Exxon Valdez Oil Spill
Restoration Project Annual Report

Survey of Octopuses in the Intertidal

Restoration Report 95009-D
Annual Report

This annual report has been prepared for peer review as part of the Exxon Valdez Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Survey of Octopuses in the Intertidal

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Study History: Restoration Project 95009-D began in 1995, and was renewed in 1996 for a second year of field work. A close-out year in 1997 is anticipated. This is the first annual report, on activities conducted during FY95.

Abstract: Fifty-seven sites were sampled for octopus using either intertidal surveys, subtidal surveys by SCUBA diving, or pot fishing during June and July 1995. Octopus dens were located, occupants were extracted and measured. A total of 31 *Octopus dofleini* were weighed and sexed. No individuals of reproductive age were found, and the sex-ratio was female biased. Densities calculated from 47 sites were on average below those reported from Clayoquot Sound, British Columbia. Based on samples of feeding litter, octopus were feeding on small crabs and bivalves close to their dens in both the intertidal and subtidal. Octopus were associated with intertidal areas adjacent to eelgrass and kelp beds, with cobble substrate, plentiful kelp cover, and shallow slope. Data suggested that the intertidal may function as a predation refuge for juvenile octopus. No visible signs were found of continuing exposure to surface or near-surface oil, and octopus densities were not significantly different between northeast sampling sites (all along unoiled shorelines) and sites in the southwest (along shorelines that received varying amounts of oil). Chiton were found on about 50% of the intertidal sites, but with few exceptions the larger species used for subsistence (bidarki and gumboot chiton) were rare.

Key Words: Giant Pacific Octopus, *Octopus dofleini*, subsistence, *Exxon Valdez*, Prince William Sound, intertidal, habitat

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EXECUTIVE SUMMARY

We surveyed intertidal and nearshore octopus (*Octopus dofleini*) in Prince William Sound during June and July 1995. Subsistence use of octopus in the Sound has resulted in the perception that these animals have declined in abundance, a situation that may concern the large proportion of Sound residents who use octopus for subsistence food. Research has shown in general that octopus species are patchily distributed. We therefore expected survey site location to be an important component of success. We used several different criteria for selection of 25 intertidal sites, 22 subtidal SCUBA sites, and ten sites for pot sampling. We used vernacular knowledge from subsistence harvesters and other area residents to determine survey sites, develop a preliminary habitat model, and search for octopus in intertidal areas. Three methods were used to locate octopus: beach walks, SCUBA surveys, and lair-pots. Once found, octopus were removed from their dens either by hand, by prodding with a stick, or by injecting a small amount of irritant into the den.

Search area for intertidal sites ranged from 200 to 15,000 m^2. Subtidal sites surveyed by SCUBA were generally smaller. Zero to six octopus were found at any intertidal site, although no more than one octopus was found at any subtidal site. Intertidal sites contained 71% of all octopus found, subtidal sites 21% and pots 8%. Small sites (less than 1000 m^2) were discarded from further analyses. For the remaining sites where octopus were found, densities ranged from 0.107-0.92 octopus per 1000 m^2 searched.

Thirty-one octopus were weighed and sexed. Females were more common and larger than males, although the difference in size was not significant. None of the females were large enough to be considered mature and no females were noted that showed signs of egg brooding.

Feeding litter at half of all subtidal dens included <u>Chlamys sp</u>; while only <u>Cancer oregonensis</u> was as common in the litter of intertidal dens. Feeding litter at intertidal dens did not contain the four taxa found at subtidal dens with the exception of <u>Chlamys sp</u>., which was much less common than at subtidal dens. The difference between subtidal and intertidal litter may be related to the distribution of prey species: all taxa found at subtidal dens are more likely to occur subtidally than intertidally. These findings suggest that most octopus are foraging within the vicinity of their dens, regardless of depth.

Greater octopus densities were found on cobble substrates, at sites where Laminarian kelps were common, and at sites adjacent to Laminarian kelp and Zostera (eelgrass) beds. However, only the association with adjacent vegetative communities was significant. Octopus were more common intertidally on sites with shallow slopes (no similar trend was apparent from subtidal sites, but the sample size (<u>N</u>=8 octopus) was small). We found no signs of oiling on the surface or in the top few centimeters of loose sediment at any of the sites we surveyed. Further, octopus densities were not significantly different between the northeast (Windy Bay to Tatitlek area) and southwest (Green Island to Fox Farm) sample sites. These northeast areas had no history of oiling (ADEC cumulative Maximum Impact Map) and

included very high sea otter densities (1993 aerial sea otter surveys, pers. comm. J. Bodkin); whereas the southwest areas generally had a history of oiling (although impact varied from site to site) and had lower sea otter densities (with the exception of the Green Island sites).

Five species of chiton were observed at 15 of the 31 sites. However, gumboot chiton were found on only one site, and bidarki were present at seven sites, but were abundant only at one site on relatively exposed, oceanic shoreline. At two sites, shells of these larger chiton species were found eaten, apparently by a land otter.

INTRODUCTION

Restoration goals for subsistence services include healthy populations of subsistence resources, subsistence harvest of those resources, as well as involvement of subsistence users in the Trustee Council's restoration process. Subsistence use of the Giant Pacific Octopus (*Octopus dofleini*) and the bidarki and gumboot chitons (*Katharina tunicata* and *Cryptochiton stelleri*, respectively) in Prince William Sound has resulted in the knowledge that these species have declined in apparent abundance. Octopus and chiton are included as injured, non-recovering species under the general headings of Subtidal Organisms and Intertidal Organisms (*Exxon Valdez* Oil Spill injured species list). Reduced octopus availability comprises a part of the decline in subsistence services.

The extent, severity, and cause of octopus and chiton declines are unknown. It is not known if changes in the abundance of these animals will adversely affect the recovery of other injured resources (e.g. sea otters, harbor seals, intertidal organisms). Without information of this type, the course of recovery cannot be predicted, nor can these resources be managed effectively.

The condition of these resources may concern a large number of the residents of the Sound. Nearly 90% of the residents of Tatitlek, Chenega Bay, and Cordova used marine invertebrate subsistence resources prior to the oil spill (Seitz, unpublished MS; data on individual species were not presented). Surveys and interviews in Tatitlek and Chenega Bay conducted during the 1980s indicate that between 50 and 90% of households use octopus as a subsistence resource, while 25 - 50% used gumboot or bidarki chiton. Use of octopus was greater in Tatitlek, where over 1600 lbs of octopus (approximately two octopus per person in the village) were reported harvested in the 1988-89 survey. However, use of chiton appeared larger in Chenega Bay (53% of households vs. approximately 25% in Tatitlek used chiton, Stratton & Chisum 1986, Stratton 1990). A similar survey in Cordova indicated that 1-5% of households use octopus or chiton. Most octopus in Cordova were harvested in conjunction with other subsistence or commercial fisheries, i.e. crab or shrimp pots (Stratton 1989). Harvest is not particularly restricted in season. Chenega Bay harvested chiton primarily from February through April and octopus occasionally from February through August while Tatitlek harvested both these resources in all months of the year (Stratton & Chisum 1986, Stratton 1990).

The life cycle of the *O. dofleini* is fairly well described (Mottet 1975, Hartwick 1983), as is the fishery biology of the species in Japan (Mottet 1975). However, the ecology of *O. dofleini* is less well known. Most knowledge of the species in the field comes from long-term work in British Columbia (Hartwick, et al. 1981, 1984, Mather et al., 1985, Robinson & Hartwick 1986), although there have been a few reports from Washington (Martin 1942, Kyte 1977). These studies focused on the animals in shallow water habitat reachable by SCUBA diving. Although the use of intertidal areas by *O. dofleini* is widely reported (Hochberg & Fields 1980, Kozloff 1993), no study has examined the use of intertidal habitats by these animals. However, it is in this restricted habitat zone that the octopus is harvested by traditional subsistence methods.

This project surveyed octopus in intertidal and subtidal habitats, to provide information regarding the current status of the population. Information on chiton occurrence was also recorded, although methods were targeted toward octopus. We relied on the involvement of subsistence users to determine study areas and to conduct sampling during minus tides in the intertidal. Use of vernacular knowledge[1] is not uncommon in studies of octopus ecology (e.g. Hartwick 1983), due to the inherent difficulties in studying these animals (see Mather & O'Dor 1991). Information on the results of the research was provided to Chenega Bay and Tatitlek during community visits.

We estimated the density of octopus using foot surveys of beaches in the intertidal and SCUBA in nearshore subtidal areas. We deployed shrimp pots in shallow and deep waters as an alternative method for finding octopus. All methods successfully located octopus, although the majority of specimens were found in the intertidal, where the largest area was searched. Octopus were identified to species, weighed, sexed and measured. All individuals found were juveniles of a single species, *O. dofleini*. The sex ratio was female biased. We examined octopus diet as represented by prey remains in the feeding litter, and characterized the habitats where octopus were found. Chiton were found on about half the beaches, but with one exception, bidarki and gumboot chitons were rare.

The densities recorded in this study were substantially lower than densities reported from surveys in British Columbia conducted in the early 1980s (Hartwick et al. 1978, 1984). Octopus were more common intertidally in flat areas with cobble substrate and dense Laminarian kelp cover, adjacent to kelp beds and Zostera beds (eelgrass). Although we looked for indications of continued exposure to oil, of breeding adults, and for an inverse correlation with sea otter density (a reported predator), none of these were found.

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[1] A note on terminology: We use the term 'vernacular' knowledge in this report in preference to alternatives such as 'local', 'traditional' or 'native' knowledge. Webster's dictionary defines the vernacular as both particular to a locality and spoken in the common language. The vernacular excludes scientific terminology and methods. We prefer this term over alternatives because much scientific knowledge is also local (but not vernacular) and because vernacular avoids denotation of cultural or racial affiliation.

OBJECTIVES

As described in the 1995 Detailed Project description, the objective are:

1 Identify survey sites using criteria of 1) historical subsistence harvest, 2) presence of bathymetric or other features suggesting good octopus habitat, 3) availability of substrate and habitat data from past surveys, 4) known otter distribution;

2 At each survey site, determine for nearshore areas judged to be good microhabitat, 1) the local density of octopus, 2) the size and sex distribution of octopus; 3) the number of brooding female octopus, 4) the species composition of feeding litter, and 5) record the presence of chiton above the water line at minus tides (NB: in the Project Description, this objective was listed as "determine the density of chiton". However, we found that the larger chiton (bidarki or leather chiton, *Katharina tunicata*, and gumboot, *Cryptochiton stelleri*) occurred on only a few beaches. We therefore reported the numbers of chiton observed, but did not calculate densities.);

3 Identify features of substrate, flora, and fauna typical of areas where octopus are captured. Using existing data, estimate the extent and location of good nearshore octopus habitat in Prince William Sound.

METHODS

1. Site Selection

Three methods were used to identify appropriate survey sites (Figures 1-3). First, we contacted area residents with vernacular knowledge about octopus. Visits were made to Tatitlek and Chenega Bay (27-31 March 1995). There, subsistence harvesters were asked about their knowledge of octopus, including where they had caught octopus during minus tides in the past, and what typical octopus habitat looked like. Jerry Totemoff (Tatitlek) and Mike Eleshansky (Chenega Bay) were hired to join the beach surveys. We contacted local fisherman and divers (Roger Trani, Dan Logan) and asked where they had encountered octopus. We also contracted with M. Kyte (Pentec Environmental), a collector of *Octopus dofleini* for the aquaria trade, to train divers in octopus handling techniques and assist with selection and surveys of subtidal sites.

Second, we developed a conceptual model of octopus habitat based on the scientific literature on *O. dofleini*, as well as the reports of area residents. From this model, we identified several features which could be readily assessed and used these in selecting study sites.

Third, preference was given to those sites for which there was background data on habitat types or sea otter density; and to areas close to the native villages of Tatitlek and Chenega Bay.

2 Survey of octopus and chiton

2.1 Density of octopus at a site

Three methods were used to locate octopus: beach walks, SCUBA surveys, and lair-pots. Once found, octopus were removed from their dens either by hand, by prodding with a stick, or by injecting a small amount of irritant (bleach) into the den. Octopus were identified to species, using Kozloff (1987). Following inspection and measurements of body size, octopus were usually released. Three octopus were kept for subsistence use by research assistants hired from Tatitlek or Chenega Bay.

Beach walks

Beach walks were used to survey intertidal sites. Surveys were conducted during the low tides between 13-18 June and 9-15 July 1995. At each site, two or more observers walked along the beach, covering the area between the upper Fucus zone (about + 120 cm MLLW) to the low water line (about -75 cm MLLW). Areas were searched by looking in suspected octopus dens (e.g. crannies along the ocean side of big boulders) and inspecting areas for octopus sign (e.g. feeding litter).

Intertidal search areas were categorized by zone, following Ricketts et al. (1968). Zone 1 ran from highest reach of spray and storm waves to about mean of high tides (about + 210-400 cm MLLW), and lichens, barnacles, and periwinkles were usually present (this zone was not searched for octopus). Zone 2 was from mean high tide to about mean of the higher of the two daily lows (about + 75- 210 cm MLLW). This zone contained the upper Fucus region, limpets, and chiton. Zone 3 was from the higher daily low tide to mean lower low water (+0-75 cm MLLW) and contains the lower Fucus region, crabs, sea stars, Thais sp. and mussels. Finally, Zone 4 was below mean lower low water (minus tides only); and was characterized by the upper Laminarian zone, red algae, and eelgrass.

The length and width of the area searched were measured using a Leitz optical rangefinder, accurate to within ten percent for distances up to 1000m. The area searched was calculated as length times width for relatively rectangular sites, or as one half length times width for points or other triangle-shaped sites.

Dens were recorded as either occupied (octopus seen or captured) or unoccupied (no octopus seen or captured). It was impossible to ascertain with certainty whether a suspected den that was unoccupied indicated the recent presence of additional octopus or merely the movement of an octopus that appeared in another den in our survey. For this reason, only occupied dens were used to calculate density. It is possible that some octopus were not seen in the den and refused to emerge, thereby resulting in a false 'unoccupied' record.

SCUBA surveys

Nearshore shallow subtidal areas were surveyed using SCUBA dives from 6-24 July 1995. We chartered the F/V *Tempest* as a support platform for dive and pot sampling. Pairs of divers searched using methods similar to those described for intertidal studies to locate dens. Divers recorded the depth upon descent. Visibility was measured using a secchi disk. A surface marker buoy was deployed at the location of descent. Divers then proceeded in a search pattern dictated by water depth, bottom topography, vegetation and other consideration. Changes in the direction of search path, or in the types of habitat being searched were noted and divers marked the location of each by deploying a tethered buoy to the surface. Tenders at the surface marked the location of such changes with a second surface buoy, and measured the length and bearing back to the previous surface buoy using a Zeiss optical rangefinder. The first buoy was then retrieved and used to mark the next leg of the survey. In this manner, the linear distance traveled through each habitat type in the subtidal was accurately measured. Area surveyed was calculated as the visibility (width) times the length recorded on the surface (length) for each leg indicated by the divers.

The location of each suspected den was recorded. Dens were assessed for occupancy visually and by introducing an irritant to encourage the octopus to leave, and recorded as either occupied (an octopus was seen or captured) or unoccupied (no octopus was seen). Only occupied dens were used in calculating octopus densities.

Lair pots

Long-line shrimp pots were deployed from the F/V *Tempest* at eleven sites to sample octopus. Pots were double-funnel commercial shrimp pots that had been seasoned by previous use. Fifty-one pots were deployed in strings of three, spaced 16 meters apart on a line. Three such lines were deployed at one site, providing a total of nine pots per sample. One pot per string was left unbaited; two were baited with stinkbait or salmon heads. Pots were retrieved following a 2-4 day soak and the occupants identified and counted.

2.2 Size & Sex distribution of octopus

Octopus size was recorded as four measures: weight, inter-pupil distance (the distance between the eyes), mantle length (distance from the mid-point between the eyes to the ventral tip of the mantle), and total length (distance from the ventral tip of the mantle to the tip of the extended first left or right arm). All measures were taken on live, unsedated animals and so reflect the variance expected from muscle contraction and relaxation. Octopus were sexed by looking for the presence of a modified tip on the third right arm, the hectocotylus. If this organ was present, the animal was recorded as male, otherwise as female. Octopus were also inspected for scars, missing arms or other signs of attack by predators. Octopus under 15 kg were considered juveniles (Hartwick 1983).

2.3 Number of brooding females

Dens were visually inspected (before application of an irritant) for the presence of eggs. However, in almost all cases, it was not possible to see very far into the den. Unusual color or condition of the octopus was also noted as octopus become grayish and unhealthy-looking towards the end of their reproductive period (brooding for females, mating for males. Ambrose 1988, Hartwick 1983).

2.4 Species composition of feeding litter

Feeding litter was examined if present and identified to the finest possible taxonomic group using Morris (1966), Kozloff (1987, 1993), and Foster (1991). Material in front of a den was considered feeding litter if it appeared fresh and either showed octopus drill marks (bivalves, crabs) or was broken in a manner typical of octopus feeding (e.g. crab carapaces broken other than at the suture mark). If necessary, samples were collected for more careful examination.

2.5 Observations of chiton

While searching for octopus, we noted any chiton encountered. When chiton were rare, or for bidarki or gumboot (used as a subsistence resource), we counted individuals. When smaller chiton were abundant, numbers were estimated or recorded categorically. Chiton were not collected or otherwise measured, although a few photographs were taken to confirm identification and vernacular names.

3. <u>Identify characteristics of octopus habitat</u>

For each site surveyed, we recorded measures of habitat type and prey availability. Substrate type was recorded as: bedrock (solid relatively unbroken rock), rock outcrop (large rock projections arising from beneath the general substrate, often containing frequent fissures and crevices), cobble (rounded rocks ranging in diameter from a meter to several centimeters), broken rubble (jagged rock fragments from a meter to several centimeters in size), gravel (small rocks from several centimeters to a few millimeters in size), or sand (finer sediments). The presence of boulders was noted. Four categories of slope were recognized: flat, with a rise-to-run ratio less than 1:8; low, from 1:8-1:6, medium, from 1:5-1:3, and steep, >1:3.

Vegetation and sessile invertebrate patches (e.g. mussels, barnacles) were recorded by categories of percent cover and by species or taxonomic division. The qualitative abundance of invertebrate and vertebrate fauna were noted as Rare (one per 1000 m^2), Occasional (two to ten per 1000 m^2), Common (11-100 per 1000 m^2) or Abundant (more than 100 per 1000 m^2).

In addition to these site-specific variables, for each octopus found we also recorded details of the den, including size of covering rock or boulder, dimensions and number of openings, and elevation or depth relative to MLLW.

RESULTS

1. Site selection

We developed a list of characteristics associated with octopus habitat as a preliminary guide to site selection and as a descriptor of octopus habitat to be tested (Table 1). Paust (1988) stresses the importance of experience in successfully finding octopus. Octopus are generally reported to be patchily distributed (*O. joubini*: Mather 1982, *O. vulgaris*: Mather & O'Dor 1991; *O. dofleini*: Hartwick 1983), and may be scarce locally, according to some reports. For these reasons, we expected survey site location to be an important component of success. We used several different criteria for selection of 25 intertidal sites, 22 subtidal SCUBA sites, and ten sites for pot sampling (Table 2).

Site selection for intertidal work began with the initial habitat model, but was finally determined through discussions with villagers in Tatitlek and Chenega Bay (Table 2). Dive sites were primarily determined by similarity to Washington habitat, with some influence from vernacular knowledge. Finally, three sites on the last day of the survey were chosen using a revised habitat model based on initial perceptions of our results. Note that at least one octopus was found at all three of these sites.

2. Survey of octopus and chiton

2.1 Octopus densities

The area searched in intertidal sites ranged from 200 to 15,000 m^2. Subtidal sites surveyed by SCUBA were smaller, ranging from 330 to 9330 m^2. Zero to six octopus were found at any intertidal site, although no more than one octopus was found at any subtidal site. Intertidal sites contained 27 (71%) of the 38 octopus found, subtidal sites contained eight (21%), and the remaining three (8%) were captured in pots (Table 2).

For sites where octopus were found, calculated densities ranged from 0.107-2.0 octopus per 1000 m^2 searched. However, small sites (less than 1000 m^2) with octopus had unusually high densities (1.46-2.0 octopus/1000 m^2). Because they represent such small sampling area, these densities were discarded from further analyses.

Results on the size and sex of octopus include three individuals that were captured in pots (Table 3): one during this survey, and two reported after the survey by N. Oppen, captain and owner of the F/V *Tempest*, which was chartered as a support vessel for the SCUBA portion of this study. Ninety-nine pot sets (11 sites, 3 strings of three at each site, soaking for 2-4 days) resulted in the capture of only one octopus.

2.2-3 Size & sex distributions

Thirty-one octopus were weighed and sexed. Two individuals were recorded as unknown sex because the tip of the third right arm was missing. Females were more common and larger than males, although the difference in size was not significant (Fig. 4. Female: $\bar{x}$=3.0$\pm$2.2 kg, N=23; males: $\bar{x}$=1.7$\pm$1.1 kgs, N=6). None of the females were large enough to be considered mature and no females were noted that showed signs of brooding, although it was not usually possible to see into the dens to check for eggs. Of 31 octopus examined, six had missing, truncated or bifurcated arms, a sign of possible encounter with a predator. Due to small sample sizes, these data were not analyzed for correlations with the octopus size, sex or depth.

2.4 Species composition of feeding litter

Litter accumulates at the mouths of dens from redistribution by waves, excavation by the octopus and from prey that octopus bring back to their dens to feed on. Only the latter represent a sample of the diet of octopus. We classified litter as food for octopus based on whether litter appeared fresh, drilled or broken. Thirteen taxonomic groups were identified as prey using these criteria (Fig. 5).

Diet as represented by den litter appeared different between subtidal and intertidal octopus. Feeding litter from subtidal octopus dens comprised Chlamys sp., Cancer magister, Acantholithodes sp., and Cryptolithodes sp. Litter at half of all subtidal dens included Chlamys sp (Fig. 5); while only Cancer oregonensis was this common in the litter of intertidal dens. Feeding litter at intertidal dens did not contain the four taxa found at subtidal dens with the exception of Chlamys sp., which occurred at only 7% of intertidal dens (Fig. 5). The difference between subtidal and intertidal litter may be related to the distribution of prey species: all taxa found at subtidal dens are more likely to occur subtidally than intertidally (Fig. 5. Kozloff 1993, Flora and Fairbanks 1977. We were unable to find a depth distribution for Acantholithodes sp.). The most common litter at intertidal dens (Cancer oregonensis) as well as the fifth most common (Cancer productus) are more likely to occur intertidally (Kozloff 1993). All other taxa identified as intertidal litter can be found from the lower intertidal to subtidal zones. Although Chlamys sp. are more often found in the subtidal (Kozloff 1993), they do extend into the low intertidal (Foster 1991) and thus are available to some intertidal octopus. These findings suggest that most octopus are foraging within the vicinity of their dens, regardless of depth.

2.5 Observations of chiton

Five species of chiton were observed at 15 of the 31 sites (Table 4). At most of these locations, only the smaller chiton species were found. The species used for subsistence were less common. Gumboot chiton were found on only one site, and Bidarki were present at seven sites, but were abundant only at one site on relatively exposed, oceanic shoreline. At two sites, shells of the larger chiton species were found eaten, apparently by a land otter.

3. Characteristics of habitats

Higher octopus densities were found on cobble substrates, at sites where Laminarian kelp was common, and at sites adjacent to Laminarian kelp and Zostera (eelgrass) beds (Fig. 6). However, only the association with adjacent vegetative communities was significant (chi-squared goodness of fit test: $df=3$; $\chi=11.5$; $p<0.05$). A trend toward a negative association with boulder fields was not significant. Octopus were found at slightly higher densities in the intertidal than in the subtidal, although the difference was not significant (intertidal: $\bar{x}=0.425 \pm 0.24$ individuals/thousand square meters, $N=8$; subtidal: $\bar{x}=0.333 \pm 0.19$, $N=6$, for sites where at least one octopus was found). Octopus densities also did not differ between northeast sites and southwest sites. Octopus were more common intertidally on sites with shallow slopes (Fig. 7). No similar trend was apparent from subtidal sites, but the sample size ($N=8$ octopus) was small.

We found no signs of oiling on the surface or in the top few centimeters of loose sediment at any of the sites we surveyed. Further, octopus densities were not significantly different between the northeast (Windy Bay to Tatitlek area) and southwest (Green Island to Fox Farm) sample sites. These northeast areas had no history of oiling (ADEC cumulative Maximum Impact Map) and included very high sea otter densities (1993 aerial sea otter surveys, pers. comm. J. Bodkin); whereas the southwest areas generally had a history of oiling (although impact varied from site to site) and had lower sea otter densities (with the exception of the Green Island sites).

DISCUSSION

Octopus were successfully surveyed in the nearshore, including both subtidal and intertidal areas. More octopus were found in the intertidal although densities were not significantly different between the two habitats. The larger area searched in the intertidal may account for the difference in numbers of octopus found. However, divers had difficulties searching dense kelp beds in the subtidal. Because of the association of octopus with dense kelp in the intertidal, it is possible that octopus present in subtidal habitats were missed because subtidal search effort was directed toward sparser areas. The survey design for the 1996 field season has been designed to address the relative densities of octopus in dense cover versus low cover areas, specifically.

Densities were variable, with many sites having no octopus present at all. No significant differences in densities were found between northeast and southwest study areas, nor between intertidal and subtidal habitats. However, over 70% of all octopus found were located in the intertidal, which suggests that intertidal densities were actually higher than subtidal. Additional sampling may allow this difference to be detected statistically.

Octopus in the intertidal were found associated with cobble substrates on shallow slopes that had abundant Laminarian cover and were adjacent to Laminarian kelps and Zostera beds. These same animals apparently fed primarily on intertidal crabs (based on feeding litter); one individual sacrificed for subsistence had a sculpin (Family Cottidae) in its stomach. The litter data and the occurrence of octopus adjacent to Zostera beds suggests that octopus feed in areas near to their dens. Because octopus occurred largely in areas with dense Laminarian cover but were not significantly associated with boulders, octopus may require cover while outside their dens in addition to denning habitat. Dense cover may act as a refuge from predation. Furthermore, intertidal areas may be out of reach of many octopus predators (e.g. large fish, seals) and possibly less utilized by sea otters. This may explain why more octopus were found in the intertidal as well.

Beachcombers and authors of general guides seem more aware than most researchers that octopus can regularly be found above the tide line at low water (e.g. Hochberg et al. 1980). When use of intertidal habitats in mentioned (e.g. *Octopus vulgaris*: Mather & O'Dor 1991, McQuaid 1994; *O. dofleini*: Hartwick et al. 1978, Paust 1988, Mather et al. 1985), it is usually in passing. It is generally assumed that octopus are found in very shallow water because food there is more prevalent (e.g. Mather 1995), although other possibilities (e.g. predator avoidance) have not been considered. The affiliation of octopus in this study with vegetative cover suggests that octopus may utilize intertidal kelp beds as predation refuges. However, we did not control for confounding factors such as prey density. The importance of intertidal habitats to octopus populations warrants further research, and will be investigated further during the second year of this study.

CONCLUSIONS

Intertidal sampling and subtidal SCUBA surveys both provided useful data on octopus. Intertidal surveys provided greater sample sizes because larger areas could be searched and due to possibly higher octopus densities in the low intertidal. Little effort was expended on pot sampling. However, results from the intertidal and subtidal sampling could allow targeted sampling using lair posts to be more successful.

Vernacular knowledge from area residents was invaluable in initial site selection and development of habitat models. Subsistence harvesters employed for the field sampling proved to be very interesting and energetic assistants, whose knowledge increased the success of our work.

Only immature individuals of the species *Octopus dofleini* were found, most of these female. We were able to search more area in the intertidal than in the subtidal, and consequently have a better idea of the areas occupied by octopus in the intertidal than in the subtidal. A slight difference in the over-all density of octopus found between intertidal and shore sites was not significant.

ACKNOWLEDGEMENTS

This project would not have been possible without the knowledge, assistance and goodwill of people in Tatitlek, Chenega Bay, and Cordova. In particular, Mike Eleshansky, Doug Bruck and Jerry Totemoff provided knowledge and assistance in the field; and Martha Vlasoff, Jody Seitz, and the fishermen of Cordova shared their knowledge and encouragement. We thank Scott Wilbur, Kathleen Pollet, Roger Trani and Cordova Water Sports, Michael Kyte, and Dan Logan for assistance with field work; and a special thanks to Neil 'Mad Dog' Oppen and the crew of the F/V Tempest for their support and interest in this project. The Alaska Department of Fish & Game provided a diver propulsion vehicle. We thank reviewers of the *Exxon Valdez* Oil Spill Restoration Office for comments on the design and analysis of this research, and the *Exxon Valdez* Oil Spill Trustee Council for financial support.

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Table 1: Characteristics associated with octopus habitat.

Character	H1[1]	Washington habitat[2]	H2[3]
Slope	Shallow	Moderate (3:1 to 10:1)	Shallow
Substrate	No bedrock or silt	Rock, coarse gravel	Cobble or broken outcrops
Relief	Boulders	Boulders, ledges, outcrops	Cobble to 2 meters
Vegetation	Zostera		Zostera, Laminarian nearby
Otters	Low		Intertidal or kelp refugia (?)
Exposure		Open or mouths of bays	
Current		Weak to moderate currents	
Water		High saline; low sediments	

[1] H1, the initial habitat model. Octopus were expected on shallow slopes with boulders (Hartwick et. al. 1978), without regard to substrate except that solid bedrock and silt would be avoided. Otters were considered a possible limiting predator on octopus (Kenyon 1969), so that densities of the two would be inversely correlated. Finally, after discussions with villagers in Tatitlek and Chenega Bay, Zostera beds were added as a component of good nearshore habitat.

[2] Washington habitat, considered as a possible model for habitat in Alaska (see Appendix 2). As reported by M. Kyte (pers. comm.), octopus in Washington were found on moderate to shallow slopes with rock or coarse gravel substrates. Boulders, ledges and outcrops for dens are critical to their presence. Further, octopus avoid fresh-water influence, and hence, are found at the mouths rather than the backs of bays. They like areas with weak to moderate currents, high salinity and low sediment.

[3] H2, the habitat model, revised in the field. The best octopus habitat occurred on areas of uniformally shallow cobble slope (which may or may not be interspersed with broken rock outcrops), in areas adjacent to Zostera beds and thick Laminarian kelp beds.

Table 2: Survey sites.

Site#[1]	Site name	Selection[2]	Date	Area[3]	Octopus	Density[4]
1	Tatitlek Outcrop	S	13-Jun-95	800	0	0.00
2	Tatitlek Reef	S	13-Jun-95	600	1	1.67
3	Ellamar Reef	S	13-Jun-95	7500	3	0.40
5	Point Tatitlek	S	14-Jun-95	1875	0	0.00
6	Point Boulder Bay	S	14-Jun-95	6000	3	0.50
7	Old Chenega 1	S	15-Jun-95	3000	0	0.00
8	Old Chenega 2	S	15-Jun-95	15000	0	0.00
9	Chenega Cove	S	15-Jun-95	7500	0	0.00
10	Chenega Bay	S	15-Jun-95	1200	0	0.00
11	Chicken Is. Reef	S	16-Jun-95	6000	3	0.50
12	Latouche Is. @ Chicken Is.	S	16-Jun-95	6250	2	0.32
13	Evan Is. shore	H1	17-Jun-95	2000	0	0.00
14	Elrington Is. shore	H1	17-Jun-95	800	0	0.00
15	Fox Farm Reef	H1	17-Jun-95	500	1	2.00
16	Inside Fox Farm1	H1	17-Jun-95	1600	0	0.00
17	Inside Fox Farm2	H1	17-Jun-95	1500	0	0.00
18	Evans Is., S Tip	H1	18-Jun-95	4000	0	0.00
19	Reef Is., SE Tip	S	9-Jul-95	7500	0	0.00
20	Reef Is. E side	S	9-Jul-95	12000	0	0.00
21	Small Is. N of Reef Is.	S	9-Jul-95	200	0	0.00
3	Ellamar Reef	S	10-Jul-95	10500	1	0.10
4	Graveyard Point	S	10-Jul-95	450	0	0.00
5	Boulder Bay	S	11-Jul-95	8000	0	0.00
22	Shelter Bay	F	12-Jul-95	3420	0	0.00
23	Shelter Bay	F	12-Jul-95	3800	1	0.26
24	Shelter Bay	F	12-Jul-95	2700	0	0.00
10	Chenega Bay	S	13-Jul-95	8300	0	0.00
11	Chicken Is. Reef	S	14-Jul-95	3400	0	0.00
12	Latouche Is. @ Chicken Is.	S	14-Jul-95	6500	6	0.92
25	Gibbon Anchor, Green Is.	H2	15-Jul-95	15000	6	0.40
D1	Hanks Is. NW	H1	6-Jul-95	329	0	0.00
D2	Windy Bay NW	F	7-Jul-95	541	1	1.85
D3	Windy Bay NE	F	7-Jul-95	838	0	0.00
D4	Gravina Rocks	F	7-Jul-95	1533	0	0.00
D5	Olson Bay, Is. @ SE corner	F	8-Jul-95	4113	1	0.24

Site#[1]	Site name	Selection[2]	Date	Area[3]	Octopus	Density[4]
D6	Goose Is, S	W	8-Jul-95	687	1	1.46
D7	Landlock Bay, outer island	W	8-Jul-95	1334	0	0.00
D8	Bligh Reef, N. of Day Mark	W	9-Jul-95	5675	1	0.18
D9	Boulder Bay, is. W. side	SW	9-Jul-95	2362	1	0.42
D10	Ellamar Reef	S	9-Jul-95	5296	0	0.00
D11	Boulder Bay, is. W. side	W	10-Jul-95	2963	0	0.00
D12	Rocky Pt., Galena Bay entr.	F	10-Jul-95	6767	0	0.00
D13	Louis Bay, SE of Disk Is.	F	11-Jul-95	1829	0	0.00
D14	Evans Is., Bishop Rock	F	12-Jul-95	457	0	0.00
D15	NE Shelter Bay, Evans I.	F	12-Jul-95	792	0	0.00
D16	Bettles Is., S side	S	12-Jul-95	2451	0	0.00
D17	Bettles Is., NE corner	S	13-Jul-95	1286	0	0.00
D18	Float Plane I, Sawmill Bay	W	13-Jul-95	3127	0	0.00
D19	W. shore, Elrington I.	W	13-Jul-95	2377	1	0.42
D20	Elrington Is., NE corner	W	14-Jul-95	4069	0	0.00
D22	Green Is. W of pinnacle	H2	15-Jul-95	9327	1	0.11
D23	Green Is. Bull Kelp Bed	H2	15-Jul-95	1585	1	0.63
P1	Gravina Rocks	FH1	5-Jul-95		0	
P2	Olson Bay	FH1	5-Jul-95		0	
P3	St. Mathews	FH1	5-Jul-95		0	
P4	Reef Island	FH1	5-Jul-95		0	
P5	Boulder Bay	SH1	5-Jul-95		0	
P6	Ellamar Reef	S	5-Jul-95		1	
P7	Chicken Island	S	11-Jul-95		0	
P8	Bettles Island	S	11-Jul-95		0	
P9	Evans Point	FH1	11-Jul-95		0	
P10	Shelter Bay	FH1	11-Jul-95		0	

[1] Site numbers beginning with a letter are subtidal (D: surveyed by SCUBA diving; P: sampled by pots); all others are intertidal. Sites #4 and D21 were not sampled for octopus.
[2] Criteria used to select each site: S, vernacular knowledge from residents of Tatitlek and Chenega Bay; F, vernacular knowledge from local fisherman and divers; W, similarity to Washington habitat as identified by M. Kyte; H1, first habitat model based on literature descriptions; H2, revised habitat model.
[3] Square meters. Sites that sampled less than 1000 m^2 were not included in analyses of density.
[4] Octopus per thousand square meters

Table 3: Details of sampling with lair pots from the F/V *Tempest.*

Site name	Date	Pots[1]	MinDepth[2]	MaxDepth[2]	Drop[3]	Octopus[4]
Gravina Rocks	5-Jul-95	9	10	40	30	0
Olson Bay	5-Jul-95	9	14	24	11	0
St. Mathews	5-Jul-95	9	14	27	14	0
Reef Island	5-Jul-95	9	6	24	18	0
Boulder Bay	5-Jul-95	9	6	30	24	0
Ellamar reef	5-Jul-94	9	6	12	6	1
Chicken Is.	11-Jul-95	6	34	35	2	0
Bettles Is.	11-Jul-95	9	24	49	24	0
Evans Pt.	11-Jul-95	6	24	38	14	0
Shelter Bay	11-Jul-95	9	122	152	30	0
Reported from the Tempest:						
Mouth of Galena Bay	9-Aug-95	8	122	152	30	1
Mouth of Galena Bay	11-Aug-95	8	122	152	30	1

[1] The number of pots set at the site; [2] the minimum and maximum depth (in meters) at which pots were dropped; [3] the vertical drop between the shallowest and deepest pot; [4] the number of octopus caught.

Table 4: Chiton observed during intertidal surveys.

Site name	Date	Gumboot[1]	Hairy[2]	Leather[3]	Lined[4]	Woody[5]
Ellamar Reef	13-Jun-95	0	0	1	0	0
Point Tatitlek	14-Jun-95	0	1	0	0	0
Point Boulder Bay	14-Jun-95	0	1	0	0	0
Old Chenega 2	15-Jun-95	0	1	0	1	0
Chicken Island Reef	16-Jun-95	0	0	0	1	0
Latouche Island at Chicken Island	16-Jun-95	0	1	0	1	0
Evans Island, Southern Tip	18-Jun-95	0	0	1	0	0
Reef Island, Southeastern Tip	9-Jul-95	0	1	2	0	0
Shelter Bay	12-Jul-95	0	0	100	0	0
Shelter Bay	12-Jul-95	0	4	3	common	0
Shelter Bay	12-Jul-95	0	occ	0	occ	0
Chenega Bay	13-Jul-95	4[a]	5[a]	0	1	2
Chicken Island Reef	14-Jul-95	0	2[b]	1[b]	2	0
Latouche Island at Chicken Island	14-Jul-95	0	1	4	0	0
Gibbon Anchorage, Green Island	15-Jul-95	0	1	0	occ	0

[a] All chiton except one Gumboot were apparently eaten by a land otter.
[b] All chiton were apparently eaten by a land otter.
[1] Cryptochiton stelleri; [2] Mopalia ciliata; [3] Katharina tunicata or bidarki; [4] Tonicella lineata; [5] Mopalia lignosa

FIGURE LEGENDS

Figure 1: The northeast and southwest study areas near the Native villages of Tatitlek and Chenega Bay in Prince William Sound, Alaska.

Figure 2: Location and results of surveys in the northeast study area. Circles indicate intertidal surveys; squares indicate subtidal surveys. A white symbol denotes that no octopus were found; a black symbol that one or more octopus were found as indicated in the key. Surveyed sites varied in size.

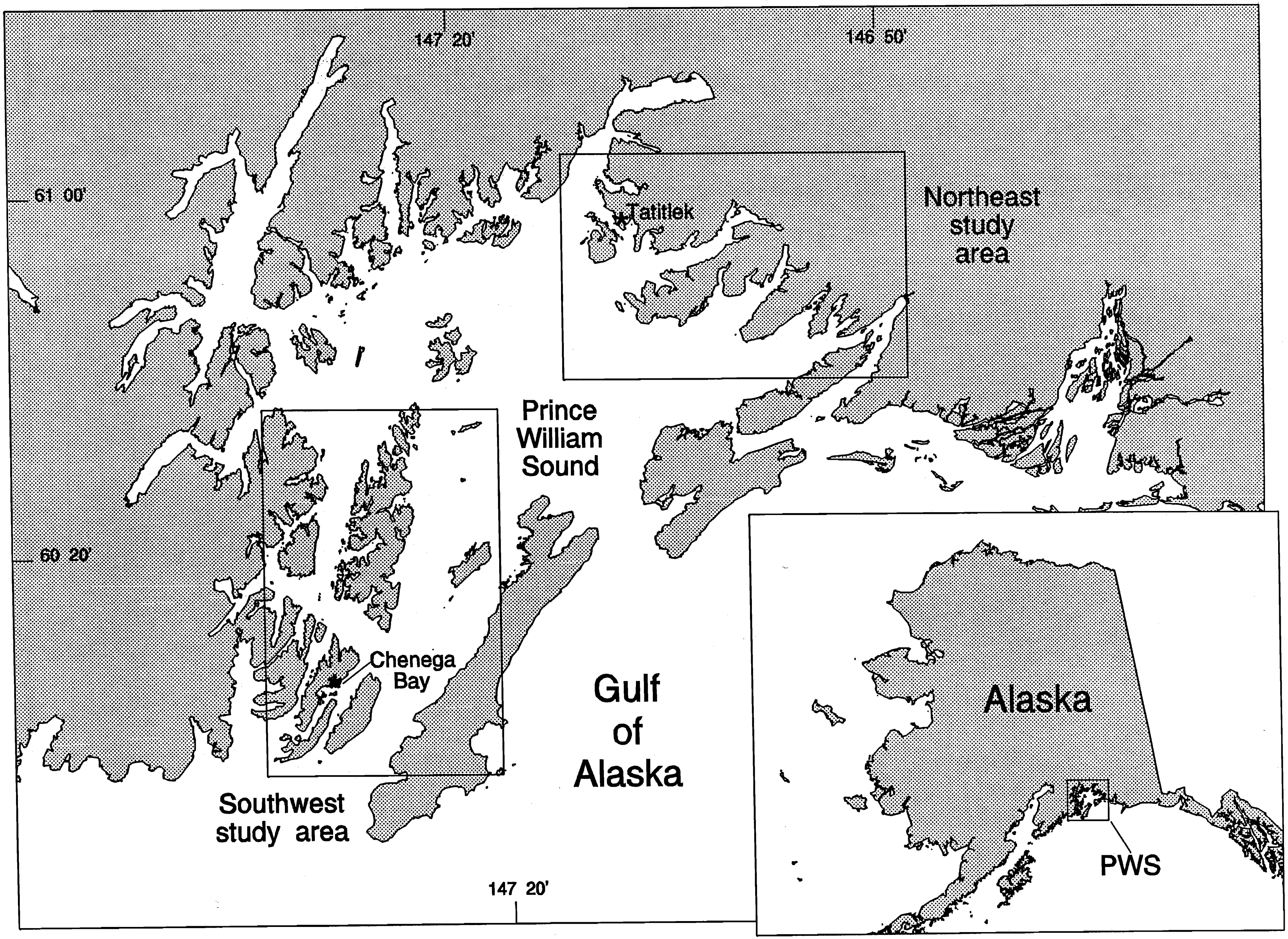
Figure 3: Location and results of surveys in the southwest study area. Details as in Figure 2.

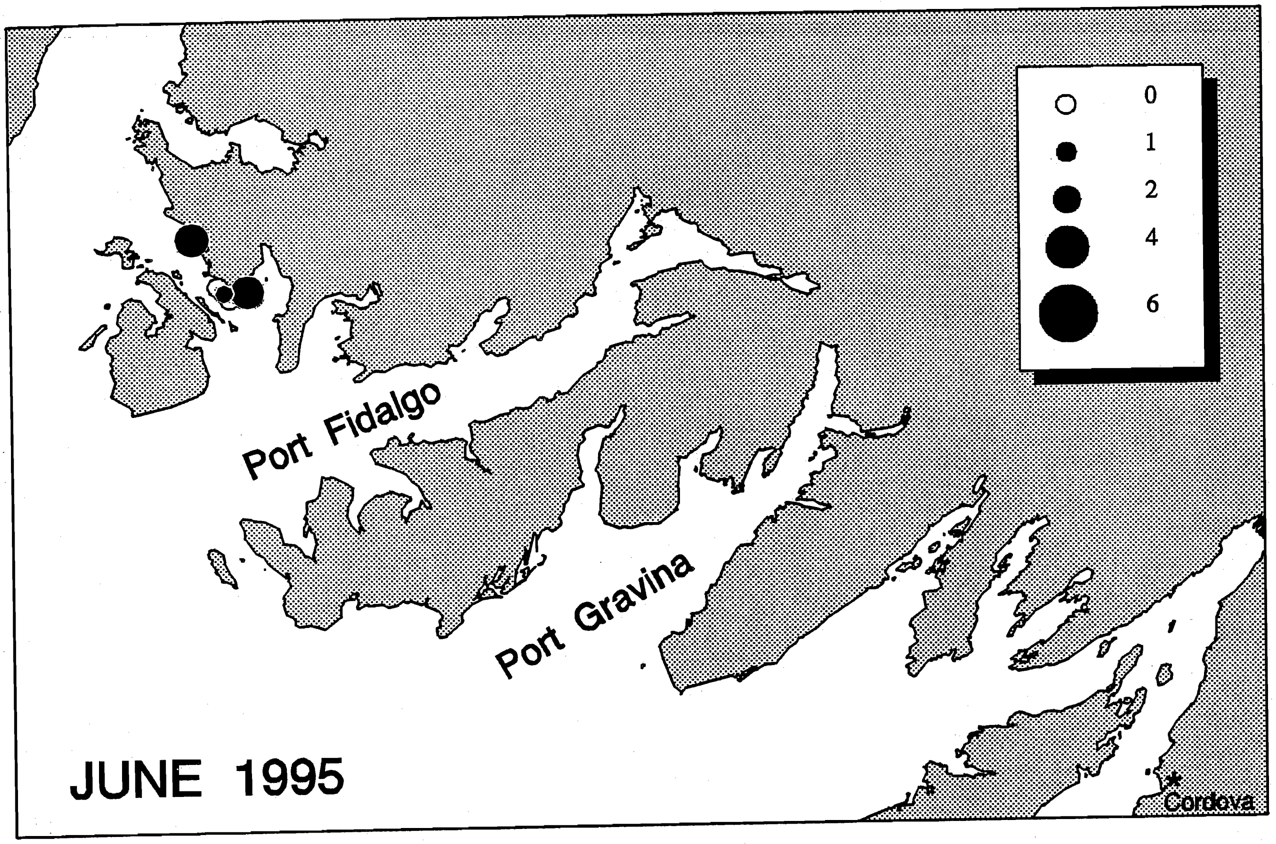
Figure 4: Age-sex distribution of octopus.

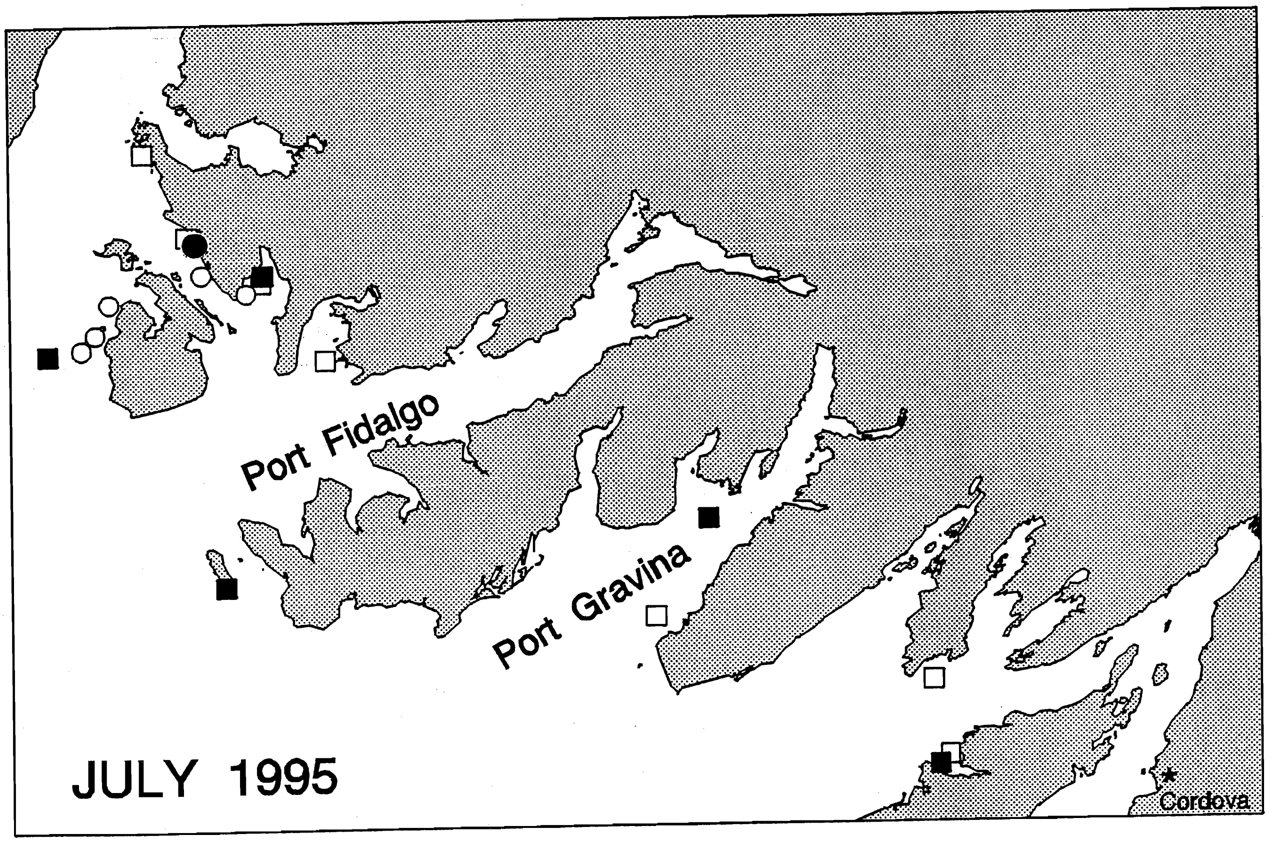
Figure 5: Litter remains found at intertidal and subtidal octopus dens. Thirteen species were identified as being food for octopus (see text for details). This graph shows the percentage of intertidal dens (n = 27) and subtidal dens (n = 8) in which litter was found for each species of likely prey. Tide zone distribution is shown for each identified litter species. Tide zones III-IV are mid to lower intertidal and tide zone V is subtidal. Litter at subtidal dens came from species that are more likely to be found subtidally than intertidally. All litter at intertidal dens came from species that can be found intertidally.

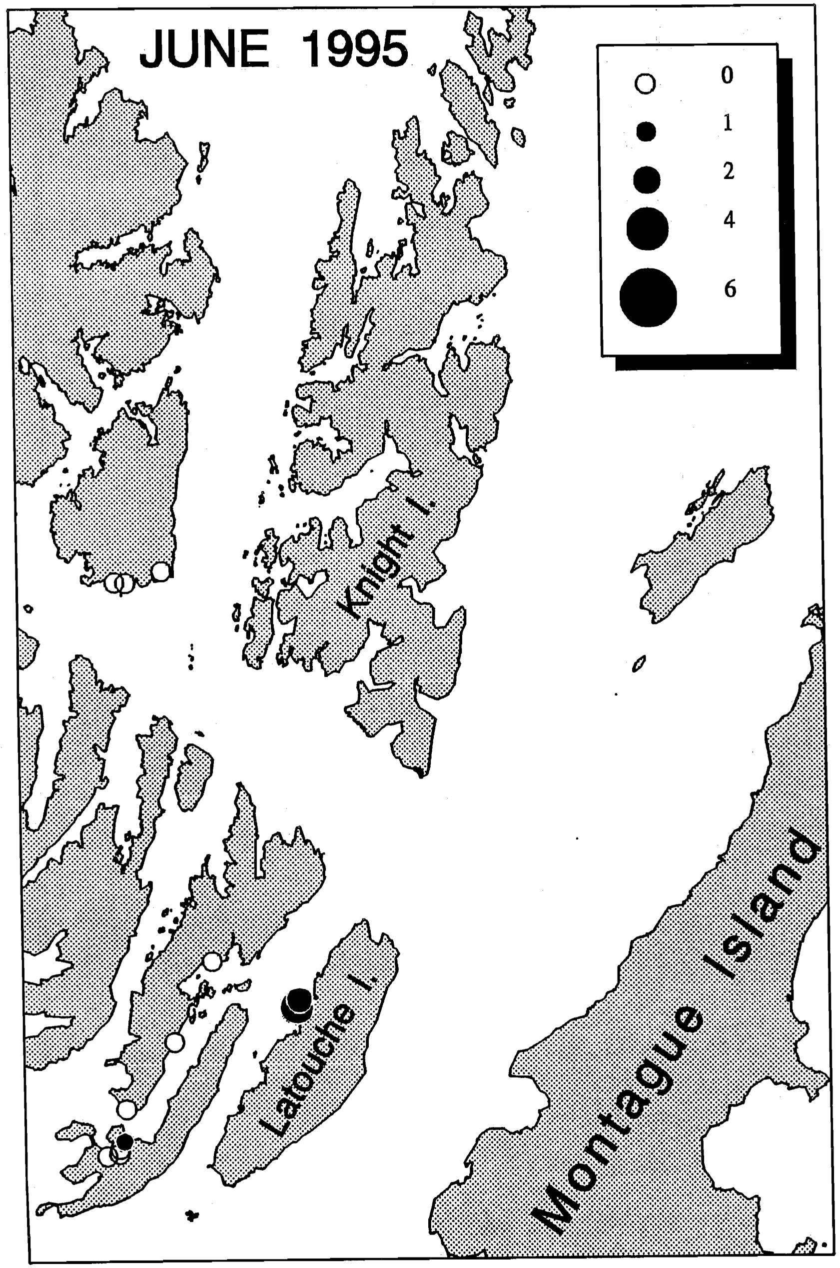
Figure 6: Characteristics of sites with octopus. Sites with octopus in medium or low densities (filled and shaded columns, respectively) were more often characterized by cobble or cobble/outcrop substrate, by Laminarian kelp as a common ground cover, and by adjacent communities of both Laminarian kelps and Zostera, than were sites where no octopus were found (open columns). Only the association with adjacent communities was statistically significant (see text).

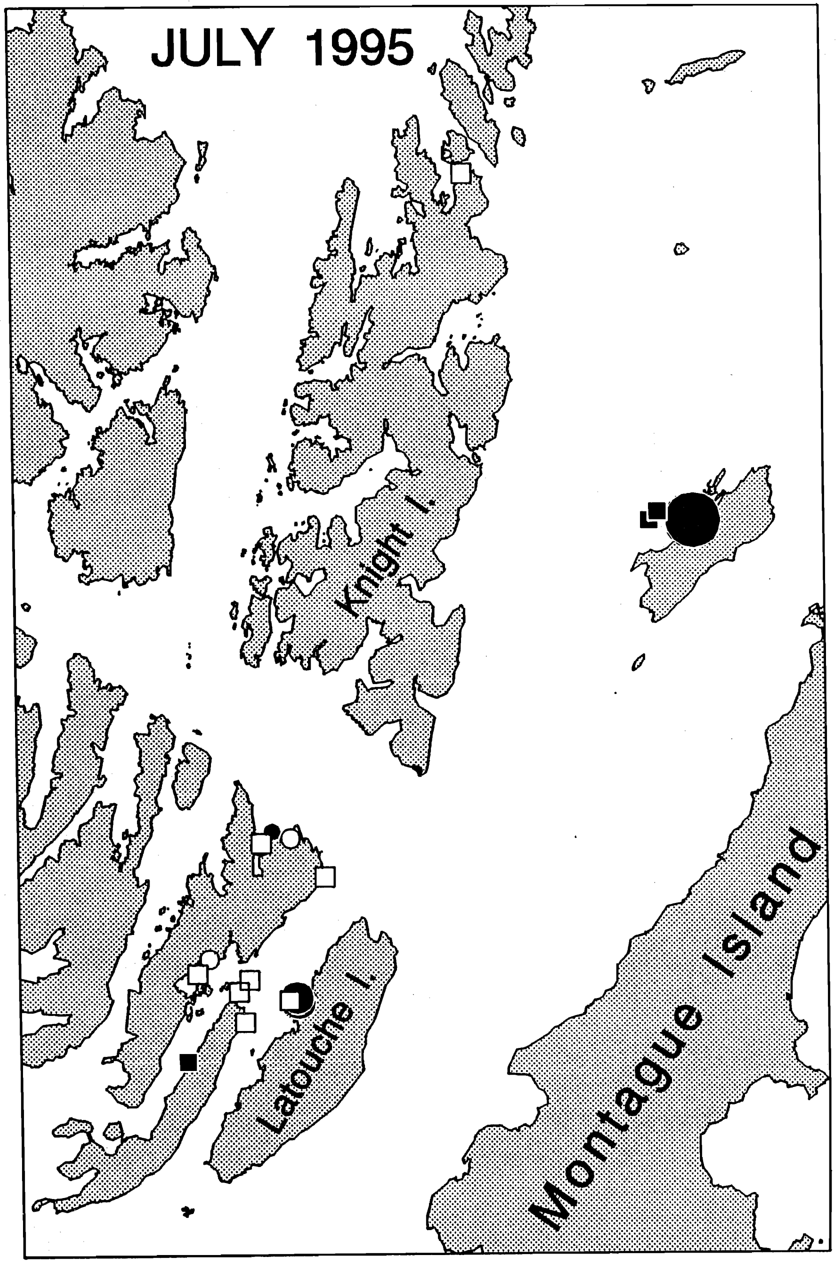
Figure 7: Most intertidal octopus were found on sites with flat slopes. The number of sites sampled is indicated above each column.

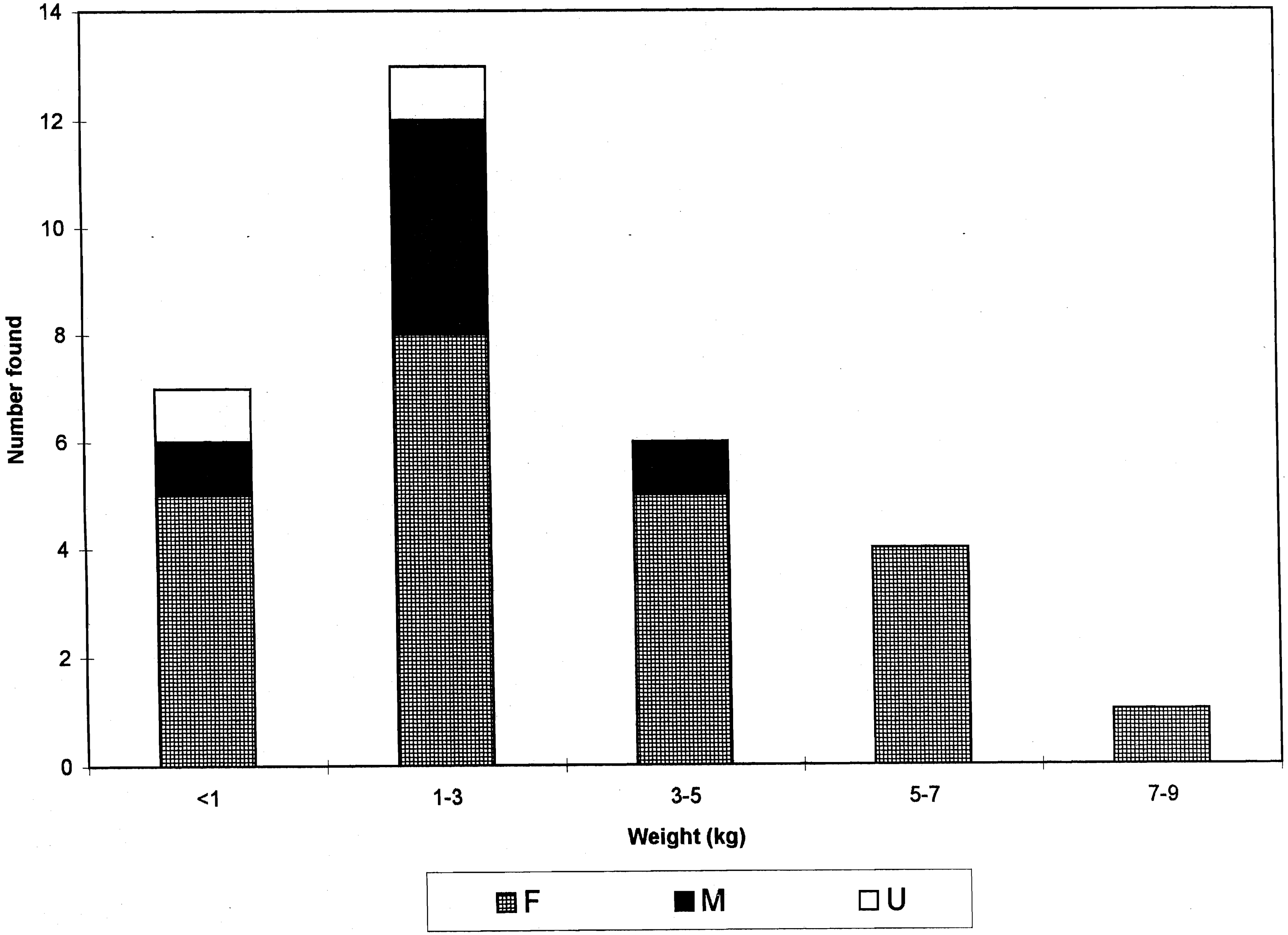

147 20'
146 50'
61 00'
60 20'
Tatitlek
Northeast study area
Prince William Sound
Chenega Bay
Gulf of Alaska
Southwest study area
147 20'
Alaska
PWS

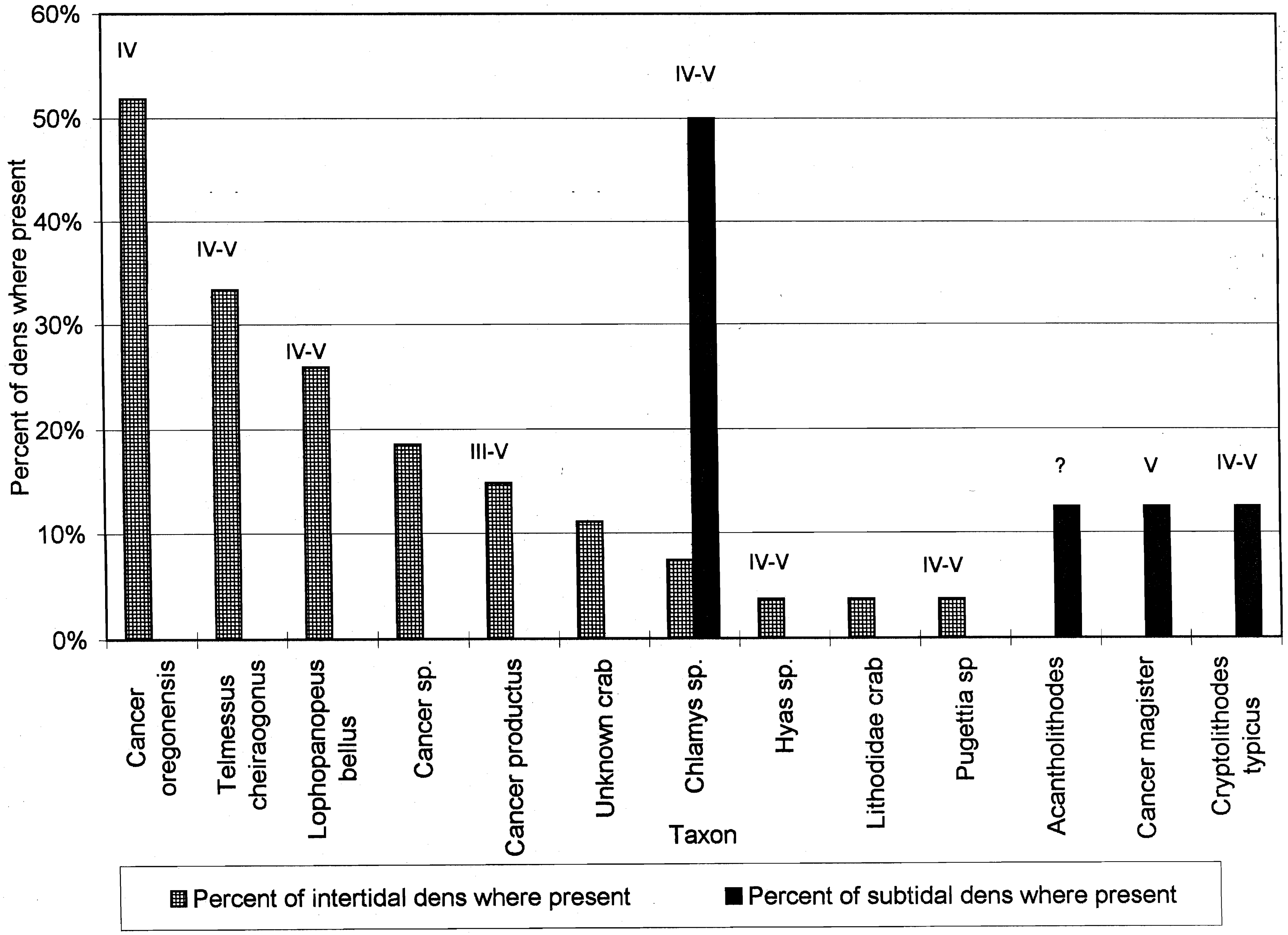

0
1
2
4
6
Port Fidalgo
Port Gravina
Cordova
JUNE 1995

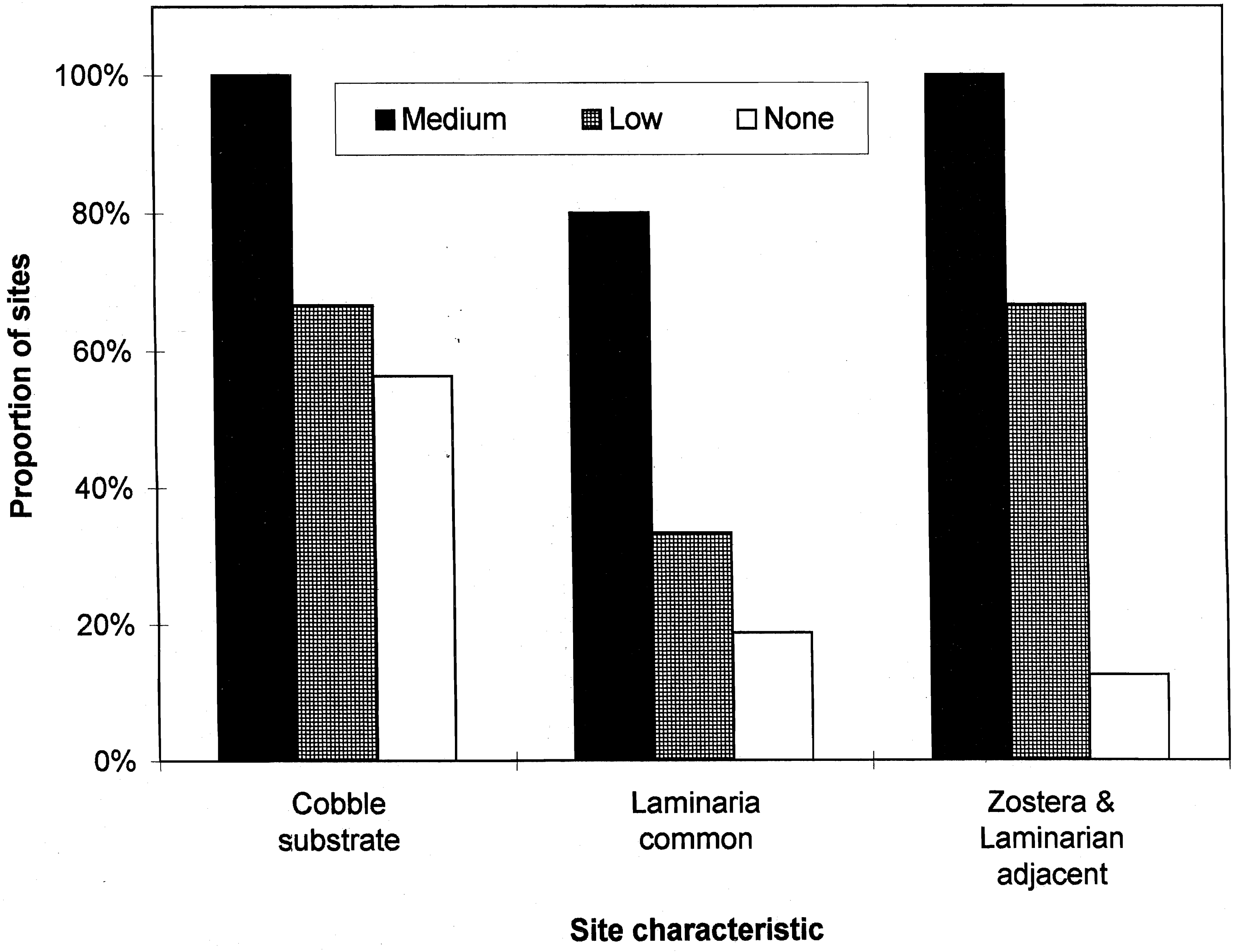

Port Fidalgo
Port Gravina
Cordova
JULY 1995


JUNE 1995
0
1
2
4
6
Knight I.
Latouche I.
Montague Island

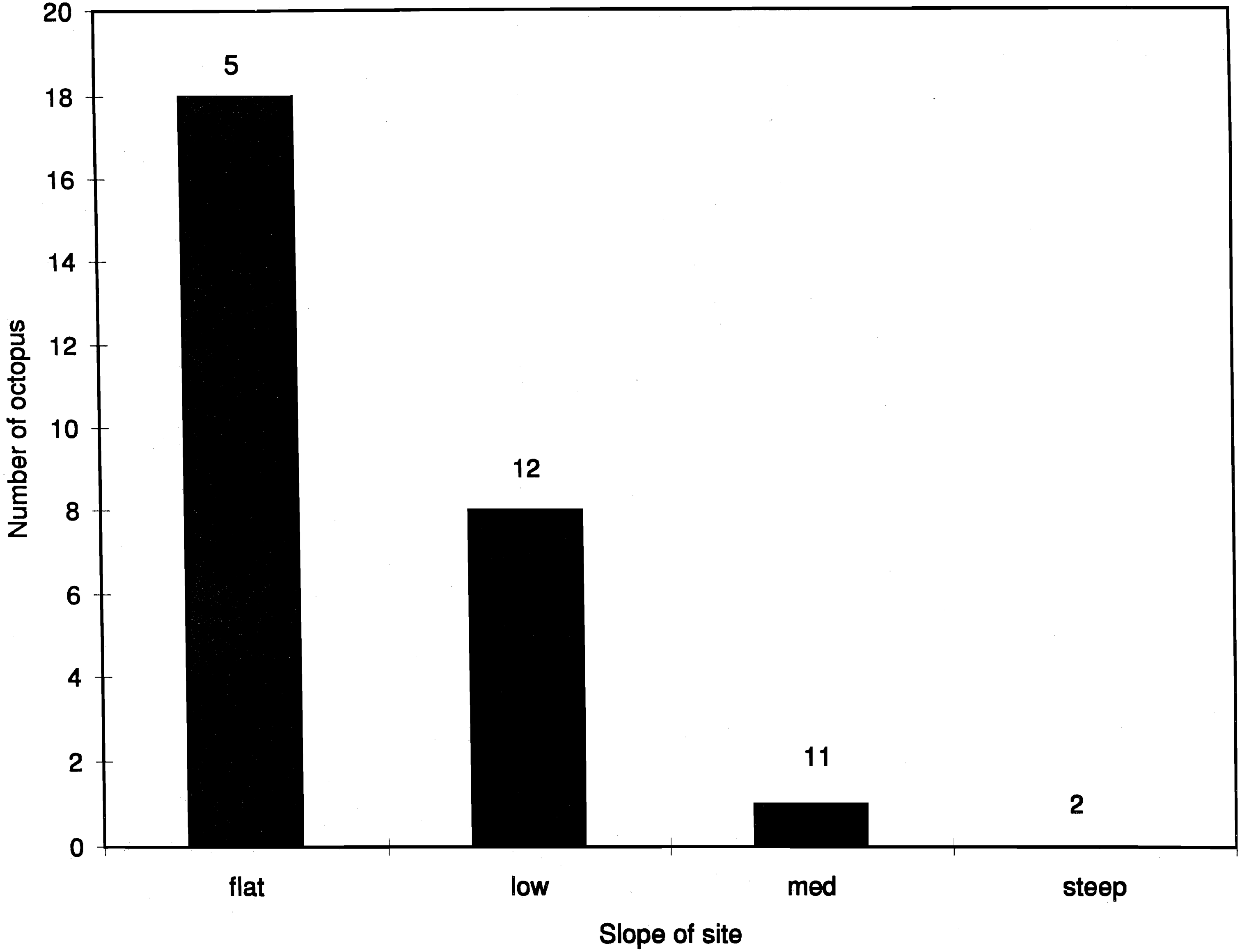

JULY 1995
Knight I.
Latouche I.
Montague Island


14
12
10
8
6
4
2
0
Number found
<1
1-3
3-5
5-7
7-9
Weight (kg)
F
M
U


60%
50%
40%
30%
20%
10%
0%
Percent of dens where present
IV
IV-V
IV-V
III-V
IV-V
IV-V
IV-V
?
V
IV-V
Cancer oregonensis
Telmessus cheiraogonus
Lophopanopeus bellus
Cancer sp.
Cancer productus
Unknown crab
Chlamys sp.
Hyas sp.
Lithodidae crab
Pugettia sp
Acantholithodes
Cancer magister
Cryptolithodes typicus
Taxon
Percent of intertidal dens where present
Percent of subtidal dens where present



Medium
Low
None
100%
80%
60%
40%
20%
0%
Proportion of sites
Cobble substrate
Laminaria common
Zostera & Laminarian adjacent
Site characteristic



20
18
16
14
12
10
8
6
4
2
0
Number of octopus
5
12
11
2
flat
low
med
steep
Slope of site

PRINCE WILLIAM SOUND
OCTOPUS HABITAT

INTRODUCTION

Octopus (presumed to be *Octopus dofleini apollyon*) are a target of subsistence fisheries in Prince William Sound (Sound). In the last few years, specifically since the *Exxon Valdez* oil spill, the abundance of octopus for these fisheries has apparently declined. To determine whether this decline is real and whether additional stocks may be available in subtidal habitats, the Prince William Sound Science Center (Center) obtained funding for a survey of selected areas to determine the following:

- The presence of octopus
- Best survey strategies for octopus
- Optimum octopus habitat
- Octopus population parameters
- Estimated octopus stock abundance

To achieve these goals, the Center contracted with Pentec Environmental, Inc. (Pentec), to have their recognized expert in the biology of Northeast Pacific octopus, Michael A. Kyte, perform the following objectives:

- Train Center personnel in species recognition and octopus biology.
- Train Center personnel in recognition of octopus habitat and survey techniques.
- Describe octopus habitat in the Sound.
- Describe (within limitations of time and budget) octopus biology in the Sound.
- Design a valid and tested survey plan for use in the Sound for future octopus studies.
- Assess the relationship of octopus distribution and abundance to the *Exxon Valdez* spill and other factors.
- Assess the potential of octopus fisheries.
- Compile a bibliography of relevant literature.

This document presents the results of a brief survey during the period of July 5 through July 15, 1995, of Prince William Sound. A description of habitat and discussion of ecological controlling factors is presented which incorporates information from existing literature and personal observations in the Puget Sound region. All references to "octopus" in this document are to the species *Octopus dofleini* (Wülker) *(O. d. apollyon* and *O. d. martini)* as defined by Pickford (1964).

OCTOPUS BIOLOGY

This section presents a brief summary of the biology of octopus as known from personal observations and existing literature. Only those aspects of octopus biology that are considered relevant to this study are discussed here. Additional details can be found in Hartwick (1983) or Wells (1978).

Octopus in Northeast Pacific nearshore regions are opportunistic predators that as adults prefer benthic decapodan crustaceans for food. However, octopus are known to eat a large variety of marine species including bivalve and gastropod molluscs, finfish, and, on rare occasions, marine birds. To find their prey, octopus are highly mobile, crawling, walking, or swimming, using their siphons and eight arms. Individuals can cover up to several kilometers per day in search of prey.

Octopus are soft-bodied invertebrates without predator defenses such as spines, armor, or teeth. Accordingly, they are actively preyed upon as juveniles, subadults, and adults by marine mammals and finfish (e.g., sea lions, sea otters, and lingcod). Thus, they construct and use dens as refuges. These dens can be holes under rocks, in rubble, crevices or overhangs in solid rock, under and in logs or other objects resting on the sea floor, or constructed pots placed in the water by fishermen. Den selection is not indiscriminate; however, individual octopus prefer different substrata configurations or compositions (Cosgrove 1987 and personal observation). Octopus use dens not only as refuge between foraging trips but also for egg laying and brooding.

Another behavioral trait of octopus that needs to be considered when describing their habitat is that they are solitary and asocial. As a result, they do not congregate except where den availability prompts proximity. The only other occasion where more than one octopus will be in a single location is during mating. At this time a male and a female will be in close proximity for some length of time. The male, in fact, will actively challenge intruders, including divers, in defense of his mate.

METHODS

Methods used to search for and survey octopus in the subtidal are described in detail in the Survey Plan (Pentec 1995a) appended to this report. Methods used in the intertidal are described by Scheel (1996). Following is a summary of the subtidal methods.

An adaptation of the line and strip transect methods described by Gunderson (1993) and LaRiviere (1981) was used for surveying subtidal octopus. Scuba divers searched strips of seafloor looking for signs of octopus presence. The width of the transect strip was determined by water clarity as measured by a secchi disk and by bottom topography and other features. Search progress and transect length, was marked and measured from the surface using marker flag buoys and an optical range finder. Surface and underwater recordings were correlated using time and signal buoys released by the divers. Locations of dens and other features were determined in the same manner.

The condition of any dens, occupied or unoccupied, was recorded. Among the parameters that were noted were depth, bottom slope, substratum, direction of the den opening, and feeding litter.

An attempt was made to capture any octopus that were encountered. Captured octopus were returned to the surface for measuring, determination of sex, weighing, and release.

RESULTS

A total of 23 dives were made during the period of July 6 through 15, 1995. Eleven of these dives were made in the northeast part of the Sound; the remainder were made in the southwest section. A total of about 14 hours were spent underwater searching with an average search time per dive of 37 minutes. The dives ranged in depth from the intertidal down to about 100 ft mean lower low water (MLLW), with an average maximum depth of about -61 ft MLLW. A total of 68,350 m^2 were searched; the average area searched per dive was 3,107 m^2.

A wide variety of bottom types were examined ranging from mixed rubble and boulders, gravel, sand, and silt to solid rock in the form of isolated ledges and outcrops and small islands or stacks. The most common situation was a solid rock shoreline fringed by loose boulders or rubble laying on finer sediments. The boulders or rubble usually stopped at about -40 to -60 ft MLLW, exposing the mixed sediments.

The boulders, rubble, and solid rock supported a biota typical of the Northeast Pacific littoral and sublittoral as described by Kozloff (1983), Carefoot (1977), Dethier (1990), Barr and Barr (1983), and McConnaughey and McConnaughey (1986). The intertidal biota within the study area has been described by Pentec (1995b). The subtidal within the study area of this survey has not been studied as thoroughly as have the intertidal or the subtidal in other parts of Alaska. Lees et al. (1980) describe several sites within the Sound; some of these were in the vicinity of the present octopus survey locations. Species that were found to be prey items for octopus will be described in following paragraphs.

The group of species encountered on this survey that were important as indicators of habitat either by their presence or their absence were the ribbon kelps or laminarians. These large brown algae were found to cover the sea bottom down to about -60 to -70 ft MLLW wherever rock particles large enough to provide attachment for their holdfasts were present. The degree of cover ranged from over 100 percent with multiple layers in the lowest intertidal to less than 50 percent at the lower edge of the kelp zone. This assemblage included the genera *Agarum, Alaria, Costaria, Cymathere, Hedophyllum,* and *Laminaria.* A large number of species with smaller forms were also present.

The subtidal diving portion of this survey found only eight octopus, all occupying dens. The five captured octopus ranged in wet weight from 0.9 to 8.7 kg, with an average weight of 3.3 kg. Based on their size, all these octopus could be considered juvenile (Young and Harman 1988) and about 1 to 2 years of age. Other details of these octopus are presented in Table 1. The octopus that could not be captured were also within this size range.

Table 1 Prince William Sound subtidal octopus data.

Wet weight (kg)	Sex	DML (mm)	Eye (mm)	Tag no.	Age
1.0	M	100.0	56.0	none	Juvenile
8.7	F	160.0	110.0	none	Subadult
1.0	M	95.0	52.0	none	Juvenile
5.0	F	163.0	98.0	8	Subadult
0.9	F	105.0	55.0	none	Juvenile
Average weight		Average DML	Average eye		
3.3		124.6	74.2		

All the octopus encountered subtidally were residing in dens. In addition, a number of apparent dens were found that may have been occupied by octopus sometime in the past. The most common (50 percent of the occupied dens) den situation was an excavation under a boulder. Other den situations included crevices in rock walls, usually at the base (25 percent), and naturally formed cavities in solid rock (25 percent). Details of the unoccupied dens are not presented here because it was uncertain whether an observed hole had been used as an octopus den and, if it had, whether it was an acceptable den, how recently it had been occupied, and whether the previous occupant had been a different octopus than one found nearby (if one had been found).

Feeding litter associated with the occupied dens consisted of remains of the following species:

- *Chlamys* sp.
- *Acantholithodes hispidus*
- *Cancer* sp.
- *Cryptolithodes typicus*
- *Oregonia gracilis*

Only *Chlamys* sp. (the pecten) was present consistently in any abundance. Shells of this bivalve were present in relatively small amounts at nearly all dens and many suspected unoccupied holes. The other species occurred only once, or in the case of *Cancer* sp., three times. Amounts of feeding litter were relatively very small compared with conditions observed and recorded in the Puget Sound and British Columbia regions (Kyte 1979 and personal observations, Cosgrove 1987, Hartwick et al. 1981a).

Ecological competitors for prey and space (dens) and predators were also observed. The apparent most important competitor and predator seen in the survey area was the sea otter (*Enhydra lutris*). In addition, sea lions (*Eumetopias jubatus*), wolfeels (*Anarrhichthys ocellatus*), and lingcod (*Ophiodon elongatus*) were seen. All these species are known to either prey on octopus (sea lions and lingcod) or compete for dens and prey (wolfeel and sea otters, respectively).

DISCUSSION

PRINCE WILLIAM SOUND OCTOPUS HABITAT

The results of this study indicated that there may be three distinct habitat types in the Sound, each with its characteristic octopus population dynamics, den characteristics, and prey resources. These habitat types are as follows:

Type I	Intertidal
Type II	Shallow Subtidal (-40 to -60 ft MLLW)
Type III	Deep Subtidal (below -100 ft MLLW)

In all habitats two environmental factors probably control octopus abundance more than anything else: den site characteristics and the availability of a prey base. Other factors such as the presence of predators or other octopus, the exact geological nature of the sea floor, oceanographic or chemical factors, current and wave regimes, are all less important than the availability of food and dens and probably not limiting except in extreme situations.

In the following discussion, optimum conditions for Types I and II habitats will be described. Type III habitat will be treated separately.

The Sound study data from which these habitats can be described is sparse and suitable only to form preliminary hypotheses and theories. However, when combined with other information gathered over the last 20 years, the Sound study results are strongly indicative. The following descriptions and discussions, however, remain preliminary and open for testing and modification by future research.

Types I and II Habitat

Den Sites–Physical Factors

Physical features necessary to harbor octopus are acceptable water quality of probably at least 25 o/oo salinity and below 12 to 14° C and substrata suitable for excavating dens or with available cavities. Tidal current regime can vary from high to low, but the optimum situation seems to be a low to moderate current that inhibits the deposition of fine sediments. Areas subject to high current velocities may be avoided because of the difficulty moving around in strong flows. However, octopus have been found in areas with currents up to 5 knots. Also, it is unlikely that dens will be found in areas of high wave energy as wave action will push the octopus around and fill dens with sediments.

The habitat aspect that an octopus is most particular about is its actual den site (Cosgrove 1987; personal observations). Dens are excavated or are simply used as the octopus finds them. The best and most common den site is an excavated hole under a boulder or rubble. For purposes of this description, boulders are defined as single rocks, rounded in outline, and larger than about 30 cm in greatest dimension (length). Rubble are rocks angular in outline and also longer than about 30 cm. The boulders or rubble are usually resting on mixed sediment containing gravel, shell debris, sand, and silt.

Bottom slope can range from low to fairly steep (approximately 10:1 to 2:1). This situation will allow octopus of all sizes to excavate dens under the rocks with the dens facing down slope. There appears to be a direct correlation between size of boulder and size of octopus; the larger octopus burrow under larger boulders. Insufficient data were gathered to quantify this correlation. This observation is based on data gathered in Prince William Sound only as no other previous study or investigator (including Cosgrove 1987, Hartwick et al. 1988) has recorded rock size with octopus size.

Other configurations in which dens, occupied or suspected, were found in the Sound were the following:

- An existing cavity in solid rock (along a joint or where a larger particle in a conglomerate was missing.
- Small overhangs at the base of rock walls.
- Vertical crevices in rock walls.
- Holes in an exposed layer in stratified sedimentary rock such as the tilted turbidites common in the Sound (see Lethcoe 1990 for a description of this geology).
- Under artifacts laying on the sea floor (e.g., an old boat hull at Ellamar).

It was observed that octopus in Puget Sound will also excavate or form dens in the ends of sunken logs, under logs, under concrete blocks or pipelines, under artificial reef materials such as bundled tires and concrete rubble, and even in metal containers of appropriate size and situation.

Because anthropogenic materials or conditions (e.g., artificial reefs) are either not present or rare in the Sound, these situations should not be considered when describing habitat except as examples of the resourcefulness and versatility of octopus.

Den Sites–Biological Factors

A den apparently has at least two important requirements: First, the entrance should be about the same diameter or smaller than the octopus. This relationship affords the octopus a balance between accessibility, visibility out of the den, and protection from predators. Second, its volume should be greater than the octopus to allow the animal to retreat some distance (perhaps as much as a body length [total length] or more) when threatened by an outside presence such as a predator. Cosgrove (1987) found that den and octopus body volume were significantly correlated. My observations generally agree with this conclusion, but I often observed that an octopus, especially a juvenile or subadult, can retreat into the rear of its den far enough to be out of sight or reach. Thus, the volume of a den is usually not equal to the octopus' volume but is proportionate.

In addition, it was seen in the Sound and in Puget Sound and was reported by Altman (1967) for *Octopus vulgaris* in the Mediterranean, that octopus apparently need to be able to see around them while in a den, outside resting on the bottom, or while foraging. This requirement may preclude the use by octopus of the thicker portions of the ribbon kelp beds.

At the same time, an octopus apparently prefers to not only be able to see its surroundings but to also have cover under which to hide. Octopus dens were not found in the more dense portions of the ribbon kelp between the lower intertidal (-3 ft MLLW) and about -30 to -40 ft MLLW. As described previously, these beds will have more than 100 percent cover of the bottom where several layers of kelp carpet the rocks. Below about -40 ft MLLW cover is reduced to about 60 percent and less; this kelp finally disappears as deep as about -60 to -70 ft MLLW due to the lack of light.

It may be possible that octopus will forage in the ribbon kelp beds, but because of the limitations on visibility, it appears that octopus will use only the thinner portions of these beds either in deep water or in the intertidal zone to process and eat their prey and to rest. In fact, it appears from the evident separation of intertidal and subtidal octopus populations in this study that the thickest beds of laminarians may act as a physical barrier to octopus. This area appears not to be used for foraging, dens, or even movement between areas above and below the ribbon kelp zone.

Type III Habitat

The characteristics and use of Type III habitat, below about the 100-ft depth, are described here based on indirect evidence gathered from commercial fisheries, a few observations during the Prince William Sound July study, and personal observations of octopus encountered in depths around 100 ft in Washington. In these depths, algae is not present because of the lack of light. Also, the prey base is apparently somewhat different in composition because of vertical distributions of various species. Octopus in Type III habitat probably prey on species such as decorator crabs (*Hyas lyratus* and *Oregonia gracilis*), shrimp, and other crustaceans found at these depths such as *Paralithodes* spp. and *Lopholithodes* sp. Den sites in these depths are probably the same as in shallow waters: excavations under boulders and outcrops.

Prey Base

As particular as individual octopus are about their dens, the overriding factor determining the abundance of octopus within physically acceptable habitats is the availability of prey. Any given area needs to have a prey base before it can support octopus. In fact, octopus have been found in commercial fishery quantities where no den sites were available but abundant food in the form of the preferred decapod crab *Cancer magister* was present (e.g., Dungeness Bay, Washington) (Clifton 1981). An octopus prey base can be composed, as discussed previously, of a variety of marine invertebrate and vertebrate species, the use of which depends on the availability and the individual octopus. The preferred prey is cancroid decapod crustaceans (*Cancer* spp.). When these are not available in sufficient numbers or if an individual prefers, bivalve and gastropod molluscs will be used (e.g., clams of several species, *Polinices lewesii, Nucella lamellosa,* etc.). In addition, individual octopus in both aquariums and in the wild have been seen to specialize on finfish and marine birds (Cosgrove 1987; personal observations).

If an adequate prey base is not available, octopus will either not be present or their populations will be reduced. Also, once the prey resource in the immediate area of an octopus' den site is exhausted, an octopus will make increasingly longer foraging trips until, at some point, it becomes more practical for the octopus to form a new den closer to harvestable prey.

The abundance and quality of food resources can not only control the presence and abundance of octopus but also their growth rate and size. It has been seen in public aquariums (e.g., Seattle and Toledo) that octopus can be fed a carefully restricted diet to maintain a relatively small size or fed *ad libitum* to allow maximum growth in a short time (e.g., an octopus was fed 2 lobster tails per day and reached 60 lbs in less than 6 months from a starting weight of less than 5 lbs). This situation has probably been seen in the wild also. Along the Washington coast of the Strait of Juan de Fuca, food resources are apparently scarce and nearly all the octopus encountered are relatively small; weights are equal to what is normally considered as juvenile or subadult. However, when these octopus are placed in captivity, their life span indicates that they were adults at the time of capture.

Optimum Habitat

Thus the optimum habitat in Prince William Sound for octopus appears to be an area with numerous small to large boulders or rubble (1 meter or more in longest dimension) laying on but not deeply embedded in a firm, mixed sediment located at the edge of ribbon kelp beds in the zone where algae percent cover is about 40 to 60 percent or less. This can be either in the intertidal or in the subtidal below the kelp beds. Four of the eight octopus found in the subtidal were in this kind of habitat. Also, nearly all of the intertidal octopus were found in dens excavated under boulders or rubble located where algae cover was less than 100 percent but at least 25 to 30 percent.

Subtidal examples of this optimum habitat were found in Elrington Passage on July 13, 1995, Dive 19, and at Green Island on July 15, 1995, Dives 22 and 23. These areas had abundant medium-size flat boulders and/or rubble embedded in or laying on a mixed sediment. Occasional very large boulders were found below or among these flat rocks. There was also an occasional outcrop of bedrock. The slope was about 4:1 or less. *Laminaria* (*L. saccharina* with *Costaria* down to about -30 to -40 ft and *L. setchelli* below that) was present on the rocks down to about -50 ft MLLW.

ECOLOGICAL CONTROLLING FACTORS

The low abundance of octopus in the Prince William Sound survey area was surprising at first. There appeared to be abundant potential den sites and the other physical habitat factors were apparently acceptable. However, as the survey progressed it was seen that the octopus prey base was impoverished, thereby probably inhibiting individual and population growth. Upon examination of the data generated during the survey and a review of the existing literature on the geological and biological history of the Sound and the Northeast Pacific, the reasons for this situation became obvious.

The 1964 Alaskan Earthquake

At most dive sites the boulder or rubble habitat terminated at or just below the lower edge of the ribbon kelp zone. Below this zone relatively featureless beds of mixed sediments were present offering little or no habitat for octopus. As discussed in the Results section and previously in this section, the ribbon kelp zone conditions probably inhibit use by octopus for foraging and den sites.

The depth distribution and configuration of boulder, sediment, and kelp beds was probably created or at least exacerbated by the 1964 earthquake. This earthquake uplifted most of Prince William Sound up to 36 ft (Lethcoe 1990). This uplift probably moved the boulder beds upward into the laminarian zone and into the intertidal. In the former case, the boulders became covered with kelp inhibiting use by octopus, thereby contributing to the low abundance of octopus in the nearshore subtidal. Where boulder/rubble beds were exposed in the intertidal, these became usable octopus habitat as shown by the results of the intertidal survey (Scheel 1996).

The earthquake alone, however, would not have been the chief cause of the low octopus density in the Sound. Sufficient habitat remained below the kelp zone to support abundant octopus if a prey base had been present.

Sea Otters

The absence of an octopus prey base together with the absence of invertebrate herbivores (urchins, chitons, abalone) was also puzzling. Urchins especially should have been abundantly present in many of the dive sites. For instance, Dive 6 on Goose Island and Dive 7 on Bligh Reef should have found large numbers of the red sea urchin *Strongylocentrotus franciscanus*. The depth, food resource (macroalgae), and current and wave regimes appeared favorable for this species. However, only one individual urchin could be found in nearly one hour of searching at Goose Island.

This situation closely resembles one of the "alternate stable-state communities" described from the Aleutian Islands by Simenstad et al. (1978), Estes et al. (1978), and Estes and Palmisano (1974). This stable-state community is characterized by the presence of abundant and diverse macroalgae, finfish, and marine pinnipeds. The alternate community is characterized by rare macroalgae severely restricted in vertical distribution, abundant sea urchins and other invertebrates including mussels (*Mytilus* sp.) and octopus, a sparse finfish fauna, and lower numbers of marine pinnipeds.

The primary factor that causes the establishment of either community is intense predation by sea otters which are characteristic to the macroalgae-dominated community (Simenstad et al. 1978, Estes et al. 1978, and Estes and Palmisano 1974). Sea otters, by their removal of invertebrate herbivores, allow the development of abundant and diverse algal populations which in turn support finfish which support populations of seals and sea lions. This cause and effect relationship has been clearly demonstrated by study of two adjacent groups of Aleutian Islands, one with and one without otters. Also, the archeological record as reviewed by Simenstad et al. (1978) shows a shift of communities as the sea otters declined from hunting by the native Aleuts.

The sea otter-dominated community description from the Aleutians matches very closely the situation found in Prince William Sound. As described previously, abundant macroalgae beds, ribbon kelps of the same genera as found in the Sound, were present wherever substrata and depth allowed; invertebrate herbivores and secondary consumers were scarce; finfish (rockfish, kelp greenling, halibut) were abundant; and sea lions were common. Also, invertebrates such as decorator crabs and pectens were present in relatively greater numbers below -70 to -100 ft MLLW, which is probably below the normal effective foraging range of sea otters (Love 1992, Estes et al. 1978). Sea urchins were found in shallow water but only in highly cryptic situations and in low numbers. Finally, mussels were present only in small patches in the high intertidal and as small, densely packed individuals.

Octopus were cited as a member of the urchin-dominated stable community that prevails in the absence of otter predation by Simenstad et al. (1978). The invertebrates that are absent from the otter and algae-dominated community form the normal prey base for octopus in areas without otters. This is evident from the observations of Cosgrove (1987), Hartwick et al. (1981a), and me in British Columbia and Puget Sound, respectively, where otters are not present. In addition to this intense competition and community shift caused by the otters, octopus are also preyed upon directly by otters (Love 1992) and harbor seals (*Phoca vitulina*) (Kenyon 1965). Thus, octopus are effectively excluded from communities with sea otters.

Dungeness Crab Decline

Following the 1964 earthquake, Dungeness crab populations declined significantly (Love 1992). This decrease was probably in part due to a loss of feeding and reproduction habitat and in part due to heavy commercial and sport fishing. Some recovery was seen until 1980 at which time, sea otters became prevalent in the Sound. There is no direct link between the otters and Dungeness crab as this crab are not a characteristic member of the urchin-dominated stable-state community discussed previously.

In any case, Dungeness crab and related species are an important prey item for octopus. The decline of *Cancer* crabs for whatever reason probably directly affected octopus populations, causing them to switch to alternate prey. In the absence of an adequate prey base because of otter predation, octopus have declined in numbers and distribution.

CONCLUSIONS

Octopus populations in Prince William Sound have probably been declining since before 1980, perhaps since the 1964 earthquake and the decline of Dungeness crab stocks in the Sound. It is likely because of the presence of abundant sea otters and the establishment of the stable otter and macroalgae-dominated community that octopus populations will continue to decline until they reach a level that is maintainable by the small available prey base. This density may have been already reached, in which case, the small and scattered populations found during the July 1995 survey were probably representative of the octopus stocks in the Sound.

It appears likely that many of the octopus found during the survey represent populations that are ecologically dead or moribund because of the lack of an adequate breeding population. Octopus spawn by laying eggs in a den. These eggs hatch a planktonic hatchling (paralarva of Young and Harman 1988) which enters the benthos after a few weeks. If population densities of mature individuals fall to levels at which males and females cannot find each other, reproduction will probably become intermittent or fail. Also, an inadequate prey base may inhibit or even prevent maturation of octopus because reproductive maturity is probably brought on by achieving an adequate weight (Van Heukelem 1988, Laubier-Bonichon 1975, personal observations).

Additional octopus resources may be present in deeper waters, the Type III habitat discussed earlier. However, these are not easily assessed or harvested. The only harvesting methods that are available for deep water octopus are traps or pots and bottom trawls. Octopus pots are notoriously undependable and generally do not catch octopus in areas that have natural dens (Clifton 1981, Adkins et al. 1980, Paust 1988, Hartwick 1981b, personal observations). Bottom trawls probably would not function well in areas that have good octopus habitat since rocky bottoms and trawls are not compatible.

In conclusion, it appears that Prince William Sound marine communities have been converted through intense predation by sea otters to a stable-state community dominated by macroalgae. This community is not supportive of octopus, and this species is probably not a viable resource in the Sound for commercial, sport, or subsistence fisheries. On the other hand, the algae-dominated community created by the sea otters encourages finfish production which is probably a major contributor to the Sound's reputation as a halibut, rockfish, and salmon producer.

ACKNOWLEDGEMENTS

I deeply appreciated the support, patience, and competence of the Alaska survey team. Without the help and unflagging enthusiasm of David and Tania Scheel, Neal Oppen, Renee Einsfeld, Dan Logan, and Scott Wilbur the survey could not have been completed. My particular thanks go to my safety divers, Dan and Neal. Also, the discussions with Dan were particularly helpful in understanding the ecology of the Sound. Finally, without Neal's *Tempest* and his outstanding boat handling skills the expedition would not have been nearly as successful or pleasurable.

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Appendix 2: Subtidal Survey designed by M. Kyte, Pentec Environmental

Below is the complete text of M. Kyte's survey plan for the subtidal (SCUBA) portions of this survey. This plan was generally followed in the field, although additional factors were considered in site selection, as described in the body of the report.

Prince William Sound
Subtidal Octopus Survey Plan

Project No. 261-001

Submitted to:
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August 18, 1995

PRINCE WILLIAM SOUND SUBTIDAL OCTOPUS SURVEY PLAN

INTRODUCTION

Octopus (presumed to be *Octopus dofleini apollyon*) are a target of subsistence fisheries in Prince William Sound (Sound). In the last few years, specifically since the *Exxon Valdez* oil spill, the abundance of octopus for these fisheries has apparently declined. To determine whether this decline is real and whether additional stocks may be available in subtidal habitats, the Prince William Sound Science Center (Center) obtained funding for a survey of selected areas to determine the following:

- The presence of octopus
- Best survey strategies for octopus
- Optimum octopus habitat
- Octopus population parameters
- Estimated octopus stock abundance.

To achieve these goals, the Center contracted with Pentec Environmental, Inc. (Pentec), to have their recognized expert in the biology of Northeast Pacific octopus, Michael A. Kyte, perform the following objectives:

- Train Center personnel in species recognition and octopus biology.
- Train Center personnel in recognition of octopus habitat and survey techniques.
- Describe octopus habitat in the Sound.
- Describe (within limitations of time and budget) octopus biology in the Sound.
- Design a valid and tested survey plan for use in the Sound for future octopus studies.
- Assess the relationship of octopus distribution and abundance to the *Exxon Valdez* spill and other factors.
- Assess the potential of octopus fisheries.
- Compile a bibliography of relevant literature.

OCTOPUS SURVEY PLAN

DESIGN FACTORS

In the following description of octopus survey plans and habitat, much information is drawn from my nearly 20 years of personal experience with octopus as a research diver and scientist. For this reason, references are given only where information not gained from this experience is drawn from an outside source.

Octopus Biology

Octopus in Northeast Pacific nearshore subtidal regions are opportunistic predators that as adults prefer benthic decapod crustaceans for food. However, octopus are known to eat a large variety of marine species including bivalve and gastropod molluscs, finfish, and, on rare occasions, marine birds. To find their prey, octopus are highly mobile, crawling, walking, or swimming using their siphons and eight arms. Individuals can cover up to several kilometers per day in search of prey.

Octopus are soft-bodied without predator defenses such as spines, armor, or teeth. Accordingly, they are actively preyed upon as juveniles, subadults, and adults by marine mammals and finfish (e.g., sea lions and lingcod). Thus, they construct and use dens as refuges. These dens can be holes under rocks, in rubble, under and in logs or other objects resting on the sea floor, or constructed pots placed in the water by fishermen. Den selection is not indiscriminate, however; individual octopus prefer different substrata configurations or compositions. Octopus use dens not only as refuge between foraging trips but also for egg laying and brooding.

Another behavioral trait that needs to be considered when designing a survey for octopus is that they are solitary and asocial. As a result, they do not congregate except where den availability forces proximity. The only other occasion where more than one octopus will be in a single location is during mating. At this time a male and a female will be in close proximity for some length of time. The male, in fact, will actively challenge intruders, including divers, in defense of his mate.

Survey Approach

As a result of their unusual and cryptic life style, octopus are not easily visible on the sea floor unless excavated sediment or litter from feeding activities is present at the entrance of a den. Even then, the den may be empty necessitating a close examination of each possible den. Thus, octopus cannot be surveyed with any reasonable degree of confidence in the usual manner by nets, hook and line, or divers swimming simple line or strip transects.

Only one approach to surveying and estimating octopus populations has been found to be reasonably successful: systematic searches by scuba divers. Pots and non-closing traps may capture octopus in certain areas and habitats but are not dependable because of the individualistic nature of the octopus and den material/substrata and size preferences. Experimental trapping studies (Adkins et al. 1980, Clifton 1981, personal experience) have shown that octopus will usually not use pots placed where natural dens are available except to prey on the crustaceans captured by the traps.

Divers can systematically search for octopus and obtain a reasonably confident estimate of a local area population density at the time of the survey. If this systematic search is combined with a tagging and recapture program conducted regularly over time, information on movements and population dynamics can be obtained. The most important factor in conducting an octopus survey is the experience level of the diver(s). Without knowledge of the appearance of octopus in its natural habitat, feeding litter, and dens, the success rate for sighting octopus and dens will be low and the survey results will not represent the true situation. Thus, the following survey plan is described with the assumption that an experienced diver or dive team will be using it in conditions with which they are familiar.

Site Factors

The survey design is also influenced by the nature of the site which can include the following factors:

- Bottom slope (flat to steep)
- Bottom topography (no relief to substantial relief)
- Substrata nature (sand to rock)
- Depth range (shallow to deep)
- Den site density (number of potential dens per square unit area)
- Water visibility (clear or turbid)
- Prevailing currents (fast or slow, periodicity)
- Objective of the survey (population density, specimen capture, etc).

It is assumed for the purposes of the surveys in Prince William Sound that two distinct situations are possible: first, the area would be relatively flat with little relief but with boulders or other objects present under which octopus could have constructed dens, and second, a shoreline would have moderate subtidal slopes with substrata composed of boulders or rubble. In either situation, it is assumed that the following general conditions prevail:

- Slopes are moderate (3:1 to 10:1 or less).
- Bottom topography has substantial relief relative to the general aspect of the bottom (ledges, small to large boulders, outcrops, etc.).
- Substrata is entirely rock or mixed coarse or may be boulders laying on sand.
- Depth range is less than 80 ft.
- Water visibility is 10 ft or greater.
- Prevailing currents are moderate and searches will be done on slack tides as necessary.

- Objective of the survey is to obtain an estimate of population density, prey regimes, and to capture individuals for biological data (sex, weight, length measurements) and tagging.

Diver Safety

As stated earlier, it is presumed that experienced divers will be conducting octopus surveys. Thus, factors affecting diver safety and well-being will generally not be discussed in this plan. However, diver safety must be considered first and foremost whenever surveys are conducted.

Two aspects of diver safety must be discussed here, however: first, the operating depth limit during surveys should be 75 to 80 ft (gauge depth). Because of the remoteness of the dive sites and the lack of availability of recompression facilities in the region, descent beyond these depths except for emergency purposes is strongly discouraged.

Second, if any member of a dive team does not feel fully comfortable at any time before or during a survey dive with the dive plan, conditions, or his ability to function, the dive must be terminated or postponed until the diver is comfortable.

Other obvious and less obvious hazards must be considered and avoided. Such hazards in my experience can include but are not be limited to the following:

- Strong and turbulent tidal currents
- Heavy wave action resulting in strong surge on the bottom
- The presence of large predatory marine mammals (e.g., sea lions)
- Surface conditions which can prevent prompt and efficient diver retrieval.

Surface Support

The divers should be closely supported by a vessel capable of close approach to the shore and of setting and retrieving marker buoys. The vessel and operator(s) must be capable and ready at all times while the divers are in the water to quickly and efficiently pick up the divers when they reach the end of their survey, become fatigued or injured, or exhaust their air.

If the vessel is too large or has other duties and cannot closely follow the divers or come close to shore in the event that the divers cannot swim into deeper water, a smaller chase boat such as a skiff or inflatable should be used to follow the divers closely. In addition to insuring diver safety and well-being, the chase boat will be needed to set and retrieve marker buoys, determine ranges, and ferry captured octopus back to the main support vessel. These latter duties are explained in the sections describing the diver survey. The chase boat should have a bucket and a 16-gallon tote for transporting octopus.

In addition to normal and standard equipment for operation of a vessel in Alaska waters (e.g., survival suits, radios, cooking and eating facilities, etc), the main support vessel needs to have a means to retrieve divers safely and efficiently. The vessel also should have facilities and space for washing dive gear and underwater cameras with fresh water. Finally, for octopus survey work, the vessel needs to have a saltwater pump (e.g., on deck wash-down pump) and space against or near the rail to secure holding containers (e.g., 32-gallon garbage cans) for temporarily holding octopus. The wash-down pump needs to have a connecting hose to allow water to be easily changed or continually run into the octopus holding container(s).

A SURVEY DESIGN

Model

Over the years that I have spent conducting surveys of marine resources and searching for octopus for a number of different objectives in areas similar to Prince William Sound, I have evolved an effective survey design. This design is similar to one developed by a graduate student at the University of Washington (LaRiviere 1981) which in turn is based on the line and strip (or belt) transect methodology used in fishery (Gunderson 1993) research. Mathematical line transect theory is presented by Gunderson (1993) and will not be reiterated here.

Distance Measuring

A diver or dive team will swim a line searching for and counting octopus or other features on either side of the line to a specified distance. For octopus this distance is controlled by the water clarity and the topography of the bottom. In other words, the strip transect is narrow if underwater visibility is low or if high outcrops or boulders are present. The search distance increases with increasing water clarity and lower relief.

The length of each leg of the search pattern (except the shorter legs in the grid pattern) can be measured by a number of methods. However, in consideration of time and the fact that octopus survey divers need to carry a relatively large amount of equipment, a relatively simple method that can be used on the surface is described here.

Two flag buoys and an optical range finder are the principal components of the distance measuring system. They are used in the following manner:

1. The first flag buoy is dropped at the beginning of a survey leg.
2. The dive team notifies the boat operator at the end of the leg using a pre-arranged signal.
3. The boat operator drops the second flag buoy at the end of the leg.
4. The boat operator uses the optical range finder to determine the distance from the second buoy to the first.
5. The boat operator then retrieves the first flag buoy and prepares to drop it when divers reach the end of the next leg.

6. The boat operator then repeats the process.
7. The boat operator records all distances, the time, and the consecutive number of the survey legs in a waterproof notebook for later transferral to permanent records.
8. The boat operator also has a small marker buoy to use in case the divers signal the end of a survey leg before the operator can retrieve a flag buoy.

The following sections present a survey plan that is adaptable to most situations.

Preliminary Site Selection

Survey sites should be initially selected using nautical charts and local knowledge. Locations should be selected using the following criteria:

- Open coasts with good circulation or
- Entrances of bays with potential of prey resources.
- Rocky bottoms with coarse substrata.
- Moderate slopes or
- Flat bottoms with deposits of medium to large boulders .
- Light to moderate currents or
- Protected from strong currents in at least one part of the tidal cycle.
- Well-removed from large sources of fresh water and fine sediments (e.g., glacial runoff or rivers).

Pre-Dive Survey

Once a potential survey site is selected, it should be examined initially from the surface using a vessel with a depth sounder. The following information should be noted:

- Evidence of current strength and direction
- General slope (from sounder readings compared to distance from shore)
- Wave exposure
- Substrata at the water surface

A location for beginning the dive portion of the survey, a direction of survey, and a probable end point should be selected and discussed among the divers and vessel operator(s) to ensure an efficient survey and diver safety. The direction of survey should be with the prevailing current to avoid diver fatigue and to achieve the maximum distance.

Once a location for the initial diver entry is selected, flag buoy number one should be dropped at this point by the chase/boat. The divers will use this buoy and its anchor rope as a descent line if they are not descending from an anchored support vessel.

Prior to entering the water, the dive team will fill out part of the Octopus Survey Dive Data form (a copy of this form is included as an appendix). The following information will be entered:

- Location (describe as much as necessary to enable a return, include latitude and longitude)
- Date
- Current/wave exposure (modify if necessary during or after the dive)
- Surface temperature and salinity (from a bucket sample)
- Observers' initials

The Diver Survey

Equipment

In addition to the standard diver equipment, a number of items will be necessary or helpful to the divers. This extra equipment carried by the divers will be used in data recording, environmental monitoring, or octopus capture. This equipment will include but may not be limited to the following:

- Underwater light, small to medium in size and brightness
- Compass for navigation on flat areas
- Watch (all divers)
- Clipboard with survey data forms and pencil
- Fiberglass measuring tape
- Secchi disk
- Octopus irritant and delivery system (in a separate net bag)
- Octopus holding/capture bags (at least 2 with more in the chase boat)
- Small marker buoy to use to mark locations or signal to personnel on the surface
- Small water sampling bottle
- Thermometer

Procedure

The diver survey team will enter the water in a shallow portion of the survey area. In most areas, a sloping bottom will allow a zigzag pattern from shallow to deep to shallow again (Figure 1). Another approach is to follow a grid or rectangular search pattern (Figure 2). This latter approach probably will be optimum for areas without significant slope such as flat boulder beds. A third search strategy can be to follow a contour line or feature such as a rock stratum, base of a wall, or an outcrop. In this latter case, the divers can signal the surface at appropriate intervals to obtain the lengths of survey legs. In any case, divers should signal the chase boat to place a flag buoy whenever a significant change of habitat or bottom type is encountered. The length and/or spacing of the search legs will also be controlled by the steepness of the slope, nature of the bottom, visibility, or some combination of these factors.

As discussed earlier, the width of the strip transect will be determined by bottom topography, substrata, visibility, or, again, a combination of factors. If water visibility is the primary determinant, the divers will measure the visibility using a black and white secchi disk attached to a measuring tape. This will be done by one diver holding the disk while the other moves away watching the disk until it disappears. The measuring diver will then move back until the disk comes into view again and then move back until it disappears. This final distance is the secchi disk distance.

LaRiviere (1981) used a black-body object in measuring visibility, but his project was with lingcod which typically have a dark body. The feeding litter associated with an octopus den and octopus themselves are normally dark and light mottled making a black and white disk more appropriate.

Upon reaching the bottom, the survey team will note the following conditions on an Octopus Survey Dive Data form which will be printed on waterproof paper:

- Start time
- Start depth
- Start secchi disk distance
- Bottom temperature

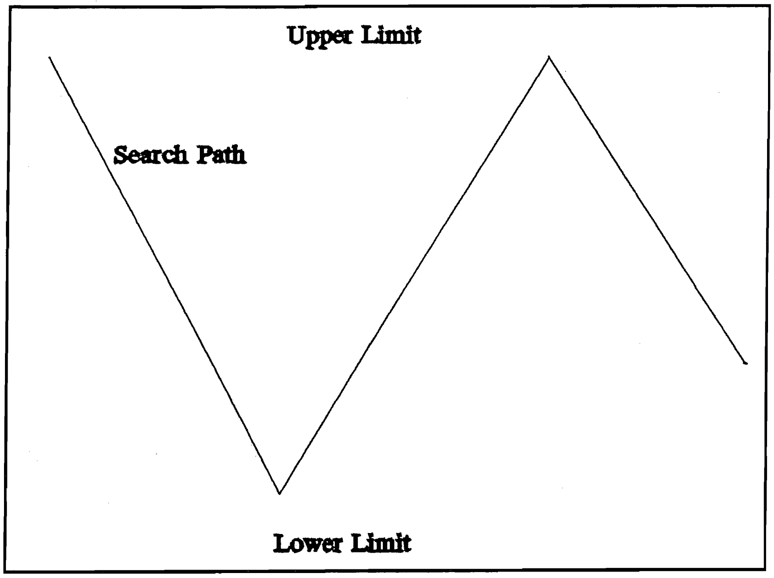

Figure 1 A zig-zag search pattern.

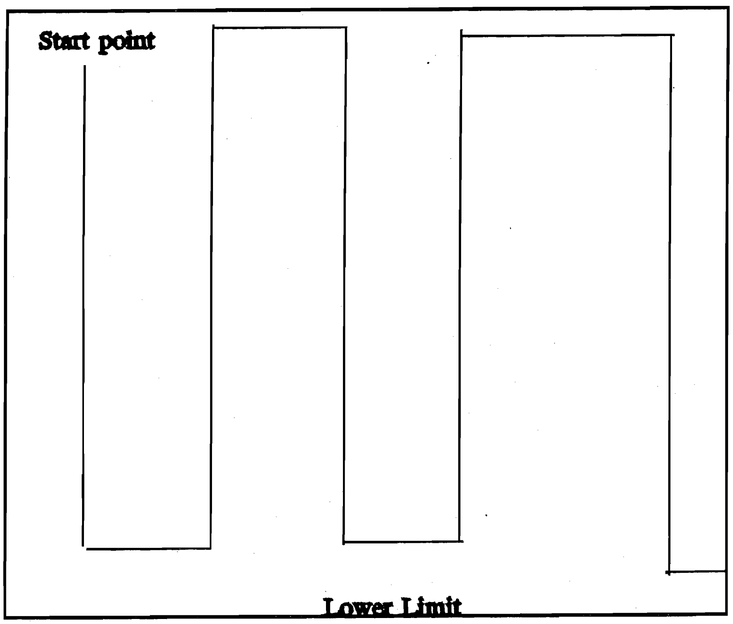

Figure 2 A rectangular search pattern.

After completing these portions of the survey data form, the divers will proceed with the survey following an appropriate search pattern described earlier. Depending on conditions, the divers may either swim freely or use a diver propulsion vehicle (dpv) (also known as a "tug"). The divers will monitor the slope, substrata, currents, other water conditions, and depth. Changes in any of these factors may require change of direction or search pattern, or even termination of the dive if currents are extreme.

Each diver will watch in front and to the side for signs of octopus: individuals, dens, or possible feeding litter. Feeding litter may be as innocuous as single scallop or crab shells down slope of a den. A trail of litter may lead to the den.

When a den is found occupied or empty, the divers will stop to examine it. An underwater flashlight should be used **briefly** to check for an octopus. Prolonged shining of a light at an octopus may irritate it and cause it to be reluctant to leave the den. This point may or may not be the end of a survey leg. If it is, the boat should be signalled to allow the operator time to drop a flag buoy. Whether the den is occupied or not the following information should be recorded on the survey dive data form, if time allows:

- Time
- Depth
- Substrata
- Slope (approximate ratio or degrees)
- Den opening direction (up or down slope or other)
- Vegetation in the immediate vicinity
- Litter (species, relative age, drilled or not)
- Den associates (fish, hermit crabs, wolf eel, etc).
- Den dimensions (height and width of opening and depth - after the octopus has been extracted). Measuring should be done carefully to avoid disturbing the octopus or after the octopus has been extracted.

If the den is occupied, the divers will attempt extraction and capture of the octopus. During this attempt, the diver not directly involved should be above and/or behind the den entrance so as not to be seen by an octopus in the den or at the den's entrance. Sight of a diver with the associated bubbles and shape and size may cause the octopus to retreat into the den. The following steps should be used in an extraction and capture attempt:

1. Check level of air in the diver's tanks (a minimum of 800 to 1,000 lbs must be available).
2. Prepare the holding bag and irritant delivery system.
3. Check with the inactive dive partner to ensure readiness and position.
4. Insert the hose of the irritant delivery system into the den and push as far back as possible.

5. Introduce a small amount, a single squeeze of the delivery bag, of irritant into the den.
6. Quickly but smoothly remove the hose.
7. Move to a position away from the den and reduce the diver's profile.
8. Wait - a small cloud of turbidity from the octopus forcefully expelling water from its siphon in response to the irritant should be seen almost immediately.
9. When the octopus is well clear of the den entrance and/or swimming, the holding bag can be placed around the octopus or the octopus can be quickly and gently scooped off the bottom and pushed into the bag (it is important to perform the actual capture quickly to prevent the octopus from gripping the bottom with its suckers and arms).
10. Secure the bag with the clip line.
11. Note bag number.
12. Record the bag number and other information on the dive data form.

The divers may carry one or two octopus in their bags with them after capture. However, the drag of a large octopus or a number of separate bags containing octopus will substantially slow the divers carrying them. Thus, the octopus should be taken to the surface and given to the chase boat operator for transport back to the main support vessel. The divers should surface from a point as close to the surface as is reasonable (i.e., the top of the slope above a den if nearby). Also, both divers should surface in case the dive is terminated at that time or a surface current separates the divers.

The octopus must be put into the 16-gallon tote in the boat for transport; towing an octopus in a bag in the water will kill it. When octopus are delivered to the surface, additional holding bags should be obtained from the boat operator.

At the same time, the divers can note their position and surface conditions, discuss their progress with the boat operator, and tell him of any plans for change of course and the probable further duration of the dive. The dive can be terminated at this time if the divers are fatigued, cold, or low on air.

If conditions allow, the divers will redescend and continue the survey. As at the beginning, descent should be on a flag buoy anchor to allow accurate measurement of the strip transect.

When the dive survey is terminated, the divers should surface from the shallowest point that is practical and/or as close to shore as is practical. This is done to reduce the risk of contact with the chase boat, main support vessel, or other boat traffic in the area. Once on the surface and in visual contact with the main support vessel, the divers can swim away from shore to allow for easier pickup by the vessel. If octopus are captured, a flag buoy should be left at the survey termination point to mark the surveyed area. This buoy can be retrieved after processing and releasing the captured octopus.

Post-Dive Activities

As soon as possible following a survey dive any captured octopus should be processed. The processing personnel should be as gentle as possible with each octopus and handle the animals only with wet bare hands. During this activity, the support vessel should stay in the immediate vicinity of the surveyed area if possible. Each octopus will be removed from the holding container and the following data recorded on the Octopus Examination Data form (example included in appendix):

- Date
- Location
- Observers
- Bag number (these four items key this form to the survey data form and notes)
- Wet weight (weigh in the holding bag, put octopus in the exam container, reweigh the bag for a tare weight)
- Sex
- DML (dorsal mantle length = distance from between the eyes to the end of the body along the dorsal surface)
- Eye (eye width = distance between the surfaces of the eyes across the dorsal surface of the head)
- Tag number (if a tag is going to be inserted)
- Any identifying marks or characteristics such as scars or missing or damaged arms.

As each octopus is processed, it should be returned to its holding bag and replaced in the on-board holding container. When processing is complete, all data forms should be checked for completeness and accuracy of correspondence of correlating data (i.e., date, location, bag numbers).

The octopus can then be returned to the survey termination point as marked by a flag buoy. The octopus should one-by-one be gently returned to the water by putting the octopus in its bag in the water, opening the bag, and lifting the bottom of the bag allowing the octopus to drop out. This can be done from the chase boat or from the support vessel.

Following release of the octopus, the dive survey is complete. All field data should be entered into the appropriate log or data forms as soon as possible. Also, all written notes should be transcribed to permanent record on a computer or other repository. The field forms should be allowed to dry (wiping will blur the writing) and then stored in safe place for later copying.

At the end of each day, octopus irritant bags should be rinsed thoroughly with sea water (not fresh water). Holding bags should also be rinsed to remove mucous and any debris that was introduced with the octopus.

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