Habitat and Depth Distribution of the Red Sea Cucumber *Parastichopus californicus* in a Southeast Alaska Bay

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ABSTRACT: A field survey of red sea cucumber *Parastichopus californicus* distribution was conducted June 18–22, 1991, using a manned submersible in Barlow Cove, Southeast Alaska. The density of sea cucumbers counted in transects averaged 20.8 individuals$\cdot$ha^{-1} in the inner, 70.9 in the middle, and 103.7 in the outer stratum of the cove. Six types of substrata were encountered: mud/sand, debris, rock, shell, rock wall, and algae. Sea cucumbers were found at almost all depths from the intertidal zone to as deep as 183 m. Higher densities were encountered in 2 distinct depth zones: above 60 m and between 100 m and 150 m. This bimodal distributional pattern was attributed to the depth distribution of the rock wall substrate, which supported the highest density of sea cucumbers at 234$\cdot$ha^{-1}. The higher densities of sea cucumbers along the nearly vertical rock walls are unexplained; rock walls may be preferred to the unstable nature of other substrates on the steeply sloped wall of the cove, or they may be selected for spawning.

INTRODUCTION

The red sea cucumber *Parastichopus californicus* commercial fishery began in Southeast Alaska in 1987 following an exploratory phase from 1983 to 1986 that was passively managed (Imamura and Kruse 1990). Since 1987, sea cucumber landings have increased rapidly, CPUE (number of sea cucumbers per dive) has decreased, and overexploitation has been reported in some fishing areas (Shirley and Tingley 1991). The current management strategy for the sea cucumber fishery includes annual dive surveys, a harvest quota, limited entry to the fishery, and closed fishing areas and fishing seasons.

This management program requires information on sea cucumber reproduction, growth, recruitment, distribution, and abundance. Reproduction, development, recruitment, and juvenile life stages of red sea cucumbers have been investigated by Cameron and Fankboner (1986, 1989), McEuen (1988), and Smiley (1994). However, information on red sea cucumber distribution by depth and habitat is scant. Using scuba gear the Alaska Department of Fish and Game conducted preliminary field surveys between 1987 and 1992 to estimate the density and population size of red sea cucumbers in portions of Southeast Alaska (Imamura and Kruse 1990; Woodby et al. 1993). Depths beyond 15 m were not surveyed because of scuba diver limitations. Sea cucumber distribution and substrate preference beyond this depth have not been reported.

In this study we used a manned submersible to explore the distribution of sea cucumbers by depth and substrate. We surveyed depths from the shallow subtidal zone, approximately 2 m below the water surface, to 200 m and estimated density within transects. Information pertinent to both the fishery and ecology of the red sea cucumber was gathered.

METHODS

A 2-man research submersible, the *Delta*, was used between June 18 and 22, 1991, to conduct the sea cucumber survey in Barlow Cove (58°22′N, 134°53′W), Southeast Alaska, about 30 km northwest of Juneau (Figure 1). Barlow Cove is a long, narrow embayment with mostly rocky intertidal areas except at the ex-

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treme southern end, which is sandy. The cove is rectangular, about 9.1 km long and 1.2 km wide; the maximum depth is approximately 200 m. To describe the topography of the cove and the distributional pattern of red sea cucumbers, the cove was arbitrarily divided into 3 geographic strata: inner, middle, and outer (Figure 1).

Dives were initiated from and perpendicular to the long axis of the cove and ran along a transect toward the shore. Two video cameras, 1 external in a fixed position and 1 hand-held inside the submersible, continuously recorded the sea floor as the submersible moved along the transects. Additional 35mm photographs were taken, and direct observations identifying animals and habitat types were recorded. The depths of transects were between the intertidal zone, approximately 2 m below the surface, and a maximum of 198 m. A total of 41 dives were made by the sub-

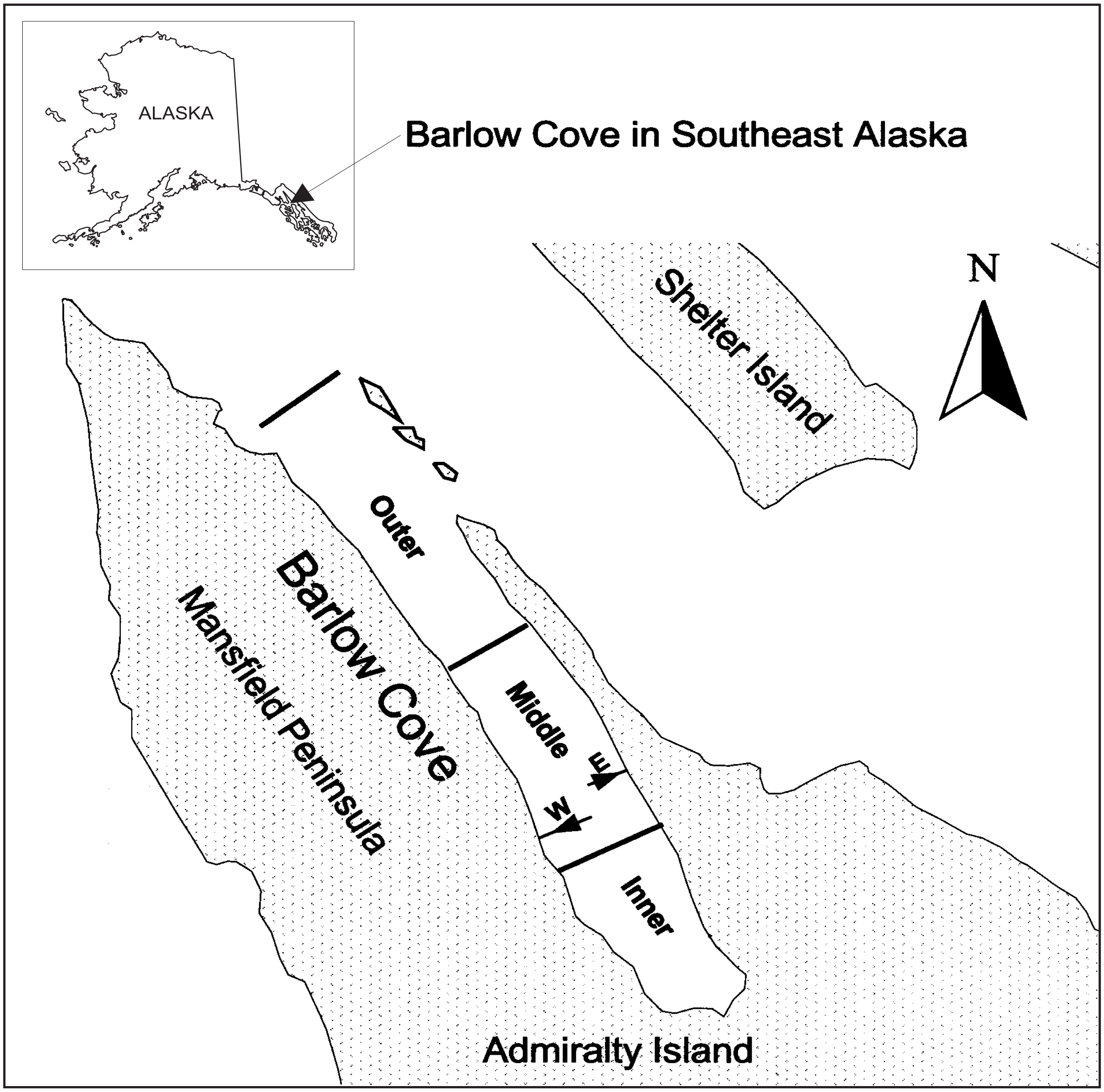

Figure 1. Map of Barlow Cove, showing the inner, middle, and outer strata. The arrows indicate the direction (east and west) of transects.

Table 1. Percent composition of substrate types observed in submersible dives.

Strata	Nr Dives	Percent of Substrates within Strata					
		Mud/Sand	Rock	Shell	Debris	Rock Wall	Algae
Inner	18	58.0	17.7	12.1	8.3	0.0	3.9
Middle	8	58.3	13.3	14.8	0.8	7.3	5.5
Outer	3	64.2	16.8	7.8	0.0	9.8	1.4
Overall	29	60.2	15.9	11.6	3.0	5.7	3.6

mersible in a period of 5 d; 29 dives had complete video data, whereas the others had only direct observations or missing records of transect time and depth.

Time, temperature, depth, and height of the submersible's sensor off the sea floor were automatically recorded at 20-s intervals. The average field of view (W) the video camera covered was obtained by $W = 1.78\,(0.93 \cdot H)^{-1}$, where 1.78 is the wider or front-side field of the video camera, 0.93 is the height at which the submersible settled on a level sea floor, and H is the height of the video camera off the sea floor. All parameters and variables are in meters. The area of camera coverage in 1 transect (A) was expressed by $A = W \cdot L$, where L is the transect length in meters. Sea cucumbers were counted from the tapes recorded by the fixed video camera, and the density was obtained by dividing this number by the area of A.

A Seabird SEACAT profiler[1] SBE 19 measuring instrument (commonly referred to as a CTD) was used to measure water temperature, salinity, oxygen, and PAR (photosynthetically active radiation) with depth. After each transect had been completed, hydrographic measurements were usually recorded on the downcast at approximately 1 $m \cdot s^{-1}$ from 1 m below the surface to 1 m above the bottom, up to a 200-m maximum.

The substrates included 6 types: mud/sand, rock, shell, debris, rock wall, and algae. Because it was difficult to identify the substrate into the sedimentary categories of sand, silt, and clay from the video tapes, they were combined as 1 habitat type, mud/sand. Rock substrates were composed of rocks predominantly 10 cm in diameter, shell substrates were composed primarily of empty bivalve shells, debris substrates were predominated by decayed wood and unattached macroalgae, and rock walls were nearly vertical, continuous rock. In most of the shallow subtidal areas of the cove, algae and sea anemones were dense so that the bottom was not easily viewed: this composed the algae substrate.

Transect distances over different substrates and depths were determined and then converted to substrate and depth percentages. The Kruskal-Wallis test was used to test density differences among the 3 geographic strata, and the G-test was used to test density differences among the 6 substrates.

[1] Mention of a trade name is included for scientific completeness and does not imply endorsement by the authors or the Alaska Department of Fish and Game.

RESULTS

Topography of Barlow Cove and Water Properties

The depth of Barlow Cove increased from the inner to the outer stratum (Figure 2). A deep, flat, mud/sand substrate prevailed along the central axis of the cove. Steep rock walls bordered the cove on both sides, except in the inner stratum. Shallower depths typically had a mud/sand substrate, dense algae, and numerous sea anemones. High densities of empty bivalve shells occupied some areas, usually at the upper and lower edges of the rock wall.

The mud/sand substrate occupied the majority of the cove's sea floor, followed by rock and shell substrates (Table 1). Rock wall was not present in the inner strata. Debris was absent in the outer stratum and was mainly found in the inner stratum on the central flat, muddy sand bottom. The algae substrate was present in depths <20 m.

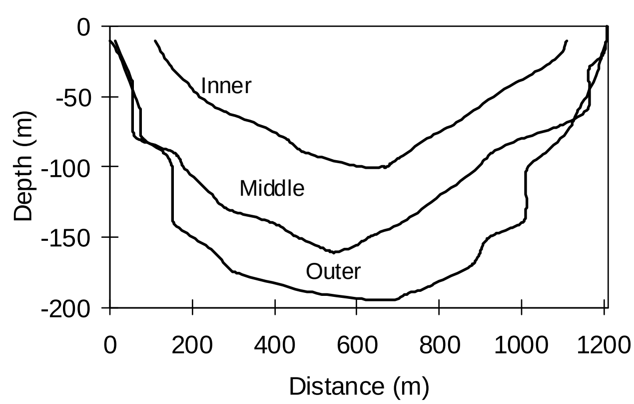

Figure 2. Bottom cross section of Barlow Cove by stratum as depicted by the means of the dives in each stratum: 18 dives in inner, 8 in middle, and 3 in outer.

Table 2. Transects data related to each of 29 submersible dives, including length of transect on the sea floor, maximum depth of the transect, height of the fixed video camera off the sea bottom, area covered by the fixed video camera during that transect, and number of red sea cucumbers observed.

Dive Number	Stratum and Direction[a]	Length of Transect (m)	Maximum Transect (m)	Height off Bottom (m)	Area Covered (m^2)	Nr Cucumbers Observed
2286	Inner E	407	70	1.16	904	0
2295	Inner E	111	61	1.26	268	0
2302	Inner E	296	78	1.15	652	0
2307	Inner E	574	92	1.18	1,295	0
2314	Inner E	519	92	1.09	1,081	0
2317	Inner E	389	79	1.36	1,011	3
2320	Inner E	315	93	1.01	608	0
2322	Inner E	593	93	1.05	1,190	0
2287	Inner W	537	77	1.16	1,191	0
2294	Inner W	37	55	1.18	84	0
2296	Inner W	222	40	1.20	510	4
2297	Inner W	556	70	1.14	1,211	0
2300	Inner W	296	40	1.11	629	0
2301	Inner W	463	53	1.09	965	0
2303	Inner W	463	77	1.01	894	0
2319	Inner W	500	82	1.05	1,004	0
2321	Inner W	259	93	1.15	570	0
2323	Inner W	185	12	1.06	375	10
2289	Middle E	241	154	1.43	658	1
2304	Middle E	444	150	1.51	1,283	2
2308	Middle E	463	151	1.18	1,045	13
2309	Middle E	463	162	1.06	938	0
2311	Middle E	537	154	1.25	1,284	18
2325	Middle E	333	135	1.25	797	2
2305	Middle W	444	153	1.16	986	2
2310	Middle W	444	122	1.09	926	21
2306	Outer E	500	189	1.32	1,262	24
2290	Outer W	685	198	1.18	1,546	8
2313	Outer W	1,259	198	1.46	3,516	24
Total		12,535			28,683	132

[a] E and W indicate the east or west sides of the cove and direction of the dives.

Temperature, salinity, and oxygen recorded by CTD had similar patterns in the 3 strata. Dramatic changes occurred within the upper 20 m. Water temperature was as high as 15°C at the surface and decreased rapidly with depth. From about 20 m deep to the bottom, the temperature was relatively stable at 3–5°C. Salinity as low as 10 ppt was recorded at the surface, increased to about 32 ppt at approximately 20 m, and increased gradually to approximately 34 ppt below 20 m. Oxygen varied between 7 and 10 $mL \cdot L^{-1}$ at <20 m and gradually decreased to about 4 $mL \cdot L^{-1}$ at 190 m.

Density Estimation of Sea Cucumbers

Of the 29 successful dives (transects with complete video data), 18 were conducted in the inner stratum, 8 in the middle stratum, and 3 in the outer stratum. Transect counts of sea cucumbers ranged from 0 to 24, and a total of 132 sea cucumbers were recorded (Table 2). The overall average density for the cove was $46 \cdot ha^{-1}$, and transect densities varied from 0 to $267 \cdot ha^{-1}$. On one portion of a transect in the outer stratum at a depth of 100–110 m, 12 sea cucumbers were recorded in 52 m^2, representing our highest recorded density of $0.23 \cdot m^{-2}$.

A total area of 28,683 m^2 was covered by video camera (Table 3). Densities of sea cucumbers increased from the inner stratum to the outer stratum and differed significantly among the 3 strata (Kruskal-Wallis test, $P = 0.003$). The mean and its standard deviation were 20.8 ± 64.4, 70.9 ± 82.7, and 103.7 ± 75.2 for the inner, middle and outer strata, respectively. Significant density differences existed between the inner and middle strata ($P = 0.004$) and between the inner and outer strata ($P = 0.007$), but not between the middle and outer strata ($P = 0.307$).

Distribution of Sea Cucumbers by Substrate

The rock wall substrate had the highest densities of sea cucumbers among the 6 substrates: $258 \cdot ha^{-1}$ in the outer stratum and $208 \cdot ha^{-1}$ in the middle stratum (Table 3). The shell substrate had the second-highest density in the outer and middle strata and the highest density in the inner stratum. As a whole, the rock substrate had an intermediate density and the mud/sand and debris substrates had relatively low densities (Figure 3). No sea cucumbers were observed in the algal habitat (Table 3). These differences were significant, even when the algae substrate was excluded (G-test; df = 4, $P < 0.001$).

Distribution of Sea Cucumbers by Depth

Sea cucumbers were observed at almost all depths in Barlow Cove from the intertidal zone to as deep as 183 m. Maximum densities were bimodally distributed by depth: one at 10–60 m and the other at 100–150 m. The highest density in the shallower region was $121 \cdot ha^{-1}$ at a depth of 10–20 m, and in the deeper region the highest density was $130 \cdot ha^{-1}$ at 110–120 m (Figure 4). The deepest depth surveyed was about 198 m; we surveyed 814 m^2 at this depth or 2.9% of all depths surveyed. In this deepest area, which was mainly mud/sand, we observed no sea cucumbers.

DISCUSSION

Along the west coast of North America, from southern California to Alaska, red sea cucumbers are the most common and the only commercially harvested sea cucumber. The species has relatively long dorsal papillae that are large and broadly conical (Lambert 1986). This characteristic was observed for most of the sea cucumbers recorded on the video tapes from the intertidal to 180-m depth. Because the video images were not clear enough to permit positive identification of all individuals, we cannot conclude that all sea cucumbers observed were *P. californicus*, but sufficient identifications were made to conclude that it was the predominate species in Barlow Cove. Furthermore, of 4 *Parastichopus* species reported from the west coast of North America, only *P. californicus* has been confirmed to occur in Alaska (Lambert 1986).

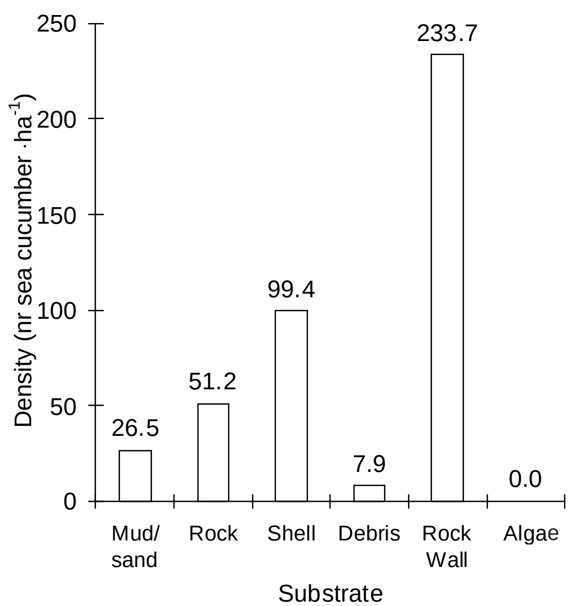

Figure 3. Distribution of red sea cucumbers by substrate. Data were combined from all 29 successful dives.

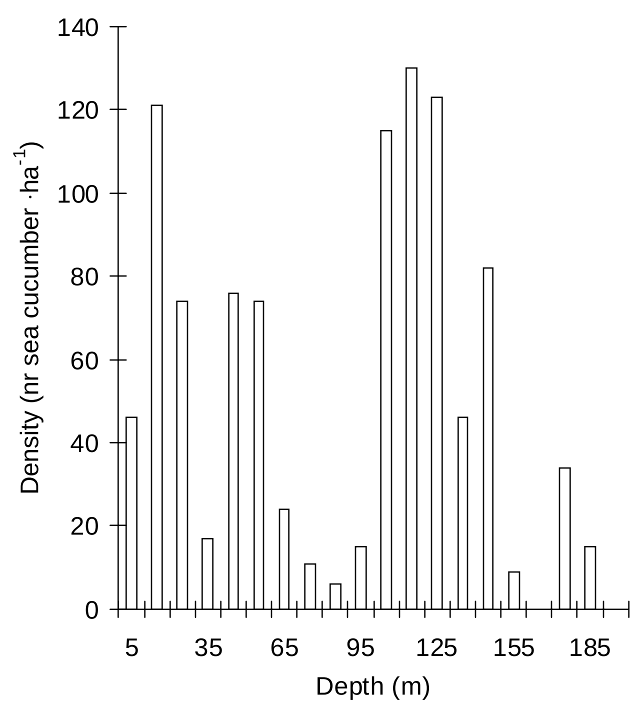

Figure 4. Distribution of red sea cucumbers by 10-m depth intervals. Data were combined from all 29 successful dives.

Table 3. Distribution of sea cucumbers by substrate and strata in Barlow Cove.

Stratum		Substrate						
		Mud/Sand	Rock	Shell	Debris	Rock Wall	Algae	Combined
Inner	Area[a]	8,376	2,556	1,747	1,199	0	564	14,442
	Density[b]	9	13	36	0		0	20.8
Middle	Area	4,616	1,053	1,172	63	578	435	7,917
	Density	50	35	164	159	208	0	82.7
Outer	Area	4,060	1,062	493	0	620	89	6,324
	Density	36	160	172		258	0	103.7

[a] The area is the total area (m^2) covered by the video in that stratum.
[b] The density is the number of sea cucumbers·ha^{-1}.

The density of sea cucumbers in Barlow Cove was relatively low compared to densities reported in other areas. The density in preharvest areas of Washington averaged 1.2·m^{-2} and in "fished out" areas was 0.2 to 0.3·m^{-2} (Bradbury, Washington Department of Fisheries, personal communication). Field surveys conducted to 60-ft depths by the Alaska Department of Fish and Game in April 1987 revealed an average density of 0.69·m^{-2} sea cucumbers in Vallenar Bay, Southeast Alaska (Imamura and Kruse 1990). After being fished, this area was resurveyed in 1989, at which time the average density had dropped by nearly 50% to 0.35·m^{-2}. Commercial fishermen in the 1980s believed that a density >0.25·m^{-2} was necessary for commercial viability (Sloan 1986); the density in Barlow Cove was too low to have commercial significance.

The submersible study method may have underestimated the density of animals because only those that were clearly visible to the camera were enumerated, while those in crevices or under rocks or shells were easily omitted. The population of sea cucumbers in rock, shell, debris, and rock wall substrates was therefore probably higher than observed. Sea anemones and dense kelps growing to depths of 10 m compromised observing and enumerating sea cucumbers; therefore, the density of sea cucumbers in the algae-covered areas was certainly higher than we could enumerate from the video tapes. However, sea cucumbers were clearly observed with the video camera on the soft, flat mud/sand substrate, which occupies more than 60% of the Barlow Cove sea floor and has few obstacles to impede viewing.

Red sea cucumbers have been collected or observed on rock, sand-shell, kelp, and soft sandy sediments and from kelp beds (Lambert 1986; McEuen 1987). However, there is no documentation on substrate preference for this species. In our survey sea cucumbers were most numerous on the rock wall substrate, rock and shell substrates had an intermediate density, and the mud/sand substrate had the lowest density. The debris substratum was mostly confined to the inner stratum (Table 1). The area covered by debris was so minor (3%) that it compromised our ability to determine red sea cucumber preference for this habitat, and because sea cucumbers were visibly obscured in the algae substrate, meaningful habitat-use data were not obtained for this habitat either.

The high density of sea cucumbers on rock walls does not seem to be related to food availability. Most holothurian species, including *P. californicus*, are epibenthic deposit-feeders (Crozier 1918; Yingst 1976; Hauksson 1979; Roberts 1979; Sloan and Bodungen 1980; Hammond 1981, 1982b, 1983; Roberts and Bryce 1982; Amon and Herndl 1991a, 1991b). Feeding consists of repeated extension, collapse, and withdrawal of the tentacles placed against the substratum. Deposited particles adhere to the sticky surface of the tentacles and are pulled from the substrate (Cameron and Fankboner 1984). Silva et al. (1986) reported that due to anatomical limits *P. californicus* is restricted to feeding with its tentacle crown oriented in an anterior-ventral posture; it is unable to feed upon material in suspension.

Sediments on the sea floor mainly come from the vertical transport of particles and marine snow from the euphotic zone (Shanks and Trent 1980). Because the rock wall in Barlow Cove is nearly perpendicular to the sea surface, a minimum amount of sinking materials from the water column collect per unit area, making food availability lower than on other substrates. Therefore, the high density of sea cucumbers in this area seems unusual in the sense that normal feeding requirements may not have been satisfied.

The high density on rock walls is not likely to have been related to predator avoidance because holothurians are toxic or otherwise unpalatable to most marine predators (Hammond 1982a; Barkai 1991). The only reported predators of sea cucumbers, other than humans, are starfish and sea urchins, which prey upon juveniles (Cameron and Fankboner 1989; Hamel and Mercier 1996). Red sea cucumbers >2 years of age avoid predation by sea stars (Cameron and Fankboner

1989) because of their size and swimming ability. Hamel and Mercier (1996) found *Cucumaria frondosa* >25 mm avoided predation by sea urchins, although this species is a dentrochirote, a different order than the red sea cucumber (aspidochirote). In our submersible survey all sea cucumbers recorded on the video tapes were relatively large (>20 cm), and sea stars were frequently observed on rock walls, the substrate with the highest sea cucumber density. Sea otters are potential predators, but the rock walls would not have provided much protection from sea otter predation.

Water movement affects the distribution of sea cucumbers (Barkai 1991). The sea cucumber *Stichopus japonicus* occurs on rock, boulder, gravel/pebble, and muddy substrates, but it is absent on coarse, clear sands of shores exposed to wave action (Selin and Chernyaev 1994). Silva et al. (1986) observed that *P. californicus* was swept from the bottom by vigorous tidal currents and noted the absence of sea cucumbers from hard substrates that, aside from strong currents, appeared to be suitable habitat for this species. Thus, Silva concluded that while this sea cucumber can withstand mild currents (≤4 km/h), stronger tidal currents can limit its movement and benthic distribution. It is unlikely the current along the rock wall was less than in other areas; therefore, current probably was not a factor affecting the distribution of sea cucumbers in Barlow Cove.

Hydrographic variables changed rapidly in the upper 20 m of Barlow Cove. Below this depth the temperature and salinity isopleths were stable at approximately 4°C and 33 ppt, and oxygen decreased slightly as depth increased. No relationship was evident between sea cucumber distribution and these environmental variables below 20 m.

Sea cucumbers may migrate seasonally or with ontogeny. The size distribution of the sea cucumber *S. variegatus* was unimodal at individual stations, but modes differed between stations, suggesting a downward migration to deeper water during life (Conand 1993). Observations of *Cucumaria frondosa* (a dentrochirote sea cucumber) on muddy or sandy bottoms were rare during spring and summer, but they became more frequent in fall and early winter. Our data only depict the distribution of red sea cucumbers during early summer, and their distribution may change seasonally (Woodby et al. 1993). Fishermen have reported that red sea cucumbers occur with high density in mud/sand habitat during winter in Southeast Alaska (G. Campbell, University of Alaska Southeast, personal communication).

The high density of sea cucumbers on rock walls during our survey may be related to reproductive behavior. *P. californicus* has an annual reproductive cycle, spawning occurring in late spring through summer within the inland waters of southwestern British Columbia (Cameron and Fankboner 1986). During spawning the anterior part of the animal is raised vertically from the substrate, and the “head” is curved forward toward the substrate. The gonopore, on the anterior dorsal surface of the animal, opens at the point of maximum elevation above the substrate. In this posture the sperm and oocytes can be released easily into the water column and carried away by currents to other spawning individuals separated by relatively large distances (up to 10 m). Our survey was conducted in June, which could be during the spawning period for *P. californicus*. We did not observe the spawning posture on the video tapes or otherwise witness it during the dives, but that does not preclude the possibility that these were spawning aggregations. Spawning in many marine invertebrates is rarely observed. For example, spawning by the commercially important and widespread pinto abalone *Haliotis kamtschatkana* was only recently reported (Stekoll and Shirley 1993). The nearly vertical rock walls may be more advantageous for red sea cucumber gamete release and dispersal than flat areas (McEuen 1988).

Another possibility for the high density on the rock walls is that they offered better protection from the downward displacement of shells and cobble dislodged from above by waves and currents. Although Barlow Cove appears to be a sheltered embayment with little current, the long, narrow cove is exposed to northerly winds that create high wave energy on the sandy beaches in the southern portion of the cove. The depth distribution of the rock wall is below wave turbulence, and debris that does cross this area will tend to free fall without much contact. Therefore, rock walls may offer a stable substrate immune to these downward flows.

P. californicus was observed at depths of 40 to 216 m in Queen Charlotte Islands, British Columbia (Lambert 1986), and has been reported as deep as 249 m (McEuen 1987). However, Fankboner and Cameron (1985) did not find this species living deeper than 25 m in their study of Woodlands Bay in Indian Arm Fjord, British Columbia. Our observations confirm that red sea cucumbers can dwell deeper than 100 m.

The bimodal depth distribution we observed was probably not caused by depth preference but by distribution of the rock wall substrate. That is, the rock wall was absent between 70 and 100 m. The fact that high sea cucumber density on the rock walls above 70 m and below 100 m was interrupted by a change in substrate between 70 and 100 m is a strong indicator that substrate effected the distribution rather than depth.

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