Determining abundance and spatial distribution of *Loligo opalescens* benthic egg beds in Monterey Bay, California using sidescan sonar.

A Capstone Project

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ABSTRACT

The squid *Loligo opalescens* (market squid) has become the most important fishery in California in both commercial landings and their monetary value. Market squid are also important to other commercially valuable species as food as well as protected marine mammals and birds. Five surveys were conducted in southern Monterey Bay to determine if sidescan sonar could be used to accurately assess egg abundance and therefore predict squid landings. The reliability of sidescan sonar in predicting egg abundance was found to be good as long as mean individual egg patch area was above the threshold of 0.25m2 and the data was of good quality and easily interpreted. Market squid was found to not have a preference for depth of egg laying activities beyond their normal limits. It was also found that sidescan sonar can predict landings (r^2=0.980) with some certainty.

INTRODUCTION

Economics and ecology of L. opalescens

Loligo opalescens, also known as the Opalescent Inshore Squid but more commonly known as market squid, has supported the California fishery since the mid 1800's(Zeidberg,). Market squid has dominated invertebrate landings in California since 1966 and is now California's largest and most valuable fishery in both landings and market value (Mason, 2004) with landings peaking in 2000 with more than 118,000 metric tons worth an estimated $27.2 million (Table 1). Since 2000, landings have been on the decline with 2006 landings being less than half of the 2000 record (Figure 1).

Table 1: California catch data for *L. opalescens* from 1981 to 2006.

year	metric tons	pounds	$
1981	23,509.8	51,829,718	5,079,669
1982	16,308.3	35,953,360	3,572,358
1983	1,823.6	4,020,353	758,032
1984	564.0	1,243,458	299,302
1985	10,276.2	22,654,927	3,745,999
1986	21,277.6	46,908,622	4,524,293
1987	19,984.1	44,056,904	3,959,428
1988	37,232.3	82,082,352	7,867,575
1989	40,893.0	90,152,660	6,954,482
1990	28,447.1	62,714,437	4,748,188

1991	37,388.6	82,426,950	6,086,561
1992	13,110.2	28,902,800	2,494,694
1993	42,829.8	94,422,595	10,162,182
1994	55,383.4	122,098,327	17,607,466
1995	70,251.5	154,876,514	22,570,968
1996	80,561.3	177,605,533	26,876,174
1997	70,328.6	155,046,468	21,881,819
1998	2,894.5	6,381,235	1,623,738
1999	91,518.7	201,762,173	33,276,814
2000	118,902.6	262,132,779	27,242,467
2001	86,127.9	189,877,472	16,917,640
2002	72,873.5	160,656,986	18,257,652
2003	44,941.9	99,078,922	25,330,794
2004	39,963.6	88,103,658	19,723,439
2005	55,739.6	122,883,576	31,465,125
2006	49,151.9	108,360,259	26,944,170

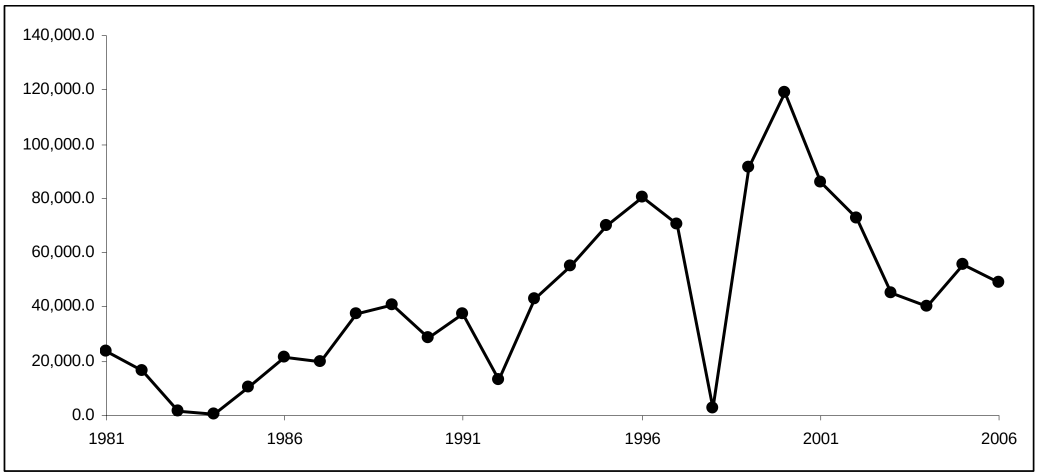


Figure 1: Plot of *L. opalescens* catch in California from 1981 to 2006. The year is displayed on the x-axis with the associated metric tons for each year on the y-axis. Note 1997-1998 El Nino event.

The majority of *L. opalescens* landings occur in southern California (about 90%) with a small amount coming from the Monterey Bay Statistical Area. From 2000 to 2002, landings in the Monterey Bay Statistical Area (Table 2) increased to peak at more than 24000 metric tons then began a sharp decline until 2006 where landings totaled only about 509 metric tons which is a 97% decrease from 2002 levels (Figure 2).

Table 2: Monterey statistical area catch data for *L. opalescens* from 2000 to 2007*. 2007 data assumed to be negligible based on anecdotal information.

year	metric tons	pounds
2000	7125.3	15,708,698
2001	7746.6	17,078,248
2002	25067.0	55,263,371
2003	13921.3	30,691,176
2004	5542.5	12,219,049
2005	1916.3	4,224,691
2006	509.3	1,122,817
2007*	0	0

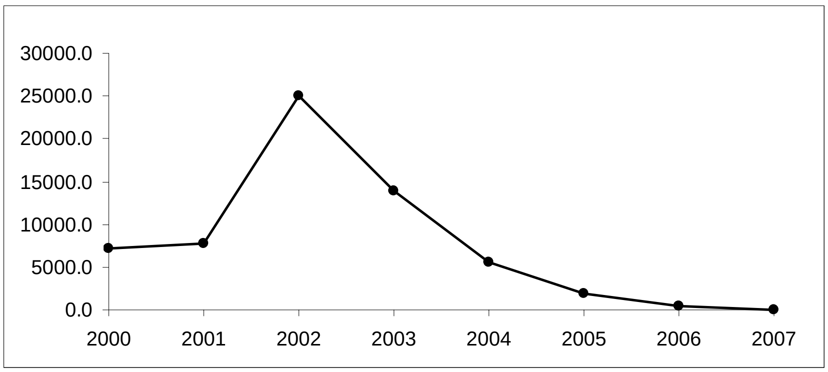


Figure 2: Plot of *L. opalescens* catch in for the Monterey Statistical area from 2000 to 2007*. The year is displayed on the x-axis with the associated metric tons for each year on the y-axis. 2007 data assumed to be negligible based on anecdotal information.

The squid season in the Monterey Bay area lasts from April 1st to March 31st of the following year with total seasonal limits of 118,000 short tons (about 107,047 metric tons) statewide (CDFG). However, as per the squid fishery management plan, squid can still be taken for commercial purposes after the limit has been reached if it is not in excess of two tons per calendar day. Squid may be taken without a squid permit when taken for live bait purposes and incidental catch as long as it does not exceed more than two tons of squid per trip or calendar day. Also, squid cannot be taken between 1200 hours Friday and 1200 hours Sunday of each week during the season. The reason for this closure time is unknown and seems to have no biological significance (CDFG).

The current Market Squid Fishery Management Plan (FMP) employs several measures in an attempt to keep the squid populations sustainable and include limits on harvest, regulation of fishing gear, limits on light wattage (used for attracting squid), closure times to allow uninterrupted spawning, limits on fleet size, seasonal closures, vessel trip limits, and possible use of marine protected areas (CDFG). However, there is currently no benthic habitat protected for *L. opalescens* egg laying (Foote et al., 2006).

El Nino Southern Oscillation (ENSO) and decadal (PDO/IPO) events can have a devastating effect on the squid fishery as witnessed during the 1997/1998 (see figure 1) season where catches dropped to 40 metric tons during the last quarter compared to 60,000 metric tons during the same time period the previous year. Coincidentally this was also the time period of one of the more severe ENSO events on record. Collecting data on the habits of *L. opalescens* and what affects them is of the utmost importance in keeping both a healthy population and the local squid fisheries in business. Unfortunately, most data on squid population and ecology, until fairly recently, came from commercial catch data and other anecdotal sources it has only been in the last few years that new technologies are allowing scientists to gather more direct data on squid ecology.

L. opalescens is the ideal species for creating a sustainable fishery due to the species short lifespan (6-9 months) and high productivity which makes it able to bounce back from perturbations to its population such as environmental changes (ENSO) and overfishing (Boyle and Rodhouse, 2005). Because the squid are harvested in their spawning grounds during spawning, it is critical that the squid are allowed to spawn and deposit the majority of their egg capsules on the seafloor before capture to ensure a strong and viable population for the following year.

Biology of L. opalescens

L. opalescens are mollusks belonging to the family Loliginidae which has approximately 30-40 members. *L. opalescens* range from central Baja and Mexico, to Southeast Alaska. The most productive areas, however, seem to be central and southern California (CDFG).

L. opalescens grows to a max length of about 30cm with a mantle length (ML) of around 16cm. The *L. opalescens* life cycle has four stages: eggs (which is what is studied here), paralarve (planktonic), juveniles, and adults (Boyle and Rodhouse, 2005).

Market squid live very short lives on the order of 6-9 months and spawn en mass in annual spawning events (Boyle, 2005). Through anecdotal data it has always been accepted that squid spawn then die soon after. However, recent research is showing that females can lay multiple egg capsules over relatively short periods of time (Hanlon et.al.,2004). Another myth in the process of being put to rest is that market squid spawn at night. Research suggest (Forsythe et.al., 2004) that market squid only spawn during daylight hours with night spawning being artificially induced by fishing lights used to attract the squid to the surface.

The market squid are an important part of the local marine food web and are central to the support of many large predatory fish species including tuna, halibut, sole, flounder, rockfish, and several species of Salmonidae which are all commercially valuable fish in their own right. Market squid are also an important food source for several mammal species such as seals, otters, and cetaceans as well as many species of migratory birds (Boyle, 2005). During the mass spawn event many species of predator congregate in the spawning area and gorge themselves on the post-spawning, dying squid.

Eggs are laid on a sandy substrate at an average depth of about 30m (Zeidberg, 2004) and are contained with a capsule excreted by the female. Usually the eggs are laid at a depth of 10-50m, however, a recent unsubstantiated claim from a shrimp trawler claim to have brought squid eggs up from a depth of 400 fathoms (about 2400 feet!). An average length egg capsule contains about 164 eggs (Zeidberg, 2004). The eggs are attached to the substrate with a short flexible stalk so they can sway back and forth with the currents and are laid in masses containing various numbers of egg capsules anywhere from a few to more than a thousand (Zeidberg, 2004).

Even though the egg masses are highly visible and accessible to predators feeding on the post-spawn squid there has been no recorded predation on the egg masses (Boyle, 2005). Other studies (Zeidberg, 2004), however, suggest that several species of invertebrates do in fact feed on the eggs such as *Asterina miniata* (Bat Star), *Kelletia kelletii* (Kellet's Whelk), and *Cypraea spadicea* (Chesnut Cowrie).

The spawning event does not happen all at once as was once thought. This claim has been proven in studies of egg masses showing different cohorts in various stages of development sharing the same egg mass. The difference in development equates to a time difference of up to eight days meaning that they were most likely laid at a later spawning event (Zeidberg, 2004). In many of the egg masses examined by Zeidberg, the more developed embryos occurred in the center of the mass and became less developed as toward the edges of the mass. If the spawning event last for a period of weeks it would be in the best interest of the fishery to study this period and from it develop a set of guidelines for harvesting squid while still allowing adequate egg escapement.

Research

The purpose of this project is to provide real data of the spatial distribution for market squid eggs in Monterey Bay for the purpose of developing fishing methods and management strategies for a more sustainable fishery rather than relying on anecdotal observations and catch data alone. It has already been demonstrated by Foote et al. (2006) that squid eggs can be detected reliably with sidescan sonar but can the data collected be used to estimate egg abundance with any reliability? If so then it offers an almost instantaneous and non-invasive method for estimating egg abundance in the Monterey area which can possibly be used for stock assessment. Sidescan sonar (elsewhere referred to as sss) data were used in conjunction with multibeam sonar data to try and answer some of the more basic questions about market squid egg laying behavior. The following questions were explored:

1. Is towed sidescan sonar (sss) a reliable means of quantifying squid benthic egg beds?

H_1: sss offers a reliable measure for quantifying market squid egg abundance.

H_2: sss consistently over-estimates egg abundance when compared to direct video observations of market squid benthic egg beds.

H_3: sss consistently under-estimates egg abundance when compared to direct video observations of market squid benthic egg beds.

H_4: The accuracy of sss estimates of egg abundance vary with egg patch size distribution.

H_0: Towed sidescan sonar is not a reliable measure for quantifying market squid egg abundance.

2. Do squid show a preference for depth within their normal egg laying depth limits within the study area in Monterey Bay?

H_1: Market squid demonstrate a preference for a particular depth for egg laying within their normal egg laying limits year to year.

H_0: Market squid do not demonstrate any preference for a particular depth within their normal egg laying depth limits year to year.

3. Is there a relationship between sss predicted egg abundance/density and commercial landings in the Monterey area?

H_1: There is a correlation between sss predicted egg abundance/density and commercial landings in the Monterey area and sss.

H_0: There is no relationship between sss predicted egg abundance and commercial landings for the Monterey area.

MATERIALS

Instrument Platform

VenTresca

The R/V VenTresca is an aluminum catamaran designed and manufactured by Armstrong Marine, was the primary research vessel for this project. The VenTresca is 35ft long, has a draft of 2ft, and a beam of 10.5ft which makes the vessel just small enough to be towed to any location where needed. Power is provided by twin Honda 225hp outboards giving a top speed of 26 knots. The R/V VenTresca is owned and operated by the Seafloor Mapping Lab of California State University, Monterey Bay.

Figure 3: Image of R/V VenTressca

Sidescan Sonar

The sidescan sonar system, or "towfish", used was an EdgeTech 260TH dual frequency system. Acoustic backscatter data (also known as sidescan data) are collected using sonar where the intensity of the return echo is recorded. This allows for the classification of different substrate types due to the differences in amplitude of the returning sound. For example, the sound returning from a rock would have greater amplitude than the sound returning from soft sediments which tend to absorb more and reflect less of the sonar’s transmitted sound. In addition, the orientation and texture of the substrate also affect the amplitude of the returning sound. The backscatter data can be converted into a georeferenced sonograph mosaic for use in the visual interpretation or supervised classification of the surface texture of the seafloor.

Drop Camera

The drop camera used was a SplashCam deep pro used in conjunction with Light&Motion SunRA Pro HD lights, and dual, parallel green lasers set at between 20 and 40cm apart. Video is recorded on mini-DV tape on a JVC-DV600U recorder as well as being record digitally onto a Focus Firestore FS-2 digital recorder.

METHODS

Field Methods

Survey operations were conducted in Monterey Bay aboard the R/V VenTresca in the southern part of the Monterey Bay by the California State University Seafloor Mapping Lab over a period of four years (the first year will not be used as it lies outside the general study area). Because of previous surveys, dives, and drop camera reconnaissance, the general region of eggs beds was known. Five surveys were made of the same general areas with some variation due to squid egg locations.

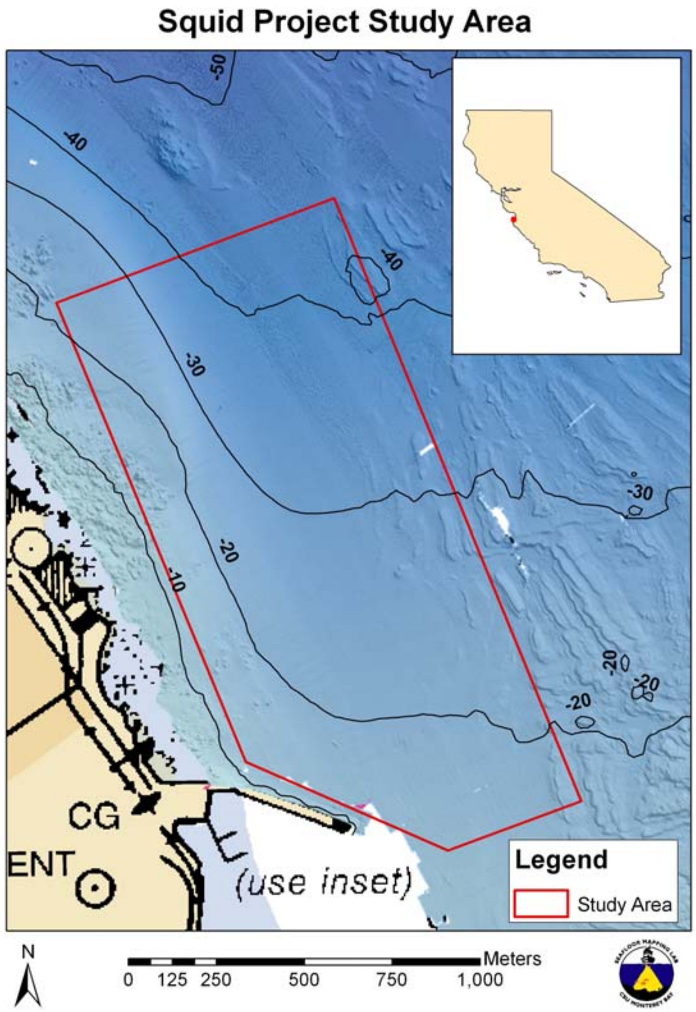


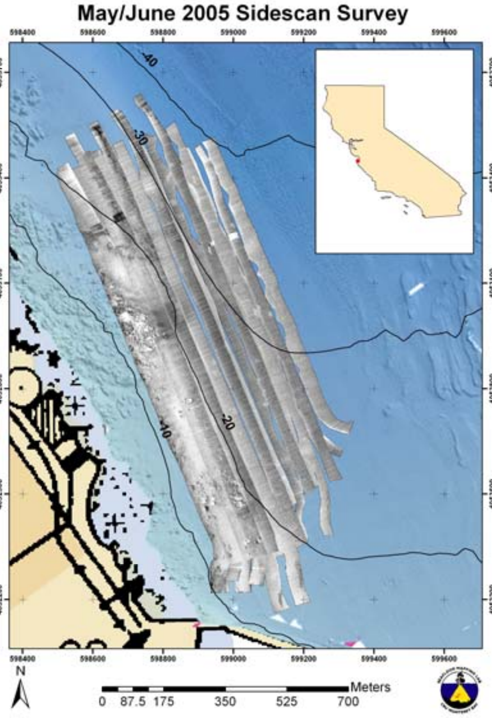
Figure 4. Map of squid project study area in Monterey Bay, Ca.

The first survey was conducted in 2005 from May 31st to June 1st, the surveys during the following year (2006) were made up of a series of three surveys conducted from April 28th to May 2nd, June 9th to June 15th, and September 1st to September 2nd. The 2007 survey was the final survey and conducted from May 27th to June 2nd (Table 3).

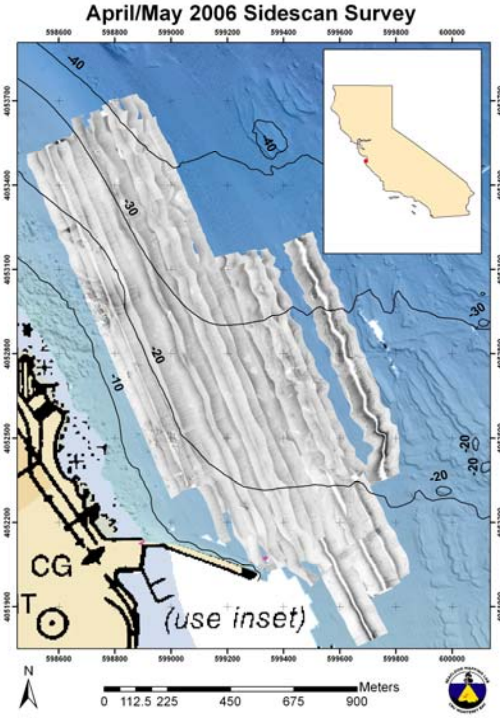
Table 3: Start and end dates for each survey each year.

Year	Start Date	End Date
2005	May 31st	June 1st
2006	April 28th	May 2nd
	June 9th	June 15th
	September 1st	September 2nd
2007	May 27th	June 2nd

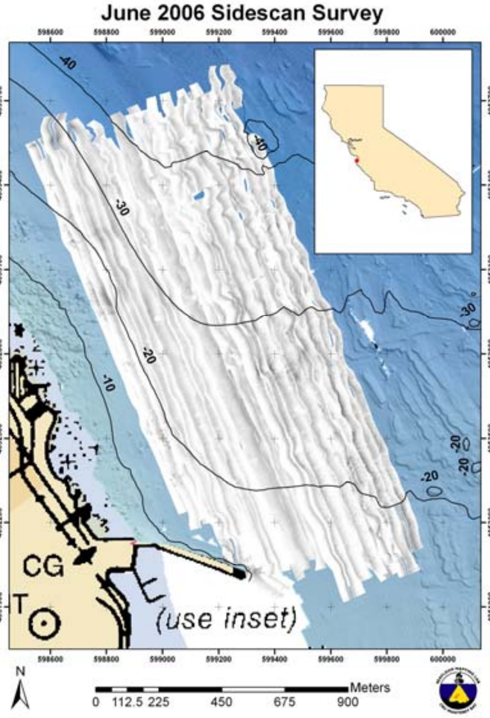
May/June 2005 Sidescan Survey



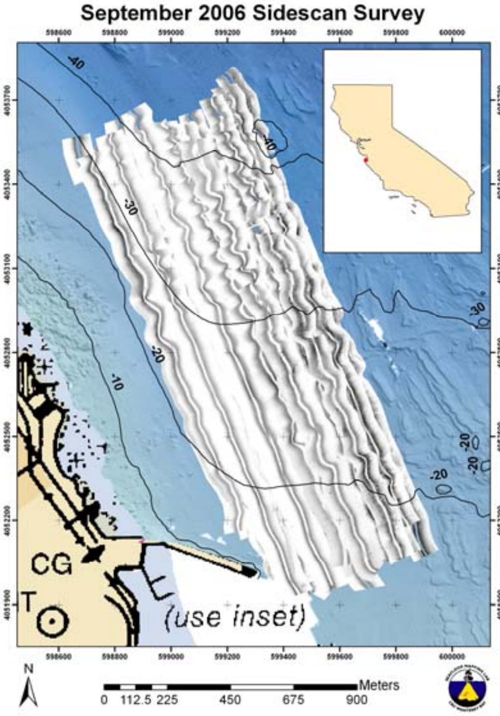
April/May 2006 Sidescan Survey



June 2006 Sidescan Survey



September 2006 Sidescan Survey



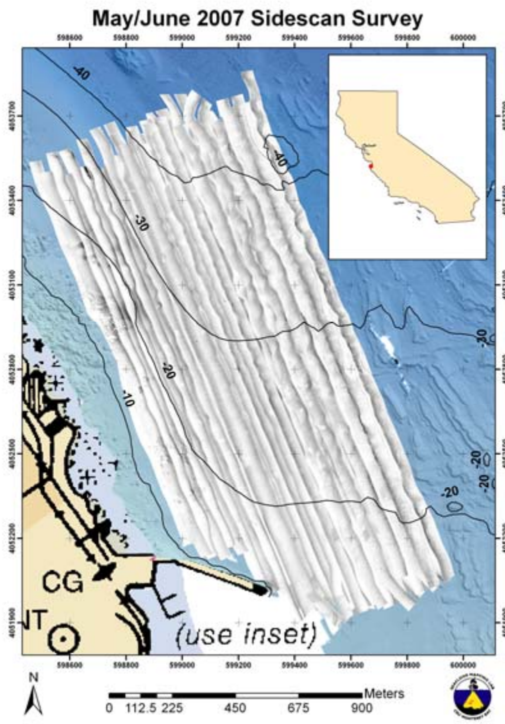


Figure 5. Maps of each of the sidescan sonar survey areas. The sidescan mosaics used in the study are shown with depth contours measured in meters.

Sidescan survey

In each survey parallel transects were made at a low speed between 2 and 5 knots depending on the amount of cable out and depth. Transects were created in Hypack navigational software and consisted of multiple even spaced parallel track lines. Driving these lines is often called "mowing the lawn" as the vessel will drive back and forth moving over in steady increments until the survey area has been covered. "Cable out" is the amount of cable let out on the towfish. The cable out is kept constant for each transect and varied from 40m to 60m in 10m increments. The altitude of the towfish was controlled with vessel speed to keep the towfish at an altitude between 3 and 7m off the substrate.

The raw sidescan data was collected by an analog system which kept a paper record of all signal data. In addition, the data were collected in XTF (eXtended Triton Format) format using a Triton Imaging, Inc. Isis Sonar data acquisition system

Drop camera survey

Camera surveys were performed using the splash cam equipped with two green light lasers. The rig was weighted with a 50 pound lead ball so the tether would remain taut and relatively straight. Position was assumed to be the same as the vessel. Camera cable sent back instantaneous images displayed on an onboard monitor so altitude above seafloor could be monitored and adjusted accordingly. The vessel was allowed to drift with none to minimal throttle input to keep the line relatively vertical. Video data was recorded onboard by a mini DV recorder.

Data Processing

Processing of the raw XTF format sidescan data was done with Triton Isis software package. The raw XTF's were played back in Isis and corrected for slant range, and then georeferenced to UTM zone 10 north (WGS84). The lines were exported with a resolution of 0.1m. Once completed, each line was opened in TritonMap where the color ramp was reversed (Isis exports in a reverse color ramp). TritonMap was then used to export the line files to a geotiff format.

The line geotiffs were imported into TNT Mips GIS for further processing. Each line geotiff was extracted, meaning bad, hard to see data on the edges; warped data in severe turns, and nadir artifacts were removed leaving only the best data for use in the analysis. As all lines from each respective survey were completed, they were laid out together to create a complete mosaic of the seafloor. The mosaics were exported as geotiffs and given a spatial reference in ESRI's ArcCatalog.

Analysis

Egg mop identification training

In order to effectively identify squid egg mops on the substrate in the sidescan mosaics, the author needed to be trained in the differences in substrate such as rocks, sediment, debris, and the differences in cross track signal strength.

All drop camera video footage that had an associated Hypack navigation file were viewed and the times when squid egg mops were in the field of view of the camera were recorded. UTC time and location was recorded on the display in all video. Individual egg cases were not recorded as they would not have shown up on sidescan. Only mops made up of a few egg cases.

Hypack navigation files were used to make georeferenced tracklines and drop track lines of the dropcam travel paths in ArcGIS. Drop track lines are point shapefiles with each point being associated with an event or time in an attribute table. The table was modified to include an “eggs” column and the times associated with egg mops being in view were given a value of 1 with no egg mops in view given a value of 2. Times of no data or questionable data were not displayed in the final drop tracks.

The final drop track lines (figure 6) were displayed in ArcGIS with times of egg mops viewed in white and times of no egg mops in view displayed as dark grey. This gave the author a way to confirm whether what was observed in the sidescan was egg mops or not.

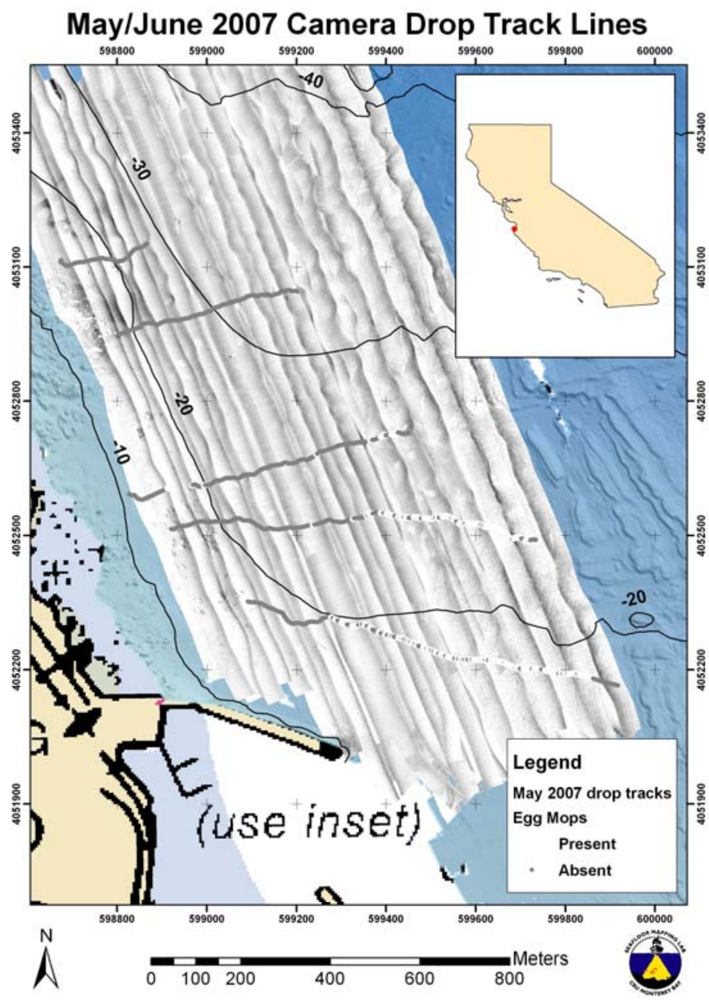


Figure 6: Example of camera drop track lines used for egg patch identification training.

Testing reliability of sidescan sonar in detection and quantification of egg beds

The first phase of this analysis was spent drawing individual polygons around each of the suspected egg mops observed in the sidescan image (figure 7). This task was completed in ArcGIS software and saved as a shapefile with a name associated to the

Julian day of the survey being analyzed. The polygons were drawn without the aid of video data, other than the training, to determine if the sidescan alone was a reliable measure of egg abundance.

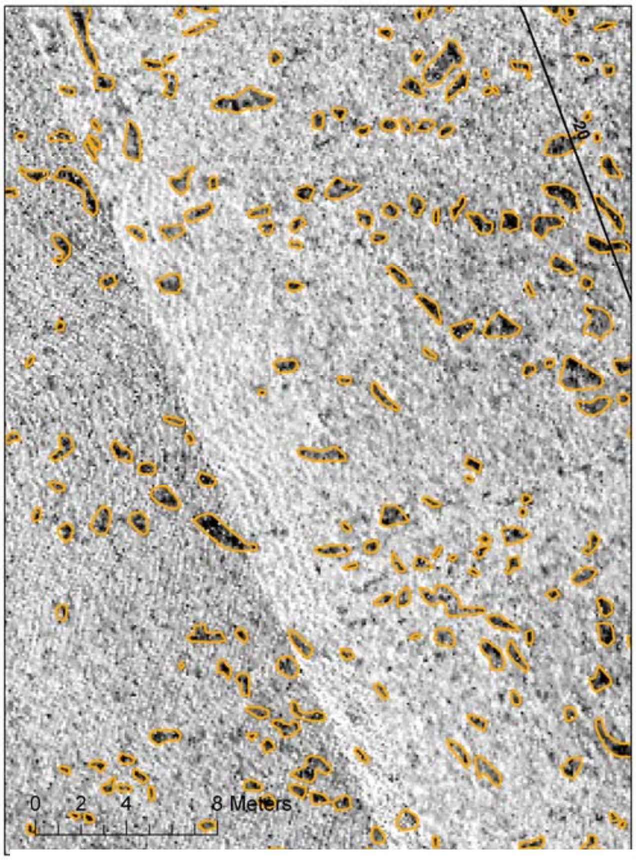


Figure 7: Sample of squid eggs with polygon features.

Once all polygons were drawn (over 18,000 for this study), the video tracklines were divided up into 20m sections which were classed into areas of "no eggs" and areas of "eggs", depending on if they visually coincided with egg patch polygon areas or not. Using a random number generator, line sections were chosen from both areas on all surveys for sub sampling of the sss polygons. A minimum amount of four sections from each area on each survey were chosen with some areas having up to seventeen. These line sections were then given a buffer area so percent coverage could be determined using only sidescan based polygons.

The buffer distance was determined by analysis of video data. In some of the video, lasers were used for scaling purposes. These lasers were 41cm apart so the field of view in the video could be mathematically determined from a sub sampling of videos. The average across track field of view was found empirically to be about 2.34m. Divided in half gave the value of 1.17m for the buffer. Unfortunately this value was biased to areas with shallow depths where the lasers could actually be seen. Video frames taken more than a few meters off the substrate could often resolve egg mops, but due to water clarity not being optimal and the low resolution of the camera, the laser light was often lost. This measurement and subsequent application proved unreliable in crossing egg mop polygons with any consistency despite being in dense areas.

The author decided to approximately double the value in to better approximate the field of view. The buffer size chosen was 3m and this was applied to the line sections. The buffer zones were approximately 6m wide and 26m long with an area of about $148m^2$. Each buffer was analyzed individually to asses the egg mop polygon area contained within it. This analysis was done in GIS by selecting polygons with their centers within the buffer area. Consulting the polygon attribute table gave a list of polygons selected and areas associated with them. These areas were summed and percent cover determined (table).

Using the camera drop tracks the video segment portion associated with each line segment could be found and viewed. Using a random dot overlay on the computer monitor, the video segment was sampled approximately every 2m. Egg mops in contact with a random dot were recorded as a contact. For each video segment contacts were summed and divided by the number of random dots on the overlay (varied) yielding a percent cover for each segment. Means were found for all surveys in “no egg” and “egg” areas classed by video and sss (table 4). A liner regression was performed using means from all sidescan and video subsamples (figure 8) using excel to generate a graph and SPPS to generate the statistics. Liner regressions wer used to determine how well video and sss sampling predicted the total percent egg cover based on the total percent cover of egg patches inside each survey area (figures 9 and 10).

Since the randomly selected sections were sampled twice, once with video and once with sidescan sonar, a paired t-test was used to test for differences (table 5) between video and sidescan sonar samples.

Squid egg bed depth analysis

The goal of the depth analysis was to find a way to assign a depth value to each of the polygons representing squid eggs and statistically test the data to see whether or not market squid tend to lay their eggs at about the same depth during each subsequent spawning event. The first attempt assigned a single depth value to each of the polygons based on their geometric center, however, it failed to take area into consideration. This could have to effect of skewing the data one way or another. For example, many very small polygons could have more statistical weight than one very large polygon so another way had to be found.

A 2m resolution bathymetric digital elevation model (DEM) was used for assigning depth values to the squid egg polygons by using the map algebra tool found in ArcToolbox and recalculating the DEM to a smaller cell size of 10cm. The squid egg polygons were used as a mask to extract the underlying DEM cells into a new layer. The new raster layer had depth values associated with the number of cells in a particular depth range. Unfortunately the staggering number of cells at the 10cm size made a statistical testing with the available software impossible. The number of cells for the 2005 polygons alone totaled more that 307,000, this made the use of excel and SPSS impossible.

The processes was repeated several times at different cell sizes in order to find the cell size that retained the most number of egg mop areas yet was still small enough to be used in the needed software. Through trial and error 60cm was found to be small enough to retain most area, yet large enough to be useful for statistic analysis. A quick look at the data showed that the 60cm cell areas actually totaled a little more than the polygons themselves, this was a negligible amount.

The data as it was in the ArcGIS attribute table was unusable for statistical analysis because the data was in automatically placed in depth bins. First the data was exported from ArcGIS into a dBase format and opened in Excel to prepare it for SPSS. To “un bin” the data and make it usable in SPSS, the vlookup command was used in Excel to arrange the data in a single column with each repeat depth value separate. The data was assigned grouping values based on survey: 1 = 2005, 2 = April 2006, 3 = June 2006, 4 = September 2006, and 5 = April 2007. The data were then copied and pasted into SPSS for analysis. Histograms of the data are found in figure 11, and summarized in table 10.

Assumptions were tested with Kolmogorov-Smirnov test comparing the distribution of each surveys data to the normal distribution, none passed so a non-parametric Kruskal-Wallis test was used to test for significant differences between the means. A significant difference was found the K-S test (tables 11 and 12) so a series of pair wise Mann-Whitney U test followed to test for which surveys were significantly different from which (table 13).

Sidescan sonar predicted egg abundance predicting landings

This analysis was broken up into two parts: one to test if squid landings could be predicted from egg abundance detected by sidescan sonar. Egg abundance was calculated by finding the cross sectional area of a squid capsule. But first the mean squid egg case diameter had to be found. Fortunately this had been done in another study within the Monterey Bay by Zeidberg et.al. which found the mean diameter of an egg case to be 12.2mm. This number is similar to another study (Foote et.al., 2006) that found an average diameter of 16mm. However, since the Ziedberg study was done with slightly larger sample (n=193) and over a wide range of development stages (Zeidberg et.al., 2004), this was considered the more accurate number. Area for polygon egg patches were found by summing all egg patch areas in ArcGIS. From this data the number of egg capsules per survey area was calculated (table 16).

The Zeidburg et.al. study had also found the mean number of eggs per capsule (n=2454) as 164. This was multiplied by number of capsules in the survey areas and summarized in table 16. This data allowed eggs/m^2 to be calculated (table 16) for each of the survey areas.

A linear regression was performed to test the sss predicted egg abundance ability to predict squid landing in the Monterey area (figure 13). The regression calculated an r^2 value of 0.980 indicating a strong relationship. Only data from May/June 2005, June 2006, and May/June 2007 could be used as they were spaced by similar time intervals of approximately one year.

The second test performed would test if the mean area of individual egg patches significantly differed in each of the surveys. Mean area was calculated by inputing data egg patch area from ArcGIS into SPSS and generating a series of histograms (figure 12). Mean area/egg patch ranged from 0.25-0.65m^2 (table 17).

The entire data set was subjected to a one way ANOVA to see if there was a significant statistical difference in mean area/egg patch (table 18). A significant difference was found between the groups so a tukey test was performed to find which surveys differed from each other (table 19).

RESULTS

Reliability of sidescan

Table 4: Mean % cover calculated from means of both egg and no egg areas from both video and sidescan sub samples.

	survey	no egg area	egg area	Mean % cover	std. dev.
Video	May/June 2005	0.1446	6.4286	3.2866	4.4435
	April/May 2005	0.0000	10.2887	5.1444	7.2752
	June 2006	0.0361	3.5431	1.7896	2.4798
	May/June 2007	2.0121	3.3961	2.7041	0.9786
Sidescan samples	May/June 2005	0.2857	5.8871	3.0864	3.9607
	April/May 2005	0.0000	5.5316	2.7658	3.9114
	June 2006	0.0709	0.7603	0.4156	0.4875
	May/June 2007	0.0644	0.4089	0.2367	0.2436

The results of the paired t-test are summarized in table 5. May/June 2005 and April/May 2006 both had results indicating that the video and sss sub samples were in agreement. For June 2006, the “no egg” result p=0.658 showed a strong agreement between video and sss sub samples but the “egg” area did not show the same strong agreement with p=0.003. September 2006 had no eggs so returned a significant value of p=1 for both areas. September had no eggs witnessed on the entire video from the one track line run during that survey. No more video surveys were undertaken at that time. May/June 2007 returned a value of p=0.025 for the “no egg” area and p=0.103 for the “egg” area indicating a difference in the video and sss for the “no egg” area.

Table 5: Results of paired sample t-tests comparing video and sidescan in egg and no egg areas for differences.

Survey	Area type	data source	mean	std. dev.	p-value
May/June 2005	no egg	video	0.1446	0.1812	
		sidescan	0.2857	0.3704	0.606
	egg	video	6.4286	4.3590	
		sidescan	5.8871	4.6699	0.595
April/May 2005	no egg	video	0.0000	0.0000	
		sidescan	0.0000	0.0000	1
	egg	video	10.2887	11.7365	
		sidescan	5.5316	4.7801	0.386
June 2006	no egg	video	0.0361	0.0954	
		sidescan	0.0709	0.1555	0.658
	egg	video	3.5431	2.8534	
		sidescan	0.7603	0.9424	0.003
September 2006	no egg	video	0.0000	0.0000	
		sidescan	0.0000	0.0000	1
	egg	video	0.0000	0.0000	
		sidescan	0.0000	0.0000	1
May/June 2007	no egg	video	2.0121	3.0105	
		sidescan	0.0644	0.0750	0.025
	egg	video	3.3961	2.5466	
		sidescan	0.4089	0.3887	0.103

Results for a linear regression (shown below in figure) show that video and sss sub samples have a small probability of being correlated.

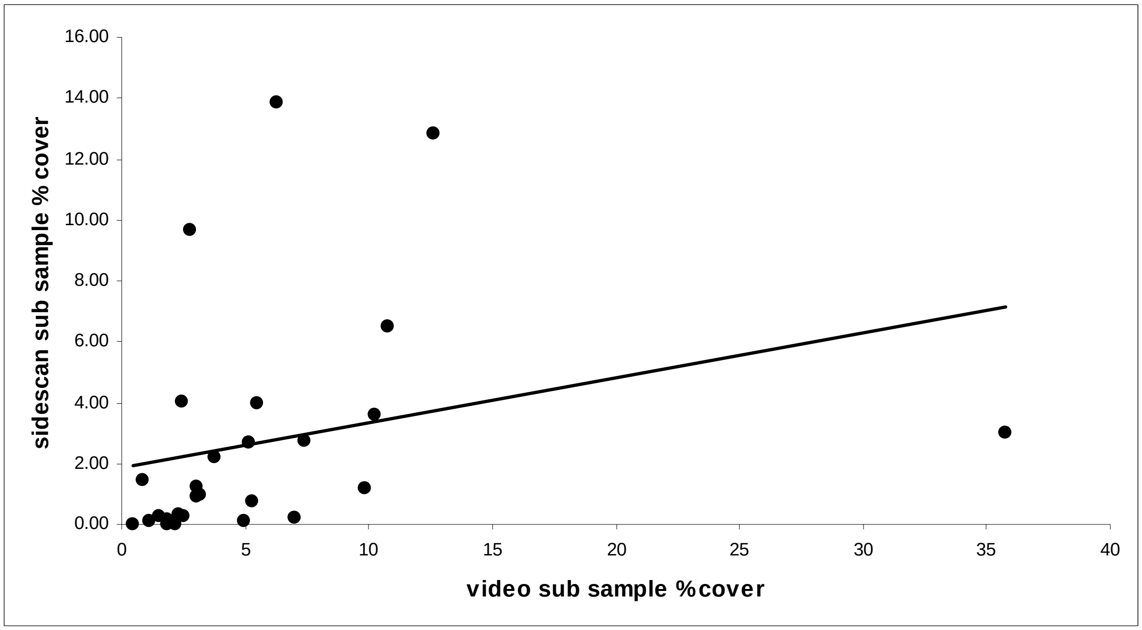


Figure 8: Linear regression of video sub sample % cover to sss sub sample % cover. R^2= 0.071.

Table 6: Statistical data for figure 5.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.266(a)	.071	.034	6.73144

The next linear regression was conducted to see how well the video sample data predicted the coverage found in the entire sss survey. The r^2 value of 0.006 indicates a weak relationship.

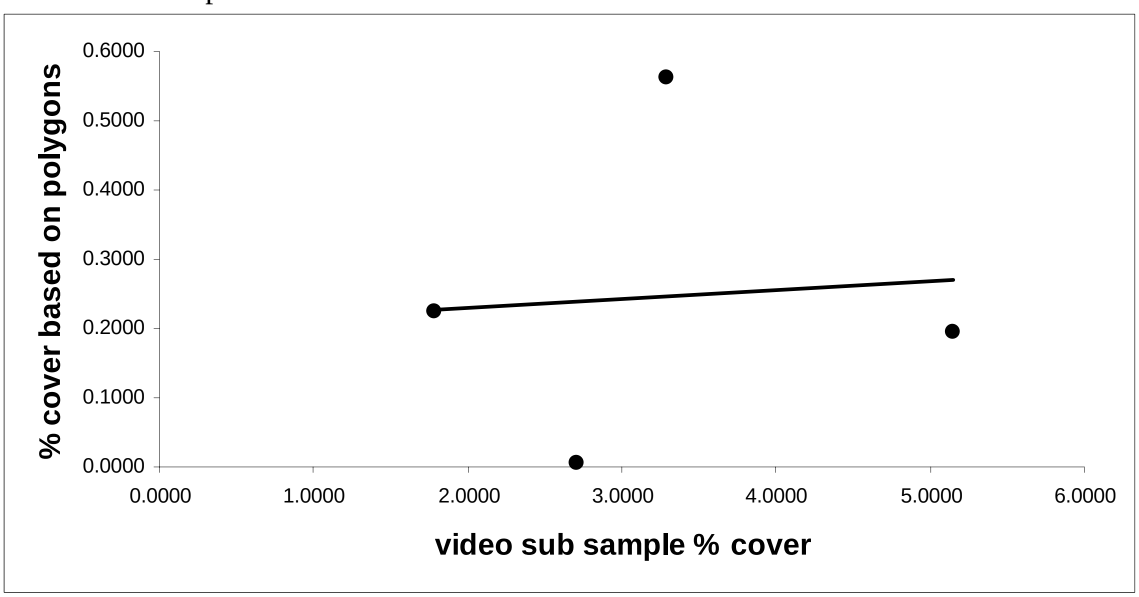


Figure 9: Liner regression test the predictability of egg percent cover using video. R^2= 0.006

Table 7: Statistical test for predicting egg % cover by sampling video.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.079(a)	.006	-.491	.28173

The second linear regression tested the sss sub samples ability to predict the percent cover from the entire survey areas. The r^2 value was 0.531 indicating that sub sampling was a good predictor.

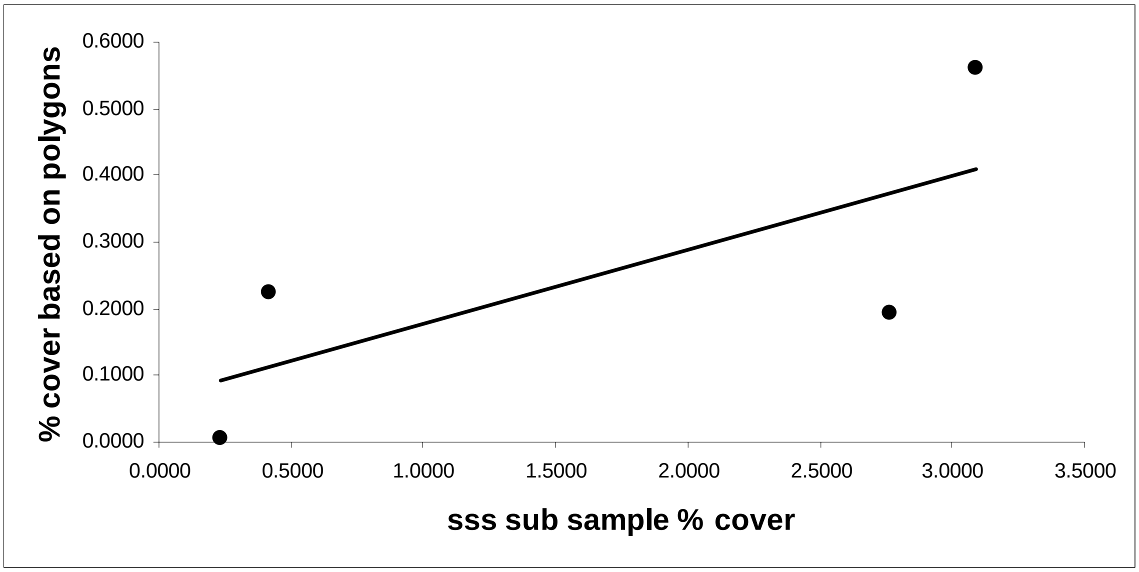


Figure 10: Liner regression testing the predictability of egg percent cover using sidescan sub sampling. R^2= 0531

Table 9: Statistical test for predicting egg % cover by sampling sidescan.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.729(a)	.531	.297	.19351

Squid depth preference results

The histograms produced in figure show the distributions of egg depth for each 60cm cell that resulted from converting sss based egg patch polygons to 60cm cells.

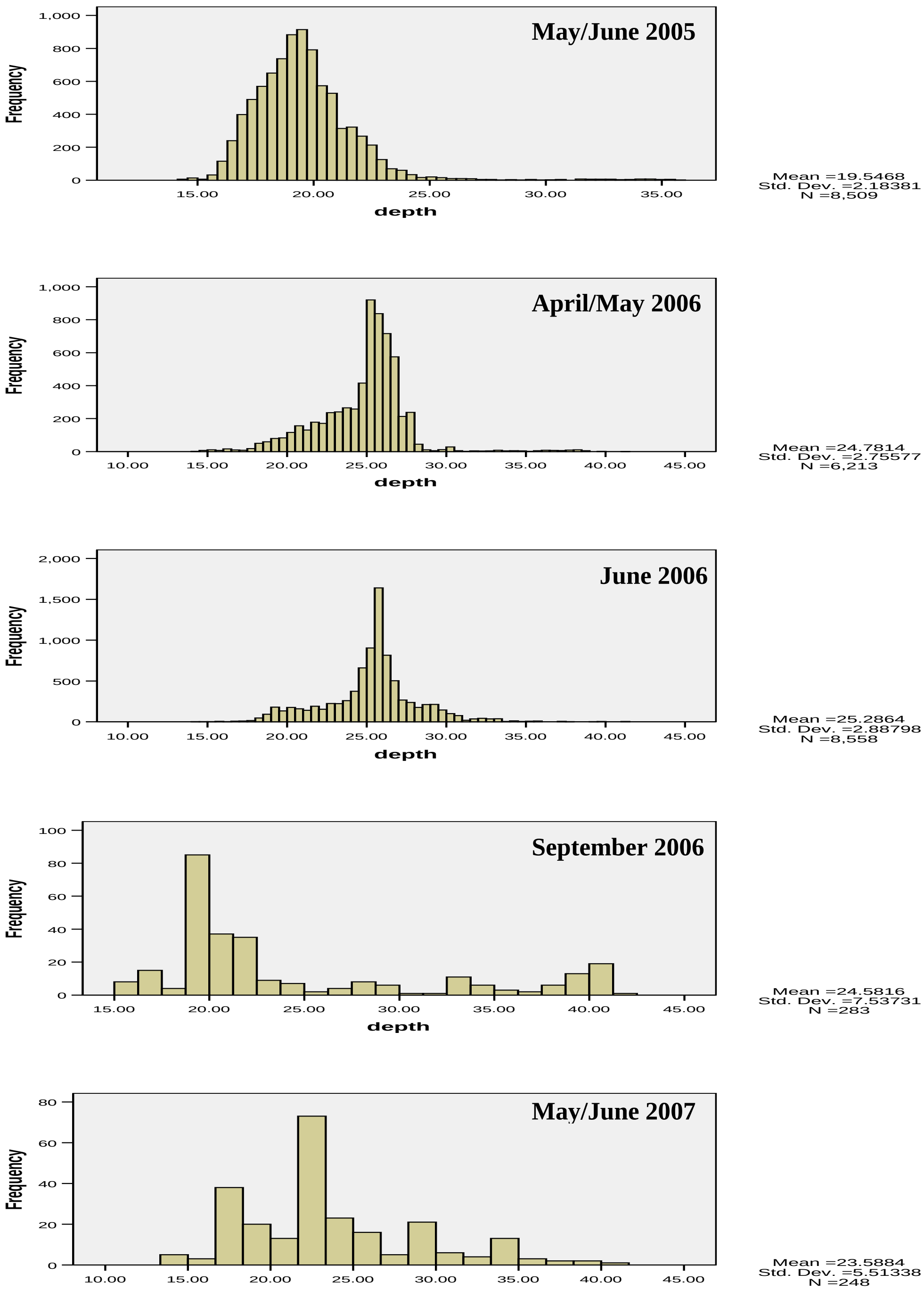


Figure 11: Histograms of egg patch depth distributions by survey.

Table 10: Mean depth of all cells (60cm) representing egg patches.

	n	mean depth (m)	std. dev.
May/June 2005	8509	19.55	2.18
April/May 2006	6213	24.78	2.76
June 2006	8558	25.29	2.89
September 2006	283	24.58	7.54
June 2007	248	23.59	5.51

The results from the Kruskal-Wallis test (table) shows p<0.001. This is a significant result meaning that at least two surveys differ from each other significantly. This test assumes that all depth data from the surveys come from populations with the same median. Since the K-S test is used for comparing three or more data sets, a series of Mann-Whitney U test are used to check for significant differences between surveys.

Table 11: Krusal Wallis test ranks for depth preference analysis.

	survey	N	Mean Rank
depth	May 2005	8509	5356.17
	April 2006	6213	15229.36
	June 2006	8558	16022.16
	September 2006	283	11571.89
	May 2007	248	11716.15
	Total	23811	

Table 12: Kruskal Wallis test statistics

	depth
Chi-Square	12247.838
df	4
Asymp. Sig.	.000

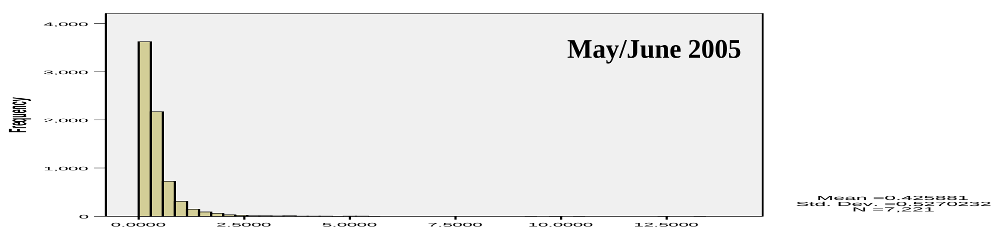
The results from the series of Mann Whitney U test yielded significant values meaning there is a difference between the most of the surveys when tested together. The only pair that were similar were September 2006 and May/June 2007 in which p=0.209. The M-W U test the hypothesis that each of the two surveys come from populations with the same distribution.

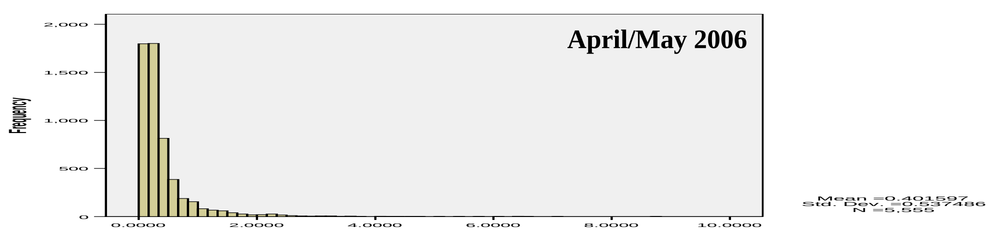
Table 13: Series of Mann Whitney U test comparing each survey's depth data to every other survey with associated p-values.

Mann Whitney U summary			
survey	**p-value**	**survey**	**p-value**
May/June 2005 April/May 2006	0.000	April/May 2006 September 2006	0.000
May/June 2005 June 2006	0.000	April/May 2006 May/June 2007	0.000
May/June 2005 September 2006	0.000	June 2006 September 2006	0.000
May/June 2005 May/June 2007	0.000	June 2006 May/June 2007	0.000
April/May 2006 June 2006	0.000	September 2006 May/June 2007	0.209

Sidescan sonar predicted egg abundance predicting landings

Distribution of individual sss based polygon egg patch areas is shown in figure 12 and summarized in table 17. Surveys from May 2005 to September 2006 all had egg patch mean area greater than 0.40m^2 with June 2006 having the greatest at 0.65m^2 while May 2007 was considerably below this with a mean of 0.25m^2.





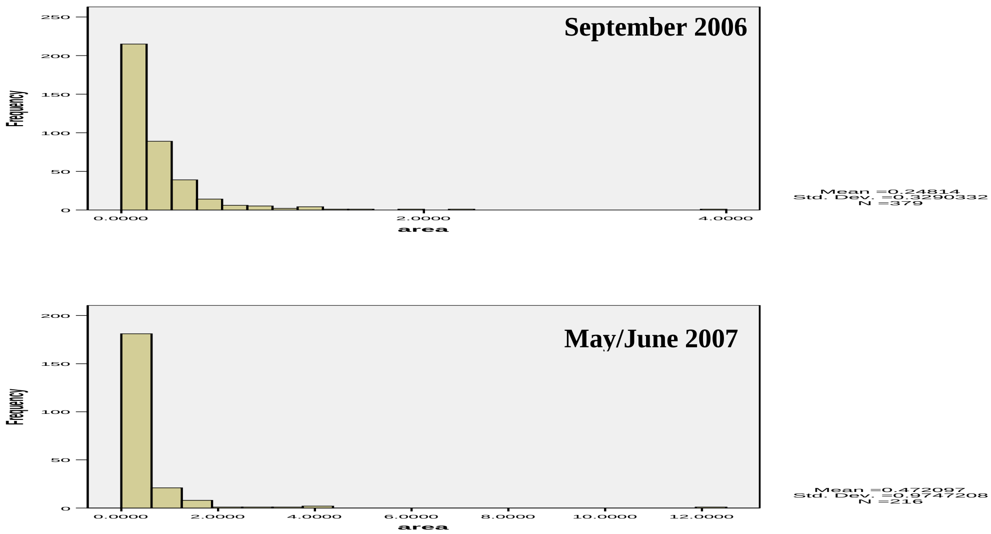


Figure 12: Histograms describing distributions of individual egg patch areas. Data summarized in table 17.

The results from the linear regression testing the relationship of sss predicted egg density in the study area to commercial catch data from the Monterey area yielded an r^2 value of 0.961 (table 14). Only the density values from May/June 2005, June 2006, and May/June 2007 were use as they were almost evenly spaced in time. These values were plotted against end of the year totals for each respective year.

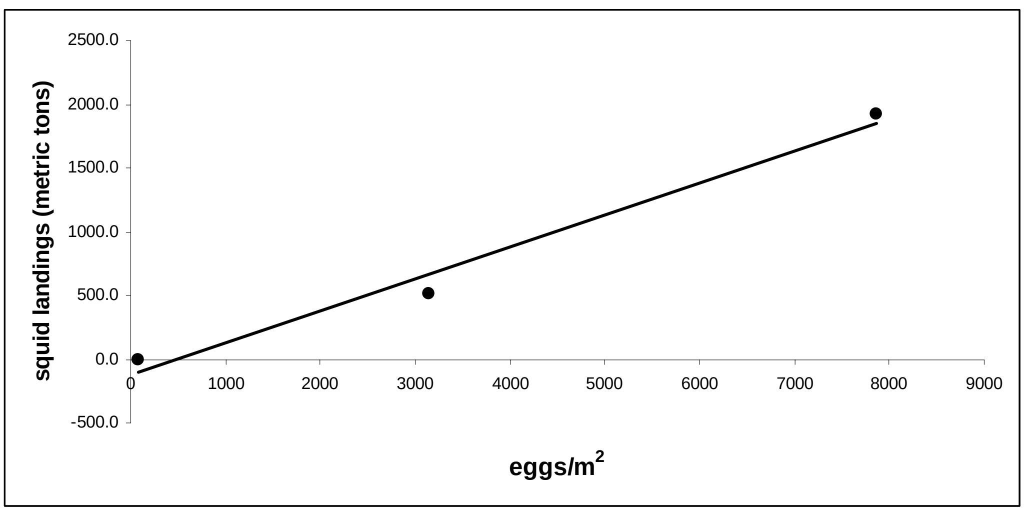


Figure 13: Linear regression testing relationship between sss predicted egg abundance and catch data. Only egg abundance data from May/June 2005, June 2006, and May/June 2007 are used and plotted against the respective years catch data. R^2= 0.980.

Table: 14 Results of linear regression testing relationship between egg abundance and catch data.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.990(a)	.980	.961	196.86601

Table 15: Summary of data from Zeidberg study with calculation of cross sectional area of egg capsule.

egg cap mean diameter (m)	egg capsule radius (m)	egg capsule cross sectional area (m^2)	mean eggs/capsule
0.0122	0.0061	0.0001169	164

Table 16: Summary of total number of capsules and egg per survey with abundance and % cover.

survey	egg patch area (m^2)	capsules	eggs	survey area (m^2)	eggs/m^2	%coverage
May-05	3074.29	26298761	4312996818	548179	7867.86	0.5608
Apr-06	2230.87	19083794	3129742220	1146428	2729.99	0.1946
Jun-06	3058.55	26164114	4290914786	1366070	3141.07	0.2239
Sep-06	101.97	872293	143056213	1194930	119.72	0.0085
May-07	94.05	804542	131945050	1527400	86.39	0.0062

Table17: Mean area of egg patches from polygons drawn from sidescan mosaics.

	n	mean area (m^2)	std. dev.
May/June 2005	7221	0.43	0.53
April/May 2006	5555	0.40	0.54
June 2006	4726	0.65	1.09
September 2006	216	0.47	0.97
June 2007	379	0.25	0.33

A one way ANOVA was performed to see if there was a diffeence in the mean area/egg patch in each of the survey areas. The one way ANOVA gave a significant result meaning there was a significant difference in at least two of the surveys. To find out wich ones a Tukey test was run and summarized below in table 19. The May/June 2007 survey was different from all other surveys with a mean area/egg patch of $0.25m^2$. The June 2006 survey was also significantly different from all other surveys with a mean area/egg patch of $0.65m^2$. These two surveys represent the lowest (May/June 2007) and the highest (June 2006) values calculated. The rest of the surveys ranged from 0.40-$0.47m^2$ and were not found significantly different in the test.

Table 18: One Way ANOVA testing for difference between groups. P<0.001.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	206.891	4	51.723	98.444	.000
Within Groups	9505.543	18092	.525		
Total	9712.434	18096			

Table 19: Tukey test results comparing all surveys.

Tukey test results			
survey	p-value	survey	p-value
May/June 2005 April/May 2006	0.330	April/May 2006 September 2006	0.626
May/June 2005 June 2006	0.000	April/May 2006 May/June 2007	0.001
May/June 2005 September 2006	0.888	June 2006 September 2006	0.005
May/June 2005 May/June 2007	0.000	June 2006 May/June 2007	0.000
April/May 2006 June 2006	0.000	September 2006 May/June 2007	0.003

DISCUSSION

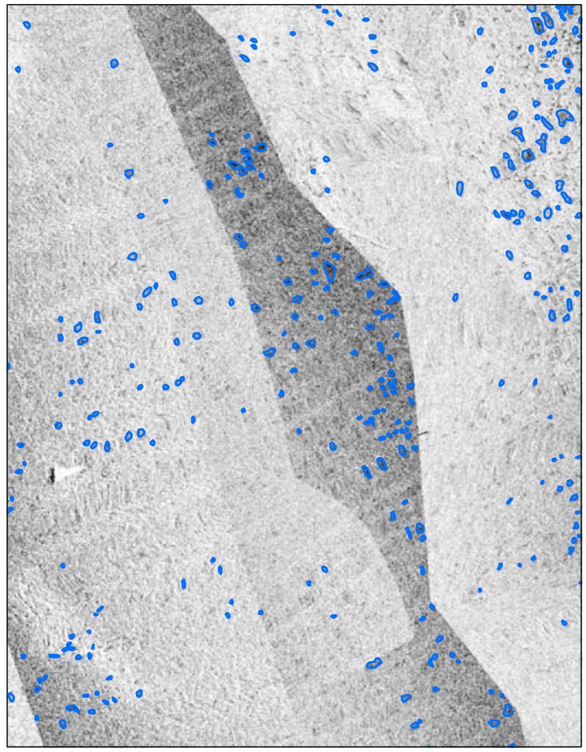
Sidescan sonar reliability

An examination of table 5 shows that May/June 2005 had high p-values which indicate a strong agreement between video and sss samples. Coincidentally the associated sidescan image was the clearest and easiest to read. Most of the egg patches in the sidescan mosaic appeared dark and distinct which aided in reliable identification. The mosaic quality across track was also very good. Many of the other mosaics suffer from signal degradation based on how for the signal has to travel and at what angle. Going towards the outside of a line from nadir the brightness and contrast of the sidescan tends to diminish. May/June 2005 data suffered somewhat from this but not to the extent of other data sets.

The video for this period was the most extensive of any survey with well over a dozen transects performed. All transects traveled approximately perpendicular to the sidescan transects and were generally at a higher altitude than other surveys with fairly clear water. Field of view could not be measured as the laser lights could not be seen on the seafloor at these altitudes.

The April/May 2006 survey also yielded favorable results (table 5) with p=0.386 for egg areas and p=1.0 for non egg areas. The result for egg areas is surprising as April's survey suffered from severe signal degradation across track. In many areas there were heavy egg mops up against hard lines with little or no egg mops due to the over lap in lines with dark data being next to lighter data from the edges. This gave the polygon egg mop distribution a striated look (see figure 14), even adjusting contrast in these light areas had little effect.

The no egg areas for April/May 2006 turned out to be just that, a no egg area, or at least very few egg mops where found there. No egg mops were recorded from video sub sampling or from the sub sampling of the sidescan. That is not to say there were none on the video, in fact there were mops in view frequently just none ever happened to be on a random dot of the overlay during sampling.



The June 2006 also suffered heavily from cross track loss of signal. The result of p=0.003 for the egg areas statistically shows that the video and sidescan are different, however, most likely this values would have been different had the video transects been perpendicular to the sidescan transects. Most of the drop camera transects ran parallel to sidescan transects and on top of light, low contrast data. The areas of no eggs were found to have approximately the same median with p=0.658. All in all the June/May 2006 results are somewhat inconclusive.

September was included for the sake of being thorough, however there were no egg mops observed with the dropcam. During this survey there was only one video transect collected in the northern section of the study area which crosses the upper parts of the sidescan mosaic. Some areas thought to be eggs were marked but as there is no video data there to confirm or deny presence of egg mops.

Results for May/June 2007 were not encouraging with a p-value for the “no egg” areas to be p=0.025. This meant no agreement between video and sidescan samples. The “egg” area does have a small probability of showing agreement between video and sss samples but with p=0.103 there is only a 10% chance that they agree. While above the 0.05 rejection level it would have made for a stronger argument that sss was reliable in detection of egg patches. However, these results for May/June 2006 are not surprising considering how light the year was in terms of catch (anecdotal evidence from local fishers summarized in table 2).

During the training exercise eggs and egg mops were observed in significant numbers throughout the same areas covered with eggs during the April/May and June 2006 surveys. The drop tracks used for training showed the same extent of egg bed fields as those two previous surveys but none showed up on the sidescan. So what was the difference?

One factor not discussed is development stage of the eggs. As an egg grows and matures the capsules gain in length and girth which logically would effect a stronger return to the echo sounder and thus showing up darker on the sidescan. The egg mop sizes were difficult to ascertain but were of a size that was thought should have been detectable by the sonar system, but the stage of development and size of the capsules were impossible to tell from the video data.

A clue to why no eggs were detected by the sidescan in May/June 2007 is found in table 17. The mean area of individual egg patches found in the sss is $0.25m^2$ which is well below that of any of the other surveys. This small size would make detection difficult as it is barely above the resolution capable by the sss system of about 10cm. This would explain why eggs could be observed on video, but not on the sidescan mosaics, or they may have been there, but at a pixel or two would have been difficult to differentiate between the background noise of the rest of the sidescan sonar.

June 2006 was inconclusive for “egg” areas due to poor quality of sidescan being coupled with the drop camera tracks being on top of said area and the results for May/June 2007 was most likely an effect of mean area/egg patch being below the threshold detectable value which based on the data must be about $0.40m^2$. The Foote et.al. study estimated the minimum detectable size of an egg mop to be 50cm long or about $0.25m^2$ assuming square shape. This is the average value for the May/June 2007 data.

The other data showed strong agreement between video and sidescan sonar so its felt that the null hypothesis can be rejected. Based on video vs. sss sample data it can be said with some confidence that sidescan sonar is a reliable measure for quantifying egg abundance.

For future work care must be taken in setting up video transects. The best results came from when the video crossed at a perpendicular angle to the sidescan sonar transects. Also, creating sidescan mosaics can be improved by cutting the sidescan into smaller widths. Much good data is covered up by the light areas on the outside edge of each transect. By cutting into thinner strips the best data available can be assured to be on top.

Squid depth preference analyzed

The hypothesis being tested is that market squid have no depth preference for egg laying. The first test aimed at answering this question was the Kruskal-Wallis test. The result of the test was $p<0.001$ (table 12), indicating that at least two of the surveys means were significantly different from each other. To determine which sites were different, a series of ten Mann-Whitney U test were conducted.

Table 13 summarizes the results and shows that all surveys were significantly different from each other in egg depth distribution except September 2006 and May 2007. These two surveys were the two latest surveys which exhibited the least amount of egg cover. Both areas visually have what egg cover there is distributed all over the survey site, no real concentration of eggs anywhere.

Its difficult to accept the results for the two odd surveys as the egg patch areas were so few and the ones there were slightly questionable on is they really were egg patches. So from these test and because of the significant values calculated by several Mann whitney U test it can be said with confidence that all surveys had different mean depths, except for when comparing June 2006 and May/June 2007, so the null hypothesis can be accepted for those survey comparisons only.

The relationship between sss predicted egg abundance and squid landings

The relationship seems to hinge around the minimum average detectable egg patch size being above $0.25m^2$. The one way ANOVA performed found a significant difference in the size distributions of at least two of the surveys (table 18) so additional test were performed.   June 2006 and May/June 2007 were the outstanding surveys found to have a significantly different mean area/egg patch values. June 2006 was not used in the liner regression (figure 13) to determine is abundance could detect landings and it's area/egg patch is larger so easily detectable so it can be excluded from the discussion. The May/June 2007 area/egg patch values was at the lower limits of detectability but through anecdotal data from local fishers the catch thus far in 2007 is thought to be negligible so its use in the regression can be justified.

The regression shows a strong ability for sidescan derived egg abundance to predict squid landings. The regression only used three surveys in the analysis so it may not be as strong as the numbers say. More data is needed for a more solid conclusion. However, based on this test and the data concerned, the null hypothesis can be rejected for the conclusion that sss derived egg abundance is a good predictor for squid landings in the Monterey Bay.

CONCLUSION

1. Sidescan sonar is reliable at measuring egg abundance assuming that the minimum individual mean egg patch area is above the threshold of $0.25m^2$ and that sidescan sonar data is clear and easily interpreted.
2. For most of the surveys squid did not show any preference in where they laid their eggs between their normal egg laying depth limits of 10-50m.
3. Sidescan derived egg abundance is a good predictor of *L. opalescens* landings for the Monterey area.

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