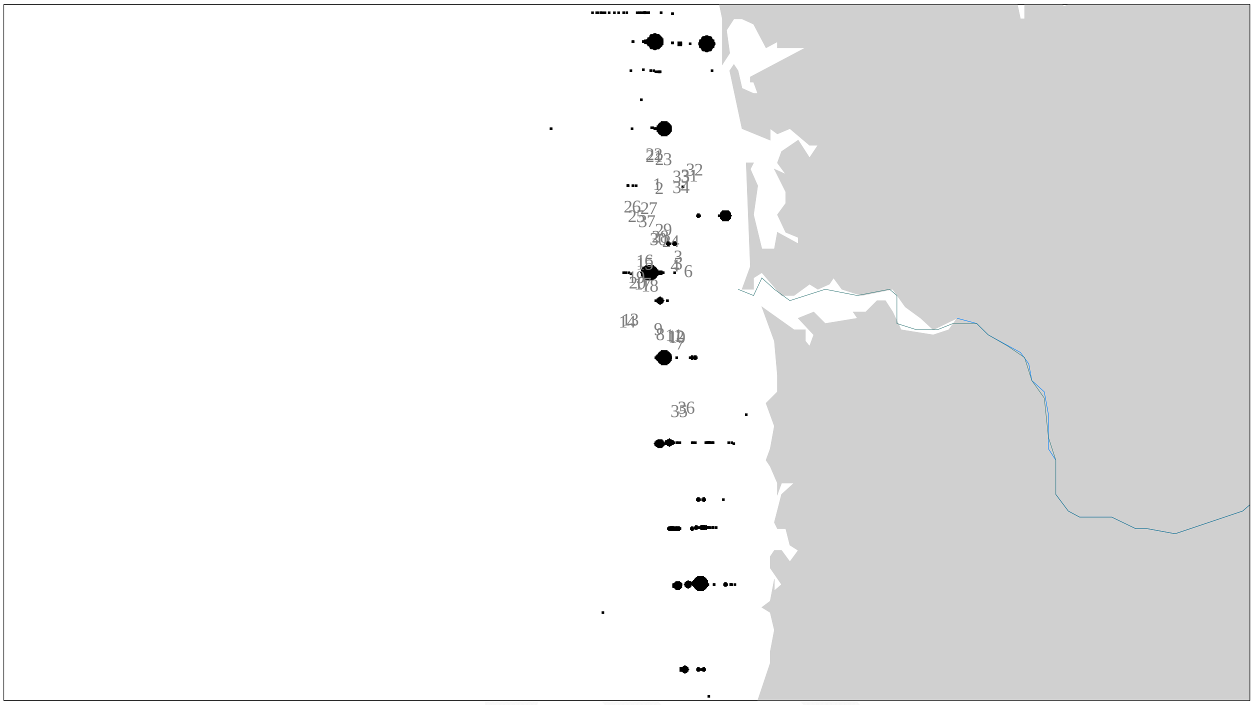


Figure 12. Locations of point sets (identified by number) with repect to sardine school locations observed on transects in 2010. Top (north); bottom (south).



Appendix I. R programs used for the 2010 survey.

```
# bscoast: computes biomass estimate and variance for north and south together
#  calculated from three replicate transect sets
#  Uses library 'MSVBAR' to simulate pointset variability
cdata <- read.csv(file="cdata2010nsp.csv")      #file of point set data (2008;2009;2010 north and south pooled)
tdata1 <- read.csv(file="transectdataCA.csv")   #file of transect surface area data for replicate A
tdata2 <- read.csv(file="transectdataCB.csv")   #file of transect surface area data for replicate B
tdata3 <- read.csv(file="transectdataCC.csv")   #file of transect surface area data for replicate C

 bscoast = function(nboots,cdata,tdata1,tdata2,tdata3){

 convert = function(yint, asymp, cc, x) {   #defines function to convert area to bms - yint = y intercept
   return((yint*cc+asymp*x)/(cc+x))}       #asymp = asymptote as x->infty, asymp/c = slope at orgin
 nls.control(maxiter = 5000,tol = 2e-6)     #control parameters for nonlinear fitting
 dimcdata <-  dim(cdata)
 larea <- log(cdata$Area) #logs of areas of point sets
 parea <- cdata$Area      #point set areas
 obs <- cdata$ObsDens
 lobs <- log(cdata$ObsDens) #log of observed densities of point sets
 #Fit Point Set Data
 mmfit <- nls(lobs~log(convert(exp(lyint),exp(lasymp),exp(lcc),parea)),
   start = list(lyint= log(0.045), lasymp= log(0.0057), lcc= log(1187)),
   upper=list(lyint= log(1.0), lasymp= log(0.1),lcc= log(10000)),
   lower=list(lyint= log(0.001), lasymp= log(0.001),lcc= log(100)),
   algorithm="port")  #fit point set data
 mmcoef <- coef(mmfit)
 yint <- exp(mmcoef[1])   #fitted coef a
 asymp <- exp(mmcoef[2])  #fitted coef b
 cc <- exp(mmcoef[3])     #fitted coef c
 print(paste("yint = ",yint),quote=F)
 print(paste("asymp = ",asymp),quote=F)
 print(paste("cc = ",cc),quote=F)
 windows()
 plot(ObsDens~Area,data = cdata,ylab="Density",pch=19) #plots point set data
 areas <- 100*(1:95)
 pdens0 <-  convert(yint,asymp,cc,areas)#predicted curve
 lines(pdens0~areas,lwd=3)  #plots predicted curve

# Estimated Biomass - replicate (SET A):
 Density1 <- convert(yint,asymp,cc,tdata1$sarea)
 tdata1$bms <- Density1*tdata1$sarea  #estimated bms of schools
 transectbms1 <- tapply(tdata1$bms,tdata1$transect,sum)#calc bms on transect by summing over schools
 tbmsrep1 <- 883*sum(transectbms1)/63  #calculate total bms
 # Note: SET A transects 37,48, and 49 not sampled; n = 63
 print(paste("Est bms Rep A = ",round(tbmsrep1)),quote=F)
# Estimated Biomass - replicate (SET B):
 Density2 <- convert(yint,asymp,cc,tdata2$sarea)
 tdata2$bms <- Density2*tdata2$sarea  #estimated bms of schools
 transectbms2 <- tapply(tdata2$bms,tdata2$transect,sum)#calc bms on transect by summing over schools
 tbmsrep2 <- 896*sum(transectbms2)/59  #calculate total bms
 # Note: SET B transects 27,28,30,31,32,33, and 34 not sampled; n = 59
```

```
print(paste("Est bms Rep B = ",round(tbmsrep2)),quote=F)
# Estimated Biomass - replicate (SET C):
Density3 <- convert(yint,asymp,cc,tdata3$sarea)
tdata3$bms <- Density3*tdata3$sarea  #estimated bms of schools
transectbms3 <- tapply(tdata3$bms,tdata3$transect,sum)#calc bms on transect by summing over schools
tbmsrep3 <- 945*sum(transectbms3)/60  #calculate total bms
# Note: transects 23,32,40,41,56 and 59 not sampled on SET C; n = 60
print(paste("Est bms Rep C = ",round(tbmsrep3)),quote=F)

# Overall biomass estimate
tbms0 <- (tbmsrep1+tbmsrep2+tbmsrep3)/3
print(paste("Est overall bms = ",round(tbms0)),quote=F)

 cof <- matrix(nrow=nboots,rep(0,3*nboots)) #set up bootstraps
 bms <- rep(0,nboots)
 library('MSBVAR')
 covmatrix <- vcov(mmfit)
 meanparams <- coef(mmfit)
 newcoef <- rmultnorm(nboots,vmat=covmatrix,mu=meanparams)
 for (i in 1:nboots){
   nyint <- exp(newcoef[i,1])
   nasymp <- exp(newcoef[i,2])
   nasymp <- min(nasymp,0.02)
   nc <- exp(newcoef[i,3])   #simulated coefficients
   if (i < 20){ #draw refitted lines on pointset plot
     pdens <- convert(nyint,nasymp,nc,areas)
     lines(pdens~areas,col=i,lwd=0.05)
      }
#   Replicate A:
    Density1 <- convert(nyint,nasymp,nc,tdata1$sarea)
    bms1 <- Density1*tdata1$sarea  #bms of schools
    transectbms1 <- tapply(bms1,tdata1$transect,sum) #bms on each transect
    tbms1 <- 883*sum(transectbms1)/63  #calculate total bms
#   Replicate B:
    Density2 <- convert(nyint,nasymp,nc,tdata2$sarea)
    bms2 <- Density2*tdata2$sarea  #bms of schools
    transectbms2 <- tapply(bms2,tdata2$transect,sum) #bms on each transect
    tbms2 <- 896*sum(transectbms2)/59  #calculate total bms
#   Replicate C:
    Density3 <- convert(nyint,nasymp,nc,tdata3$sarea)
    bms3 <- Density3*tdata3$sarea  #bms of schools
    transectbms3 <- tapply(bms3,tdata3$transect,sum) #bms on each transect
    tbms3 <- 945*sum(transectbms3)/60  #calculate total bms

#   Overall biomass estimate:
    repbms <- c(tbms1,tbms2,tbms3)
    ii <- sample(seq(from=1,to=3),size=3,replace=T)
    yy <- repbms[ii]
    bms[i] <- mean(yy)
   }
    windows()
    hist(bms,breaks=20,density=10,col='dark blue') #histogram of bootstrapped biomasses
```

```
    print(paste("SE = ",round(sd(bms,na.rm=TRUE))),quote=F)
    print(paste("CV = ",round(sd(bms,na.rm=TRUE))/tbms0), quote=F)
}
```

 # bsnorth: computes biomass estimate and variance for northern area

```
#  calculated from three replicate transect sets
#  Uses library 'MSVBAR' to simulate pointset variability
cdata <- read.csv(file="cdata2010n.csv")     #file of point set data (2010 north)
tdata1 <- read.csv(file="transectdataNA.csv")   #file of transect surface area data for replicate A
tdata2 <- read.csv(file="transectdataNB.csv")   #file of transect surface area data for replicate B
tdata3 <- read.csv(file="transectdataNC.csv")   #file of transect surface area data for replicate C

  bsnorth = function(nboots,cdata,tdata1,tdata2,tdata3){

  convert = function(yint, asymp, cc, x) {   #defines function to convert area to bms - yint = y intercept
    return((yint*cc+asymp*x)/(cc+x))}      #asymp = asymptote as x->infty, asymp/c = slope at orgin
  nls.control(maxiter = 5000,tol = 2e-6)     #control parameters for nonlinear fitting
  dimcdata <-  dim(cdata)
  larea <- log(cdata$Area) #logs of areas of point sets
  parea <- cdata$Area      #point set areas
  obs <- cdata$ObsDens
  lobs <- log(cdata$ObsDens) #log of observed densities of point sets
  #Fit Point Set Data
  mmfit <- nls(lobs~log(convert(exp(lyint),exp(lasymp),exp(lcc),parea)),
    start = list(lyint= log(0.045), lasymp= log(0.008), lcc= log(1187)),
    upper=list(lyint= log(1.0), lasymp= log(0.1),lcc= log(10000)),
    lower=list(lyint= log(0.001), lasymp= log(0.0057),lcc= log(100)),
    algorithm="port")  #fit point set data
  mmcoef <- coef(mmfit)
  yint <- exp(mmcoef[1])   #fitted coef a
  asymp <- exp(mmcoef[2])  #fitted coef b
  cc <- exp(mmcoef[3])     #fitted coef c
  print(paste("yint = ",yint),quote=F)
  print(paste("asymp = ",asymp),quote=F)
  print(paste("cc = ",cc),quote=F)
  windows()
  plot(ObsDens~Area,data = cdata,ylab="Density",pch=19) #plots point set data
  areas <- 100*(1:95)
  pdens0 <-  convert(yint,asymp,cc,areas)#predicted curve
  lines(pdens0~areas,lwd=3)  #plots predicted curve

# Estimated Biomass - replicate (SET A):
 Density1 <- convert(yint,asymp,cc,tdata1$sarea)
 tdata1$bms <- Density1*tdata1$sarea  #estimated bms of schools
 transectbms1 <- tapply(tdata1$bms,tdata1$transect,sum)#calc bms on transect by summing over schools
 tbmsrep1 <- 385*sum(transectbms1)/26  #calculate total bms
 print(paste("Est bms Rep A = ",round(tbmsrep1)),quote=F)
# Estimated Biomass - replicate (SET B):
 Density2 <- convert(yint,asymp,cc,tdata2$sarea)
 tdata2$bms <- Density2*tdata2$sarea  #estimated bms of schools
 transectbms2 <- tapply(tdata2$bms,tdata2$transect,sum)#calc bms on transect by summing over schools
 tbmsrep2 <- 383*sum(transectbms2)/26  #calculate total bms
```

```
print(paste("Est bms Rep B = ",round(tbmsrep2)),quote=F)
# Estimated Biomass - replicate (SET C):
Density3 <- convert(yint,asymp,cc,tdata3$sarea)
tdata3$bms <- Density3*tdata3$sarea  #estimated bms of schools
transectbms3 <- tapply(tdata3$bms,tdata3$transect,sum)#calc bms on transect by summing over schools
# Note: transect No. 23 not sampled on SET C; n = 25
tbmsrep3 <- 377*sum(transectbms3)/25  #calculate total bms
print(paste("Est bms Rep C = ",round(tbmsrep3)),quote=F)

# Overall biomass estimate
tbms0 <- (tbmsrep1+tbmsrep2+tbmsrep3)/3
print(paste("Est overall bms = ",round(tbms0)),quote=F)

 cof <- matrix(nrow=nboots,rep(0,3*nboots)) #set up bootstraps
 bms <- rep(0,nboots)
 library('MSBVAR')
 covmatrix <- vcov(mmfit)
 meanparams <- coef(mmfit)
 newcoef <- rmultnorm(nboots,vmat=covmatrix,mu=meanparams)
 for (i in 1:nboots){
   nyint <- exp(newcoef[i,1])
   nasymp <- exp(newcoef[i,2])
   nasymp <- min(nasymp,0.02)
   nc <- exp(newcoef[i,3])   #simulated coefficients
   if (i < 20){ #draw refitted lines on pointset plot
     pdens <- convert(nyint,nasymp,nc,areas)
     lines(pdens~areas,col=i,lwd=0.05)
      }
#   Replicate A:
   Density1 <- convert(nyint,nasymp,nc,tdata1$sarea)
   bms1 <- Density1*tdata1$sarea  #bms of schools
   transectbms1 <- tapply(bms1,tdata1$transect,sum) #bms on each transect
   tbms1 <- 385*sum(transectbms1)/26  #calculate total bms
#   Replicate B:
   Density2 <- convert(nyint,nasymp,nc,tdata2$sarea)
   bms2 <- Density2*tdata2$sarea  #bms of schools
   transectbms2 <- tapply(bms2,tdata2$transect,sum) #bms on each transect
   tbms2 <- 383*sum(transectbms2)/26  #calculate total bms
#   Replicate C:
   Density3 <- convert(nyint,nasymp,nc,tdata3$sarea)
   bms3 <- Density3*tdata3$sarea  #bms of schools
   transectbms3 <- tapply(bms3,tdata3$transect,sum) #bms on each transect
   tbms3 <- 377*sum(transectbms3)/25  #calculate total bms

#   Overall biomass estimate:
   repbms <- c(tbms1,tbms2,tbms3)
   ii <- sample(seq(from=1,to=3),size=3,replace=T)
   yy <- repbms[ii]
   bms[i] <- mean(yy)
  }
   windows()
   hist(bms,breaks=20,density=10,col='dark blue') #histogram of bootstrapped biomasses
```

```
    print(paste("SE = ",round(sd(bms,na.rm=TRUE))),quote=F)
    print(paste("CV = ",round(sd(bms,na.rm=TRUE))/tbms0), quote=F)
}
```

 # bssouth: computes biomass estimate and variance for southern area

```
#  calculated from three replicate transect sets
#  Uses library 'MSVBAR' to simulate pointset variability
cdata <- read.csv(file="cdata2010s.csv")       #file of point set data (2010 south)
tdata1 <- read.csv(file="transectdataSA.csv")   #file of transect surface area data for replicate A
tdata2 <- read.csv(file="transectdataSB.csv")   #file of transect surface area data for replicate B
tdata3 <- read.csv(file="transectdataSC.csv")   #file of transect surface area data for replicate C

  bssouth = function(nboots,cdata,tdata1,tdata2,tdata3){

  convert = function(yint, asymp, cc, x) {   #defines function to convert area to bms - yint = y intercept
    return((yint*cc+asymp*x)/(cc+x))}       #asymp = asymptote as x->infty, asymp/c = slope at orgin
  nls.control(maxiter = 5000,tol = 2e-6)     #control parameters for nonlinear fitting
  dimcdata <-  dim(cdata)
  larea <- log(cdata$Area) #logs of areas of point sets
  parea <- cdata$Area      #point set areas
  obs <- cdata$ObsDens
  lobs <- log(cdata$ObsDens) #log of observed densities of point sets
  #Fit Point Set Data
  mmfit <- nls(lobs~log(convert(exp(lyint),exp(lasymp),exp(lcc),parea)),
    start = list(lyint= log(0.045), lasymp= log(0.0057), lcc= log(1187)),
    upper=list(lyint= log(1.0), lasymp= log(0.1),lcc= log(10000)),
    lower=list(lyint= log(0.001), lasymp= log(0.005),lcc= log(100)),
    algorithm="port")  #fit point set data
  mmcoef <- coef(mmfit)
  yint <- exp(mmcoef[1])   #fitted coef a
  asymp <- exp(mmcoef[2])  #fitted coef b
  cc <- exp(mmcoef[3])     #fitted coef c
  print(paste("yint = ",yint),quote=F)
  print(paste("asymp = ",asymp),quote=F)
  print(paste("cc = ",cc),quote=F)
  windows()
  plot(ObsDens~Area,data = cdata,ylab="Density",pch=19) #plots point set data
  areas <- 100*(1:95)
  pdens0 <-  convert(yint,asymp,cc,areas)#predicted curve
  lines(pdens0~areas,lwd=3)  #plots predicted curve

# Estimated Biomass - replicate (SET A):
 Density1 <- convert(yint,asymp,cc,tdata1$sarea)
 tdata1$bms <- Density1*tdata1$sarea  #estimated bms of schools
 transectbms1 <- tapply(tdata1$bms,tdata1$transect,sum)#calc bms on transect by summing over schools
 # Note: SET A transects 37,48, and 49 not sampled; n = 37
 tbmsrep1 <- 498*sum(transectbms1)/37  #calculate total bms
 print(paste("Est bms Rep A = ",round(tbmsrep1)),quote=F)

# Estimated Biomass - replicate (SET B):
 Density2 <- convert(yint,asymp,cc,tdata2$sarea)
 tdata2$bms <- Density2*tdata2$sarea  #estimated bms of schools
```

```
transectbms2 <- tapply(tdata2$bms,tdata2$transect,sum)#calc bms on transect by summing over schools
# Note: SET B transects 27,28,30,31,32,33, and 34 not sampled; n = 33
tbmsrep2 <- 513*sum(transectbms2)/33  #calculate total bms
print(paste("Est bms Rep B = ",round(tbmsrep2)),quote=F)

# Estimated Biomass - replicate (SET C):
Density3 <- convert(yint,asymp,cc,tdata3$sarea)
tdata3$bms <- Density3*tdata3$sarea  #estimated bms of schools
transectbms3 <- tapply(tdata3$bms,tdata3$transect,sum)#calc bms on transect by summing over schools
# Note: transects 32,40,41,56 and 59 not sampled on SET C; n = 35
tbmsrep3 <- 568*sum(transectbms3)/35  #calculate total bms
print(paste("Est bms Rep C = ",round(tbmsrep3)),quote=F)

# Overall biomass estimate
tbms0 <- (tbmsrep1+tbmsrep2+tbmsrep3)/3
print(paste("Est overall bms = ",round(tbms0)),quote=F)

 cof <- matrix(nrow=nboots,rep(0,3*nboots)) #set up bootstraps
 bms <- rep(0,nboots)
 library('MSBVAR')
 covmatrix <- vcov(mmfit)
 meanparams <- coef(mmfit)
 newcoef <- rmultnorm(nboots,vmat=covmatrix,mu=meanparams)
 for (i in 1:nboots){
   nyint <- exp(newcoef[i,1])
   nasymp <- exp(newcoef[i,2])
   nasymp <- min(nasymp,0.02)
   nc <- exp(newcoef[i,3])   #simulated coefficients
   if (i < 20){ #draw refitted lines on pointset plot
     pdens <- convert(nyint,nasymp,nc,areas)
     lines(pdens~areas,col=i,lwd=0.05)
      }
#   Replicate A:
   Density1 <- convert(nyint,nasymp,nc,tdata1$sarea)
   bms1 <- Density1*tdata1$sarea  #bms of schools
   transectbms1 <- tapply(bms1,tdata1$transect,sum) #bms on each transect
   tbms1 <- 498*sum(transectbms1)/37  #calculate total bms
#   Replicate B:
   Density2 <- convert(nyint,nasymp,nc,tdata2$sarea)
   bms2 <- Density2*tdata2$sarea  #bms of schools
   transectbms2 <- tapply(bms2,tdata2$transect,sum) #bms on each transect
   tbms2 <- 513*sum(transectbms2)/33  #calculate total bms
#   Replicate C:
   Density3 <- convert(nyint,nasymp,nc,tdata3$sarea)
   bms3 <- Density3*tdata3$sarea  #bms of schools
   transectbms3 <- tapply(bms3,tdata3$transect,sum) #bms on each transect
   tbms3 <- 568*sum(transectbms3)/35  #calculate total bms

#   Overall biomass estimate:
   repbms <- c(tbms1,tbms2,tbms3)
   ii <- sample(seq(from=1,to=3),size=3,replace=T)
   yy <- repbms[ii]
```

```
    bms[i] <- mean(yy)
   }
    windows()
    hist(bms,breaks=20,density=10,col='dark blue') #histogram of bootstrapped biomasses
    print(paste("SE = ",round(sd(bms,na.rm=TRUE))),quote=F)
    print(paste("CV = ",round(sd(bms,na.rm=TRUE))/tbms0), quote=F)
}
```

#Bootsard3: Computes biomass and CV estimate for the 2009 Survey

```
# Covariance on point set data obtained from library 'MSVBAR'
cdata <- read.csv(file="cdata2010nsp.csv")            #file of point set data
transectdata <- read.csv(file="transectdata2009.csv") #file of transect surface area data

 bootsard3 = function(nboots,cdata,transectdata){
  convert = function(yint, asymp, cc, x) {   #defines function to convert area to bms - yint = y intercept
    return((yint*cc+asymp*x)/(cc+x))} #asymp = asymptote as x->infty, asymp/c = slope at orgin
  nls.control(maxiter = 5000,tol = 2e-6) #control parameters for nonlinear fitting
  ntransects <- 41
  dimcdata <-  dim(cdata)
  npdata <- dimcdata[1] #number of point sets
  larea <- log(cdata$Area) #logs of areas of point sets
  parea <- cdata$Area  #point set areas
  obs <- cdata$ObsDens
  lobs <- log(cdata$ObsDens) #log of observed densities of point sets
  mmfit <- nls(lobs~log(convert(exp(lyint),exp(lasymp),exp(lcc),parea)),
    start = list(lyint= log(0.045), lasymp= log(0.0057), lcc= log(1187)),
    upper=list(lyint= log(1.0), lasymp= log(0.1),lcc= log(10000)),
    lower=list(lyint= log(0.001), lasymp= log(0.005),lcc= log(100)),
    algorithm="port")  #fit point set data
  mmcoef <- coef(mmfit)
  yint <- exp(mmcoef[1])  #fitted coef a
  asymp <- exp(mmcoef[2])  #fitted coef b
  cc <- exp(mmcoef[3])  #fitted coef c
  predobs <- convert(yint,asymp,cc,cdata$Area)
  res <- predobs - obs  #residuals of point sets
  windows()
  plot(ObsDens~Area,data = cdata,ylab="Density",pch=19) #plots point set data
  areas <- 100*(1:95)
  pdens0 <-  convert(yint,asymp,cc,areas)#predicted curve
  lines(pdens0~areas,col='dark red',lwd=3)  #plots predicted curve
  Density <- convert(yint,asymp,cc,transectdata$sarea)
  transectdata$bms <- Density*transectdata$sarea  #estimated bms of schools
  transectbms1 <- tapply(transectdata$bms,transectdata$transect,sum)#calc bms on transect by summing over
schools
  tbms0 = 599*sum(transectbms1)/41  #calculate total bms
  print(paste("Est bms = ",round(tbms0)),quote=F)
  cof <- matrix(nrow=nboots,rep(0,3*nboots)) #set up bootstraps
  bms <- rep(0,nboots)
  library('MSBVAR')
  covmatrix <- vcov(mmfit)
  meanparams <- coef(mmfit)
  newcoef <- rmultnorm(nboots,vmat=covmatrix,mu=meanparams)
```

```
  for (i in 1:nboots){
    nyint <- exp(newcoef[i,1])
    nasymp <- exp(newcoef[i,2])
    nasymp <- min(nasymp,0.02)
    nc <- exp(newcoef[i,3])   #simulated coefficients
    if (i < 20){ #draw refitted lines on pointset plot
      pdens <- convert(nyint,nasymp,nc,areas)
      lines(pdens~areas,col=i,lwd=0.05)
       }
    Density <- convert(nyint,nasymp,nc,transectdata$sarea)
    bms1 <- Density*transectdata$sarea  #bms of schools
    transectbms <- tapply(bms1,transectdata$transect,sum) #bms on each transect
    tresample <- sample(1:ntransects,replace=T)  #sample the transect indicies
    retransect <- transectbms[tresample] #bootstrap of transects
    bms[i] <- 599*sum(retransect)/41  #calculated bms of this bootstrap
   }
   windows()
   hist(bms,breaks=20,density=10,col='dark blue') #histogram of bootstrapped biomasses
   print(paste("yint = ",yint),quote=F)
   print(paste("asymp = ",asymp),quote=F)
   print(paste("cc = ",cc),quote=F)
   print(paste("SE = ",round(sd(bms,na.rm=TRUE))),quote=F)
   print(paste("CV = ",round(sd(bms,na.rm=TRUE))/tbms0), quote=F)
}
```

 # fpsdata: fits and plots pointset data

```
cdata <- read.csv(file="cdata.csv")         #point set data: 2008 and 2009 pooled
cd2010n <- read.csv(file="cdata2010n.csv")   #point set data: 2010 (north)
cd2010np <- read.csv(file="cdata2010np.csv") #point set data: 2008; 2009; 2010 (north) pooled
cd2010s <- read.csv(file="cdata2010s.csv")   #point set data: 2010 (south)
cd2010nsp <- read.csv(file="cdata2010nsp.csv") #point set data: 2008; 2009; 2010 (north); 2010 (south) pooled

 fpsdata = function(cdata, cd2010n,cd2010np,cd2010s,cd2010nsp){
  convert = function(yint, asymp, cc, x) {   #defines function to convert area to bms - yint = y intercept
    return((yint*cc+asymp*x)/(cc+x))}       #asymp = asymptote as x->infty, asymp/c = slope at orgin
  nls.control(maxiter = 5000,tol = 2e-6)     #control parameters for nonlinear fitting

# fit pooled 2008 and 2009 pointset data (cdata.csv)
  larea <- log(cdata$Area) #logs of areas of point sets
  parea <- cdata$Area  #point set areas
  obs <- cdata$ObsDens
  lobs <- log(cdata$ObsDens) #log of observed densities of point sets
  mmfit <- nls(lobs~log(convert(exp(lyint),exp(lasymp),exp(lcc),parea)),
    start = list(lyint= log(0.045), lasymp= log(0.0056), lcc= log(1187)),
    upper=list(lyint= log(1.0), lasymp= log(0.1),lcc= log(10000)),
    lower=list(lyint= log(0.001), lasymp= log(0.001),lcc= log(100)),
    algorithm="port")  #fit point set data
  mmcoef <- coef(mmfit)
  yint <- exp(mmcoef[1])  #fitted coef a
  asymp <- exp(mmcoef[2])  #fitted coef b
  cc <- exp(mmcoef[3])  #fitted coef c
```

```
# fit 2010 pointset data (north - cdata2010n.csv)
larea2 <- log(cd2010n$Area) #logs of areas of point sets
parea2 <- cd2010n$Area  #point set areas
obs2 <- cd2010n$ObsDens
lobs2 <- log(cd2010n$ObsDens) #log of observed densities of point sets
mmfita <- nls(lobs2~log(convert(exp(lyint2),exp(lasymp2),exp(lcc2),parea2)),
  start = list(lyint2= log(0.045), lasymp2= log(0.0056), lcc2= log(1187)),
  upper=list(lyint2= log(1.0), lasymp2= log(0.1),lcc2= log(10000)),
  lower=list(lyint2= log(0.001), lasymp2= log(0.001),lcc2= log(100)),
  algorithm="port")  #fit point set data
mmcoef2 <- coef(mmfita)
yint2 <- exp(mmcoef2[1])  #fitted coef a
asymp2 <- exp(mmcoef2[2])  #fitted coef b
cc2 <- exp(mmcoef2[3])  #fitted coef c

# fit 2008; 2009 and 2010(north) pointset data - pooled  (cdata2010np.csv)
larea3 <- log(cd2010np$Area) #logs of areas of point sets
parea3 <- cd2010np$Area  #point set areas
obs3 <- cd2010np$ObsDens
lobs3 <- log(cd2010np$ObsDens) #log of observed densities of point sets
mmfitb <- nls(lobs3~log(convert(exp(lyint3),exp(lasymp3),exp(lcc3),parea3)),
  start = list(lyint3= log(0.045), lasymp3= log(0.0056), lcc3= log(1187)),
  upper=list(lyint3= log(1.0), lasymp3= log(0.1),lcc3= log(10000)),
  lower=list(lyint3= log(0.001), lasymp3= log(0.001),lcc3= log(100)),
  algorithm="port")  #fit point set data
mmcoef3 <- coef(mmfitb)
yint3 <- exp(mmcoef3[1])  #fitted coef a
asymp3 <- exp(mmcoef3[2])  #fitted coef b
cc3 <- exp(mmcoef3[3])  #fitted coef c

# fit 2010 pointset data(south - cdata2010s.csv)
larea4 <- log(cd2010s$Area) #logs of areas of point sets
parea4 <- cd2010s$Area  #point set areas
obs4 <- cd2010s$ObsDens
lobs4 <- log(cd2010s$ObsDens) #log of observed densities of point sets
mmfitc <- nls(lobs4~log(convert(exp(lyint4),exp(lasymp4),exp(lcc4),parea4)),
  start = list(lyint4= log(0.045), lasymp4= log(0.0056), lcc4= log(1187)),
  upper=list(lyint4= log(1.0), lasymp4= log(0.1),lcc4= log(10000)),
  lower=list(lyint4= log(0.001), lasymp4= log(0.001),lcc4= log(100)),
  algorithm="port")  #fit point set data
mmcoef4 <- coef(mmfitc)
yint4 <- exp(mmcoef4[1])  #fitted coef a
asymp4 <- exp(mmcoef4[2])  #fitted coef b
cc4 <- exp(mmcoef4[3])  #fitted coef c

# fit 2008;2009;2010 (north); 2010 (south) pooled (cdata2010nsp.csv)
larea5 <- log(cd2010nsp$Area) #logs of areas of point sets
parea5 <- cd2010nsp$Area  #point set areas
obs5 <- cd2010nsp$ObsDens
lobs5 <- log(cd2010nsp$ObsDens) #log of observed densities of point sets
mmfitd <- nls(lobs5~log(convert(exp(lyint5),exp(lasymp5),exp(lcc5),parea5)),
  start = list(lyint5= log(0.045), lasymp5= log(0.0056), lcc5= log(1187)),
```

```
   upper=list(lyint5= log(1.0), lasymp5= log(0.1),lcc5= log(10000)),
   lower=list(lyint5= log(0.001), lasymp5= log(0.001),lcc5= log(100)),
   algorithm="port")  #fit point set data
 mmcoef5 <- coef(mmfitd)
 yint5 <- exp(mmcoef5[1])  #fitted coef a
 asymp5 <- exp(mmcoef5[2])  #fitted coef b
 cc5 <- exp(mmcoef5[3])  #fitted coef c

#resmmfit <- residuals(mmfit)
#resmmfita <- residuals(mmfita)
#resmmfitb <- residuals(mmfitb)
#resids <- cbind(resmmfit,resmmfita,resmmfitb)
#write.csv(resids, file = "resids.csv")

 print(paste("yint = ",yint),quote=F)
 print(paste("asymp = ",asymp),quote=F)
 print(paste("cc = ",cc),quote=F)
 dfmmfit <- df.residual(mmfit)
 print(paste("df mmfit = ",dfmmfit),quote=F)
 llmmfit <- logLik(mmfit)
 print(paste("logLik mmfit = ",llmmfit),quote=F)

 print(paste("yint2 = ",yint2),quote=F)
 print(paste("asymp2 = ",asymp2),quote=F)
 print(paste("cc2 = ",cc2),quote=F)
 dfmmfita <- df.residual(mmfita)
 print(paste("df mmfita = ",dfmmfita),quote=F)
 llmmfita <- logLik(mmfita)
 print(paste("logLik mmfita = ",llmmfita),quote=F)

 print(paste("yint3 = ",yint3),quote=F)
 print(paste("asymp3 = ",asymp3),quote=F)
 print(paste("cc3 = ",cc3),quote=F)
 dfmmfitb <- df.residual(mmfitb)
 print(paste("df mmfitb = ",dfmmfitb),quote=F)
 llmmfitb <- logLik(mmfitb)
 print(paste("logLik mmfitb = ",llmmfitb),quote=F)

 print(paste("yint4 = ",yint4),quote=F)
 print(paste("asymp4 = ",asymp4),quote=F)
 print(paste("cc4 = ",cc4),quote=F)
 dfmmfitc <- df.residual(mmfitc)
 print(paste("df mmfitc = ",dfmmfitc),quote=F)
 llmmfitc <- logLik(mmfitc)
 print(paste("logLik mmfitc = ",llmmfitc),quote=F)

 print(paste("yint5 = ",yint5),quote=F)
 print(paste("asymp5 = ",asymp5),quote=F)
 print(paste("cc5 = ",cc5),quote=F)
 dfmmfitd <- df.residual(mmfitd)
 print(paste("df mmfitd = ",dfmmfitd),quote=F)
 llmmfitd <- logLik(mmfitd)
```

```
print(paste("logLik mmfitd = ",llmmfitd),quote=F)

windows()
plot(ObsDens~Area,data = cd2010nsp,ylab="Density",pch=19,col="blue",type="n")
  #sets the xy scale for plots to follow
points(ObsDens~Area,data = cdata,ylab="Density",pch=19,col="blue")
 #plots point set data for 2008 and 2009 pooled
areas <- 100*(1:95)
pdens2009 <-  convert(yint,asymp,cc,areas)
                  #predicted curve
lines(pdens2009~areas,col='black',lwd=3)
                    #plots predicted curve for 2008 and 2009 pooled

points(ObsDens~Area,data= cd2010n,pch=19,col="green")
          #plots point set data for 2010 north
pdens2010n <-  convert(yint2,asymp2,cc2,areas)
               #predicted curve
lines(pdens2010n~areas,col='black',lwd=3,lty="dotted")
         #plots predicted curve for 2010 north

windows()
plot(ObsDens~Area,data = cd2010nsp,ylab="Density",pch=19,col="blue",type="n")
  #sets the xy scale for plots to follow
points(ObsDens~Area,data = cd2010np,ylab="Density",pch=19,col="blue")
     #plots point set data for 2008;2009 and 2010-n  - all pooled
pdens2010np <-  convert(yint3,asymp3,cc3,areas)
                    #predicted curve
lines(pdens2010np~areas,col='black',lwd=3)
                        #plots predicted curve for pooled 2008;2009 and 2010 north data

points(ObsDens~Area,data= cd2010s,pch=19,col="green")
         #plots point set data for 2010 south
pdens2010s <-  convert(yint4,asymp4,cc4,areas)
              #predicted curve
lines(pdens2010s~areas,col='black',lwd=3,lty="dotted")
        #plots predicted curve for 2010 south

windows()
plot(ObsDens~Area,data = cd2010nsp,ylab="Density",pch=19,col="blue")  #plots point set data for 2008; 2009;
2010-n; 2010-s pooled
pdens2010nsp <-  convert(yint5,asymp5,cc5,areas)
lines(pdens2010nsp~areas,col='black',lwd=3)

}
```