DUNGENESS CRAB DEPTH DISTRIBUTION: EFFECTS OF SEA OTTERS

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By

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ABSTRACT

The distribution and abundance of Dungeness crabs in the Glacier Bay area were observed with a submersible in five bays with and three bays without sea otters. A matrix design was used with three levels of sea otter occupation and three depth categories. Goals of this study were to determine: 1) the depth distribution of crabs; 2) if depth was a refuge from sea otter predation; and, 3) the habitat of ovigerous female aggregations. Scuba was used to calibrate submersible counts and collect substrate samples; crab pots were used to confirm submersible sightings. Abiotic and biotic variables were analyzed to interpret distribution data and aggregation sites. A regional, long-term crab survey dataset was also examined. Sea otters may have decreased crab abundance in shallow waters. Two aggregations of ovigerous Dungeness crabs were observed in shallow water with sand substrate. However, only 1% of the 33 km of transects were classified as sand, suggesting that sand may be a limiting resource. No conclusions could be made about the independent effects of sea otter presence or depth due to strong interaction. Submersible observations, crab pot surveys, and marine topography together however, point towards a shift in crab depth distribution with sea otter presence.

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INTRODUCTION

The sea otter, *Enhydra lutris*, population within southeastern Alaska has been steadily increasing since their reintroduction in the late 1960's (Burris and McKnight 1973). Four hundred and two sea otters were translocated to six sites in southeastern Alaska from remnant populations in Amchitka Island and Prince William Sound (Burris and McKnight 1973). The current regional population estimate is 15,000 individuals (J. Bodkin, USGS, Alaska Biological Center, Biological Resources Division, personal comm.). Sea otters feed primarily on benthic macroinvertebrates and preferentially consume calorie rich prey items such as crabs and sea urchins when available (Estes et al. 1978, Breen et al. 1982, Garshelis et al. 1986, Kvitek et al. 1992, Kvitek et al. 1993). The net result of this behavior has been a depletion of several commercially important fishery species as the sea otter population has expanded into its former range (Kimker 1984, Garshelis et al. 1986, Pitcher and Imamura 1990, Shirley et al. 1996).

A recent study on the impact of the commercial fishery on the population structure of Dungeness crab, *Cancer magister*, found an apparent anomaly in the bathymetric distribution in one of the bays under investigation, Outer Dundas Bay (Shirley et al. 1996). Data collected from scuba divers and baited crab pots showed that Dungeness crabs were absent or scarce in shallow waters (≤ 25 m) and increased markedly with increasing depth (maximum depth sampled was 95 m). Even though the other bays usually were not sampled at depths greater than 25 m, the trend was decreasing abundance with increasing depth. A key difference between Outer Dundas

Bay and the other sites was the presence of a resident sea otter colony of approximately 40 individuals. Prior to the immigration of sea otters into Dundas Bay the catch per unit effort (CPUE) was relatively high at 10.49 crabs$\cdot$pot$^{-1}\cdot$day^{-1} in 1989 (Pitcher and Imamura 1990).Within a few years the CPUE decreased to almost zero, with only 0.2 crabs$\cdot$pot$^{-1}\cdot$day^{-1} being recorded in 1995 (Shirley et al. 1996). These observations prompted some focusing questions. Could depth be acting as a refuge for Dungeness crabs against sea otter predation or were Dungeness crabs often present at depth, but previously underestimated because fishing and research efforts were concentrated in shallow water due to logistical constraints?

The primary objectives of the current study were therefore to determine the bathymetric distribution of Dungeness crabs; and to correlate the presence of sea otters with variations in abundance of Dungeness crab with depth. A manned submersible with a fixed video camera for recording transects was chosen as the primary means of collecting data. An accurate estimate of crab abundance can be obtained, in conjunction with important auxiliary information such as spatial dispersion and habitat association. By comparison, scuba divers can survey efficiently only at limited depths, while crab pots do not give an accurate assessment of density, because the sampled area is controlled by the distance over which that the bait can attract crabs (unknown), and also changes with the direction and speed of currents (Gage and Tyler 1992).

Observations made in the initial study led to a second investigation. Two of the bays investigated that did not have sea otters present contained large aggregations of ovigerous (i.e., crabs with an egg clutch) female Dungeness crabs. However, there is limited knowledge about brooding behavior and about the specific habitat characteristics of brooding sites. Both of the observed aggregations sites had similar physical profiles: occurring in shallow water (< 10 m in depth) overlying a substrate containing a high percentage of sand. Sand was not a frequently encountered substrate type in the initial study, so the purpose of the follow up study was: (1) to quantify the substrate type by area within each bay; (2) to determine the reliability of visual assessments of substrate type made from submersible videos; and, (3) to determine salinity, temperature, oxygen saturation, and percent organics within aggregation sites to see if any common factors for habitat selection were indicated.

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Chapter 1: Sea otter (*Enhydra lutris*) predation and the bathymetric distribution of Dungeness crab (*Cancer magister*) near Glacier Bay, Alaska

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Abstract

A manned submersible was used to observe the bathymetric distribution and abundance of Dungeness crabs in eight bays with different levels of sea otter occupation: well established, seasonal, and none. The goals of the study were to examine if depth provided a refuge against predation by sea otters and to determine the bathymetric distribution of crabs within southeastern Alaska. Depths surveyed ranged from 10 to 200 m with transects categorized as shallow, intermediate, or deep. Transect videotapes were used to estimate abundance and several habitat parameters. Crab pots corroborated submersible sightings; also, a regional, long-term pot survey was analyzed to examine depth distribution of crabs over a broader geographical area. Crab abundance in shallow water (≤ 50 m) was significantly lower in bays with sea otters; however, strong interaction between depth and sea otter presence confounded statistical analysis of whether crabs moved deeper in the presence of sea otters. In bays without or with only seasonal presence of sea otters, crabs uniformly were in shallow waters; in the only bay with deep water adjacent to typical crab habitat, crabs were abundant at 200 m depth. As sea otters continue to expand their range in southeastern Alaska, crabs may move to deeper depths to avoid predation where habitat bathymetry and physiography permit.

Introduction

One of the causes of mortality of Dungeness crabs (*Cancer magister*) is predation, and in Alaska the predator that has attracted the most attention is the sea otter (*Enhydra lutris*). Sea otter populations within southeastern Alaska are expanding in geographical range and in numbers of individuals (current estimate 15,000, J. Bodkin, USGS, Alaska Biological Center, Biological Resources Division, U.S. Geological Survey, 1011 E. Tudor Rd. Anchorage, A.K., 99503, personal comm.). The immigration of sea otters into important commercial crabbing regions has created a conflict, since commercial crabbing occurs in relatively shallow waters of ≤ 25 m (Pitcher and Imamura 1990, Shirley et al. 1996) and this range is well within the diving capability of sea otters (Newbry 1975).

Little information exists on the impact of sea otters on Dungeness crab abundance in southeastern Alaska. Most studies on the influence of sea otter predation on community assemblages have been on the outer coast of the Pacific Northwest (Rosenthal and Barilotti 1973, Estes et al. 1978, Estes et al. 1982, Kvitek et al. 1992, Kvitek et al. 1993, Breen et al. 1982). An adverse effect of sea otters on the abundance of Dungeness crabs was found in the few studies in Alaska, conducted either in Prince William Sound (PWS) (Calkins 1978, Kimker 1984, Garshelis et al. 1986) or in the inner coastal waters of southeastern Alaska (Pitcher and Imamura 1990, Kvitek and Oliver 1992, Shirley et al. 1996).

The Orca Inlet fishing district within PWS was once a major contributor to the Dungeness crab fishery (Kimker 1984). Sea otters migrated into this fishing district in

1979 and were later documented consuming an average of 14 Dungeness crabs$\cdot$day^{-1} for each adult sea otter, with subadults consuming 10 crabs$\cdot$otter$^{-1}\cdot$day^{-1} (Garshelis et al. 1986). Eighty-seven sea otters, of which 42% were adults, had an estimated annual consumption rate of 370,000 crabs. High levels of predation by sea otters, led to the closure of commercial crabbing (Kimker 1984).

Sea otters have also been moving into Glacier Bay and the surrounding area (Pitcher and Imamura 1990) (Figure 1). A three-year study using crab pots and scuba divers in this region found that the catch per unit effort (CPUE) and abundance of Dungeness crabs in Outer Dundas Bay (with sea otters) was significantly less than in Inner Dundas Bay (without sea otters) in waters $\leq$ 60 m depth (Shirley et al. 1996). However, there was a significant increase in Dungeness crab CPUE in Outer Dundas Bay when pots were set deep (95 m). Although Inner Dundas Bay bathymetry is not as deep as outer Dundas Bay, the trend within its limited depth range was opposite to that in Outer Dundas Bay. Pots set between 0 and 10 m contained higher numbers of crabs than pots set in slightly deeper waters (10-20 m), and CPUE continued to decline to depths of 58 m (Shirley et al. 1996).

The above findings invited formulation of two related hypotheses: firstly, that deeper water may act as a refuge for Dungeness crabs against predation by sea otters; and secondly, that Dungeness crabs may be found throughout their range in waters deeper than commonly fished. To test these hypotheses, this study used two techniques for collecting data, as well as a preexisting data set to obtain a comprehensive view of the bathymetric distribution and relative abundance of Dungeness crabs in southeastern

Alaska. The primary source of data was videotaped seafloor transects made from a manned submersible at sites with varying levels of sea otter occupation. Crab pots were also placed on several transects that had been traversed by the submersible in order to determine if crabs existed within a depth range if none were observed from the submersible; the CPUE's were used to estimate relative differences in the number of crabs between treatments. Finally, a larger, long-term regional scale Dungeness crab bycatch data set was examined to determine what the typical bathymetric distribution of Dungeness crabs was in areas unaffected by sea otters.

Methods

Study sites

The eight study sites chosen had similar depth profiles with all sites having waters that were deeper (> 25 m) than those normally commercially fished for Dungeness crab. For five of the locations we had preexisting data on both Dungeness crab abundance in shallow water and number of sea otters present. Six of the sites were located within or adjacent to Glacier Bay National Park (Bartlett Cove, the Beardslee Islands, Outer Dundas Bay, Port Althorp, Idaho Inlet, and Excursion Inlet). The seventh site (Tenakee Inlet) was located at the northern end of Chicagof Island and the eighth (St. James Bay) is on the western shore of Lynn Canal (Figure 1). The three sites (Excursion Inlet, St. James Bay and Tenakee Inlet) that did not support sea otter populations acted as controls for the first hypothesis, that otters influence the depth distribution of crabs. Bartlett Cove and the Beardslee Islands are used seasonally over winter months by transient sea otters (J. Bodkin, USGS, personal comm.); Outer Dundas Bay, Port

Althorp, and Idaho Inlet have resident populations of sea otters with sightings for at least the last 10 years (Pitcher and Imamura, 1990).

Submersible sampling

Most data were collected during seabed transects with the R/S *Delta* (Delta Oceanograhics Inc.), a two person submersible that had an external video camera for recording transects. The external video was mounted starboard, in a fixed position, perpendicular to the direction of the submersible facing up slope and was equipped with parallel laser beams (20 cm apart) to allow scaling of objects within the field of view. The scientific observer's audio description was recorded onto hi-8 videotapes as a sound track. Depth, height above bottom, water temperature, date and time were also displayed on the tape using instrumentation on the submersible referred to as the Pisces remote unit. The videotaped transects were analyzed to estimate Dungeness crab abundance, fauna, seafloor gradient, sediment type, flora, visibility, and biogenic structures such as mounds and pits.

The course for each transect was maintained by using a directional gyro compass onboard the submersible and a Trimble global positioning system (GPS) with differential correction along with the Ocean Research and Engineering (O.R.E.) Trackpoint II system on the support the ship, R/V *Medeia*, a 34-m Alaska Department of Fish and Game (ADF&G) research vessel. The transects were conducted from 10-18 May1998 prior to the opening of the commercial fishery. All dives occurred during daylight hours, with a total of sixty-three 500 m transects being completed at a cruising speed of approximately $0.26 \text{ m} \cdot \text{s}^{-1}$ with one day allocated for each site.

To reduce habitat variability within transects and to simplify comparisons between bays, transects followed predetermined bathymetric contours within substrate types that Dungeness crabs are known to frequent. Transect placement began at the 10 meter depth contour, continued with the 25 m, and was then increased in 25 m increments to a maximum of 200 m depth, where available, with all depths corrected to mean lower low water. The first four depth categories (10-75 m) are within the diving capability of sea otters, while the 100 m category is close to the limit of their diving range (Newbry 1975). Depths greater than 100 m are unlikely to be used by foraging sea otters and are considered potential refuges for Dungeness crab.

All organisms observed on transects were identified to the lowest possible taxon. Seafloor gradient was classified into 4 categories: flat (0-5 %); shallow (6-15%); steep (16-30 %); and very steep (>30 %). Substrate classification followed the Wentworth scale, with the clay and silt fractions being combined into a more generalized mud category, followed by sand, granule, pebble, cobble, and boulder. The four other substrate types used were macroalgae, shell, bedrock, and rock wall. Transects were divided into 20 m increments with the percentage of each substrate type along with visibility, gradient, and height above the seafloor being recorded. To quantify the area for each substrate type and to determine density estimates for species, transect area was calculated by multiplying the length of the transect (determined by the Trackpoint system and the GPS) by the width of the camera's field of view. Transect width was determined from the average height of the camera above the sea floor (0.57 m while on bottom) and the camera declination of 37 degrees below horizontal. Visibility and seafloor gradient also affected transect width. To obtain an accurate estimate of the area surveyed, a matrix of width values was calculated for a range of gradients and visibilities and each 20 m increment was assigned a width accordingly. The area for each increment was calculated and summed to provide the area of each transect.

Since variance in Dungeness crab abundance may be caused by factors other than presence or absence of sea otters, the data were stratified by depth to reduce variance within a treatment. A General Linear Model (GLM) for an unbalanced analysis of variance (ANOVA) with fixed effects was used to determine whether a difference existed in the abundance of Dungeness crabs between treatments groups, i.e., bays with and without sea otters. The crabs observed were divided by the area covered in a given transect and then standardized to number of $\text{crabs}\cdot\text{hectare}^{-1}$. A one-way unbalanced ANOVA was performed on all bays for the shallow portion of the bay and an unbalanced ANOVA for a two-factor design with interaction was also performed for all depth categories. The limited number of transects within each depth required that transects be grouped into one of three larger categories: shallow (10, 25, 50) m; intermediate (75, 100, 125) m; and deep (150, 175, 200). Assumptions of normality and equal variances were not met, so data were log transformed (n + 1). This also reduced the coefficient of variation by 40%. The statistical package SAS version 6.12 was used (SAS Institute Inc. 1996).

Crab pot sampling

Crab pots were set at 100 m intervals along a number of transects which had previously been traversed by the submersible. The logistics of pulling and setting pots at different locations on the same day allowed only the first five bays to be surveyed in this fashion, since the last three locations were much more widely separated. The R/V *Tamnik*, a 16 m U.S. Geological Survey (USGS) research vessel, was used in the crab pot survey. After the submersible had completed its transects, GPS coordinates were used to set crab pots along 4 to 6 transects within each bay. Pots were baited with salmon as hanging bait and a bait jar of squid and herring with a soak time of 24 hours. The protocol for handling pots was the same as that used in Multi Agency Dungeness Study (MADS) (Leder et al. 1995, O'Clair et al. 1995, O'Clair et al. 1996, Schultz et al. 1996 Schultz and Shirley 1997, Shirley et al. 1996, Taggart et al. 2003). The total number of pots for each bay varied due to logistical problems: 49 in Bartlett Cove, 35 in the Beardslee Islands, 26 in Dundas Bay, 23 in Port Althorp and 24 in Idaho Inlet. Several explanations exist for the uneven number of pots.

King and Tanner crab surveys

To augment the submersible and crab pot distribution data, a regional, long-term survey of king and Tanner crabs in southeastern Alaska was analyzed. This survey is conducted annually, usually mid-June through July by the ADF&G. Although this survey did not target Dungeness crab, they are a bycatch species and it does provide insight into the typical bathymetric distribution of Dungeness crab over a broader area and in areas unaffected by sea otter predation. A total of 4881 pots were set within the 18 locations surveyed over a 12 year period, although not all bays were sampled every year (Figure 6). Pots within each location are randomly set using latitude and longitude coordinates; as pots are pulled their depth is recorded. However there are a few caveats about the dataset: the survey is usually conducted during the Dungeness crab fishery (opened from June 1st to August 15th, and from October 1st to November 30th); and the type of pots used were square Tanner crab pots rather than Dungeness crab pots, and may fish less efficiently as a result.

Results

Submersible sampling

In the bays without sea otters (Excursion inlet, St. James Bay, and Tenakee Inlet), crabs were observed only in the shallow (≤ 50 m) portions of the bays (Figure 2). The highest densities of Dungeness crabs were found in the shallowest transects (10 m depth) of St. James Bay and Excursion Inlet, where 2340 $\text{crabs}\cdot\text{ha}^{-1}$ and 688 $\text{crabs}\cdot\text{ha}^{-1}$ were recorded, respectively (Figure 3a). In both bays, a single large aggregation of ovigerous females (females with an egg clutch) was the principal cause for the high abundance estimate and sand was a primary component of the substrate mix. Dungeness crabs were also observed along the 25 m depth transects in both bays (27 $\text{crabs}\cdot\text{ha}^{-1}$ and 444 $\text{crabs}\cdot\text{ha}^{-1}$, respectively) and at 50 m depth in Excursion Inlet ($497\cdot\text{ha}^{-1}$). The density estimates for Excursion Inlet's 25 and 50 m depths are based on relatively small effective areas due to poor visibility; drift algae may have also biased some density estimates. Only two Dungeness crabs were observed in Tenakee Inlet at 10 m depth, yielding a density estimate of $17\cdot\text{ha}^{-1}$.

The two sites used seasonally by sea otters, Bartlett Cove (≤ 60 m depth) and the Beardslee Islands (≤ 80 m depth), were relatively shallow bays, therefore only transects $\leq$

50 m in depth could be conducted. Bartlett Cove displayed a trend of decreasing abundance with increasing depth while in the Beardslee Islands, Dungeness crabs were only observed at 25 m depth (Figure 3b). Both sites did have sand substrate in shallow water (10 m). In the three bays with sea otters present year round, the deepest transects for each bay were as follows: 75 m for Idaho Inlet, 150 m for Port Althorp, and 200 m for Dundas Bay (Figure 3c). These bays displayed few or no crabs at shallow or intermediate depths. Dundas Bay was the only bay where crabs were observed at depths ≥ 150 m. In terms of substrate composition, Idaho Inlet was the only bay with a sand fraction in shallow water (10 m).

A significant difference in the density of Dungeness crabs existed between treatments (differing levels of sea otter occupation) for the shallow (≤ 50 m) portions of the bays, with less than a 1% chance that this result could have been produced randomly (GLM for an unbalanced one-way ANOVA, $p = 0.0085$). The number of $\text{crabs}\cdot\text{hectare}^{-1}$ in the absence of sea otters was 102, compared to 52 $\text{crabs}\cdot\text{hectare}^{-1}$ for seasonally used sites, and only 2 $\text{crabs}\cdot\text{hectare}^{-1}$ for areas with well established sea otter populations (Figure 4).

A GLM for an unbalanced two-way ANOVA (two-factor design with interaction) was performed to compare the effects of sea otters on the distribution of Dungeness crabs at all depths (Figure 2). A significant interaction was found between depth and sea otter presence ($p = 0.0006$), preventing any conclusions being drawn on the independent effect of sea otters or the effect of depth.

Crab pot sampling

The crab pot data were stratified in the same manner as the submersible data, by depth and sea otter presence. To compare the two methods as a measure of crab abundance, only duplicate transects were included. Eighty-four of the stratified pots were in the seasonal, shallow depth category, while 48, 12, and 21, pots were in the shallow, intermediate, and deep categories with sea otters present. The crab pot data had the same basic pattern as the submersible data (Figure 5). Higher densities of crabs were found in seasonally used bays compared to bays with sea otters present, for the shallow category (≤ 50 m), and higher densities of crabs (CPUE of 1.6 crabs$\cdot$pot$^{-1}\cdot$day^{-1} in Dundas Bay) at depth, in bays with sea otters present. The crab pot method, however, appeared to record more crabs in the shallow portions of the bays and fewer at depth, relative to the submersible procedure.

King and Tanner crab surveys

The locations of all the sites sampled in the annual king and Tanner crab surveys are shown on the map of southeastern Alaska (Figure 6). The total number of locations surveyed were combined for all years, with most pots set at intermediate depths (20 – 120 m), resulting in a relative paucity of samples from deeper and shallower than this depth range (Figure 7). The highest density of crabs (1.74 CPUE) occurred at the shallowest depths (mean of 17 m), with a progressive reduction in the catch rate towards 60 m (0.009 CPUE). The average CPUE of Dungeness crabs at depths ≥ 100 m was effectively zero. No crabs were found deeper than 112 m even though 9 of the 18 sites had waters deeper than 150 m. Dungeness crabs were found in 14 of the 18 bays surveyed, and a total of 902 Dungeness crabs were recorded (347 males and 555 females).

A comparison of the bathymetric distribution of Dungeness crabs was made between the ADF&G bycatch data and the pot data from this study for Outer Dundas Bay, a bay with a long-term sea otter community (Figure 8). To compare CPUE rates, the bycatch data were regrouped into the same depth categories as Outer Dundas Bay. Each category included all pots within a 10 m depth range with the depth category being the mid point (e.g., 10 m was 5 to 15m). The trend for the pot data in Outer Dundas Bay was an increase in abundance (CPUE) with increasing depth (Figure 8A). The combined data set for portions of southeastern Alaska, from which sea otters were absent, exhibited the opposite pattern. Dungeness crabs were more prevalent in shallow water than in deep water. Although our sampling effort for Outer Dundas Bay in the current pot survey was lower than the accumulated ADF&G survey, with only six pots in the four shallow transects and four pots in each of the two deep sets, these data are not considered outliers (Figure 8B).

Discussion

The impact of sea otters on Dungeness crab abundance in shallow water

Sea otters had a significant negative effect on the number of crabs present in the shallow (≤ 50 m) portions of the bays we studied in southeastern Alaska. The submersible results displayed a negative linear relationship between sea otter presence (none, seasonal, and well-established) and Dungeness crab abundance (102, 52, and 2 crabs$\cdot$hectare^{-1}, respectively). The crab pot data presented a similar profile of crab abundance in shallow water. Bays with limited sea otter presence had higher crab abundance estimates than bays with well established sea otter colonies.

The three bays without otters displayed variable crab abundance, but had a consistent trend of increasing abundance with decreasing depth. This is considered to be the typical distribution of crabs in bays where sea otter predation is absent (Shirley et al. 1996) and is corroborated by the bycatch data from the ADF&G king and Tanner crab surveys. The small number of crabs caught and the unequal sex ratio in this regional survey may be partially explained by crab behavior and fishing effort during the time of surveys (mid June through July). Both sexes are found in relatively shallow water from May through July (Stone and O'Clair 2001). Therefore the actual number of crabs present in shallow water may be underrepresented due to the design objectives of the ADF&G survey, with a relatively low number of pots set in the shallowest water (≤ 10 m). Also, an interspecific antagonistic interaction may have occurred due to the sympatric distributions of king, Tanner, and Dungeness crabs, resulting in a negative bias. Finally, the Dungeness crab fishery is opened while the survey is ongoing and targets only legal sized males, which further reduces the number of Dungeness males available to the ADF&G survey.

Inverse correlations between sea otter prevalence and Dungeness crab abundance has also been observed in several other studies in both soft bottom habitats (Garshelis and Garshelis 1984, Kimker 1984, Pitcher and Imamura 1990, Kvitek et al. 1992, Shirley et al. 1996) and rocky shore environments (Estes et al. 1978, Estes et al. 1982). Shallow waters are those most frequently foraged by sea otters, (Calkins 1978, Estes et al. 1978, Kvitek et al. 1992), particularly when sea otters first migrate into an area where prey is plentiful (Kvitek et al. 1992) and when females with pups start feeding independently (Garshelis and Garshelis 1984).

The decline in CPUE of Dungeness crabs in several bays in the Cross Sound-Icy Strait region of southeastern Alaska in the late 1980s was documented by Pitcher and Imamura (1990) through the use of commercial crab pots and direct observations. Outer Dundas Bay had a CPUE of 10.49 crabs$\cdot$pot$^{-1}\cdot$day^{-1} in depths less than 40 m in 1989 (Pitcher and Imamura 1990). The MADS study followed the study by Pitcher and Imamura and recorded a further decrease in crab density estimates for several inlets within Glacier Bay proper and for Outer Dundas Bay. The latter had a CPUE of 0.2 crabs$\cdot$pot$^{-1}\cdot$day^{-1} ($\leq$ 20 m) in 1995 for Outer Dundas Bay (Shirley et al. 1996); while the CPUE for the present study was 0 crabs$\cdot$pot$^{-1}\cdot$day^{-1} ($\leq$ 25 m). The soak times for both studies were the same, but number of pots, locations, and depths were different, so that direct comparisons were not possible. However, the long-term trend is a decrease of abundance of Dungeness crab in shallow water in Outer Dundas Bay. A similar decline in Dungeness crab abundance was observed in the Orca Inlet fishing region of Prince William Sound. This fishery appeared to be recovering from an earlier loss of habitat and prey availability following the Good Friday earthquake of 1964, but collapsed shortly after the immigration of a large number of sea otters (Kimker 1984). Direct observations of sea otters consuming a large number of Dungeness crabs in this region were reported prior to this closure (Garshelis 1983).

Similar declines in preferred prey item abundance for sea otters have been reported for populations of sea urchins (Estes et al. 1978, Breen et al. 1982), and bivalves (Kvitek et al. 1992). Habitat changes, lower abundance, and a reduction in maximal size of grazers, were also documented after the reintroduction of sea otters in British Columbia (Breen et al. 1982). Specifically, sea urchins and other grazers were smaller than those found in areas not occupied by sea otters and were either scarce or cryptic in areas inhabited by sea otters.

Ovigerous female crab aggregations

One of the key observations between study sites was the presence or absence of ovigerous Dungeness crab aggregations. Excursion Inlet and St. James Bay, two of the three sites without sea otters, were the only bays where ovigerous female aggregations were observed. Tenakee Inlet, the third site without otters, was also known to have an aggregation site (personal communication, D. Hart, P.O. Box 240106 Douglas, AK, 99824), however it was not encountered during submersible transects. The aggregation sites found in each of the first two bays were both located in areas of sandy substrate and shallow water (≤ 10 m). In the spring, Dungeness crabs are generally found in waters less than 25 m in depth (Stone and O'Clair 2001, Stone and O'Clair 2002) and ovigerous crabs are found in aggregations (O'Clair et al. 1996).

The Beardslee Islands, Bartlett Cove, and Idaho Inlet all had a small sand fraction, 6, 13, and 11% respectively, in shallow water (≤ 10 m), yet no aggregations were observed. A plausible explanation is that aggregation sites exist but were missed because of their relatively small size and the limited area viewed using the submersible. Thirteen aggregation sites have been found at 5 locations in Glacier Bay, with two of those locations in the Beardslee Islands and Bartlett Cove (O'Clair et al. 1996). One of the aggregations in Bartlett Cove was estimated to comprise 1858 crabs·ha^{-1} (O'Clair et al. 1996), a similar density estimate to that observed at St. James Bay (2340 crabs·ha^{-1}). High density aggregations in areas used seasonally by sea otters may suggest that sea otter predation is not having an effect on female Dungeness crab abundance. This earlier study (O'Clair et al. 1996), however, was conducted in 1992 and 1993, several years before the current study and at a time when sea otter numbers were low. Sea otter counts from aerial surveys over Glacier Bay proper by the U.S. Geological Survey have increased markedly from 5 sea otters in 1995 to almost 400 in 1998 (personal communication, J. Bodkin, U.S. Geological Survey). Therefore, it is possible that the densities for these aggregation sites may have changed.

Idaho Inlet, a bay occupied by sea otters since 1987, was the only other bay that had a sandy substrate in shallow water. Historically Dungeness crabs were commercially harvested near the head of the bay (Pitcher and Imamura 1990). Crab populations within southeastern Alaskan bays are localized (Stone and O'Clair 2001), so the presence of an ovigerous aggregation site within Idaho Inlet at that time was probable. The current survey found no crabs by submersible or in pots at any depth, despite favorable substrate and depth profile for both aggregation sites and crab habitat. The recently observed paucity of Dungeness crabs in Idaho Inlet is at odds with the previous harvesting history and occurred after the arrival of sea otters.

Ovigerous crabs appear to have high fidelity to aggregation sites and many sites are used annually (O'Clair et al. 1990, O'Clair et al. 1996, Scheding et al. 2001, Stone and O'Clair 2001, Stone and O'Clair 2002). Specific environmental conditions appear to be sought by ovigerous female Dungeness crabs (O'Clair et al. 1996, Scheding et al. 2001). Sand and shallow water ($\leq$ 10 m) may be two of the prerequisites for site selection in southeastern Alaska (O'Clair et al. 1996, Scheding et al. 2001, Stone and O'Clair 2001, Stone and O'Clair 2002).

Aggregations afford ovigerous females some protection through safety in numbers. Their flight response behavior is to simultaneously scatter in all directions, even when only a few individuals are disturbed within an aggregation (O'Clair et al. 1996, Scheding et al. 2001). This response, however, would not be sufficient protection from a swift and clever predator such as a sea otter. Ovigerous crabs also move slowly, due to the awkwardness of the egg clutch and soon return to the same site to brood their clutch (Stone and O'Clair 2002). When ovigerous females are forcibly removed from an aggregation site, they "home" back to that site (Stone and O'Clair 2002). The specific habitat needs and behaviors listed above appear to place ovigerous females at elevated risk from sea otter predation at a particularly vulnerable life history stage.

The abundance of Dungeness crab in deeper waters

Although crabs were in lower abundance in shallow water in the presence of sea otters, they were not found consistently in deeper water in the presence of sea otters; no conclusions could be drawn with respect to the independent effects of sea otter presence or depth due to the strong interaction ($p = 0.0006$) between depth and sea otter occupancy, and possibly small sample size of bays. Among the three bays with long-established sea otter colonies, Idaho Inlet was relatively shallow ($\leq$ 75 m) and all of its seafloor would be accessible to sea otters. Only two bays with established populations of sea otters (Dundas Bay and Port Althorp) had sufficiently deep water (150 m) to afford a refuge from sea otter predation. The deep water (165 m maximum) of Port Althorp covered a small area (1.4 km^2), was distant from typical crab habitats, and the bay had a gentle gradient; crabs would have to traverse a long distance to be afforded the depth refuge. In contrast, Dundas Bay has several morphological features that may help explain the presence of what appears to be a Dungeness crab population at depth. First, Dundas Bay has a large area of approximately 11.2 km^2 of deep water (maximum depth of 275 m) that is readily accessible from the shallower water; its steep slope could help in shortening the escape route to a refuge of deep water. Finally, Dundas Bay's deep water section is not isolated, but contiguous with the larger, deep water area of Icy Straits. When all of the data is viewed collectively (submersible and crab pot data, previous work in Dundas Bay, and the king and Tanner crab surveys), a shift in the depth distribution of crabs to deeper waters in the presence of sea otters appears likely, where favorable marine topography is available.

Outer Dundas Bay, with its long-established sea otter colony (10 years), was the only bay in this study with Dungeness crabs found at depths greater than 150 m. The trend in crab abundance with respect to depth was similar in both the submersible and crab pot data; few to no crabs at depths less than 125 m with a sharp increase in abundance at depths exceeding the diving capabilities of sea otters. This finding is not an anomaly, but it does appear to be unique to this particular bay, among those investigated in the current study. Dundas Bay was sampled every April (1993 – 1996) by the MADS project, following the same protocol for pots as the current study. Although the pots in the MADS study were not set as deeply as in the current study, Outer Dundas Bay has consistently had a dearth of crabs in shallow water, with abundance increasing with depth (Shirley et al. 1996). The average CPUE for pots set at < 20 m were: 0.04 ± 0.03 in 1994, 0.2 ± 0.1 in 1995; pots set between 20 – 60 m depth were 0.4 ± 0.2 for both years and pots placed at depths ranging from 60 to 95 m were 3.9 ± 0.8 in 1994 and 4.0 ± 1.0 in 1995, respectively (Shirley et al 1996). In April of 1996 the deepest pot (123 m), also had the largest yield of crabs (Shirley et al. 1996). These deeper CPUE averages are comparable to what was observed in this study at 175 m (4.75 ± 4.92), but the standard deviation for the current study is much higher, most likely a result of the small sample size (n = 4). Unexpectedly, ovigerous crabs were found at depth in both the MADS study (60 – 90 m) (Shirley et al 1996) and in the current study (150 m). In 1999, a local commercial fisherman pulling Tanner pots in Outer Dundas Bay recorded over 500 Dungeness crabs of all sizes (≥ 130 mm) and sexes at 260 m with another pot set in slightly shallower waters, also containing a large number of crabs (personal communication, A. Morin, commercial crabber, F/V Jenny, P.O. Box 211034 Auke Bay, AK, 99821-1034).

In our study, only one bay without sea otters (Tenakee Inlet) had deep waters (≥ 150 m). However, the pot data in my study produced similar trends to the submersible data for Dungeness crab abundance. This similarity in results permitted an analysis of data contained in the larger regional scale pot-based king and Tanner survey to effectively increase our deep water sample size, since 9 of the 18 bays surveyed by ADF&G had pots set in water 150 m or greater. The results of the ADF&G surveys agree with our observations in bays without sea otters (control sites), but are in sharp contrast to that observed in Dundas Bay (with sea otters). The pot data at similar depths for Outer Dundas Bay and the king and Tanner crab surveys displayed opposite trends. In Outer Dundas Bay, Dungeness crab abundance increased with increasing depth; while abundance decreased with increasing depth for the combined king and Tanner crab survey dataset. Furthermore, not a single location out of the 9 surveyed presented any exception to this trend, in any of the 12 years for which data are available.

Limited information exists on the bathymetric distribution of adult Dungeness crabs, whether in southeastern Alaska or in other areas of the Pacific Northwest. Tagging, trawl, and pot surveys have been conducted in California (Gotshall 1978, Diamond and Hankin 1985) and British Columbia (Smith and Jamieson 1991), but the focus has been primarily on migration patterns rather than depth distribution. However, the general pattern that emerged for all regions is that most Dungeness crabs of both sexes are in shallow water during spring and summer. In fall and winter, males move to waters deeper than those occupied by ovigerous females (Smith and Jamieson 1991, Stone and O'Clair 2001). Another consensus is that Dungeness crabs typically remain within a restricted locale (Diamond and Hankin 1985, Smith and Jamieson 1991, Stone and O'Clair 2001). A few crabs were found in the winter months in deeper water, but at intermediate depths (66 m, 89 m) (Gotshall 1978, Stone and O'Clair 2001). Dungeness crabs have also been found at depths greater than 90 m in Washington, but only 2% of the crabs observed were in this depth category (no upper limit given) with the study occurring in January (Dinnel et al. 1987).

In light of what is known about the typical bathymetric distribution of Dungeness crabs, Outer Dundas Bay appears to have a unique physiography which permits depth to be a successful refuge against sea otter predation. Not only are there many crabs at depth in this location in the spring when most adult Dungeness crabs are found in shallow waters, but ovigerous females were also found at depth. Dundas Bay was the only site in our study where a large number of Dungeness crabs were found at depth; this phenomenon was not observed elsewhere, but no other bays had similar morphology and sea otter activity characteristics. In all other study sites, crabs were found either in shallow waters or were absent when sea otters were present. The ADF&G survey also supports this trend over 12 years, with only a few Dungeness crabs found at depths > 75 m in the nine deep (≥ 150 m) bays unaffected by sea otters. As sea otters continue to expand their range in southeastern Alaska, crabs may move to deeper depths to avoid predation where bathymetry and physiography of habitats permit. We urge that the depth distribution of Dungeness crabs and the expansion of sea otters continue to be observed over time.

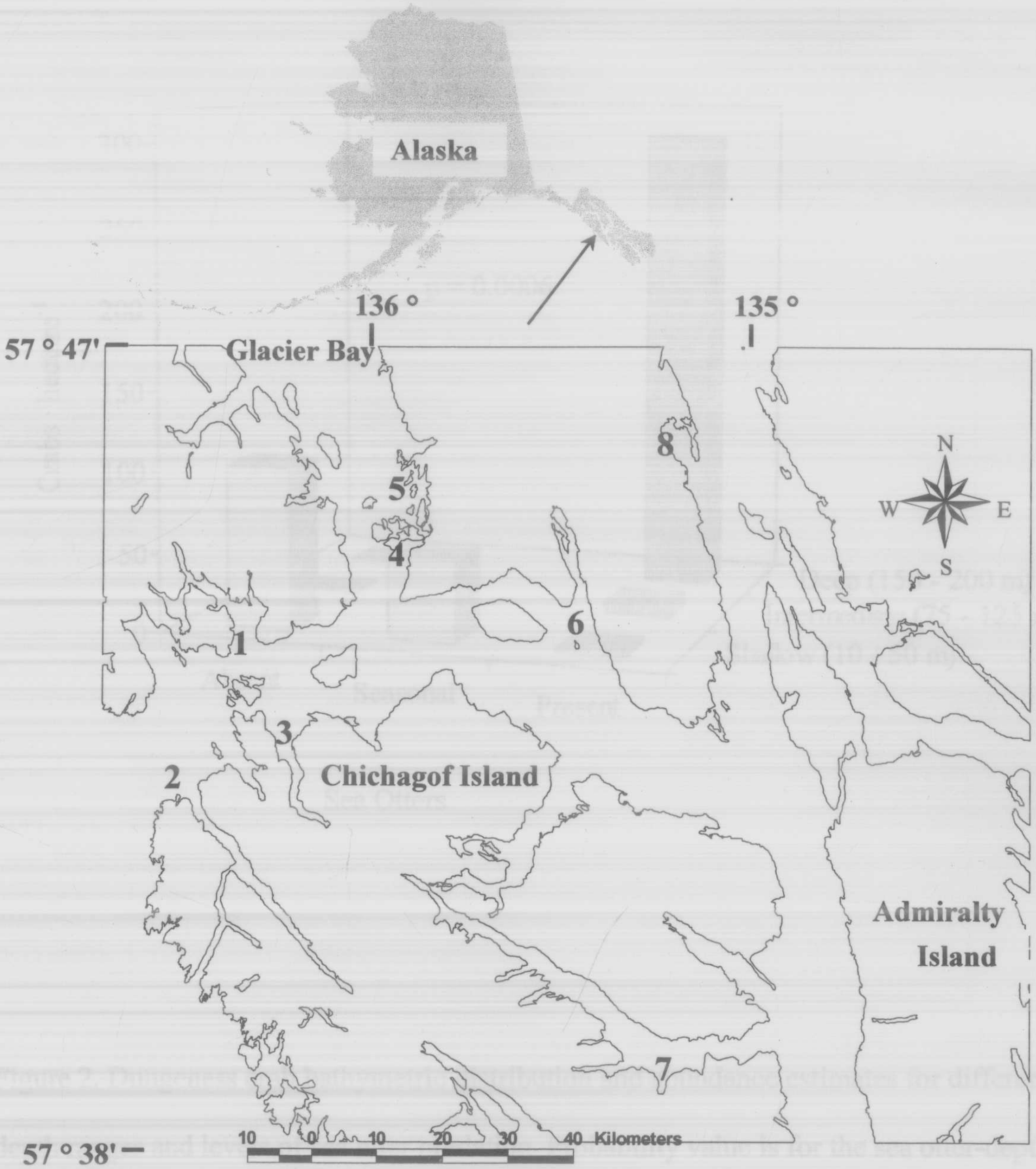


Figure 1. Regional map of study sites in the Glacier Bay area: with sea otters – Dundas Bay (1), Port Althorp (2), Idaho inlet (3); bays used seasonally – Bartlett Cove (4), Beardslee Islands (5); bays without sea otters – Tenakee Inlet (6), Excursion Inlet (7), St. James Bay (8).

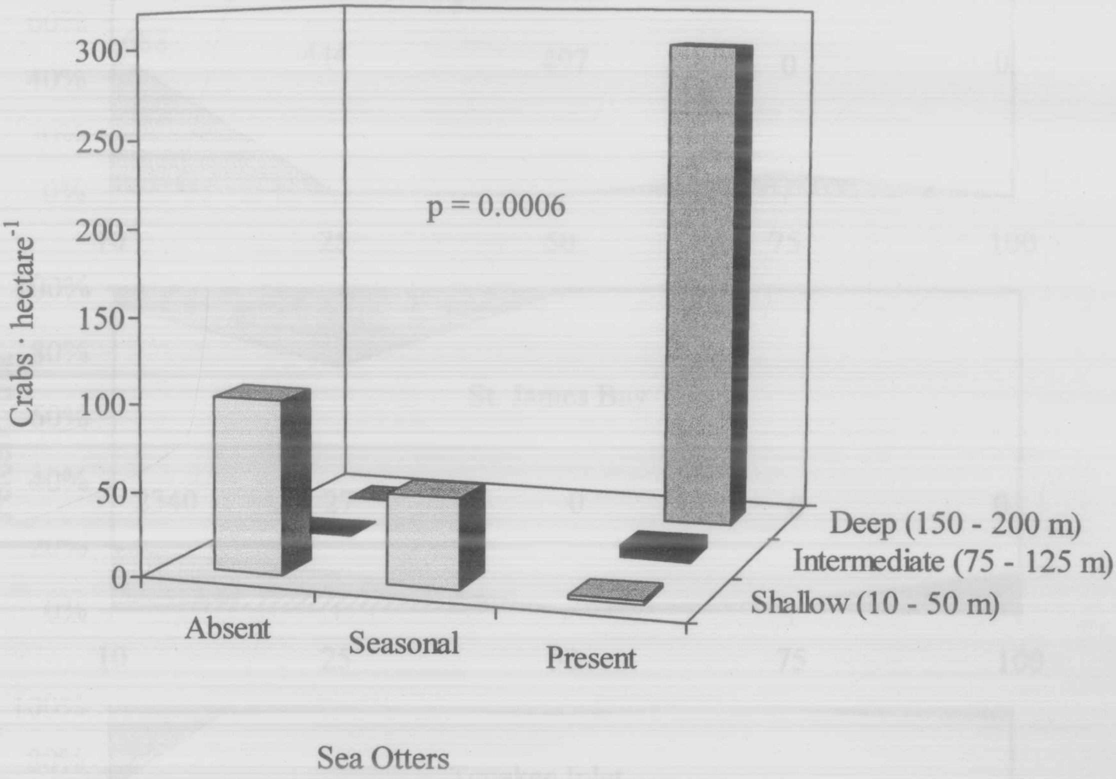


Figure 2. Dungeness crab bathymetric distribution and abundance estimates for different depth ranges and levels of sea otter predation. Probability value is for the sea otter-depth interaction from the GLM for an unbalanced two-way ANOVA.

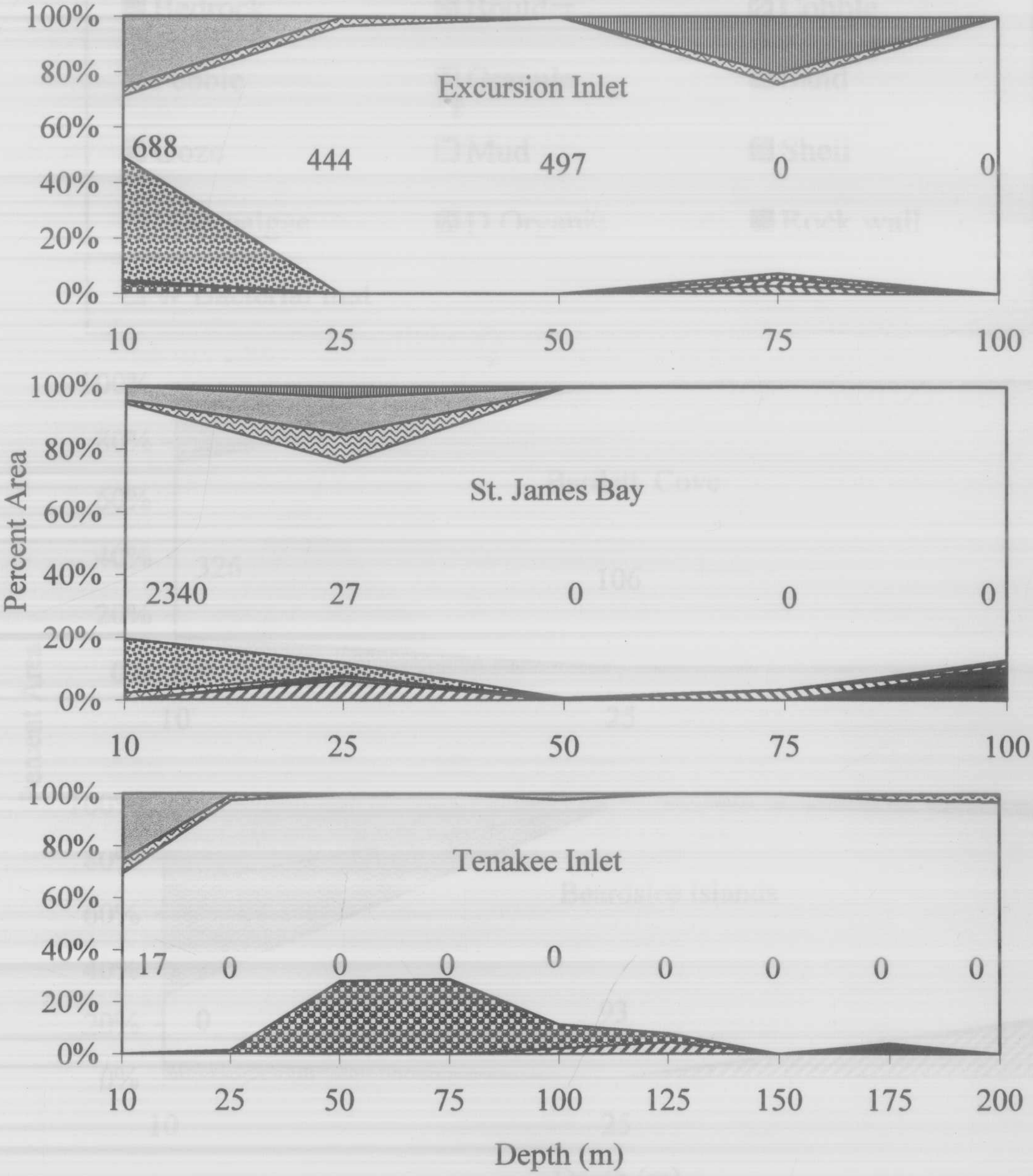


Figure 3a. Substrate composition and crab density - bays without sea otters. Density of Dungeness crabs per hectare and the percentage of each substrate type found for the depths surveyed. The figure legend is found in Figure 3b.

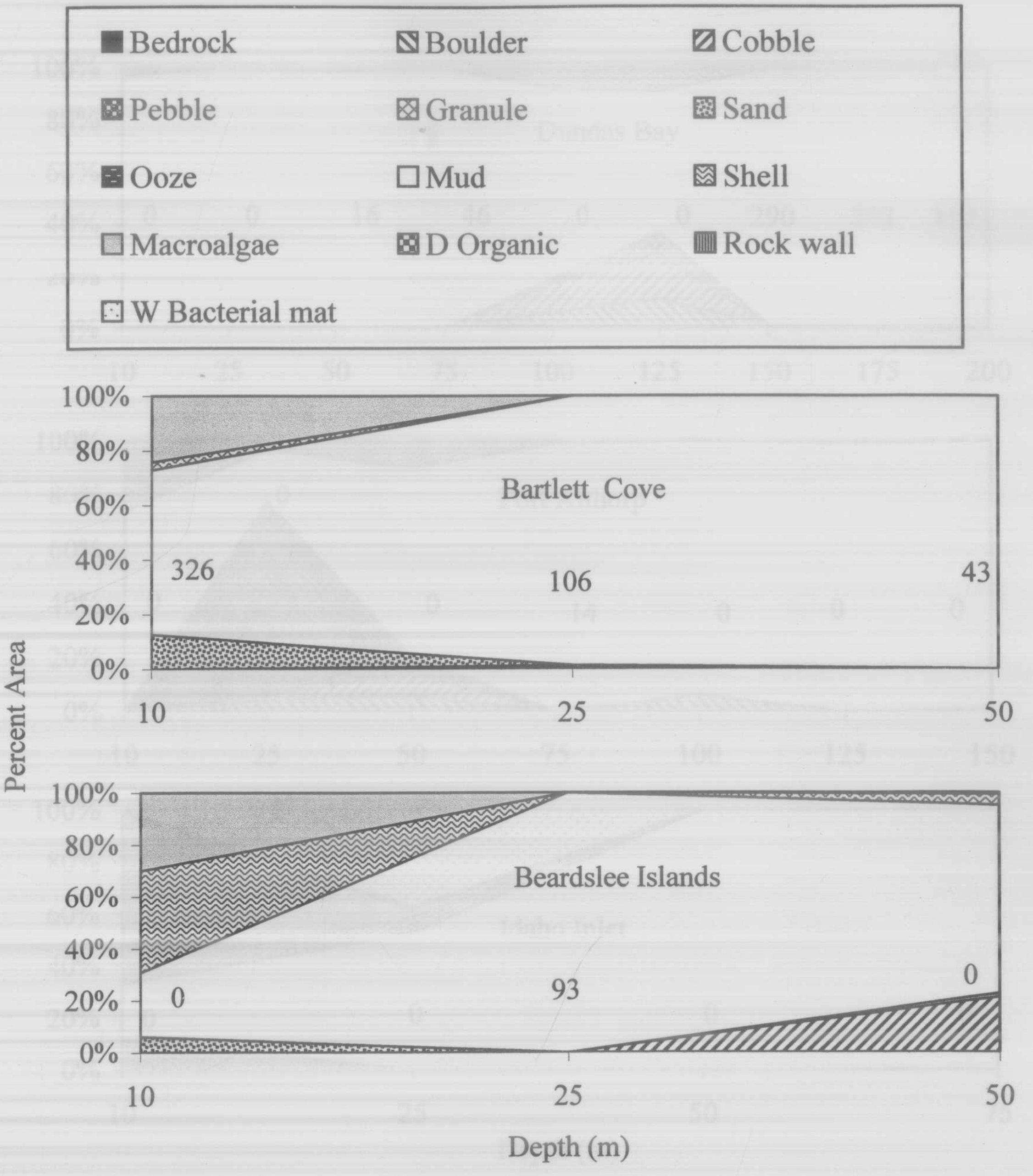


Figure 3b. Substrate composition and crab density - bays used seasonally by sea otters. Density of Dungeness crabs per hectare and the percentage of each substrate type found for the depths surveyed.

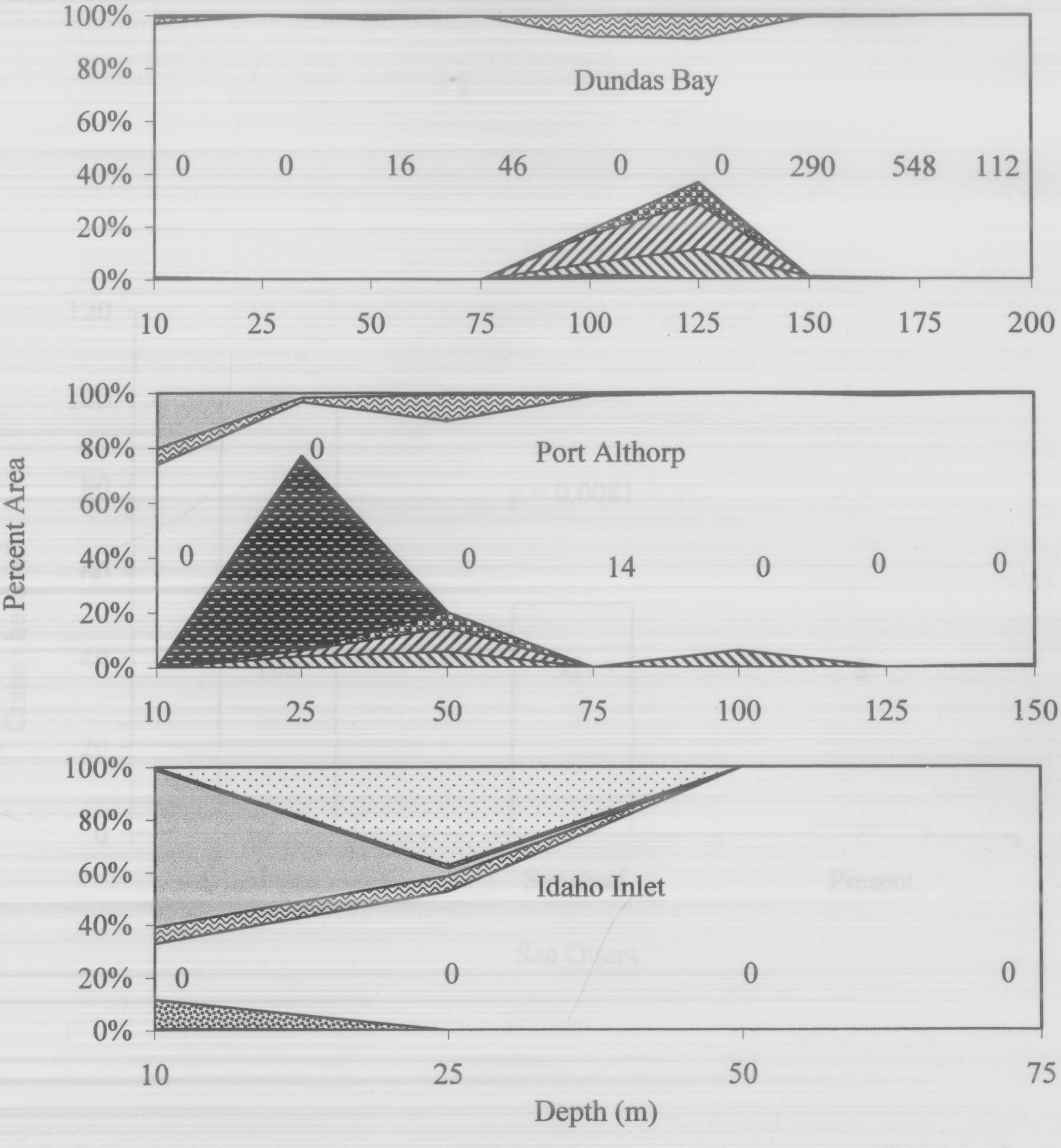


Figure 3c. Substrate composition and crab density - bays with sea otters. Density of Dungeness crabs per hectare and the percentage of each substrate type found for the depth surveyed.The figure legend is found in Figure 3b.

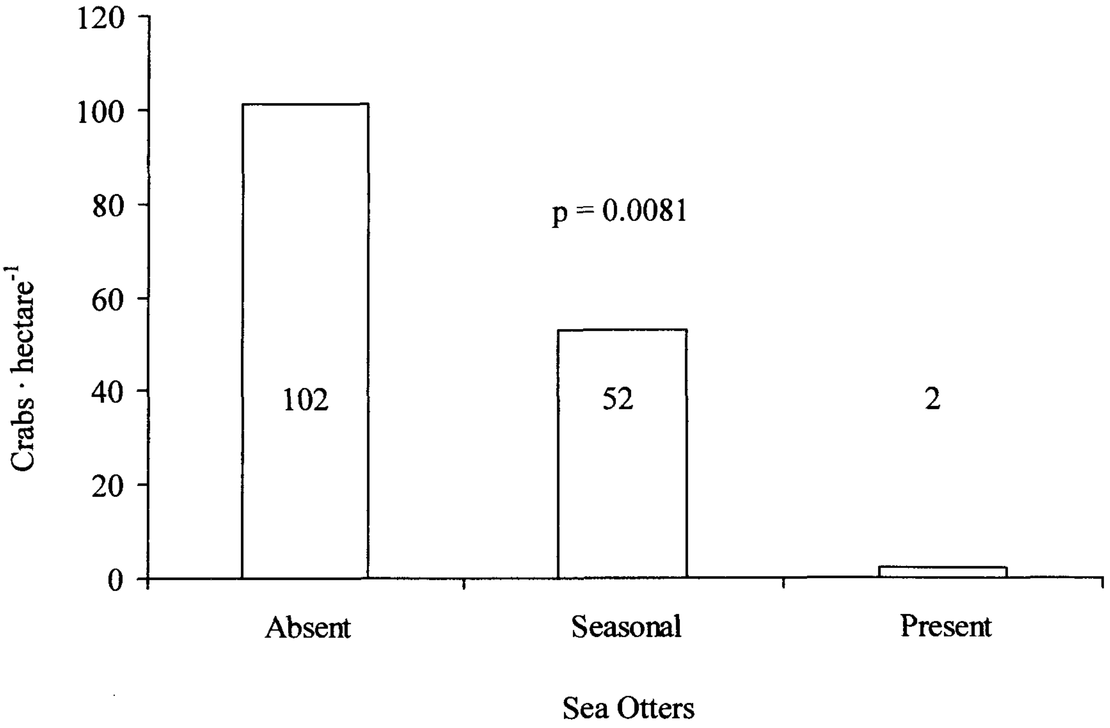
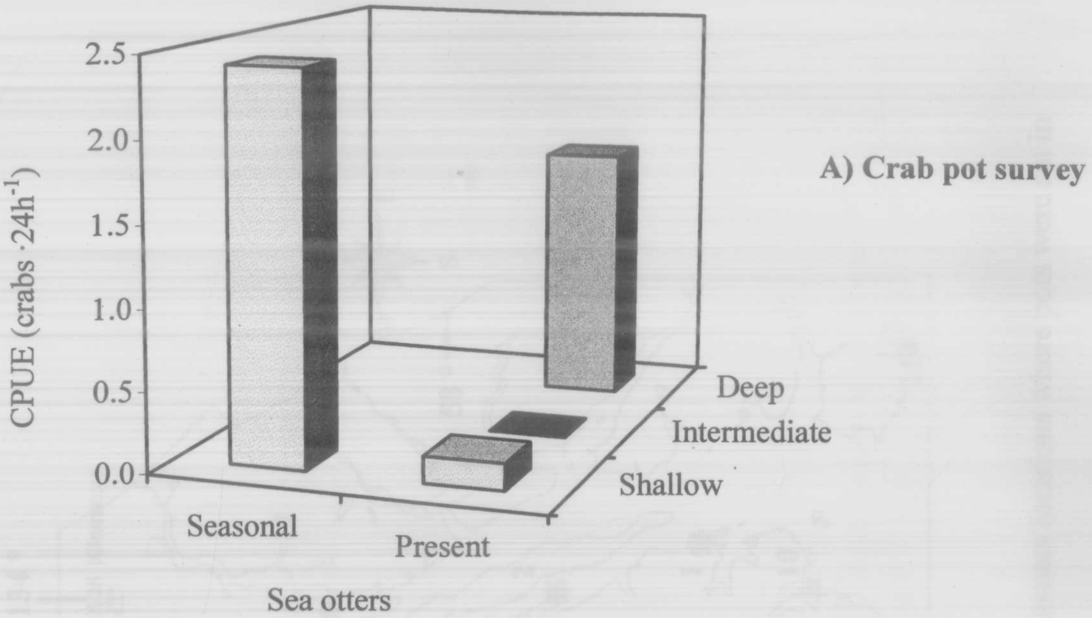


Figure 4. Dungeness crab abundance estimates in shallow waters (10 – 50 m) in bays with differing levels of sea otter predation. Probability value shown is for a GLM for an unbalanced one-way ANOVA.



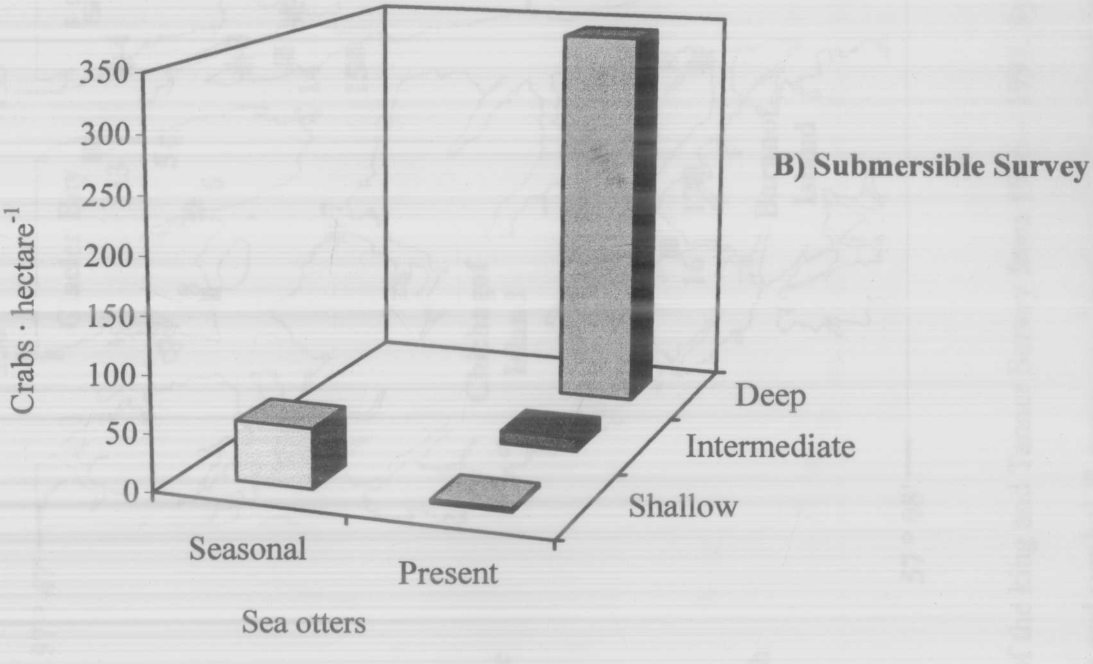


Figure 5. Dungeness crab density comparisons for the two methods employed. Crab pot survey (A) vs submersible observations (B) for the same locations. Crab pot survey results are in mean catch per unit effort (CPUE).

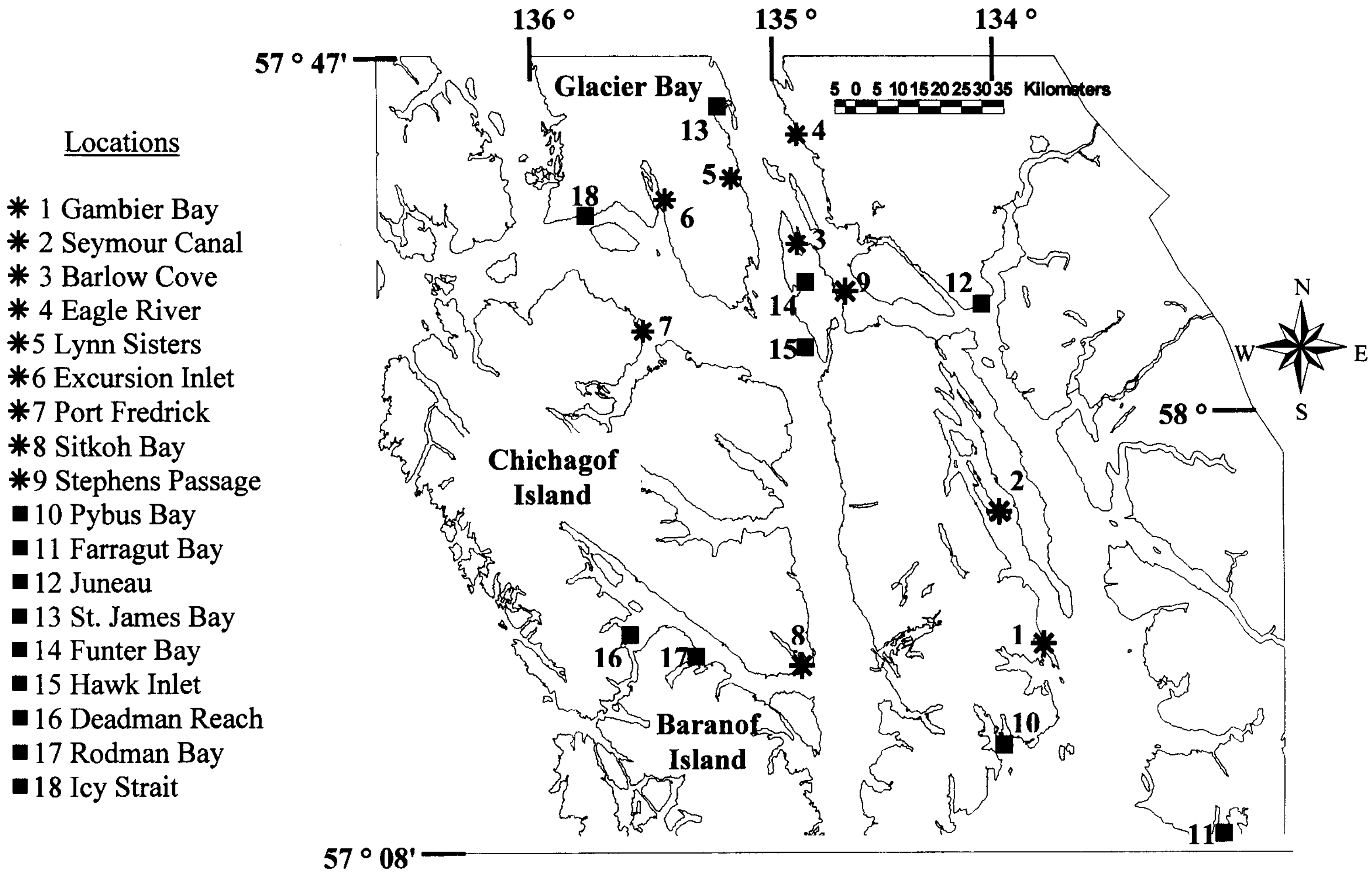


Figure 6. Locations of the king and Tanner Survey from 1986 – 1997. Symbol ✱ denotes locations where pots were set in waters ≥ 150 m depth and symbol ■ represents locations with pots set only in shallower waters.

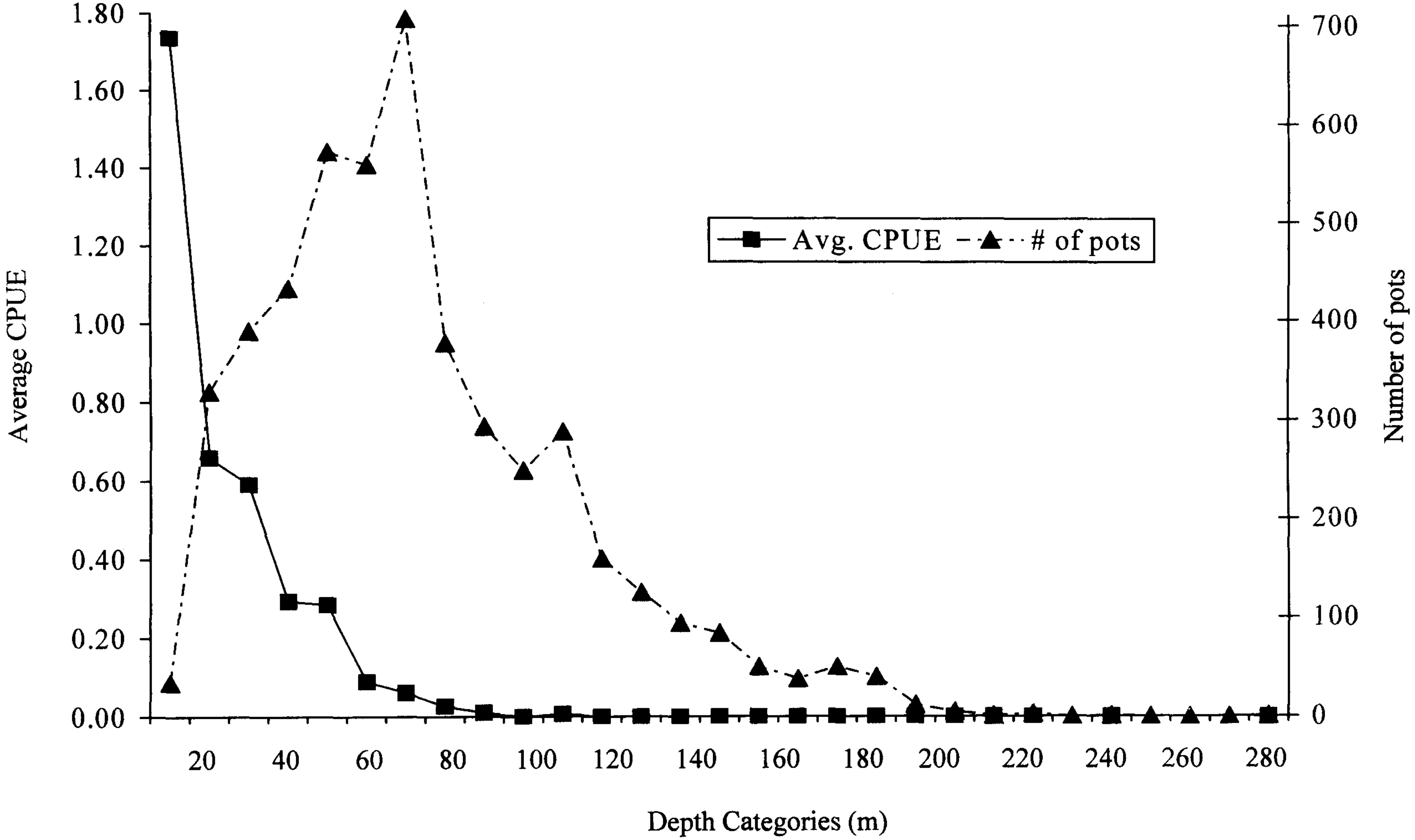


Figure 7. Dungeness crab CPUE and pot depths for all bays for ADFG survey from 1986 to 1997.

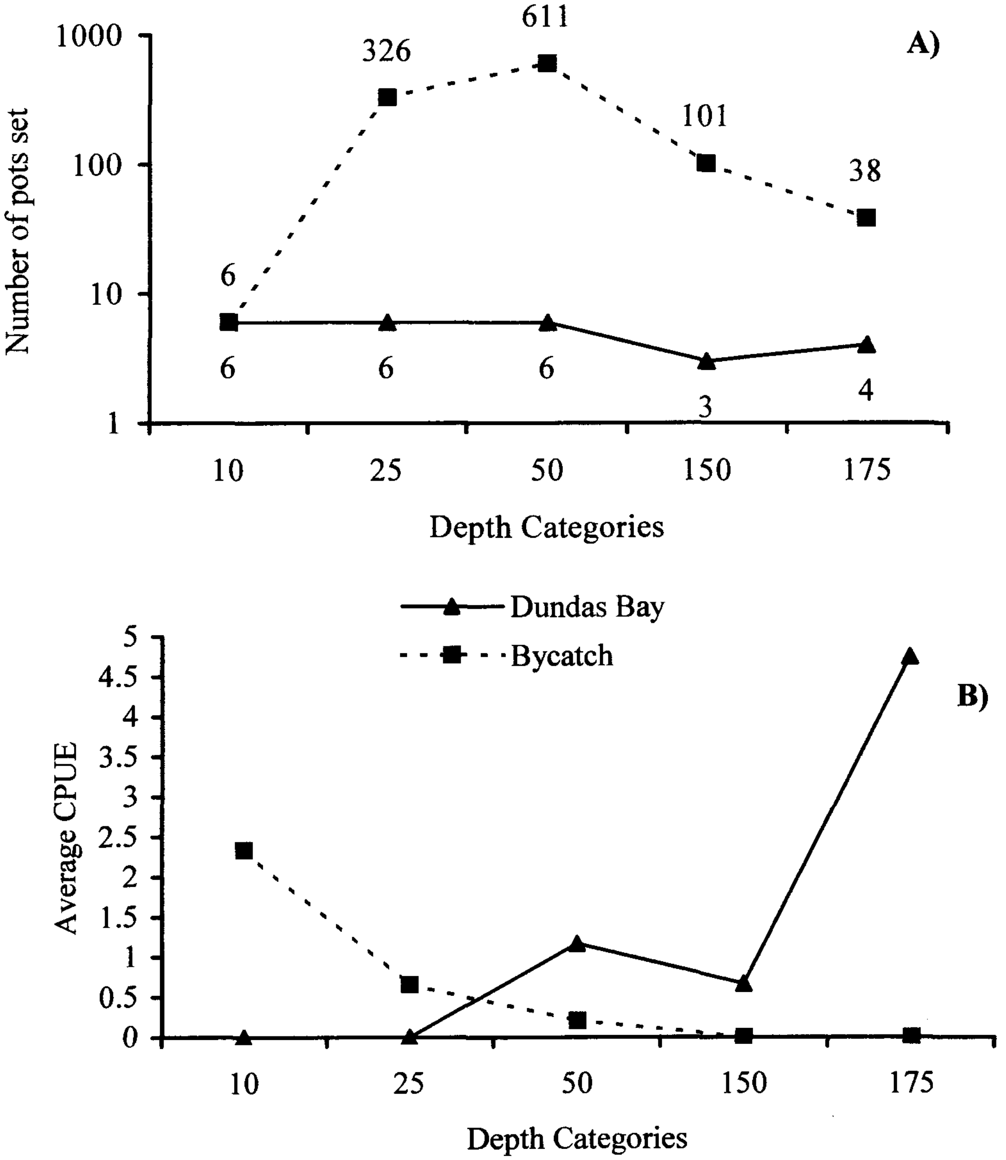


Figure 8. Comparison of ADF&G Dungeness crab bycatch data with Dundas Bay: the composite ADF&G data were regrouped into the same depth categories as Dundas Bay. A) Fishing effort – number of crab pots set at each depth. B) Average CPUE (catch per unit effort) at each depth.

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Chapter 2: Critical Habitat for Ovigerous Dungeness Crab

Scheding, K.A., Shirley, T. C., O'Clair, C. E. and Taggart, S. J. 2001. Critical habitat for ovigerous Dungeness crabs. In Spatial Processes and Management of Marine Populations, G. H. Kruse, N. Bez, A. Booth, M. W. Dorn, S. Hills, R. N. Lipcius, D. Pelletier, C. Roy, S. J. Smith, and D. Witherell (Editors). University of Alaska Sea Grant, Fairbanks, Alaska. pp. 431– 445.

Abstract

Limited knowledge exists on the brooding locations and behavior of female Dungeness crab, *Cancer magister*. Ovigerous crabs aggregate at the same brooding locations for many years and within these locations, crabs occur in high densities, with the majority of the aggregation buried within the sediment. These aggregation sites often have similar water depths, sediment types, and appear to be critical for this life history stage. Our study was designed to examine the bathymetric distribution of Dungeness crabs in eight bays with and without sea otters within the Glacier Bay area by conducting transects with a video-equipped, manned submersible. Two of the bays contained large aggregations of ovigerous females. At both sites, the substrate where the aggregation occurred was composed primarily of sand. However, only 1% of the 33 km of transects were classified as sand, suggesting sand substrate may be a limiting resource. Since crab brooding aggregations represent a large portion of the crab population within a small area, and because they are a critical component of Dungeness life history, areas with these characteristics need to be investigated further to determine if protection from development or exploitation is needed. The areas requiring protection from the impact of anthropogenic wastes, fishing and logging activities could be quite small thus limiting conflict with alternative users, but perhaps increasing the vulnerability of the crab population.

Introduction

Dungeness crab (*Cancer magister*) is an important commercial fishery species in Alaska and the northeastern Pacific. Their range extends from the Pribilof Islands to Baja California (Jensen and Armstrong, 1987). The total monetary value generated by the fishery (Alaska, British Columbia, Washington, Oregon and California) in 1997-1998 was $83,665,600 (Anon 1999). In Alaska, this represented a harvest of $5,685,000, with $4,500,000 coming from southeastern Alaska (Anon 1999). The Dungeness fishery in Alaska is managed by sex, size, season, and a season length. An early season projection of total season catch is made by the Alaska Department of Fish and Game to determine the duration of the summer and fall seasons (Southeastern Alaska Area Dungeness Fisheries Management Plan, State of Alaska 5ACC 31.146). Males with a hard carapace of 165 mm or greater can be legally harvested (Koeneman 1984). Males become reproductively active in their third or fourth year while they are still sublegal in size, allowing them one year to mate prior to reaching a legally harvestable size (Cleaver 1949).

In Alaska, several aspects of the Dungeness crab reproductive cycle differs from those at lower latitudes. Egg incubation is longer, hatching is considerably later (Shirley and Shirley 1988), and not all mature females produce a clutch every year (Swiney and Shirley 2001, Swiney et al. 2003). Mating begins in June or July (Stone and O'Clair, 2001) with egg extrusion occurring from August to January (Swiney and Shirley 2001), Other aspects of the Dungeness crab reproductive life history are similar to those found in lower latitudes. Females reach sexual maturity in their second year (Hoopes 1973) and mate, but their gonads are not sexually mature, so eggs are not extruded until the following year (Swiney and Shirley 2001, Shirley and Kruse, unpubl. observations). Mating occurs between hard-shell males and females in a soft-shell condition (Snow and Neilsen 1966, Hoopes 1973). Females mate with males that are at least two molts larger (Shirley and Kruse, unpubl. observations). In Alaska, a portion of the females do not extrude eggs every year (Swiney 1999). The females that do reproduce will follow one of two pathways depending on their size. Females smaller than 141 mm in carapace width are likely to mate and subsequently extrude eggs once their shells have hardened. Females larger than 141 mm are less likely to mate but will rely instead on stored sperm and extrude their eggs early on in the season (Swiney and Shirley 2001).

Spermatophores are stored in the spermathecae and eggs are fertilized during extrusion (Cleaver 1949, Hoopes 1973, Shirley et al. 1987). Sperm may be stored for up to 2.5 years (Hankin et al. 1989). Eggs are deposited onto the pleopods (Wild 1980) and an egg clutch may contain as many 1.5 to 2 million eggs (Hoopes 1973, Wild 1980, Hankin et al. 1989). Females must be partially buried for the eggs to form an egg mass (Wild 1980). The large clutch size forces the abdominal flap away from the thorax, making locomotion awkward (O'Clair et al. 1996). When eggs are first extruded, they are bright orange, but darken with time. Just prior to hatching they are brown or black as a result of lipid depletion and eye formation (Cleaver 1949, Hoopes 1973). Eggs for both size classes of females usually hatch between May and June (Shirley et al. 1987, Swiney 1999). Alaskan Dungeness may not produce an egg clutch every year (Swiney and Shirley 2001) as a result of the longer brooding times compared to the rest of their range and their reduced feeding activity when in an ovigerous state (female with an egg clutch) (O'Clair et al. 1990, Schultz and Shirley1997). Molting and thus mating probability also decreases with increasing carapace width (Hankin et al. 1989).

Although many aspects of Dungeness crab biology and life history have been investigated, knowledge of the attributes of brooding location and the behavior of ovigerous females is limited. Our study was prompted by observations made in a study designed to measure the impact of sea otters on the bathymetric distribution of Dungeness crabs in several bays near or within Glacier Bay (Scheding, Chapter 1). Two of the bays investigated, Excursion Inlet and St. James Bay, contained large aggregations of ovigerous females. Both sites were near the mouths of rivers in water less than 10 m in depth with a primarily sand substrate. Of the 33 km of sea floor transected, only 1% was classified as sand substrate. A sandy substrate may be a limited resource in inner coastal waters. This study was undertaken to investigate the relationship between habitat types used by brooding females and the availability and quality of those habitats. Specific objectives were: (1) to quantify the substrate by area within each bay; (2) to determine reliability of visual assessments of substrate type made from submersible videos; and, (3) to determine salinity, temperature, oxygen saturation, and percent organics within aggregation sites to see if any of these are important factors for habitat selection.

Methods

Nine study sites were selected for a companion study on sea otter effects in northern southeastern Alaska (Figure 1). Eight of these sites were chosen because: they currently contain Dungeness crabs or have historically; they have different levels of sea otter occupancy; and all have waters deeper than those normally commercially fished for Dungeness crab (≤ 25 m), with several bays deeper then the maximal diving capabilities of sea otters (Newbry 1975). A number of locations also had data on both sea otter numbers and Dungeness crab abundance in shallow water.

Three of the sites had resident sea otter populations (Dundas Bay, Port Althorp, and Idaho Inlet), two sites (Bartlett Cove and the Beardslee Islands) were used over the winter months by transient otters (personal communication, J. Bodkin, U.S. Geological Survey,), and the other three sites (Excursion Inlet, Tenakee Inlet, and St. James Bay) did not have sea otters and served as controls for the main study. The last site, Sunshine Cove, was added the following year for quantitative sediment analysis of an aggregation site, in addition to the St. James Bay site. Sunshine Cove and St. James Bay were selected for quantitative sediment analysis, because of their proximity to Juneau (Figure 1).

All transects were conducted with a two person submersible, the R/S *Delta* (Delta Oceanographics Inc.). The submersible operator sat in the navigation station, which was located in the middle of the submersible's fuselage. The scientific observer occupied the forward portion of the fuselage in a prone position. Porthole windows provided views to port, starboard, and forward. An external video camera was mounted on the starboard side to provide a video record of the transects. The camera angle of view was perpendicular to the direction of the submersible. An audio description by the observers was recorded onto hi-8 videotapes along with a display of physical variables including depth, height above the seafloor, and water temperature were provided by a CTD (conductivity-temperature-salinity profiler, sea-Bird SBE-19 SEA CAT).

The manned submersible was deployed beginning May 9, 1998: divers collected sediment and hydrographic data on the same calendar dates in 1999. These dates coincide with a time when the commercial fishery is closed and prior to most females hatching their eggs.

Sixty-three transects (500 m each) were completed at a cruising speed of approximately 0.26 m per second over 8 days. Transects were conducted at predetermined bathymetric contours in each bay. The method of following a depth contour was selected to reduce the component of habitat variability due to depth when comparing results between bays. Transects began at the 10 m contour, followed by 25 m and then increased in 25 m increments up to a maximum of 200 m, depending upon the depth of the bay (all depths corrected to MLLW datum). The first four categories (10-75 m) are within the diving capability of sea otters, while the 100 m category is close to the limit of their diving range (Newbry 1975). Depths greater than 100 m are unlikely to be utilized by sea otters.

The R/V *Medeia*, a 34-m-long Alaska Department of Fish and Game research vessel, was the support ship. Macrofauna and substrate types of the video taped transects were quantified immediately after each dive onboard the research vessel and in more detail in the laboratory after the cruise. All species observed were either identified to the lowest possible taxon or placed into broad categories when identifications could not be made. Specific habitat variables were recorded, including gradient, substrate type, and biogenic activity or evidence of benthic activity (e.g., burrows, mounds, tracks). Seafloor gradient was classified into 4 categories: flat (0-5 %); shallow (6-15%); steep (16-30 %); and very steep (>30 %). Substrate type was classified into 10 categories: macroalgae; shell; mud (including clay and silt), 1-62 µm; sand, 62µm to 2 mm; granule, 2 – 4 mm; pebble, 4 – 64 mm; cobble, 64 – 256 mm; boulder >256 mm; bedrock; and rockwall. Particle size classification followed the Wentworth scale. To quantify the amount of each substrate we first estimated the transect area. The area was calculated by multiplying the length of the transect (determined by the O.R.E. Trackpoint II system and Global Positioning System (GPS)) by the width of the camera's field of view. Transect width was determined from the average height of the camera above the sea floor (0.57 m) and the camera declination of 37° from the horizontal. Visibility and seafloor gradient also affected transect width. To obtain an accurate estimate of the area surveyed, each transect was sampled every 20 m for height off the bottom, visibility, and seafloor gradient. A matrix of width values was calculated for a range of gradients and visibilities and each 20 m increment was assigned a width accordingly. The area for each increment was calculated and summed to provide the area of each transect. Substrate type (size) and gradient were determined by references to diagrams drawn to scale.

Several edaphic variables were examined the following year to characterize physical parameters that might be important for brood site selection. Divers on this occasion collected sediment core and interstitial water samples. The aggregation site at St. James Bay was relocated in 1999 with GPS coordinates recorded in 1998. Ten core samples were randomly collected at each aggregation site. Modified 50 ml syringes were used by divers to extract substrate samples at both aggregation sites, which were immediately placed in plastic bags. The samples were collected either within a crab pit (crab burial site) or on the edge of a pit. Ten additional samples were collected at Sunshine Cove in June 1999 using the same procedures used at St. James Bay. On this later sampling trip, five cores were from within the aggregation and five others were collected approximately 20 m away from the site at the same depth.

Water samples were collected at both sites by inserting a 15 cm cannula into the sediment and extracting an interstitial water sample. Dissolved oxygen, temperature (both measured with a YSI 55 oxygen meter [± 0.2 mg per liter at calibration temperature]) and salinity (measured with an Atago refractometer [± 0.5 ‰]) were measured from the interstitial water samples and from sea surface water samples.

In the laboratory, core samples were transferred to glass jars. Samples were left to settle for 24 hrs and then excess seawater was removed with a syringe. The samples were desiccated in drying ovens on aluminum trays at 60°C until a constant weight was obtained. These samples were randomly assigned to two equal groups. One set of samples was used for grain size analysis and the other was used to determine percent organic matter in the sediment. For particle size analysis, the dry weight of each sample was recorded prior to being placed in a sieve shaker for 15 minutes. Sieve sizes used were: 4mm, 2mm, 1mm, 500 μm, 250 μm, 125 μm, and 64 μm. The percentage by dry weight of each size class was calculated.

To measure organic content, samples were treated with an acid wash to remove carbonates (Holme & McIntyre 1971) prior to combustion of the samples at 600 °C in a

Thermolyne muffle furnace. Samples were transferred to 250 ml beakers and 1.0 M hydrochloric acid was added to each sample to form a thick slurry. Glass lids were placed on the beakers to prevent sample loss while drying. The samples were then dried on hot plates in a fume hood. The weight of the samples was recorded prior to and after combustion in a muffle furnace for 24 h. Percent organic content was calculated from the weight loss.

Results

The three sites with ovigerous female aggregations (Excursion Inlet, St. James Bay, and Sunshine Cove) all had similar bathymetric profiles. Aggregations were found in shallow waters of 10 m or less and sand was the main substrate type. The aggregation site at St. James Bay began at 2 m on a flat seafloor and continued down slope at a gradient of ~ 25% to 5.5 m in depth (depths referenced to MLLW). The aggregation density was highest on the slope but was more unevenly distributed than the aggregation at Sunshine Cove. However, the overall size of the aggregation at St. James Bay appeared to be larger than the aggregation at Sunshine Cove. At the latter site all of the aggregation was on the shelf, and the slope had a more gradual incline. This aggregation site began at approximately 3 m in depth and extended to approximately 10 m depth. Female densities for the St. James Bay and Excursion Inlet aggregations were 0.86 (43 crabs per 50.1 m^2) and 0.75 (10 crabs per 13.4 m^2) crabs/m^2 respectively, estimated from crabs counted on videotapes. However, these estimates are probably conservative, as buried crabs are difficult to detect.

The area surveyed in each bay was initially categorized by depth (Figure 2). Large differences existed among bays with respect to area surveyed. The smallest area surveyed was Bartlett Cove (759 m^2), followed by Excursion Inlet (1989 m^2), the Beardslee Islands (1918 m^2), Idaho Inlet (2610 m^2), Port Althorp (2787 m^2), St. James Bay (5835 m^2), Dundas Bay (6134 m^2), and Tenakee (9792 m^2). Part of the reason for area differences was the variation in depths among bays. Bartlett Cove and the Beardslee Islands are both shallow bays with maximal depths of 50 m. Idaho Inlet, Excursion Inlet, and St. James Bay had intermediate maximal depths that were 75 m, 100 m and 100 m, respectively. Port Althorp (150 m), Tenakee Inlet (200 m), and Dundas Bay (200 m) were the deepest bays. The variations in depth resulted in the number of transects within each bay varying from 6 to 10. The first 5 depth categories (10-100 m) had similar area surveyed (approximately 5000 m^2), but the average for the next 4 depth groupings (125 - 200 m) was only 1750 m^2 (Figure 3). The deepest four depth categories were found in only three bays (Port Althorp, Dundas Bay, and Tenakee Inlet). The depth differences explain most of the area variation among bays, but visibility and seafloor gradient also contributed. For example, transect lengths were the same in Dundas Bay and Tenakee Inlet, but the areas surveyed (6134 m^2 versus 9792 m^2) varied. The majority of the difference was due to variation in visibility among the two bays. Average visibility in Tenakee Inlet was higher than in Dundas Bay (3.5 m compared to 2.5 m).

Mud was the predominant substrate type at all depth categories (Figure 4). In the 10 m category mud comprised 43% of the total substratum, with macroalgae being 34%. The other two common substrates for this depth were shell at 14% and sand at 8%. Mud was the primary substrate for all other depth categories, varying from a low of 76% to a high of 98%. Sand comprised only a 1% of the total area and was restricted to shallow water. In the 10 m category, sand comprised only 8% and decreased rapidly with depth, to 2% in the 25 m category. Pebble, cobble and boulders were more prevalent in the intermediate depth ranges, along with a rockwall and bedrock. At deeper depths, mud was the predominant substrate.

Dissolved oxygen (DO) content for both St. James Bay and Sunshine Cove was low in the interstitial water. St. James Bay had 1.32 mg per liter of oxygen and Sunshine Cove had 2.93 mg per liter (100% saturation for the water characteristics at both sites would be approximately 6.83 mg per liter). Salinity of interstitial water at St. James Bay was higher (33 ‰) than the surface salinity (24 ‰), probably due to fresh water discharge layering above the denser saline water. Sunshine Cove had the opposite trend (25.5 and 30 ‰), but it is not adjacent to a river. Temperature at St James Bay was higher in the interstitial water: 12.3 °C compared to 9.3 °C at the surface.

Substrate data collected from submersible videos and the quantitative data from the core samples were similar. However, there were differences in granule size particles (13.9% compared to 2.6%) and mud (2.2% compared to 20.1%), respectively. These differences are probably due to slight differences in where the core samples were collected in relation to the transect location. Given the accuracy of the navigational equipment, it is unlikely that the divers could sample the exact locations of the submersible transects. The majority of the initial submersible dive was on a steep slope with a gradient of about 25%. The divers sampled both from the slope and above the slope on the relatively flat seafloor.

Fine and very fine sand was the primarily substrate at both aggregation sites. The St. James Bay grain size distribution was finer than Sunshine Cove. Both had similar amounts of very fine sand particles (St. James Bay, 37.6%; Sunshine Cove, 35.8%), but St. James Bay had a smaller fraction of fine sand particles (15.4% compared to 44.8% for Sunshine Cove) and so had a larger silt/clay fraction (20.1% compared to 3.1%).

Core samples collected at Sunshine Cove within the aggregation and those collected 20 m away have almost identical particle size distributions. Both samples were primarily fine sand (within the aggregation, 50.9%; away, 43.9%), with lesser amounts of very fine sand particles (within the aggregation, 36.1%; away, 37.7%).

The percentage of organic matter in the sediment may affect oxygen availability to the crab and, more critically, to the eggs being brooded, since oxygen is being consumed by the detrito-bacteria. The amount of organic material was relatively high at both aggregation sites, ranging from a low of 6.3% at Sunshine Cove in May to a high of 11.5% in June at a location 20 m away from the aggregation site at Sunshine Cove. Measurements at St. James Bay and Sunshine Cove were not significantly different in May 1999 samples (8.1% and 6.3%) ($p = 0.1013$; arcsin transformed single factor ANOVA) and between the later dives at Sunshine Cove (11.2% and 11.5%) ($p = 0.8441$). However, there is a significant difference when all samples are compared ($p = 0.0035$). A multiple comparison of means was performed (Scheffe's Test, Table 1) which suggested that the earlier sample taken at Sunshine Cove was not significantly different to the St. James Bay sample (taken at approximately the same time), but that it was significantly different than the samples collected a month later at Sunshine Cove. The differences in percent organics between samples are probably temporal with the most plausible explanation being an increase in sedimentation rate brought on by the onset of the spring phytoplankton bloom. To obtain a more consistent estimate of percent organics within the sediment and possible effects on oxygen availability, it may be better to collect samples prior to the spring bloom sedimentation.

Discussion

Within or near Glacier Bay, the overall density estimates for Dungeness crabs not found within an aggregation vary from 0 to 0.02 crabs per m^2 for males and nonovigerous females. For ovigerous females, the two largest aggregations observed had abundance estimates of 0.12 and 0.18 crabs per m^2 (O'Clair et al. 1996). These estimates were determined by counting crabs along scuba transects in five bays over five seasons. The density estimates for the two aggregation sites of ovigerous females found in our study were much higher: St. James Bay (0.86 crabs per m^2) and Excursion Inlet (0.75 crabs per m^2). However, even these estimates are probably biased low for a number of reasons. Some ovigerous females were disturbed by the presence of the submersible, and the rapid departure of one crab would often elicit the same behavior from others. This behavior may have enabled us to record more crabs on the scuba transects; however, crabs immediately ahead of the submersible may have scattered prior to being recorded. Also, no attempt was made to uncover any of the buried crabs. Ovigerous Dungeness crabs spend much of their time brooding either partially or completely buried within the sediment (O'Clair et al. 1996). Investigations previously made by one of the coauthors (C.E.O'Clair, unpubl. data) have found ovigerous females buried as deep as 0.5 m within the sediment. A mesh enclosure was used to prevent ovigerous crabs from escaping from the aggregation site prior to being counted; densities as high as 20 crabs per m^2 were found (Stone and O'Clair 2002). Density estimates of 2.6 and 5.6 crabs per m^2 have also been reported for aggregations found within Glacier Bay (Stone and O'Clair 2002). Finally, transects in our study were straight line transects, set to follow a depth contour, so the densest part of the aggregation may not have been intersected.

Brooding locations appear to be used on an annual basis (O'Clair et al. 1996, Stone and O'Clair 2002). The aggregation site in St. James Bay was found in the same location in 1998 and 1999; similarly, the Sunshine Cove aggregation was found from prior knowledge of this site (D. Russell, University of Alaska Southeast, Juneau, pers. comm.). Ovigerous Dungeness crabs have been reported to have high interannual site fidelity to specific brooding locations (O'Clair et al. 1996). In a 4-year study examining 13 dense aggregation sites at several bays in Glacier Bay, 77 % of these sites were reused at least once (O'Clair et al. 1996). Brooding locations with the highest densities were primarily in sand substrate, with four located near the mouths of rivers. Another aggregation site in southeastern Alaska has been occupied annually for 12 years and the main substrate type is also sand (Stone and O'Clair 2002). Two of our sites were near the mouth of rivers (Excursion Inlet and St. James Bay) and all three had substrate composed primarily of sand.

Sand for brooding sites may be a limited resource. Our study over eight bays found that sand substrate covered only 1% of the transect area and 80% of this was at a depth of less than 10 meters. This zone is well within the sea otter's diving range. It is interesting to note that no crabs were observed in a sand habitat found in shallow water at Idaho Inlet. Since Idaho Inlet is a bay with sea otters, one explanation for the lack of ovigerous crabs may be sea otter predation. Aggregations have been suggested (O'Clair et al. 1996) to act as a group defense mechanism when ovigerous females are at a vulnerable stage in their life history. O'Clair et al. (1996) reported that when ovigerous crabs were initially disturbed, they seemed reluctant to move, probably because of the size of their egg clutch, making movement awkward and slow. However, after a sufficient number had been disturbed, neighboring crabs scattered until the entire aggregation area was deserted. These aggregations are probably not an effective defense mechanism against an intelligent predator like sea otters. Sea otters could deplete a breeding population within a short period of time when brooding aggregations are in shallow water and are occupied annually. Adult sea otters in Prince William Sound were documented consuming an average of 14 Dungeness crabs per day with subadults consuming 10 crabs per day (Garshelis et al. 1986). For 1980-1981 this resulted in an estimated annual consumption of 370,000 crabs, half of these being of legal size. In Prince William Sound, this level of predation eventually led to the closing of Orca Inlet which had been an important commercial source of Dungeness crabs (Kimker 1984).

Given the locomotive difficulties of ovigerous females and their increased risk from predation, it is not surprising that ovigerous females have a reduced activity rate, use less of the available habitat and have shorter and less frequent feeding bouts (O'Clair et al 1990, Schultz and Shirley 1997).

Several hypotheses have been proposed as to why sand is the preferred substrate for ovigerous females. Finer sediments might cause fouling of the egg clutch, thereby limiting oxygen availability to the eggs (O'Clair et al. 1996) and may also make burying within the sediment more difficult due to compaction properties of fine particles (Stone and O'Clair 2002). Sand may allow for increased interstitial water flow and therefore increased dissolved oxygen availability (O'Clair et al. 1996, Stone and O'Clair 2002). We found that the oxygen content for both of our sites to be relatively low, in the range of 19-43 % saturation. However, sampling occurred in mid-May, a month after the spring phytoplankton bloom. The latter is followed by the senescence of phytoplankton and an increase in microbial action, which leads to a reduction of available oxygen within the sediments. The percentage of organic matter found in the sediment samples was relatively high (6.3-8.1 %), which may have reduced oxygen availability to the eggs. At one aggregation site in southeastern Alaska, ovigerous crabs left their preferred aggregation site in mid-April from waters greater than 16m in depth and moved to waters less than 10 m in depth (Stone and O'Clair 2002). This shift appears to coincide with the spring bloom and is not without risk, due to significant concurrent predation by birds (Stone and O'Clair 2002). Suggested reasons for this behavior included an increase in oxygen availability for the embryos, due to the first part of the phytoplankton spring bloom and the higher water temperatures in shallower waters (Stone and O'Clair 2002). However, no interstitial water samples were collected to determine whether an increase in oxygen was a potential reason for this shift in aggregation site depth. A recent laboratory study on a congener *Cancer setosus* found that oxygen consumption by ovigerous females and embryos increased markedly with embryo development

(Fernándaz et al. 2000, Baeza and Fernándaz 2002). Much of the increase in oxygen demand was obtained though behaviors exhibited by the brooding females, most notably, abdominal flapping (Baeza and Fernándaz 2002). A delicate balance may exist between egg size and oxygen availability along a latitudinal gradient (Brante et al. 2003). Ovigerous female crabs taken from the colder waters of southern Chile had larger embryos and higher fecundity rates compared to females taken from warmer waters (Brante et al. 2003). Longer incubation times and adverse environmental conditions at higher latitudes may be the reason for these differences. In warmer waters, there was an increase in embryo loss and in the overall ventilation time as well as flapping frequency for the brooding females. These data suggest that there may be an upper limit to reproductive effort in ovigerous females at higher temperatures and that this may be why clutch and eggs sizes are smaller in warmer waters (Brante et al. 2003).

Alternately, low oxygen content has been proposed as a mechanism of decreasing the metabolic rate of the eggs for *Cancer pagurus*, keeping eggs in diapause for an extended period. This could help to retard hatching of larvae until more favorable conditions prevailed later in the season (Naylor et al. 1999). Whether this is the case for Dungeness crabs is unknown, since no studies have investigated how varying levels of oxygen affect the behavior of the adult crab, or what effects oxygen availability have on embryo development. However, *C. pagurus* is a congener of *C. magister* and they have similar behaviors when in an ovigerous state. Both species spend most of the 6 to 9 months of their ovigerous state either partially or completely buried within the sediment, with reduced feeding and activity rates (Naylor et al. 1997, Schultz and Shirley 1997, Stone and O'Clair 2002). Developmental stage may play an important role in how Brachyuran crab embryos will be affected by temperature and oxygen levels (Naylor et al. 1999, Fernándaz et al. 2000, Baeza and Fernándaz 2002, Brante et al. 2003). The ovigerous females appear to be able to detect critically low levels of oxygen, (especially at later stages of embryo development) and change their behavior accordingly, by ventilating the egg mass with their pleopods in a raised position above the surface of the sediment. This behavior was observed primarily at night and was prolonged as embryo development progressed (Naylor et al. 1999). Burial within a sand substrate may allow the females maximum control over embryonic development.

As indicated by the previous example, aggregating behavior is not unique to Dungeness crabs. Several other species in Alaska form aggregations, some of which are formed at different life history stages. Tanner crabs (*Chionoecetes bairdi*) also aggregate, with ovigerous females aggregating diurnally and then dispersing to feed nocturnally (Stevens and Haaga 1994). These aggregations have been observed at the same location for several consecutive years, but the substrate characteristics do not appear to be determinants in selection of the aggregation sites, since the surrounding environment (level, mud substrate) appears to be homogeneous for many kilometers and the aggregating females do not bury (Stevens et al. 1994). The aggregating behavior may be a way of attracting mates, since males mated with females on the periphery of an aggregation (Stevens et al. 1994), but the aggregations are primarily thought to be a method of releasing larvae above the benthic substrate (B. Stevens, National Marine Fisheries Service, Kodiak, personal communication).

Juvenile red king crabs (*Paralithodes camtschaticus*) also exhibit aggregating behavior, forming pods of individuals from the same year cohort. They continue this podding behavior until they reach maturity, forming tight aggregations during the day, then dispersing at night to feed (Dew 1990). This behavior may be a way of avoiding predation. Ovigerous female red king crabs continue to aggregate into large pods, probably for reasons similar to those of Tanner crabs (Stone et al. 1993).

The common purpose of the aggregating behavior of these species may be predator avoidance at a vulnerable life history stage. When aggregations are disturbed, crabs tend to scatter. However, burial within sediments in Alaska for extended periods of time appears to be unique to Dungeness crabs, and may be an adaptation to compensate for their large clutch size. It may provide protection to the exposed eggs from predation or environmental factors or may increase the safety of the female, when quick movements are more awkward and difficult. Both king and Tanner crabs can maintain their abdominal flap tight against their thorax. Selection of sand as the preferred primary substrate may be a way for Dungeness crabs to exert maximal control over their environment (oxygen concentration, therefore egg development) by allowing them to burrow readily and deeply within the sediment while minimizing fouling of their eggs by smaller particle sizes.

Conclusions

Our study suggests that sand may be a limiting resource for ovigerous Dungeness crabs in some bays. Since Dungeness crab brooding aggregations represent a substantial portion of the adult crab population, and all of the future population during a vulnerable life history stage it would seem important to assess, map, and possibly protect such areas from anthropomorphic disturbances such as log storage or log transfer activities, vessel anchorage, discharge, and fishing. Suitable substrate for brooding aggregations appears to cover only a small fraction of the total area available in many bays. Areas requiring protection could therefore be quite small, which would limit conflict with alternative uses.

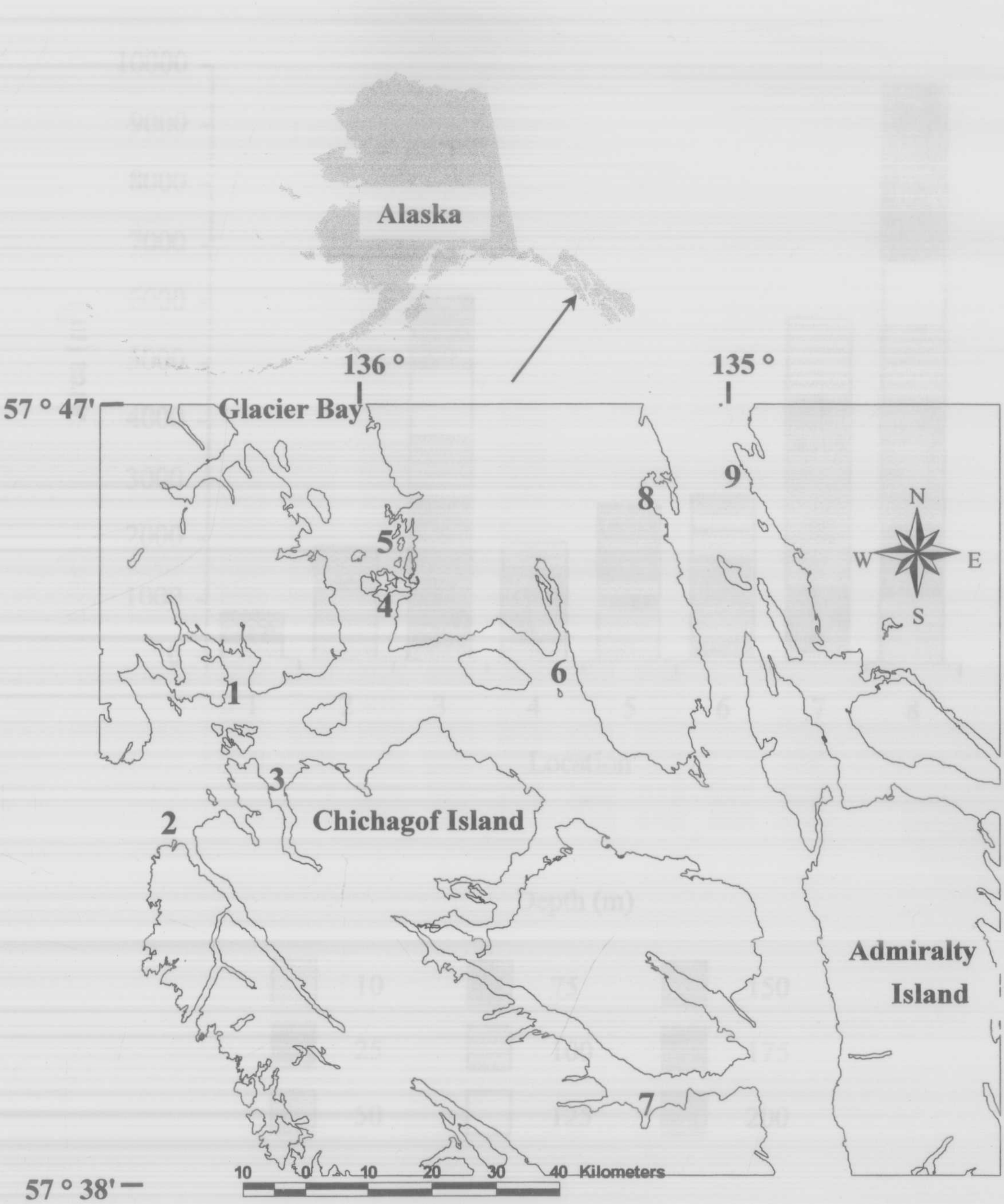

Figure 1. Regional map of study sites in the Glacier Bay area: with sea otters – Dundas Bay (1), Port Althorp (2), Idaho inlet (3); bays used seasonally – Bartlett Cove (4), Beardslee Islands (5); bays without sea otters – Tenakee Inlet (6), Excursion Inlet (7), St. James Bay (8). Additional site for quantitative analysis: (9), Sunshine Cove.

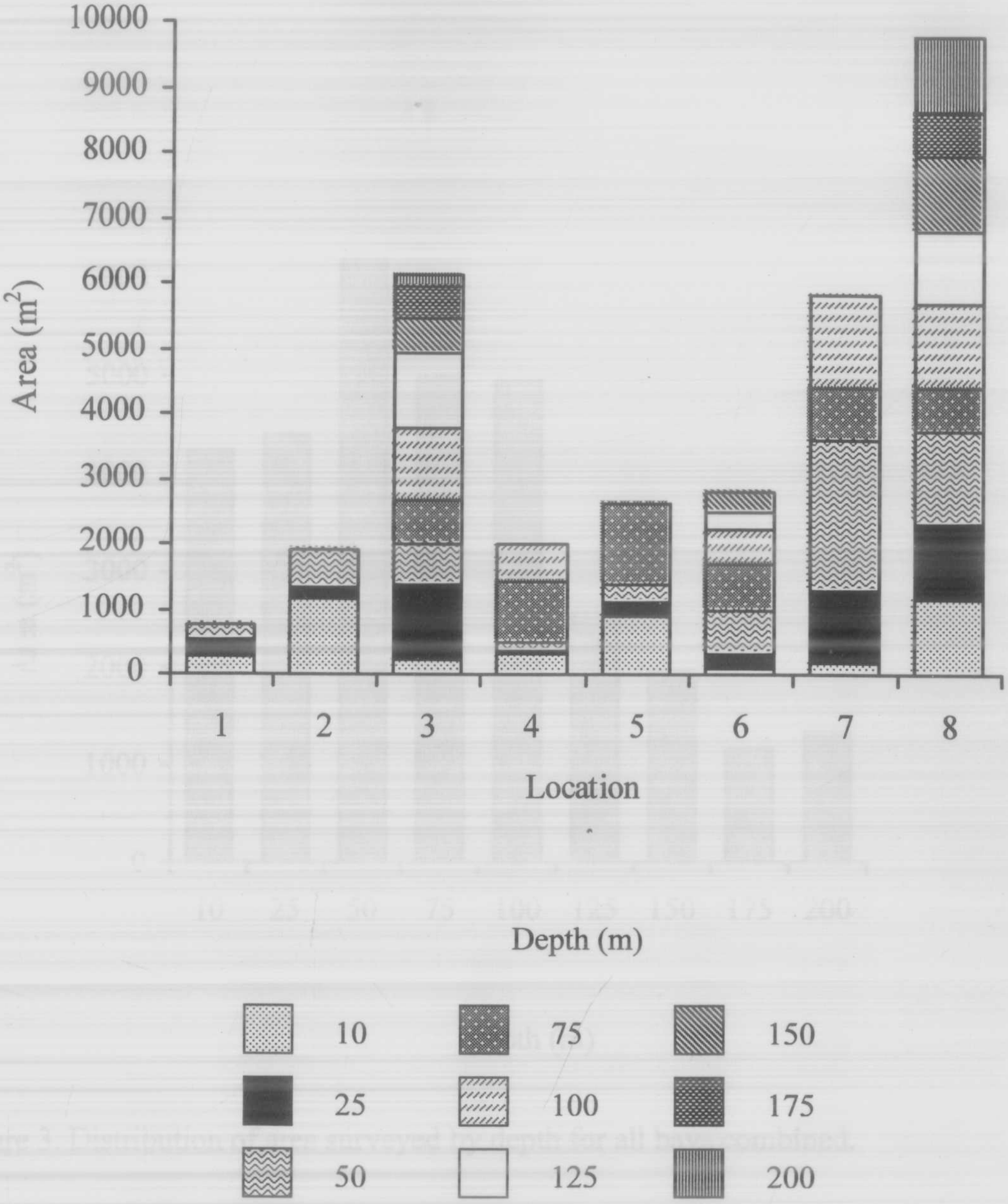

Figure 2. Distribution of area surveyed in each bay by depth. 1, Bartlett Cove; 2, Beardslee Islands; 3, Dundas Bay; Excursion Inlet; 5, Idaho Inlet; 6, Port Althorp; 7, St. James Bay; 8, Tenakee Inlet.

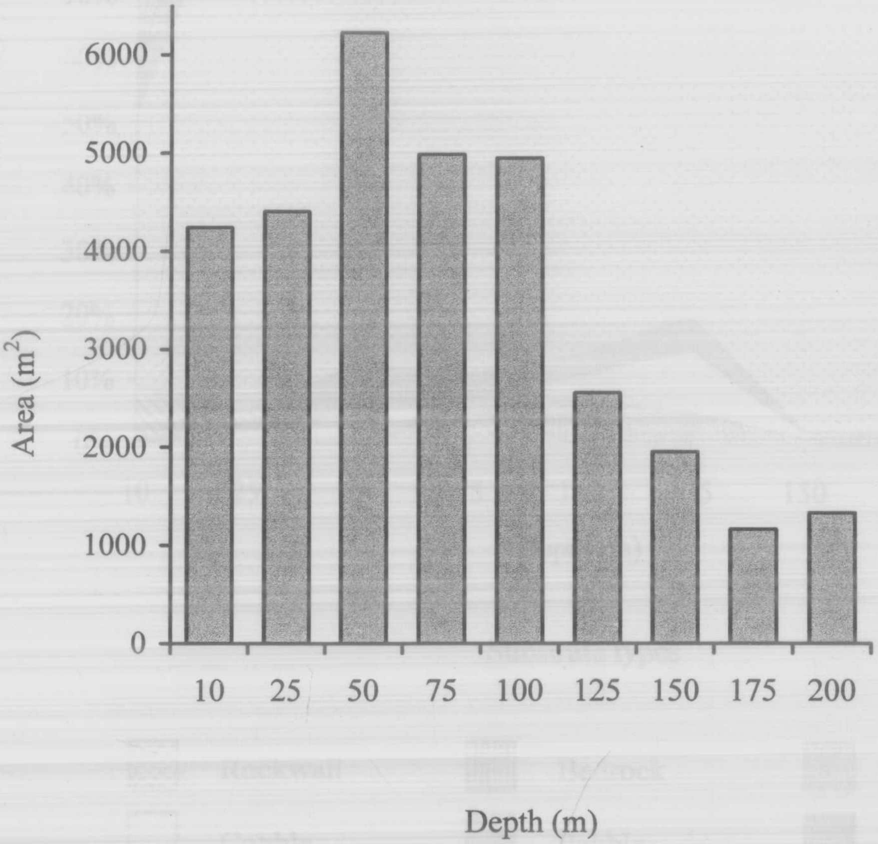

Figure 3. Distribution of area surveyed by depth for all bays combined.

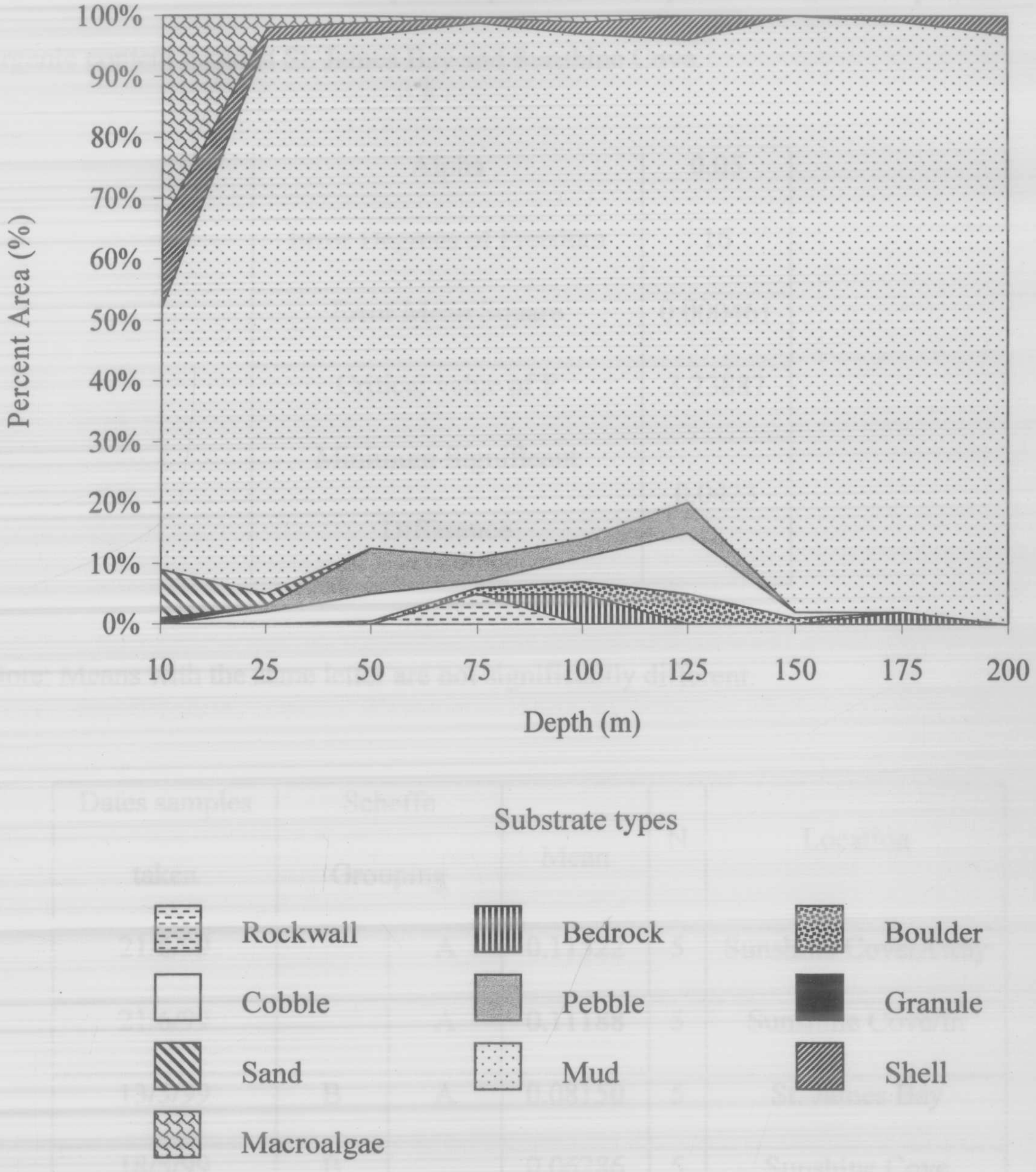

Figure 4. Distribution of substrate types by depth and percent area covered for all bays combined.

Table 1. Scheffe's Test – A multiple comparison of sample mean values for percent organic content taken at St. James Bay and Sunshine Cove.

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	0.000461
Critical value of F	3.23887
Minimum Significant Difference	0.0423

Note: Means with the same letter are not significantly different.

Dates samples taken	Scheffe Grouping		Mean	N	Location
21/6/99		A	0.11522	5	Sunshine Cove/Away
21/6/99		A	0.11188	5	Sunshine Cove/In
13/5/99	B	A	0.08150	5	St. James Bay
18/5/99	B		0.06286	5	Sunshine Cove

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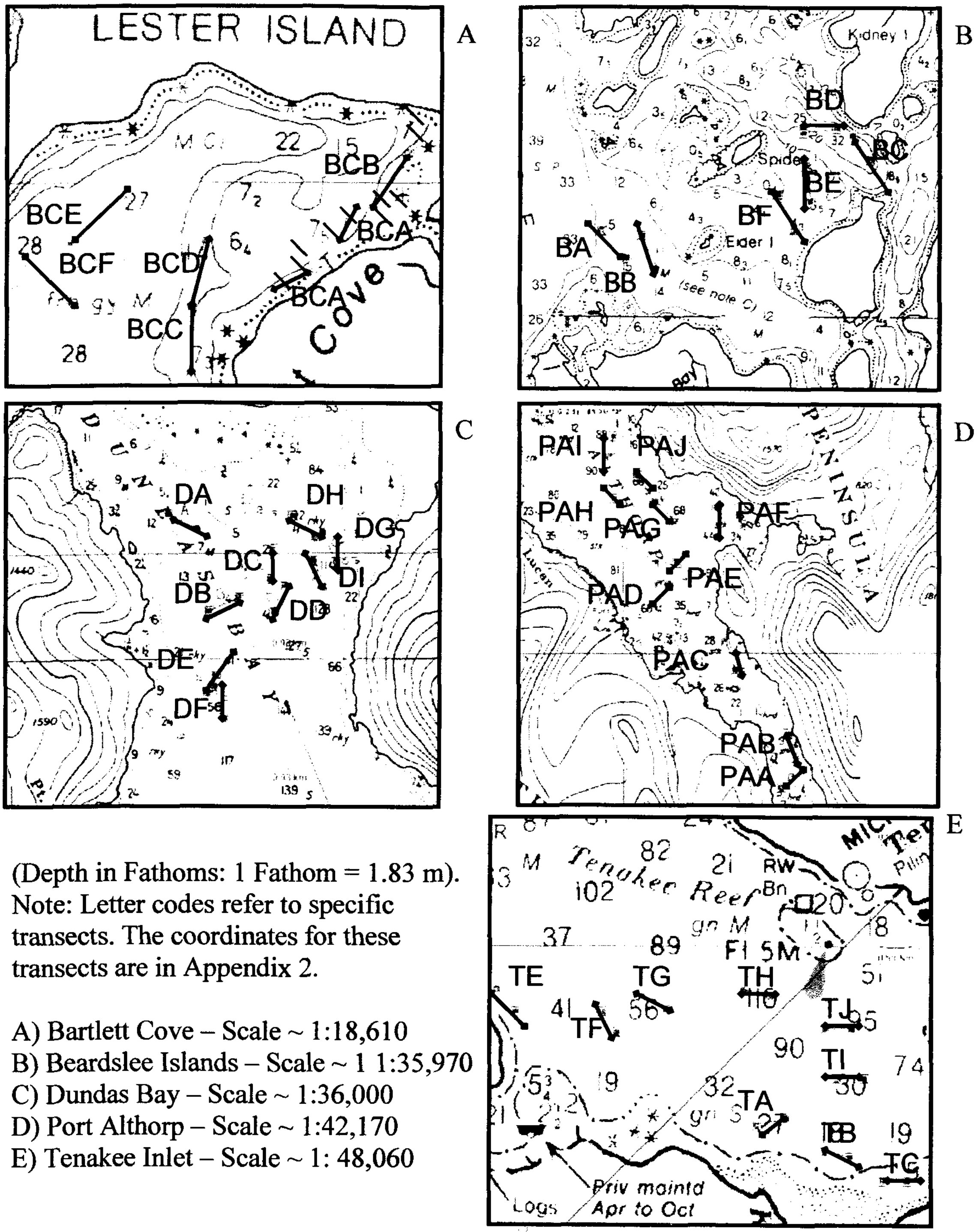
CONCLUSIONS

Sea otters have an adverse effect on Dungeness crab abundance in shallow water (≤ 50 m). Both the control sites (bays without sea otters) in the current study and the ADF&G king and Tanner crab surveys suggested that Dungeness crabs are more prevalent in the shallowest reaches of the bays and decreased in density with increasing depth. However, in the bays with long established sea otter colonies the opposing pattern was true; the shallowest transects contained no crabs with only one bay having a low density of crabs at 50 m depth.

Ovigerous Dungeness crabs may be more susceptible to sea otter predation than the population as a whole due to their aggregating behavior. No aggregation sites were observed in any of the long established sea otter bays, even though suitable habitat appeared to be available at one of the sites. It is possible that aggregation sites did exist but were missed due to the limited area covered and the relatively small size of these sites; however, no crabs were observed at any depth within this bay, either by the submersible or with baited crab pots. Physical and behavioral characteristics observed which may put ovigerous females at higher risk include: 1) aggregation sites occur in shallow waters (≤10 m depth); 2) aggregation sites often have high densities of ovigerous crabs, both horizontally and vertically within the sediment in a relatively small area; 3) movement of females appears to be inhibited by distension of their abdominal flap, as a result of the large egg clutch; there is high site fidelity; and 4) finally, after a flight response is initiated by perturbation, conspecifics follow suit and a mass exodus from the site ensues.

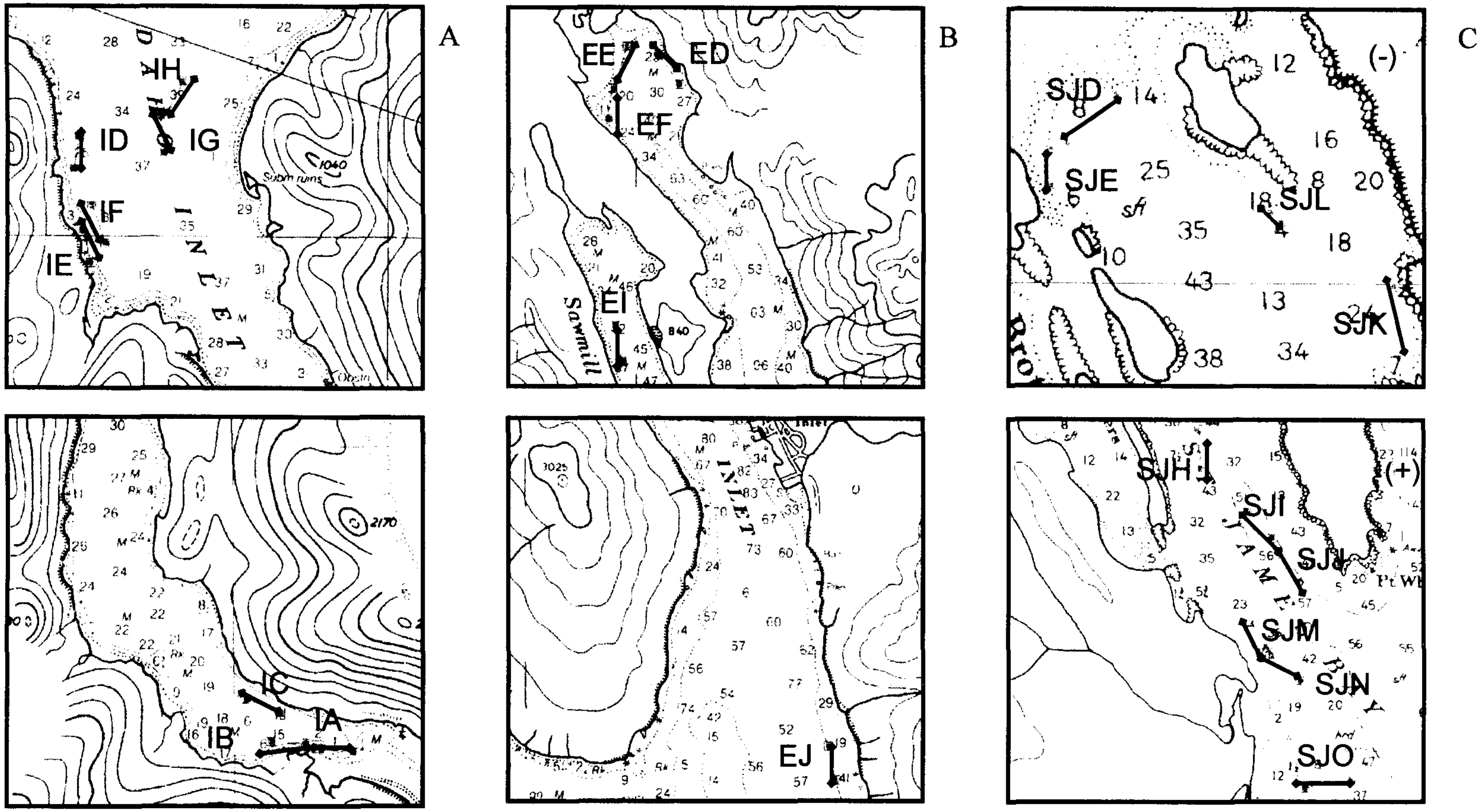
Depth may act as a refuge for Dungeness crab against sea otter predation. When all depth categories were analyzed for all treatment groups (sea otters – present, seasonal or absent) no clear conclusions could be drawn due to a strong interaction between the variables. However, when bays with a long established sea otter colony were examined from a different perspective, such as marine topography, it became apparent why Dundas Bay was a refuge while the other bays were not; the physical features which allowed depth to act as a refuge in Dundas Bay were not replicated by any of the other bays studied. Maximum depth of a bay, size of the area at depths greater than those foraged by sea otters, and seafloor gradient appeared to be important. The crab pot data also corroborated the submersible findings, displaying the same basic trends in all bays studied. Only Dundas Bay with its unique physical features had Dungeness crabs at depth ($\geq$ 150 m). The ADF&G king and Tanner crab survey also supported the findings that Dungeness crabs are only rarely found at depth; all bays examined displayed the same trend as the control sites, with the Dungeness crabs being found primarily in shallow water and decreasing in abundance with depth.



(Depth in Fathoms: 1 Fathom = 1.83 m). Note: Letter codes refer to specific transects. The coordinates for these transects are in Appendix 2.

A) Bartlett Cove – Scale ~ 1:18,610
B) Beardslee Islands – Scale ~ 1 1:35,970
C) Dundas Bay – Scale ~ 1:36,000
D) Port Althorp – Scale ~ 1:42,170
E) Tenakee Inlet – Scale ~ 1: 48,060

Appendix 1a. Maps of each study site with transect locations.



Appendix 1b. Maps of each study site with transect locations (Bathymetry in Fathoms: 1 Fathom = 1.83 m). A) Idaho Inlet – Scale ~ 1:53,333; B) Excursion Inlet – Scale ~ 1:53,333; C) St. James Bay – Scale ~ 1:43,640(+); 1:29,225 (-).Note: Letter codes refer to specific transects. The coordinates for these transects are in Appendix 2.

Appendix 2. Coordinates, depth and distance traversed for each transect by bay. Note: all video tapes were reviewed by author to confirm counts and other physical parameters.

Bartlett Cove (May 10,1998)

Observer	Dive #	Transect	Beginning & End point	Latitude	Longitude	Length (m)	Depth (m)	Depth (m) MLLW
Debbie	3	BC3	B	58°27.807′	135°52.634 ′	100		
Hart	4298		E	58°27.787′	135°52.560′			
		BC4	B	58°27.759′	135°52.702′	100		
			E	58°27.758′	135°52.681′			
Tom	2	BC10	B	58°27.525′	135°52.723′	100		
Shirley	4297		E	58°27.539′	135°52.821′			
		BC11	B	58°27.476′	135°52.746′	100		
			E	58°27.497′	135°52.836′			
		BC12	B	58°27.430′	135°52.778′	100		
			E	58°27.453′	135°52.869′			
		BC13	B	58°27.392′	135°52.867′	100		
			E	58°27.426′	135°52.947′			
		BC14	B	58°27.370′	135°52.965′	100		
			E	58°27.411′	135°53.034′			
Chuck	1	BC18	B	58°27.315′	135°53.447′	100		
O'Clair	4296		E	58°27.274′	135°53.360′			
		BC19	B	58°27.286′	135°53.490′	100		
			E	58°28.251′	135°53.404′			
		BC20	B	58°27.24′	135°53.72′	100		
			E	58°27.21′	135°53.56′			
Deborah	4	A	B	58°27.18′	135°53.55′	250	10	
Mercy	4299		E	58°27.26′	135°53.37′			
		A′	B	58°27.36′	135°53.11′	250	10	
			E	58°27.44′	135°52.89′			
		B	B	58°27.48′	135°52.94′	500	10	
			E	58°27.70′	135°52.64′			
Jimmy Dee	5	C	B	58°26.85′	135°54.23′	500	25	29
La Bruere	4300		E	58°27.11′	135°54.23′			
		D	B	58°27.12′	135°54.20′	500	25	29
			E	58°27.16′	135°54.21′			
Karen	6	E	B	58°27.53′	135°54.80′	500	50	52
Scheding	4301		E	58°27.35′	135°55.07′			
		F	B	58°27.28′	135°55.38′	325	50	52
			E	58°27.14′	135°55.08′			

Appendix 2. (Continued)
Beardslee Islands (May 11,1998)

Observer	Dive #	Transect	Beginning & End point	Latitude	Longitude	Length (m)	Depth (m)	Depth (m) MLLW
Paul	7	BA	B	58°30.628′	135°57.264′	500	25	25
Carlson	4302		E	58°30.427′	135°56.904′			
Phillip	8	BC	B	58°31.160′	135°53.494′	500	50	50
Hooge	4304		E	58°31.347′	135°53.726′			
Karen	9	BD	B	58°31.395′	135°53.974′	500	50	50
Scheding	4305		E	58°31.362′	135°54.433′			
Tom	10	BE	B	58°31.115′	135°54.410′	500	10	14
Shirley	4306		E	58°30.851′	135°54.339′			
Tom	10	BF	B	58°30.64′	135°54.59′	500	10	14
Shirley	4306		E	58°30.906′	135°54.784′			
George	12	BB	B	58°30.599′	135°56.707′	500	25	29
Esslinger	4308		E	58°30.357′	135°56.485′			

Note: Two dive numbers. The 4000 series refer to the accumulating dives of the submersible DELTA and the lower dive numbers (1-56) represent the order and number of dives on this specific cruise. Transect BG (75m) aborted due to strong currents (Dive # 11/4307).

Appendix 2. (Continued)
Dundas Bay (May 12,1998)

Observer	Dive #	Transect	Beginning & End point	Latitude	Longitude	Length (m)	Depth (m)	Depth (m) MLLW
Chuck	13	DA	B	58°21.04′	136°20.78′	500	10	10
O'Clair	4309		E	58°21.197′	136°21.238′			
Chuck	14	DB	B	58°20.509′	136°20.099′	500	25	25
O'Clair	4310		E	58°20.392′	136°20.579′			
Jim	15	DC	B	58°20.909′	136°19.561′	500	50	50
Bodkin	4311		E	58°20.658′	136°19.603′			
Jim	15	DD	B	58°20.614′	136°19.403′	500	75	75
Bodkin	4311		E	58°20.389′	136°19.561′			
Debbie	16	DE	B	58°19.863′	136°20.468′	500	100	100
Hart	4312		E	58°19.705′	136°20.613′			
Debbie	16	DF	B	58°19.768′	136°20.519′	500	125	125
Hart	4312		E	58°19.502′	136°20.358′			
Tom	17	DG	B	58°20.798′	136°18.543′	250	150	153
Shirley	4315		E	58°21.043′	136°18.752′			
Tom	17	DH	B	58°20.999′	136°18.863′	500	175	177
Shirley	4315		E	58°21.186′	136°19.244′			
Karen	18	DI	B	58°20.598′	136°18.56′	187	200	200
Scheding	4316		E	58°20.680′	135°18.546′			

Appendix 2. (Continued)
Port Althorp (May 13,1998)

Observer	Dive #	Transect	Beginning & End point	Latitude	Longitude	Length (m)	Depth (m)	Depth (m) MLLW
Karen	19	PAA	B	58°06.325′	136°16.990 ′	500	10	10
Scheding	4317		E	58°06.480′	136°16.593′			
Karen	19	PAB	B	58°06.609′	136°16.739′	500	25	25
Scheding	4317		E	58°06.838′	136°16.875′			
Debbie	20	PAC	B	58°07.697′	136°18.028′	500	50	50
Hart	4318		E	58°07.446′	136°17.862′			
Tom	21	PAD	B	58°08.036′	136°19.278′	500	75	75
Shirley	4319		E	58°08.259′	136°19.088′			
Tom	21	PAE	B	58°08.255′	136°19.279′	500	100	101
Shirley	4319		E	58°08.458′	136°18.965′			
Jim	22	PAF	B	58°08.704′	136°18.190′	500	75	77
Bodkin	4320		E	58°08.977′	136°18.204′			
George	23	PAG	B	58°08.870′	136°18.995′	250	125	128
Esslinger	4321		E	58°09.057′	136°19.332′			
Karen	24	PAJ	B	58°09.144′	136°19.511′	500	125	128
Scheding	4322		E	58°09.296′	136°19.692′			
Chuck	25	PAH	B	58°09.082′	136°20.143′	300	150	153
O'Clair	4323		E	58°09.176′	136°20.351′			
Chuck	26	PAI	B	58°09.466′	136°20.207′	400+	150	153
O'Clair	4324		E	58°09.667′	135°20.159′			

Appendix 2. (Continued)
Idaho Inlet (May 14,1998)

Observer	Dive #	Transect	Beginning & End point	Latitude	Longitude	Length (m)	Depth (m)	Depth (m) MLLW
Tom	27	IA	B	58°04.785′	136°08.753 ′	500	10	10
Shirley	4325		E	58°04.760′	136°08.293′			
Tom	27	IB	B	58°04.835′	136°09.475 ′	500	25	25
Shirley	4325		E	58°04.828′	136°08.974′			
Larry	28	IC	B	58°05.052′	136°09.324′	500	25	25
Basch	4326		E	58°05.147′	136°09.815′			
Kathy	29	IE	B	58°10.047′	136°14.319′	500	10	10
Swiney	4329		E	58°09.789′	136°14.209′			
Larry	30	IF	B	58°10.221′	136°14.189′	500	50	52
Basch	4330		E	58°09.938′	136°14.008′			
Kathy	31	ID	B	58°10.750′	136°14.372′	500	50	52
Swiney	4331		E	58°10.490′	136°14.443′			
Karen	32	IH	B	58°11.166′	136°12.898′	250	75	75
Scheding	4332		E	58°10.930′	136°13.118′			
Karen	32	IG	B	58°10.893′	136°13.221′	500	75	75
Scheding	4332		E	58°10.615′	136°13.159′			

Appendix 2. (Continued)
Excursion Inlet (May 15,1998)

Observer	Dive #	Transect	Beginning & End point	Latitude	Longitude	Length (m)	Depth (m)	Depth (m) MLLW
Switgard Duesterloh		EA	B E	Cancelled		500	10	10
Switgard Duesterloh	33 4334	ED	B E	58°29.702′ 58°29.922′	135°29.383 ′ 135°29.671′	500	50	50
Liz Soloman	34 4335	EE	B E	58°29.999′ 58°29.785′	135°29.122′ 135°30.223′	~ 400	10	12
Liz Soloman	35 4335	EF	B E	58°29.672′ 58°29.445′	135°30.235′ 135°30.391′	500	25	27
Karen Scheding	4336	EC	B E	Cancelled		500	75	78
Jim Taggart	4337	EH	B E	Cancelled		500	75	79
Jim Taggart	36 4338	EI	B E	58°27.901′ 58°27.637′	135°30.290′ 135°30.202′	250	75	79
Karen Scheding	37 4339	EJ	B E	58°22.348′ 58°22.614′	135°25.594′ 135°25.707′	500	100	103

Appendix 2. (Continued)
Tenakee Inlet (May 16,1998)

Observer	Dive #	Transect	Beginning & End point	Latitude	Longitude	Length (m)	Depth (m)	Depth (m) MLLW
Liz	38	TA	B	57°44.421′	135°15.136′	500	50	53
Soloman	4340		E	57°44.570′	135°14.454′			
Karen	39	TB	B	57°44.276′	135°13.758′	500	25	26
Scheding	4342		E	57°44.217′	135°13.288′			
Karen	40	TC	B	57°44.217′	135°12.699′	500	10	10
Scheding	4343		E	57°43.983′	135°12.220′			
Switgard	41	TE	B	57°45.778′	135°19.687′	500	100	100
Duesterloh	4344		E	57°45.569′	135°19.358′			
Jim	42	TF	B	57°45.578′	135°17.792′	500	125	125
Taggart	4345		E	57°45.379′	135°17.479′			
Jim	43	TG	B	57°45.707′	135°17.019′	500	150	151
Taggart	4346		E	57°45.597′	135°16.557′			
Karen	44	TH	B	57°45.771′	135°15.224′	500	200	202
Scheding	4347		E	57°45.744′	135°14.712′			
Bob	45	TI	B	57°44.957′	135°13.528′	500	75	79
Thomas	4348		E	57°44.953′	135°13.019′			
Tom	46	TJ	B	57°45.424′	135°13.746′	500	175	179
Shirley	4349		E	57°45.413′	135°13.227′			

Appendix 2. (Continued)
St. James Bay (May 17-18,1998)

Observer	Dive #	Transect	Beginning & End point	Latitude	Longitude	Length (m)	Depth (m)	Depth (m) MLLW
Doug	47	SJJ	B	58°34.512′	135°09.255′	500	100	100
Woodby	4350		E	58°34.724′	135°09.569′			
Jim	48	SJI	B	58°35.044′	135°09.985′	500	100	101
Taggart	4351		E	58°34.840′	135°09.644′			
Bob	49	SJH	B	58°35.648′	135°10.688′	500	75	78
Thomas	4352		E	58°35.369′	135°10.670′			
Karen	50	SJD	B	58°36.913′	135°11.516′	500	10	13
Scheding	4353		E	58°36.738′	135°11.851′			
Karen	50	SJE	B	58°36.706′	135°11.869′	500	10	14
Scheding	4353		E	58°36.581′	135°11.961′			
Tom Shirley	4354	Photo fix – Dungeness Aggregation		58°36.829′	135°11.641′			
Tom	51	SJK	B	58°35.943′	135°09.418′	500	25	29
Shirley	4356		E	58°36.199′	135°09.537′			
Doug	52	SJL	B	58°36.428′	135°10.328′	200	25	28
Woodby	4347		E	58°36.482′	135°10.415′			
Tom	53	Examining		57°45.424′	135°11.508′		2	4
Shirley	4359	Aggregation		57°45.413′	135°11.478′			
Switgard	54	SJM	B	58°34.212′	135°09.684′	500	50	51
Duesterloh	4360		E	58°33.987′	135°09.704′			
Switgard	54	SJN	B	58°33.962′	135°09.676′	500	50	51
Duesterloh	4360		E	58°33.780′	135°09.268′			
Jim	55	SJO	B	58°33.713′	135°08.697′	500	75	75
Taggart	4361		E	58°33.448′	135°08.498′			
Doug	56	SJP	B	58°33.048′	135°08.498′	500	25	25
Woodby	4362		E	58°32.980′	135°09.175′			

Appendix 3. Sample data sheet

Date: May 1 , 1998 | Dive # : | Delta dive #: | Location: | Visibility: | Page of

Pilot: | Observer: | Transect code: | Depth category m | Weather:

Latitude: | Longitude: | Use the tally method when entering count data. eg. 𝍸 ( )

Time (in 5 minute intervals) Start: Stop: (24 hour clock) | Depth – Start: m Stop: m

Count														
Species code	Cm-1	Cb-2	Pc-3	Tc-4	P-5	Hl-6	Cp-7	Og-8	Ah-9	Lf-10	Mq-11	Pp-12	M-13	Pd-14
Scientific name	*Cancer magister*	*Chionoecetes bairdi*	*Paralithodes camtschaticus*	*Telmessus cheiragonus*	*Paguridae*	*Hyas lyratus*	*Cancer productus*	*Oregonia gracilis*	*Acantholithodes hispidus*	*Lopholithodes foraminatus*	*Munida quadrispina*	*Paralithode platypus*	*Mysidae*	*Pandalus danae*
Common name	Dungeness crab	Tanner crab	King crab	Helmet crab	Hermit crab	Lyre crab	Red Rock crab	Decorator crab	Spiny Lithode crab	Brown Box crab	Squat Lobster	????	Opossum shrimp	Dock shrimp

Count															
Species code	Nl-18	Fo-19	Bp-20	C-25	O-26	S-27	T-28	Cr-29	Ch-30	Pg-31	Tn-32	E-33	O-34	Pc-35	A-36
Scientific name	*Neptuni ilrata*	*Fusitriton oregonensis*	*Buccinum plectrum*	*Collus sp*	*Octopus sp*	*Sepioidea*	*Teuthoidea*	*Chlamys rubida*	*Chlamys hastata*	*Panope generosa*	*Tresus nuttalli*	*Echinoidea*	*Ophiuroids*	*Prastichopus californicus*	*Actiniara*
Common name		Oregon triton				Cuttlefish	Squid	Reddish scallop	Spiny scallop	Geoduck clam	Horse Neck clam	Sea Urchins	Brittle star	California Sea cucumber	Sea Anemone

Count													
Species code	Lp-40	Hl-41	Gs-42	Hl-43	Ma-44	Ok-45	Sf-46	Hs-47	La-48	Mp-49	La-50	Ps-51	Hh-52
Scientific name	*Leptasteria Polaris*	*Pteraster tesselatus*	*Gephyreaster swifti*	*Henricia leviuscula*	*Mediaster aequalis*	*Orthasterias koehleri*	*Stylasterias forreri*	*Hippoglossus stenolepis*	*Leptocottus armatus*	*Myoxocephalus polcanthocephalus*	*Limanda aspera*	*Platichthys stellatus*	*Hemilepidtous hemilepidotus*
Common name	star	Cushion star	star	Blood star	Vermillion star	Rainbow star	Fish eating star	Pacific Halibut	Pacific Staghorn sculpin	Great sculpin	Yellowfin sole	Starry flounder	Red Irish lord

Count													
Species code	Pb-56	Sm-57	Sc-58	Sm-59	Sn-60	Z-61	Pe-15	Ph-16	Pp-17	N-37	Ph-38	Et-39	Ls-54
Scientific name	*Pleuronectes bilineata*	*Sebastes maliger*	*Sebastes caurinus*	*Sebastes migrocinctus*	*Sebastes nebulosus*	*Zoarcidae*	*Pandalus eous*	*Pandalus hupsinotus*	*Pandalus platyceros*	*Nudibranchia*	*Pycnopodia helianthoides*	*Evasterias troschelli*	*Lumpenuss sagitta*
Common name	Rock sole	Quillback rockfish	Copper rockfish	Tiger rockfish	China rockfish	Eelpout	Alaskan Pink shrimp	Coonstriped shrimp	Spot shrimp	Nudibranch	Sunflower star	False Ochre star	Snake prickleback

Substrate type	Bedrock	Boulder	Cobble	Pebble	Gravel	Sand	Mud	Shell	Eelgrass
Substrate code	BR-1	B-2	C-3	P-4	G-5	S-6	M-7	SH-8	E-9

Start: | Stop: | Additional information:

Note: Please classify the substrate as one of the following, at most two categories can be combined to describe a substrate. Give a description at the start and stop times, but also note if the substrate changes in between set times (record time given on tape when this occurs).

Gradient type	Level (0-5%)	Gradual incline (5-15%)	Medium Incline (15-30%)	Steep Incline (30% or >)
Gradient code	L-1	G-2	M-3	S-4

Start: | Stop: | Additional information:

Note: Please classify the gradient as one of the following. Give a description at the start and stop times, but also note if the gradient changes in between set times (record time given on tape when this occurs).
Remember 45 degrees is the same as 100%

Any observations that you feel are noteworthy:

Appendix 4. Scuba diver transect data for Dungeness crabs abundance (May 1998).

Substrate code

Code	1	2	3	4	5
Substrate	Silt	Pebble	Cobble	Boulder	Shell

*Substrate column is a 3 number series. The transect width is 2 m. The numbers describe the left, middle, and right portion of the transect.

						Crab abundance – Count/20 m^2			
Location	Date (m/d)	Trans. code	Trans. Dist.	Depth (ft)	*Sub-strate	Left Buried	Left Unburied	Right Buried	Right Unburied
BART C	05/09	BC-1	0	38	111	0	0	0	0
BART C	05/09	BC-1	10	40	111	0	0	0	0
BART C	05/09	BC-1	20	45	111	0	0	0	0
BART C	05/09	BC-1	30	49	111	0	0	0	0
BART C	05/09	BC-1	40	52	111	0	0	0	0
BART C	05/09	BC-1	50	58	141	0	0	0	0
BART C	05/09	BC-1	60	58	111	0	0	0	0
BART C	05/09	BC-1	70	60	111	0	0	0	0
BART C	05/09	BC-1	80	62	111	0	0	0	0
BART C	05/09	BC-1	90	64	111	0	0	0	0
					Mean	0	0	0	0
BART C	05/09	BC-2	0	26	131	2	0	0	0
BART C	05/09	BC-2	10	30	131	0	0	0	0
BART C	05/09	BC-2	20	32	131	1	1	0	0
BART C	05/09	BC-2	30	35	131	0	0	0	0
BART C	05/09	BC-2	40	37	131	0	0	0	0
BART C	05/09	BC-2	50	40	131	0	0	0	0
BART C	05/09	BC-2	60	44	131	0	0	0	0
BART C	05/09	BC-2	70	47	131	0	0	0	0
BART C	05/09	BC-2	80	56	131	0	0	0	0
BART C	05/09	BC-2	90	56	131	0	0	0	0
					Mean	0.3	0.1	0	0
BART C	05/09	BC-3	0	18	111	0	0	0	0
BART C	05/09	BC-3	10	22	111	0	0	0	0
BART C	05/09	BC-3	20	26	111	0	0	2	0
BART C	05/09	BC-3	30	29	111	0	0	2	0
BART C	05/09	BC-3	40	32	111	0	0	0	0
BART C	05/09	BC-3	50	35	111	0	0	0	0
BART C	05/09	BC-3	60	38	111	0	0	1	0
BART C	05/09	BC-3	70	42	111	0	0	0	0
BART C	05/09	BC-3	80	45	131	0	0	0	0
BART C	05/09	BC-3	90	47	141	0	0	0	0
					Mean	0	0	0.5	0

Appendix 4. (Continued) Crab abundance – Count /20 m^2

Location	Date (m/d)	Trans. code	Trans. Dist.	Depth (ft)	Sub-strate	Left Buried	Left Unburied	Right Buried	Right Unburied
BART C	05/09	BC-4	0	27	111	0	0	0	0
BART C	05/09	BC-4	10	30	111	0	0	1	0
BART C	05/09	BC-4	20	33	111	0	1	1	0
BART C	05/09	BC-4	30	36	111	0	0	0	0
BART C	05/09	BC-4	40	39	111	0	0	0	0
BART C	05/09	BC-4	50	44	111	0	0	0	0
BART C	05/09	BC-4	60	46	111	0	0	0	0
BART C	05/09	BC-4	70	48	111	0	0	0	0
BART C	05/09	BC-4	80	52	111	0	0	0	0
BART C	05/09	BC-4	90	54	111	0	0	0	0
					Mean	0	0.1	0.2	0
BART C	05/09	BC-5	0	45	111	0	0	0	0
BART C	05/09	BC-5	10	50	111	0	0	0	0
BART C	05/09	BC-5	20	54	111	0	0	0	0
BART C	05/09	BC-5	30	58	111	0	0	0	1
BART C	05/09	BC-5	40	62	111	0	0	0	0
BART C	05/09	BC-5	50	65	111	0	0	0	0
BART C	05/09	BC-5	60	67	111	0	0	0	0
BART C	05/09	BC-5	70	69	111	0	0	0	0
BART C	05/09	BC-5	80	71	111	0	0	0	0
BART C	05/09	BC-5	90	74	111	0	0	0	0
					Mean	0	0	0	0.1
BART C	05/09	BC-6	0	44	151	0	0	0	0
BART C	05/09	BC-6	10	47	151	0	0	0	0
BART C	05/09	BC-6	20	50	111	0	0	0	0
BART C	05/09	BC-6	30	53	111	0	0	0	0
BART C	05/09	BC-6	40	57	111	0	0	0	0
BART C	05/09	BC-6	50	61	111	0	0	0	0
BART C	05/09	BC-6	60	64	111	0	0	0	0
BART C	05/09	BC-6	70	67	111	0	0	0	1
BART C	05/09	BC-6	80	70	111	0	0	0	0
BART C	05/09	BC-6	90	72	111	0	0	0	0
					Mean	0	0	0	0.1
BART C	05/09	BC-7	0	38	111	0	0	0	0
BART C	05/09	BC-7	10	40	111	0	0	0	0
BART C	05/09	BC-7	20	43	111	0	0	0	0
BART C	05/09	BC-7	30	46	111	0	0	0	0
BART C	05/09	BC-7	40	49	111	0	0	0	0
BART C	05/09	BC-7	50	52	111	0	0	0	0
BART C	05/09	BC-7	60	54	111	0	0	0	0
BART C	05/09	BC-7	70	57	111	0	0	0	0
BART C	05/09	BC-7	80	60	111	0	0	0	0
BART C	05/09	BC-7	90	62	111	0	0	0	0
					Mean	0	0	0	0

Appendix 4. (Continued) Crab abundance – Count /20 m^2

Location	Date (m/d)	Trans. code	Trans. Dist.	Depth (ft)	Sub-strate	Left Buried	Left Unburied	Right Buried	Right Unburied
BART C	05/09	BC-8	0	33	151	0	0	0	0
BART C	05/09	BC-8	10	35	111	0	0	0	0
BART C	05/09	BC-8	20	39	111	0	0	0	0
BART C	05/09	BC-8	30	41	111	0	0	0	0
BART C	05/09	BC-8	40	43	111	0	0	0	0
BART C	05/09	BC-8	50	45	111	0	0	0	0
BART C	05/09	BC-8	60	46	111	0	0	0	0
BART C	05/09	BC-8	70	48	111	0	0	0	0
BART C	05/09	BC-8	80	50	111	0	0	0	0
BART C	05/09	BC-8	90	52	111	0	0	0	0
					Mean	0	0	0	0
BART C	05/09	BC-9	0	28	111	0	0	0	0
BART C	05/09	BC-9	10	29	111	0	0	0	0
BART C	05/09	BC-9	20	30	111	0	1	0	0
BART C	05/09	BC-9	30	34	111	0	0	0	0
BART C	05/09	BC-9	40	36	111	0	0	0	0
BART C	05/09	BC-9	50	40	111	0	0	0	1
BART C	05/09	BC-9	60	41	111	0	0	0	0
BART C	05/09	BC-9	70	42	111	0	0	0	0
BART C	05/09	BC-9	80	44	111	0	0	0	0
BART C	05/09	BC-9	90	46	111	0	0	0	0
					Mean	0	0.1	0	0.1
BART C	05/09	BC-10	0	37	125	1	0	0	0
BART C	05/09	BC-10	10	38	151	0	0	0	0
BART C	05/09	BC-10	20	39	151	0	0	0	0
BART C	05/09	BC-10	30	40	111	1	0	0	0
BART C	05/09	BC-10	40	41	111	0	0	0	0
BART C	05/09	BC-10	50	43	111	0	0	0	0
BART C	05/09	BC-10	60	44	111	1	0	0	0
BART C	05/09	BC-10	70	45	111	0	0	0	0
BART C	05/09	BC-10	80	46	111	0	0	0	0
BART C	05/09	BC-10	90	47	111	0	0	0	0
					Mean	0.3	0	0	0
BART C	05/09	BC-11	0	24	111	0	0	0	0
BART C	05/09	BC-11	10	24	111	0	0	0	0
BART C	05/09	BC-11	20	24	111	1	0	0	0
BART C	05/09	BC-11	30	24	111	1	0	1	0
BART C	05/09	BC-11	40	24	111	0	0	0	0
BART C	05/09	BC-11	50	24	111	0	1	0	0
BART C	05/09	BC-11	60	25	111	0	0	0	0
BART C	05/09	BC-11	70	26	111	0	0	0	0
BART C	05/09	BC-11	80	27	111	0	0	0	0
BART C	05/09	BC-11	90	28	111	0	0	0	0
					Mean	0.2	0.1	0.1	0

Appendix 4. (Continued)

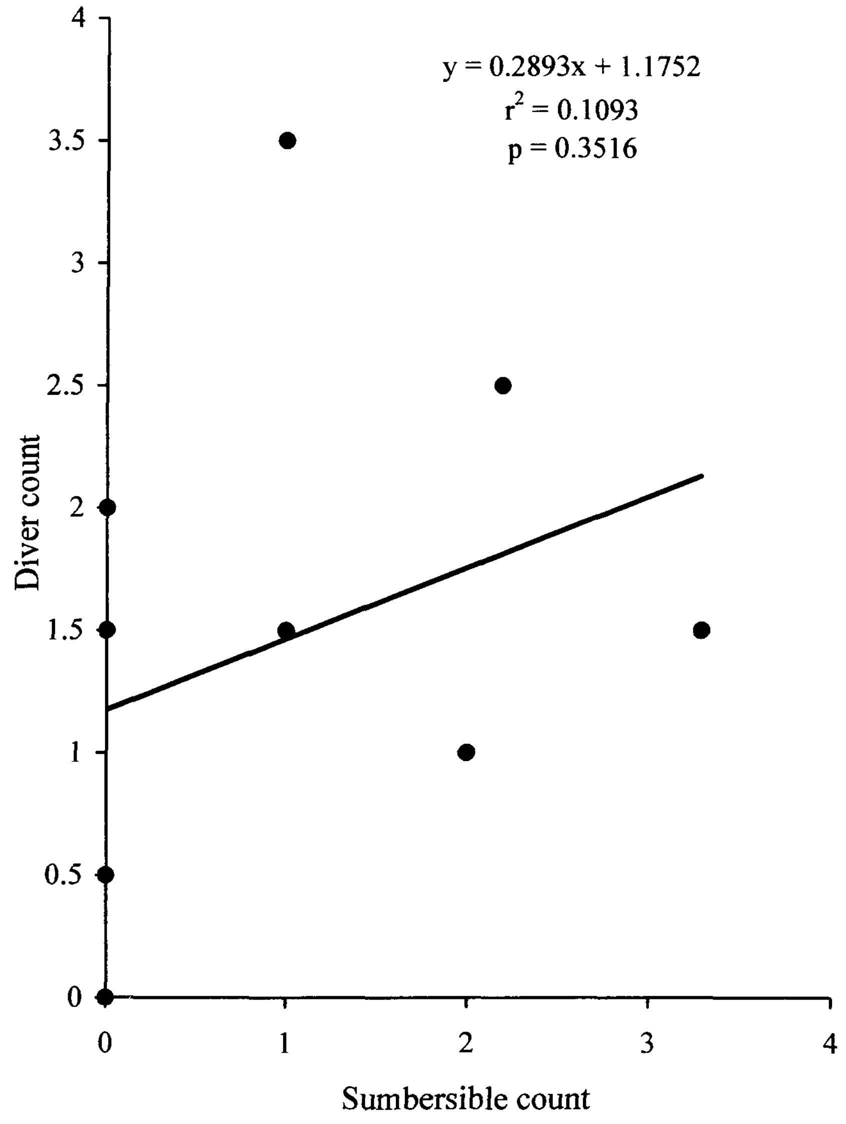
						Crab abundance – Count /20 m^2			
Location	Date	Trans. code	Trans. Dist.	Depth (ft)	Sub-strate	Left Buried	Left Unburied	Right Buried	Right Unburied
BART C	05/09	BC-12	0	28	151	0	0	0	0
BART C	05/09	BC-12	10	29	151	0	0	0	0
BART C	05/09	BC-12	20	29	151	0	0	0	0
BART C	05/09	BC-12	30	29	151	0	0	0	0
BART C	05/09	BC-12	40	29	151	0	0	0	0
BART C	05/09	BC-12	50	30	151	0	0	0	0
BART C	05/09	BC-12	60	30	111	0	0	0	0
BART C	05/09	BC-12	70	32	111	0	0	1	1
BART C	05/09	BC-12	80	32	111	0	1	0	0
BART C	05/09	BC-12	90	33	111	0	0	0	0
					Mean	0	0.1	0.1	0.1
BART C	05/09	BC-13	0	28	111	0	0	0	0
BART C	05/09	BC-13	10	30	111	0	0	0	0
BART C	05/09	BC-13	20	31	111	1	0	1	0
BART C	05/09	BC-13	30	31	111	0	0	0	0
BART C	05/09	BC-13	40	32	111	0	0	0	0
BART C	05/09	BC-13	50	33	111	0	0	0	0
BART C	05/09	BC-13	60	33	111	0	0	0	0
BART C	05/09	BC-13	70	32	111	0	0	0	0
BART C	05/09	BC-13	80	32	111	0	0	0	0
BART C	05/09	BC-13	90	33	111	0	0	0	0
					Mean	0.1	0	0.1	0
BART C	05/09	BC-14	0	27	111	0	0	0	0
BART C	05/09	BC-14	10	29	111	0	0	0	0
BART C	05/09	BC-14	20	32	111	1	0	0	0
BART C	05/09	BC-14	30	33	111	1	0	0	0
BART C	05/09	BC-14	40	34	111	0	0	0	0
BART C	05/09	BC-14	50	34	111	0	0	1	0
BART C	05/09	BC-14	60	35	111	0	0	1	0
BART C	05/09	BC-14	70	34	111	0	0	0	0
BART C	05/09	BC-14	80	35	111	0	0	0	0
BART C	05/09	BC-14	90	34	111	1	1	0	1
					Mean	0.3	0.1	0.2	0.1
BART C	05/09	BC-15	0	26	151	0	0	0	0
BART C	05/09	BC-15	10	28	151	0	0	0	0
BART C	05/09	BC-15	20	32	151	0	0	0	0
BART C	05/09	BC-15	30	34	151	0	0	0	0
BART C	05/09	BC-15	40	35	151	0	0	0	0
BART C	05/09	BC-15	50	37	151	0	0	0	0
BART C	05/09	BC-15	60	37	111	0	0	0	0
BART C	05/09	BC-15	70	38	111	0	1	0	2
BART C	05/09	BC-15	80	38	111	0	0	0	0
BART C	05/09	BC-15	90	38	151	0	0	0	0
					Mean	0	0.1	0	0.2

Appendix 4. (Continued)

						Crab abundance – Count/20 m^2			
Location	Date (m/d)	Trans. code	Trans. Dist.	Depth (ft)	Sub-strate	Left Buried	Left Unburied	Right Buried	Right Unburied
BART C	05/09	BC-16	0	36	151	0	0	0	0
BART C	05/09	BC-16	10	37	151	1	0	0	0
BART C	05/09	BC-16	20	37	151	0	1	0	0
BART C	05/09	BC-16	30	37	151	0	0	0	0
BART C	05/09	BC-16	40	38	151	0	0	0	0
BART C	05/09	BC-16	50	39	111	0	0	0	0
BART C	05/09	BC-16	60	40	111	0	0	0	1
BART C	05/09	BC-16	70	40	111	0	0	0	0
BART C	05/09	BC-16	80	41	111	0	0	0	0
BART C	05/09	BC-16	90	42	111	0	0	0	0
					Mean	0.1	0.1	0	0.1
BART C	05/09	BC-17	0	34	111	0	0	0	0
BART C	05/09	BC-17	10	35	111	0	1	0	0
BART C	05/09	BC-17	20	34	111	0	0	0	0
BART C	05/09	BC-17	30	35	111	0	0	0	0
BART C	05/09	BC-17	40	38	111	0	0	0	0
BART C	05/09	BC-17	50	38	141	0	0	0	0
BART C	05/09	BC-17	60	39	111	0	0	0	0
BART C	05/09	BC-17	70	39	111	0	0	0	0
BART C	05/09	BC-17	80	42	111	0	0	0	0
BART C	05/09	BC-17	90	42	111	0	0	0	0
					Mean	0	0.1	0	0
BART C	05/09	BC-18	0	35	151	0	0	0	0
BART C	05/09	BC-18	10	37	151	0	0	0	0
BART C	05/09	BC-18	20	39	151	0	0	0	0
BART C	05/09	BC-18	30	40	111	0	0	0	0
BART C	05/09	BC-18	40	42	111	0	0	0	0
BART C	05/09	BC-18	50	42	111	0	0	0	0
BART C	05/09	BC-18	60	44	111	0	0	0	0
BART C	05/09	BC-18	70	45	111	0	0	0	0
BART C	05/09	BC-18	80	46	111	0	0	0	0
BART C	05/09	BC-18	90	50	111	0	0	0	0
					Mean	0	0	0	0
BART C	05/09	BC-19	0	31	141	0	0	0	0
BART C	05/09	BC-19	10	34	111	0	0	0	0
BART C	05/09	BC-19	20	36	141	0	0	0	0
BART C	05/09	BC-19	30	38	151	0	0	0	0
BART C	05/09	BC-19	40	38	111	0	0	0	0
BART C	05/09	BC-19	50	43	111	0	0	0	0
BART C	05/09	BC-19	60	47	111	0	0	0	0
BART C	05/09	BC-19	70	47	111	0	0	0	1
BART C	05/09	BC-19	80	49	111	0	0	0	0
BART C	05/09	BC-19	90	49	111	0	0	0	0
					Mean	0	0	0	0.1

Appendix 4. (Continued)

Location	Date (m/d)	Trans. code	Trans. Dist.	Depth (ft)	Sub-strate	Crab abundance – Count/20 m^2 Left Buried	Left Unburied	Right Buried	Right Unburied
BART C	05/09	BC-20	0	35	111	0	0	0	0
BART C	05/09	BC-20	10	39	111	0	0	0	0
BART C	05/09	BC-20	20	42	111	0	0	0	0
BART C	05/09	BC-20	30	44	111	0	0	0	0
BART C	05/09	BC-20	40	46	111	0	0	0	0
BART C	05/09	BC-20	50	47	111	0	0	0	0
BART C	05/09	BC-20	60	48	111	0	0	0	0
BART C	05/09	BC-20	70	50	111	0	0	0	0
BART C	05/09	BC-20	80	50	111	0	0	0	0
BART C	05/09	BC-20	90	51	111	0	0	0	1
					Mean	0	0	0	0.1



Appendix 5. Regression analysis – Submersible counts vs diver counts. Regression analysis was used to test the strength of the relationship between the two methods used in double sampling for estimating crab abundance.

Appendix 6. GLM for an unbalanced one-way ANOVA on the log transformed (n+ 1) data for Dungeness crab density estimates in shallow waters (10 – 50 m) for all bays.

Source	DF	Sum of Squares	Mean Square	F value	Pr > F
Model	2	12.3098	6.1549	5.50	0.0085
Error	34	38.0601	1.1194		
Corrected Total	36	50.3700			
	C.V.	R-square	Root mean	Density mean	
	117.4172	0.5444	1.0580	0.9011	

Appendix 7. GLM for an unbalanced two-way ANOVA on the log transformed (n+ 1) data for Dungeness crab density estimates at all depth and all bays.

Source	DF	Type I SS	Mean Square	F value	Pr > F
Otters	2	3.6992	1.8496	2.12	0.1296
Depth	2	5.3301	2.6651	3.05	0.0551
Otters * Depth	2	14.7967	7.3983	8.47	0.0006
	C.V.	R-square	Root mean	Y mean	
	136.1357	0.3237	0.9344	0.6864	