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SURVEY OF ABALONE POPULATIONS AT DALLAIN POINT AND HIGGINS PASS, CENTRAL COAST OF BRITISH COLUMBIA, 1995 - 96

by

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1.0 ABSTRACT

Cripps, K., and A. Campbell. 1998. Survey of abalone populations at Dallain Point and Higgins Pass, central coast of British Columbia, 1995-96. Can. Manuscr. Rep. Fish. Aquat. Sci. 2445: 31 p.

Random transect surveys were conducted to determine the density of the northern abalone, *Haliotis kamtschatkana*, from intertidal to 8 m depth, near Dallain Point during May, 1995, and Higgins Pass during May, 1996. Most (>97 %) abalone greater than 70 mm shell length were exposed or emergent (visible on rocks). Mean densities for all sizes of abalone were similar (0.425 and 0.519 per m^2) between sites. Mean abalone sizes and densities were generally largest in the 1-3 m depth range, with fewer abalone found in the intertidal areas and to depths of about 8 m.

RESUME

Cripps, K., and A. Campbell. 1998. Survey of abalone populations at Dallain Point and Higgins Pass, central coast of British Columbia, 1995-96. Can. Manuscr. Rep. Fish. Aquat. Sci. 2445: 31 p.

Nous avons réalisé des relevés sur transects aléatoires pour mesurer la densité des ormeaux nordiques (*Haliotis kamtschatkana*), de l'estran jusqu'à une profondeur de 8 m, près de la pointe Dallain en mai 1995 et dans la passe Higgins en mai 1996. La plupart (>97 %) des ormeaux dont la coquille mesurait plus de 70 mm de longueur étaient exposés ou émergents (visibles sur les rochers). Les densités moyennes, pour toutes les tailles d'ormeaux, étaient comparables (0,425 et 0,519 au m^2) d'un site à l'autre. Les tailles et les densités moyennes étaient généralement les plus élevées dans la fourchette de profondeur de 1-3 m, et les ormeaux étaient moins nombreux dans la zone intertidale et jusqu'à des profondeurs d'environ 8 m.

2.0 INTRODUCTION

The northern or 'pinto' abalone, *Haliotis kamtschatkana*, is found from Sitka Island, Alaska to Baja California and generally occurs in a patchy distribution on exposed and semi-exposed rocky shores of British Columbia (B.C.) (Sloan and Breen 1988). Northern abalone were harvested in commercial, first nations and recreational fisheries in B.C. until 1990 when the fishery was closed for conservation. Surveys at index sites in southeastern Queen Charlotte Islands and the north central coast of B.C. indicated that the abundance of northern abalone had declined more than 75% between the period of 1978 to 1984 and remained low until 1994 (e.g., Winther *et al.* 1995; Thomas and Campbell 1996). Faced with the possibility of abalone population collapse, the northern abalone fishery has remained closed since 1990. The survey design has remained the same since 1978 (Breen and Adkins 1979) and consisted of counting and measuring abalone in 16 alternate 1 m^2 quadrats per sample in each indicator sites for the whole area. Several authors (e.g., Sloan and Breen 1988; Campbell 1996) have suggested that the survey estimate may not be sufficiently powerful to detect small changes in population densities of abalone and have recommended an evaluation of this survey method and examination of other sampling designs. To date, there have been no published reports on alternative survey methods tested on *H. kamtschatkana* in B.C. Two areas (Dallain Point and Higgins Pass) in the Central coast of B.C. were chosen (Fig. 1, 2, 3) because initial observations indicated that abalone were present and that they were within the Kitasoo First Nations traditional territory providing an opportunity to conduct an inventory of this resource.

The objectives of the present study were to (1) estimate the density of abalone in two sites in central B.C. using a random transect method, (2) determine whether there is a relationship between density and depth, and (3) determine an appropriate sample size in each of these two areas in the central coast of B.C. (Fig. 1, 2, 3).

2.1 SUMMARY OF ABALONE BIOLOGY

Although the biology of *H. kamtschatkana* was reviewed by Sloan and Breen (1988) summary is provided here. The northern abalone is typically dioecious, however, there have been a few cases where simultaneous hermaphrodites, protrandric hermaphrodites, and protogynous hermaphrodites have been reported (Breen and Adkins 1982). Sexes are differentiated on the basis of gonad color where females are known to possess green colored gonads and the males creamy white to pink colored gonads. Visual identification of the sex of immature abalone less than 35 mm shell length (SL) is difficult. However, greater than 25 mm SL, gonads have developed to the point where they are identifiable, even though they do not start becoming sexually mature until they are approximately 50 mm SL (Quayle 1971). Campbell *et al.* (1992) found that the smallest size that 100 % of abalone were mature was about 70 mm SL.

Northern abalone are synchronous broadcast spawners, however mature gonads are found throughout the year and trickle spawning is thought to occur (Quayle 1971). The majority of the spawning probably occurs during April to July where elevated water temperatures stimulate the spawning activity (Sloan and Breen 1988). During spawning male and females aggregate in shallow waters, many stacked on each other, simultaneously broadcast their gametes into the water column (Breen and Adkins 1980). Fertilized eggs sink to the bottom and subsequently hatch within days into free swimming lecithotrophic trochophore larvae which are phototactic (Olsen 1984). After approximately 40 hours, these trochophore larvae metamorphose into a veliger larvae which remain as plankters for up to 4 days before settlement occurs (Morse and Morse 1984).

Larval settlement is found to be more successful in bathometrically complex habitats (Tanaka *et al.* 1986). Growth is found to vary between locations, with growth being most rapid in locations that are semi-protected and with a rich supply of food (Sloan and Breen 1988). Breen and Adkins (1979) suggested that northern abalone grew faster in protected or semi-exposed locations with high quality food, such as *Macrocystis* and *Nereocystis*, than abalone in exposed places with low quality food, such as *Pterygophora*. However this difference in growth may not be a function of food quality but rather may result from the fact *Macrocystis* and *Nereocystis* produce more drift than *Pterygophora* forests. Also, *Pterygophyra* typically occupies more turbulent regions of coastline which may not allow for drift to deposit for any length of time.

Abalone are considered to have a low instantaneous rate of natural mortality (M) although this parameter is difficult to estimate. Breen (1986) found M to be 0.15 to 0.20 in some sites closed to fishing. Predators of adult abalone include sea otters, fishes, crabs, starfish, and octopus. Predation on juvenile northern abalone has not been observed, although they probably are highly susceptible to predation. Random environmental events such as winter storms, episodic high temperatures or low salinities, may cause mass mortality in abalone populations (Sloan and Breen 1988).

2.2 SUMMARY OF ABALONE EXPLOITATION AND MANAGEMENT

The harvesting of abalone by Aboriginal people along the northwest coast of North America is an ancient tradition (Holm 1965). Harvests were usually carried out at low tide when exposed abalone were picked by hand and subtidal abalone were captured with a long hooked pole. The first non-aboriginal fishery began in the early 1900's when abalone were harvested using long hooked poles or by diving (Thompson 1914). This product was typically canned for oriental markets. With the advent of SCUBA in the 1950's, a recreational fishery began and commercial abalone harvesting became viable, with landed abalone directed towards local markets (Sloan and Breen 1988). Commercial landings were sporadic prior to the early 1970's, after which the annual landings increased dramatically to a maximum of 433 t in 1978 then declined under a quota management system to 47 t in 1985-90 (Farlinger and Campbell 1992). A minimum size limit of 101.6 mm SL during 1908-81 and 100 mm SL during 1981-90 was enforced for all three fishery categories since 1908 (Farlinger and Campbell 1992). Surveys conducted between 1978 and 1990 indicated that abalone stocks were being over-exploited, so harvest for all three fishery categories was stopped in 1990 and all abalone fisheries in B.C. have remained closed since that time.

3.0 METHODS

3.1 PRE- SURVEY INVENTORY

Several locations throughout the Kitasoo First Nations territory (i.e., occupying parts of Statistical Areas 6 and 7) were examined during April, 1995, using SCUBA, for the presence of abalone populations suitable for study. The extent of these populations were recorded on the Canadian Hydrographic Service (CHS) nautical charts. Potential study areas ranged from a structurally simple 3 km stretch of shoreline to 15 km long stretches of complex habitat containing small island outcrops and submerged reefs (K. Cripps unpublished data).

3.2 SURVEY LOCATIONS

3.2.1 Dallain Point

A 3 km length of shoreline was surveyed in the southern portion of Laredo Channel (Stat Area 6-16) during 3 - 14 May, 1995 (Fig. 2). Gradually-sloping bedrock / boulder substrate predominated, with the occasional steeply sloping bedrock headland. The study area is exposed and subject to an intense south west ground swell. Red sea urchins were abundant and consequently macrophytes were restricted to the intertidal and the shallow subtidal.

3.2.2 East Higgins Pass

A 5.3 km length of shoreline on the south side of Swindle Is. in East Higgins Pass Channel (Stat Area 7-3) was surveyed during 15 - 23 May, 1996 (Fig. 3). Substrate consisted of moderately steep sloping bedrock and boulders. Red sea urchins were not abundant and lush *Macrocystis/Laminaria* forests were found in the protected west side of the site and *Laminaria sitchelli/Alaria* were dominant in the more exposed easterly portion of the bed. The study area is exposed with intense south east wave activity coming from Milbanke Sound.

3.3 TRANSECT LOCATIONS

Transects were randomly placed on a nautical chart by positioning a metric ruler, marked in mm, along the length of shoreline to be surveyed. A random numbers table was used to select the position along the ruler where survey transects were to be placed. Thirty transects were surveyed off Dallain Point while 32 transects were surveyed in Higgins Pass (Fig. 2, 3).

3.4 TRANSECT SURVEYS

The primary sampling unit was a "transect", made up of a variable number of secondary sampling units. Each transect was one meter wide and variable in length depending on the slope of the substrate within the sampling depth range of 0 to approximately 8 m. The secondary sampling unit consisted of a 1 m^2 quadrat that was placed on the right side of the transect line. Lead line was deployed perpendicular to the isolepths to a depth of approximately 8 m below chart datum. Transect origin was determined by indescriminantly throwing a lead cannon ball into the intertidal zone. Divers flipped the 1m x 1m quadrat along to the transect line, from deep to shallow, and the number of "emergent" or "exposed" or visible abalone, shell length of each abalone, depth, substrate type, and dominant algal cover was recorded for each quadrat. All kelp, sea urchins and starfish were removed from the quadrat to ensure the abalone were easily detectable. However no effort was made to look for cryptic abalone that may have been hidden under boulders or in crevices. Caution was exercised to ensure that abalone in upcoming quadrats were not disturbed to reduce the chance of abalone moving out of view. Sampling only exposed abalone is more efficient since the majority of mature abalone (i.e., ≥70 mm SL) are exposed (Campbell 1996).

All depth recordings were converted to depth below chart datum. The surveys were conducted from the intertidal zone to about 8 m below chart datum because the majority of northern abalone are usually found in this depth range. Surveying deeper would have greatly reduce the number of transects that could be safely completed in a day.

3.5 INTENSIVE TRANSECTS

To determine the detectability of exposed animals and the cryptic proportion of the population, transects were randomly chosen and subjected to a more intensive sampling protocol. Four transects and six transects were intensively surveyed at Dallain Point and Higgins Pass, respectively. The intensive survey protocol involved examining each quadrat three times before moving onto subsequent quadrats. Depth, substrate, number of exposed abalone, number of emergent abalone missed on first examination, and number of cryptic abalone were recorded for each quadrat. The first examination involved counting and collecting all of the exposed animals. The quadrat was then more closely examined to see if any exposed animals were missed during the first pass. If an abalone was missed on the first pass, the animal was removed and placed in a separate labeled collection bag. Only one abalone was missed during the 1995 survey on the first pass and it was questionable whether this animal should have been classified as exposed or cryptic. Finally, the cryptic component of the population was sampled by removing and inspecting of all the moveable material within the quadrat. These cryptic animals were also removed and placed in a labeled collection bag.

The collected abalone were taken to the surface where shell length (mm), weight (g) and sex were recorded for all the animals in each collection bag. For the Higgins Pass 1996 intensive survey, shell width and height were also recorded. Sex of each abalone was determined by examining gonad color. Gonads of the abalone were made visible by gently moving the epipodium with a spoon. Abalone ≤ 35 mm SL were difficult to sex so they were classified as sex undetermined. Once the abalone were measured and weighed they were returned to the area from which they were harvested.

3.6 DATA ANALYSIS

To account for the variable length of the sample units (transects) the mean density, d (number / m^2), was calculated as

$$d = \frac{\sum_i c_i}{\sum_i a_i} \quad (1)$$

The standard error of the mean density, se (d), was calculated as

$$\text{se}(d) = \sqrt{1 - n/N}\sqrt{\frac{\sum_i (c_i - da_i)^2}{n(n-1)a^2}} \quad (2)$$

where for each i[th] transect, c_i = the number of abalone observed in a transect, a_i = the area of transect surveyed in square metres, a = the mean transect area for all transects, n is the number of transects sampled, and N is the total population of possible transects. Adjusting densities for detectability was calculated by substituting c_i with c_i / e, where e = mean proportion of total population estimated to be detectable (exposed abalone / (exposed + cryptic abalone)). Mean and standard error of densities by depth range, by substrate type and by abalone size class can also be calculated by subsampling each transect. The depth ranges were (1) <0 m, (2) 0 - 1.5 m, (3) 1.51 - 3.0 m, (4).3.01 - 4.50 m, (5) 4.51 - 6.00 m, (6) 6.01 - 7.50 m, (7) 7.51 - 9.00 m. The substrates were categorised as 1 = hard smooth bedrock, 2 = hard complex boulders and cobbles, 3 = mixed hard/soft with hard substrate abundant, 4 = mainly soft with some hard substrate). The size classes were "mature" ≥ 70 m SL, "prerecruit" 92-99 mm SL, "legal" ≥ 100 mm SL, "new recruit" 100-106 mm SL and "total" which included all size classes. Although some of these size categories overlap they were included in the analyses so that the results could be compared with those from previous surveys of abalone from other areas. The "immature" <70 mm SL size class was not included in the density estimates (except as part of the "total") because of the difficulty of finding small abalone.

The allometric relationship between shell length (SL) and total wet weight (w) was estimated, using the abalone data collected at the two sites, with the power equation of the linear form ln(w) = ln a + b ln(SL) where a and b are constants calculated using the least squares method. From this equation, the predicted weights for each abalone with known shell length could be calculated and a mean weight of individual abalone for each transect estimated. All general statistical and graphical analysis were conducted with SYSTAT (1996).

A crude estimate of target sample size (n_{t+1}) for a given precision was calculated as

$$n_{t+1} = ((cv_t / cv_{t+1})\sqrt{n_t})^2 \quad (3)$$

where cv_t = the precision (se_t / d_t), se_t = the standard error of estimated mean density of abalone (d_t), n_t = the number of transects at the time of survey (t), and n_{t+1} = the target number of transects given the desired precision cv_{t+1} (e.g., 0.10, 0.15, 0.20) for the next survey (t+1). A number of different n_{t+1} values were calculated by varying cv_{t+1} values and assuming that both cv_t and n_t were constant.

4.0 RESULTS

4.1 SURVEY LOGISTICS SUMMARY

Thirty and 32 transects were surveyed with a total of 1,227 and 1,032 quadrats for Dallain Point and Higgins Pass, respectively (Table 1, 2, 3). Mean transect length was 40.5 m (min. 11, max. 92 m) for Dallain Point and 32.1 m (min. 13, max. 59 m) for Higgins Pass (Tables 1, 2, 3). Surveys were completed with a total dive time of 1761 and 1291 minutes and an average 58.7 and 40.3 minutes per transect for Dallain Point and Higgins Pass, respectively (Table 3).

4.2 POPULATION SIZE AND WEIGHT STRUCTURE

Juvenile abalone (less than 50 mm shell length) made up 18 % and 23 % of the population for Dallain Point and Higgins Pass, respectively. The length frequency distribution of exposed abalone indicated that the majority of the animals sampled at both locations were less than 100 mm SL, with most abalone between 70 and 100 mm SL (Fig. 4, Table 4). Abalone ≥ 70 mm SL were 60 and 54 % of the population for Dallain Point and Higgins Pass, respectively. Pre-recruits represented 11% of the population at both locations and newly recruited animals (100 to 106 mm SL) to the "legal" size (when the fishery was open) represented 8 % and 5 % of the population for Dallain Point and Higgins Pass, respectively. The percentage of legal abalone (≥ 100 mm SL) was greater for Dallain Point (16 %) than for those Higgins Pass (8 %).

Overall mean length and weight for abalone collected on the intensive transects were similar between males and females at both locations. A sex ratio for males to females was 1:1 at both locations. Approximately 11 % of the population at both locations were sexually unidentifiable (immature). The power length-weight regressions for the males and females combined were $\ln(w) = -8.447 + 2.915 \ln(SL)$ ($r^2 = 0.984$, n = 130) for Dallain Point, and $\ln(w) =-8.657+ 2.948 \ln(SL)$ ($r^2 = 0.988$, n = 128) for Higgins Pass. There were no differences between these two regressions in slope and elevation ($p>0.05$, ANCOVA). The average SL and predicted mean weight for each size group are shown in Table 4.

Detectability expressed as a percent of exposed compared to total (exposed + cryptic) abalone was higher for sizes ≥ 70 mm SL than smaller abalone (Table 5, Fig. 5). Most cryptic animals were < 70 mm SL. These detectabilities were used as correction factors in the density calculations (Table 5).

Size frequencies and mean SL of exposed abalone generally decreased as depth increased (Fig. 6, 7). Adult abalone were more abundant < 5 m depths and no small juveniles (<40 mm SL) were found shallower than 1 m.

4.3 DENSITY ESTIMATES

There were no differences in abalone density between study areas for each size category (Table 6). Mean densities per transect ranged from 0 to 1.38 total exposed abalone per m^2 (Fig. 8). Abalone densities were generally highest in the 1-3 m depth range, although abalone were found at all depths surveyed (Fig. 9). There were no differences in abalone density between substrate types for either survey ($p>0.05$, Kruskal-Wallis non-parametric test).

4.4 PROJECTED SAMPLE SIZES FOR A GIVEN PRECISION

Table 9 provides estimates for the sample size required for a desired precision from 0.10 to 0.20. Clearly, the number of transects required for each area is larger for less abundant abalone in a specific size range than the total number of abalone (Table 7).

5.0 DISCUSSION

The percent "legal" sized abalone of total exposed abalone (16 %) and the mean density of legal sized abalone (0.065) were almost twice that for Higgins Pass (Table 4, 6). In general, the estimated mean densities of abalone found in this study appear to be similar to the densities found in previous surveys of abalone in the central coast and eastern Queen Charlotte Islands. Thomas and Campbell (1996) reported slightly higher densities from a survey of abalone at 25 sites further north along the B.C. coast conducted during 1993 (in this survey, the mean density of the total was 0.53, legals was 0.09; mean abalone length was 75 mm SL; percent legal was 16 %). Winther *et al.* (1995) reported similar results to the present survey, from a survey of abalone at 68 sites on the Queen Charlotte Islands conducted during 1994 (Mean density of the total was 0.30, legals was 0.063; mean abalone length was 77.6 mm SL, percent legal was 23.3 %). The present survey methodology was different from that reported by Thomas and Campbell (1996) and Winther *et al.* (1995) and the results probably can not be statistically compared without some understanding of how the results of the two survey methods should be calibrated. Comparison and calibration of the two survey techniques in the same area and time would be useful. The survey methods used by our study were an attempt to determine the density of abalone populations from the intertidal zone to approximately 8 m below chart datum in two localized regions in the central coast of B.C. The previous index-site surveys revisited index sites over a broad area to determine relative changes in abundance and population structure (e.g., Thomas and Campbell 1995). Although both survey types concentrated on areas of known abalone habitat, the index-site surveys generally concentrated closer to the "feed line" and did not survey all of the depth range examined in the present study. The results obtained using the transect method are probably not directly comparable to results obtained using the existing index-site survey method. Therefore, a correction factor may have to be developed to ensure comparison can be made between results obtained from both methods.

This study showed that there were some adult (>70 mm SL) abalone in the intertidal areas of both study areas, but at low densities. Abalone were most abundant between 1 to 3 m depth, and both density and mean abalone size declined with increasing depth at both study areas. Reduced density and size with increasing depth has been reported previously for *H.*

kamtschatkana (Sloan and Breen 1988). Abalone were found on all firm substrates in this survey, although they are capable of moving across sand or gravel (Sloan and Breen 1988). The decrease in mean length with depth could probably be attributed to adult abalone preferentially inhabiting shallow water habitats for spawning (Breen and Adkins 1980), although juveniles (< 50 mm SL) were found throughout the 1 - 7 m depths in this study. Other studies (Breen and Adkins 1979, 1982; Sloan and Breen 1988) also have reported that adults of northern abalone were usually found in depths less than 10 m and that juveniles were usually found deeper (1-15 m) than adults.

The Length/Weight relationship was nearly identical between locations and were similar to those determined for other locations on the BC coast (Quayle 1971, Breen and Adkins 1982). In future surveys, the time spent sampling abalone for length and weight would be better spent in surveying more transects in any given bed. Also, any mortality associated with abalone removal and transport to the weighing facility would be eliminated.

Future surveys and studies of abalone in these two study areas should involve estimates of growth, mortality and recruitment rates so that the productivity and surplus abalone production for possible exploitation can be determined. At present, because of the uncertainties in abalone productivity, ability to recover from previous exploitation, and comparisons with other surveys, there still remains conservation concerns for *H. kamtschatkana* in these areas as in the other index sites along the central coast of B.C. Depending on the type of study, the size of abalone to be enumerated, and the precision expected, the sample size required could range from 16 to over 300 transects. If high precision and sufficient power to show small changes in abalone density is required a more efficient survey method may have to be devised.

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Table 1. Dive summary for Abalone transects surveyed off Dallain Point during May 1995.
Substrate r = bedrock b = boulders, c = cobble, s = sand

Transect	Date	Time IN/OUT	Bottom Time	Depth (m) Min	Depth (m) Max	Transect Length (m)	Total # of Abalone	Density (No./m^2)	Subsrate
1	May 5	11:57 - 14:19	142	-0.67	6.58	92	24	0.261	r/b
2	May 6	13:30 - 14:45	75	-1.31	2.56	68	2	0.029	b/c
3	May 3	14:00 - 15:22	82	-1.19	4.15	48	15	0.313	r/b/s
4	May 8	08:51 - 09:17	26	-0.98	6.46	11	1	0.091	r
5	May 8	09:23 - 10:08	45	-1.74	6.80	22	24	1.091	r/b/c
6	May 8	10:37 - 11:01	24	-1.52	8.41	15	6	0.400	r/b/c
7	May 8	11:09 - 11:56	47	-1.28	6.40	39	6	0.154	r/b/c
8	May 8	13:02 - 14:45	103	0.06	6.28	93	12	0.129	b/c/r
9	May 9	08:28 - 09:52	104	-1.74	5.67	75	38	0.507	b/c
10	May 13	12:10 - 13:29	79	-1.74	5.00	62	15	0.242	b/c/g
11	May 9	12:30 - 13:34	64	-0.85	4.79	36	0	0.000	c/b/g
12	May 14	09:58 - 11:03	65	-1.46	6.28	44	35	0.795	r/c/b
13	May 13	10:19 - 10:58	39	-1.74	5.64	22	1	0.045	r
14	May 13	09:16 - 10:06	50	-1.71	6.68	42	6	0.143	c/b/r
15	May 12	12:20 - 12:54	34	-1.31	8.90	23	7	0.304	r
16	May 12	13:58 - 16:14	76	-0.91	7.86	49	24	0.490	b/c/g
17	May 12	11:19 - 12:03	44	-1.25	7.50	30	12	0.400	r/b/c
18	May 11	11:53 - 12:48	55	-1.65	7.25	36	44	1.222	b/r/c
19	May 11	10:57 - 11:46	49	-1.46	7.16	33	27	0.818	r
20	May 11	14:10 - 15:03	53	-1.37	5.21	28	11	0.393	c/b/r
21	May 11	15:31 - 16:41	70	-0.64	8.23	55	12	0.218	b/c/r
23	May 7	13:05 - 14:03	58	-1.55	5.09	27	29	1.074	r/c/b
24	May 14	12:24 - 13:14	50	-1.28	6.04	26	19	0.731	r/b
25	May 7	15:27 - 15:57	30	-1.49	4.39	14	4	0.286	r/b/s
26	May 6	11:12 - 12:00	48	-0.34	5.30	50	21	0.420	r/b
27	May 7	14:45 - 15:19	34	-1.52	7.10	31	10	0.323	r
28	May 7	10:22 - 11:05	43	-1.74	2.77	33	3	0.091	b/c/s
29	May 7	09:13 - 10:07	54	-1.04	6.68	35	25	0.714	r
30	May 6	09:06 - 10:12	66	-1.28	7.22	53	32	0.604	r/b/c
31	May 7	12:00 - 12:52	52	-1.71	7.59	35	10	0.286	r

Table 2. Dive summary for abalone transects surveyed in Higgins Pass during May 1996.
Substrate: r = bedrock, b = boulder, c = cobble, and sh = shell.

Transect	Date	Time In/Out	Bottom Time	Depth (m) Min	Depth (m) Max	Transect Length(m)	Total # of Abalone	Density (No./m²)	Substrate
1	15-May-96	14:10-14:52	42	-1.19	8.17	36	0	0.000	b/r
13	19-May-96	13:18-13:35	17	-2.16	7.80	24	0	0.000	b/sh/r
14	23-May-96	11:09-11:41	32	-0.67	7.50	38	4	0.105	m/sh/b
15	23-May-96	11:57-13:04	67	-0.91	9.69	40	4	0.100	b/c/sh
16	23-May-96	13:20-14:20	60	-1.52	8.11	25	12	0.480	b
17	22-May-96	11:57-12:23	26	-1.37	7.62	27	7	0.259	r/sh/c
18	22-May-96	11:18-11:45	27	-0.85	7.74	25	6	0.240	r/b
19	22-May-96	10:31-11:02	31	-1.10	7.71	34	6	0.176	r/b/c
20	21-May-96	15:50-16:32	42	-2.32	7.25	23	16	0.696	b/c/r
21	21-May-96	14:45-15:37	52	-2.10	7.47	45	34	0.756	b/c
22	21-May-96	13:18-13:53	35	-1.71	7.86	51	10	0.196	r/b
23	21-May-96	12:12-13:07	55	-1.16	7.99	48	46	0.958	b/r
24	21-May-96	11:37-12:05	28	-0.79	7.38	26	5	0.192	b/c
25	21-May-96	10:46-11;29	43	-1.10	7.93	27	22	0.815	b/c/r
26	19-May-96	12:10-13:03	53	-1.77	7.80	56	50	0.893	r/b
27	19-May-96	10:50-11:30	40	-1.37	8.26	43	22	0.512	r/b/sh
28	19-May-96	10:16-10:43	27	-1.13	7.96	29	4	0.138	r/b
29	19-May-96	9:43-10:08	25	0.40	8.17	23	16	0.696	r/b/c
30	18-May-96	13:50-14:09	19	-1.62	7.04	22	8	0.364	r/b
31	18-May-96	12:30-13:36	66	-1.40	7.59	48	30	0.625	b
32	18-May-96	11:28-11:45	17	-1.22	8.81	14	0	0.000	r
33	18-May-96	09:50-10:22	32	-0.98	8.23	20	7	0.350	r/b/c
34	18-May-96	10:30-10:43	13	-1.52	7.77	13	0	0.000	r
35	18-May-96	10:55-11:14	19	-0.15	8.66	13	4	0.308	r
36	17-May-96	15:46-16:22	36	-1.46	8.23	38	10	0.263	b/c/r
37	17-May-96	14:37-15:19	42	-1.16	7.44	39	15	0.385	r/b
38	17-May-96	13:32-14:28	56	-1.43	7.47	32	10	0.313	r/b
39	17-May-96	12:55-13:20	25	-1.62	7.71	19	7	0.368	r/b
40	17-May-96	11:11-12:10	59	-1.22	7.83	39	54	1.385	b/r
41	17-May-96	09:50-10:55	65	-1.68	8.08	26	10	0.385	r/b
42	15-May-96	10:44-12:21	97	-1.68	7.32	59	13	0.220	r
43	15-May-96	09:48-10:31	43	-2.59	8.65	30	9	0.300	b/c

Table 3. Summary statistics of transect survey of emergent abalone from Dallain Point and Higgins Pass, May 1995, 1996, respectively. Values in brackets are standard errors.

Details per transect	Dallain Point	Higgins Pass
Number of transects	30	32
Mean Depth (m)	2.59 (0.15)	3.34 (0.14)
Mean quadrats or length (m)	40.5 (3.8)	32.1 (2.1)
Mean minutes	58.7 (4.6)	40.3 (3.3)
Mean minutes/quadrat	1.54 (0.06)	1.28 (0.08)

Table 4. Mean shell length (mm SL) and mean predicted weight (g) of exposed abalone of different size groups for all transects from survey of Dallain Point and Higgins Pass, May, 1995 and 1996, respectively. Total for all sizes include abalone < 70 mm SL. N = number of abalone. Values in brackets are standard errors.

	Dallain Point				Higgins Pass			
Size group mm SL	N	% of total	Shell length	Weight	N	% of total	Shell length	Weight
Mature ≥ 70	222	60.00	91.2 (0.9)	118.1 (3.5)	196	53.85	87.6 (0.8)	83.9 (2.4)
Prerecruit 92 - 99	39	10.54	95.4 (0.3)	126.9 (1.4)	41	11.26	95.3 (0.4)	102.2 (1.1)
Legal ≥ 100	61	16.49	109.1 (0.9)	189.5 (4.9)	30	8.24	107.0 (1.0)	144.3 (4.3)
New recruit 100-106	30	8.11	103.1 (0.3)	158.9 (1.5)	17	4.67	103.1 (0.5)	128.5 (1.8)
Total all sizes	370	100.00	74.8 (1.3)	80.4 (3.2)	364	100.00	69.7 (1.2)	53.4 (2.2)

Table 5. Detectability, as percent of total abalone by road size category (mature and immature) for cryptic or exposed animals from intensive samples at all depths from Dallain Point 1995 (4 transects) and Higgins Pass 1996 (6 transects).

Details	Dallain Point		Higgins Pass	
	Number	% of Total	Number	% of Total
Immature abalone < 70 mm SL				
Cryptic	8	15.68	22	33.85
Exposed	43	84.31	43	66.15
Total	51		65	
Mature abalone ≥ 70 mm SL				
Cryptic	2	2.78	0	0.0
Exposed	70	97.22	63	100.00
Total	72		63	
All sizes of abalone				
Cryptic	10	8.13	22	17.19
Exposed	113	91.87	106	82.81
Total	123		128	

Table 6. Mean density (number per m^2) of exposed abalone by size group for all depths from Dallain Point and Higgins Pass, May, 1995 and 1996, respectively. Values in brackets are standard errors.

Size group mm SL		Dallain Point	Higgins Pass
Unadjusted			
Mature	≥ 70	0.228 (0.045)	0.234 (0.048)
Prerecruit	92 - 99	0.037 (0.009)	0.049 (0.013)
Legal	≥ 100	0.064 (0.064)	0.037 (0.007)
New recruit	100-106	0.027 (0.009)	0.018 (0.004)
Total	all sizes	0.391 (0.057)	0.429 (0.067)
Adjusted for detectability			
Mature	≥ 70	0.235 (0.046)	0.234 (0.048)
Prerecruit	92 - 99	0.038 (0.009)	0.049 (0.013)
Legal	≥ 100	0.065 (0.023)	0.037 (0.007)
New recruit	100-106	0.027 (0.009)	0.018 (0.004)
Total	all sizes	0.425 (0.062)	0.519 (0.081)
Number of transects		30	32

Table 7. Estimates of the sample size (number of transects) required for a given precision (cv = se/mean) for Dallain Point (original transect number = 30) and Higgins Pass (original transect number = 32).

Abalone	Dallain Point						Higgins Pass					
size	Density		se/mean	Predicted sample size			Density		se/mean	Predicted sample size		
mm SL	mean	se	cv =	0.10	0.15	0.20	mean	se	cv =	0.10	0.15	0.20
Unadjusted, exposed only												
≥ 70	0.228	0.045	0.20	117	52	29	0.234	0.048	0.21	135	60	34
92-99	0.037	0.009	0.24	178	79	44	0.049	0.013	0.27	225	100	56
≥100	0.064	0.023	0.36	387	172	97	0.037	0.007	0.19	115	51	29
100-106	0.027	0.009	0.33	333	148	83	0.018	0.004	0.22	158	70	40
All sizes	0.391	0.057	0.15	64	28	16	0.429	0.067	0.16	78	35	20

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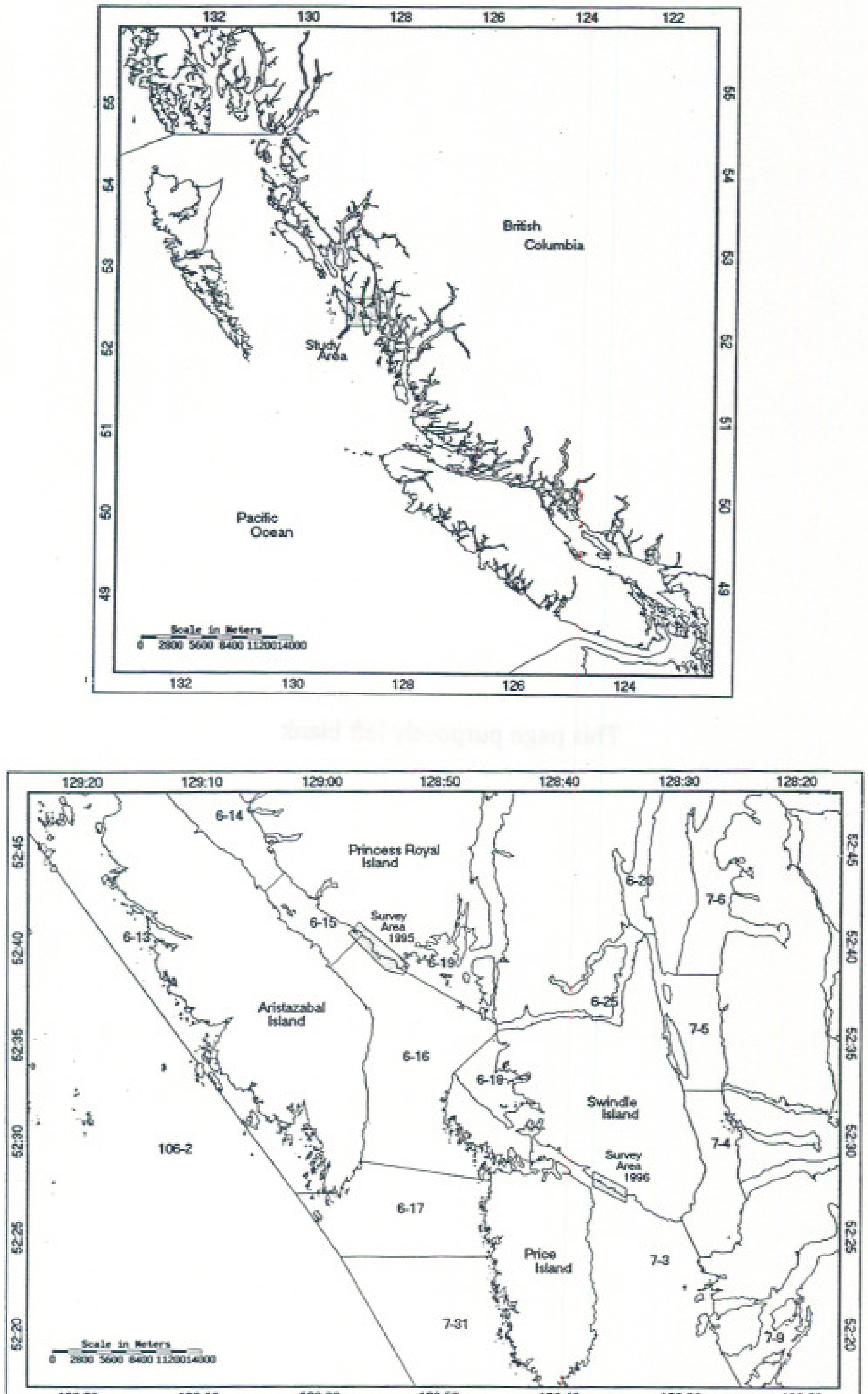

Fig. 1. General location of study areas along British Columbia coast.

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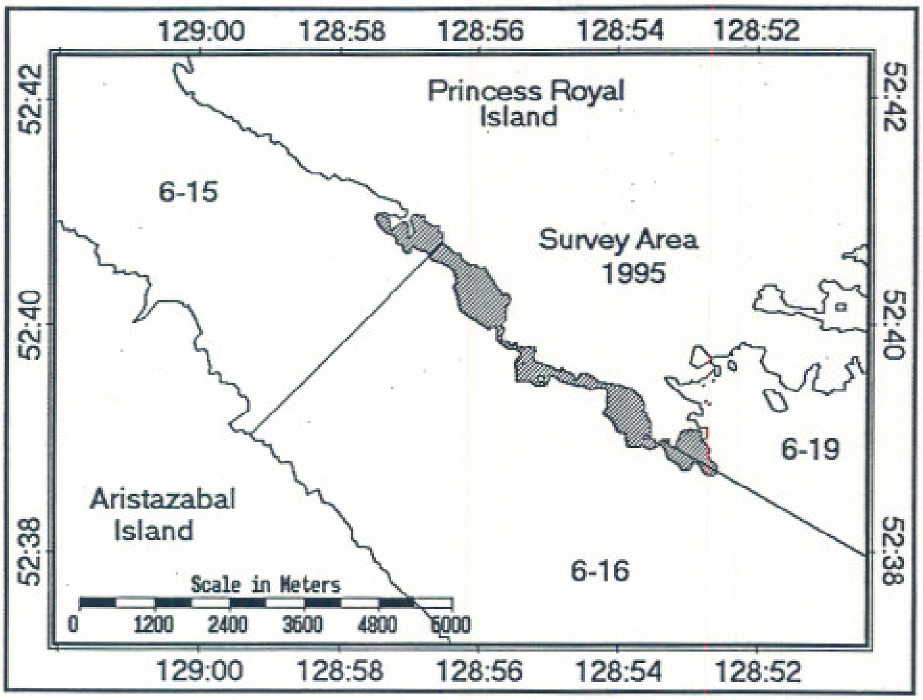

Fig. 2. Location of study area near Dallain Point.

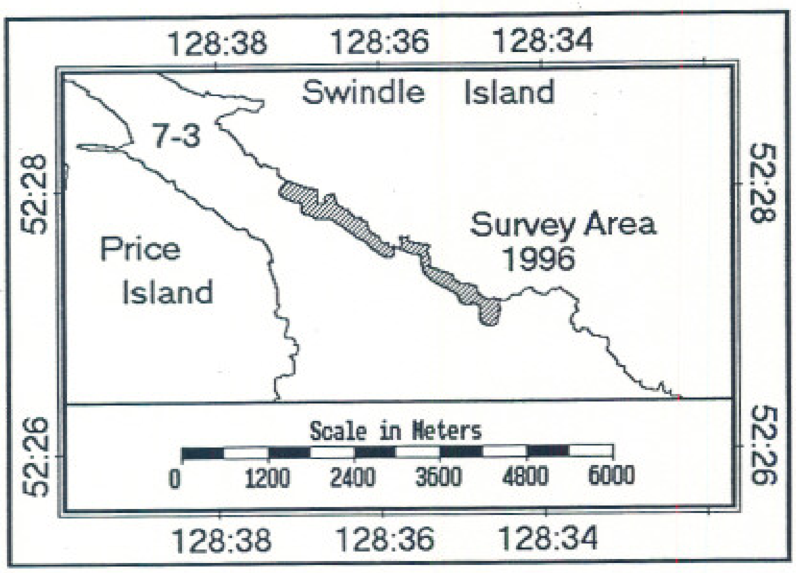

Fig. 3. Location of study area near Higgins Pass.

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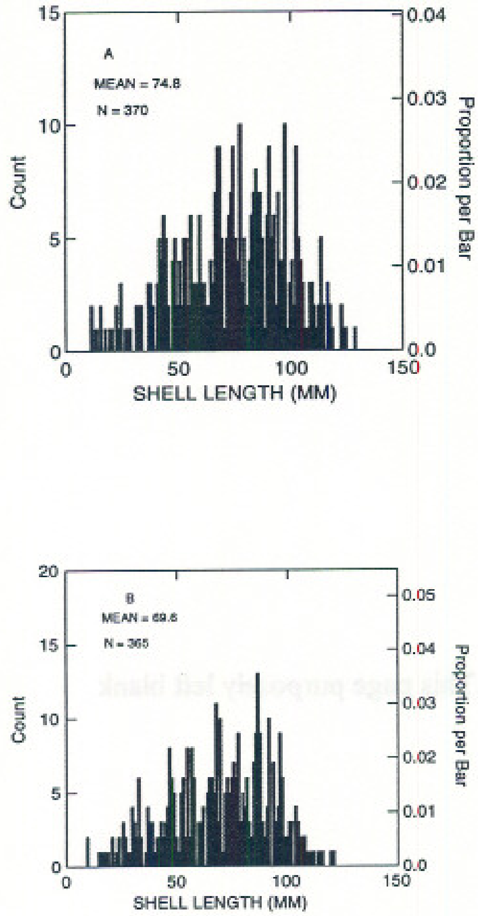

Fig. 4. Size frequencies of exposed abalone from (A) Dallain Point , May 1995, and (B) Higgins Pass, May 1996.

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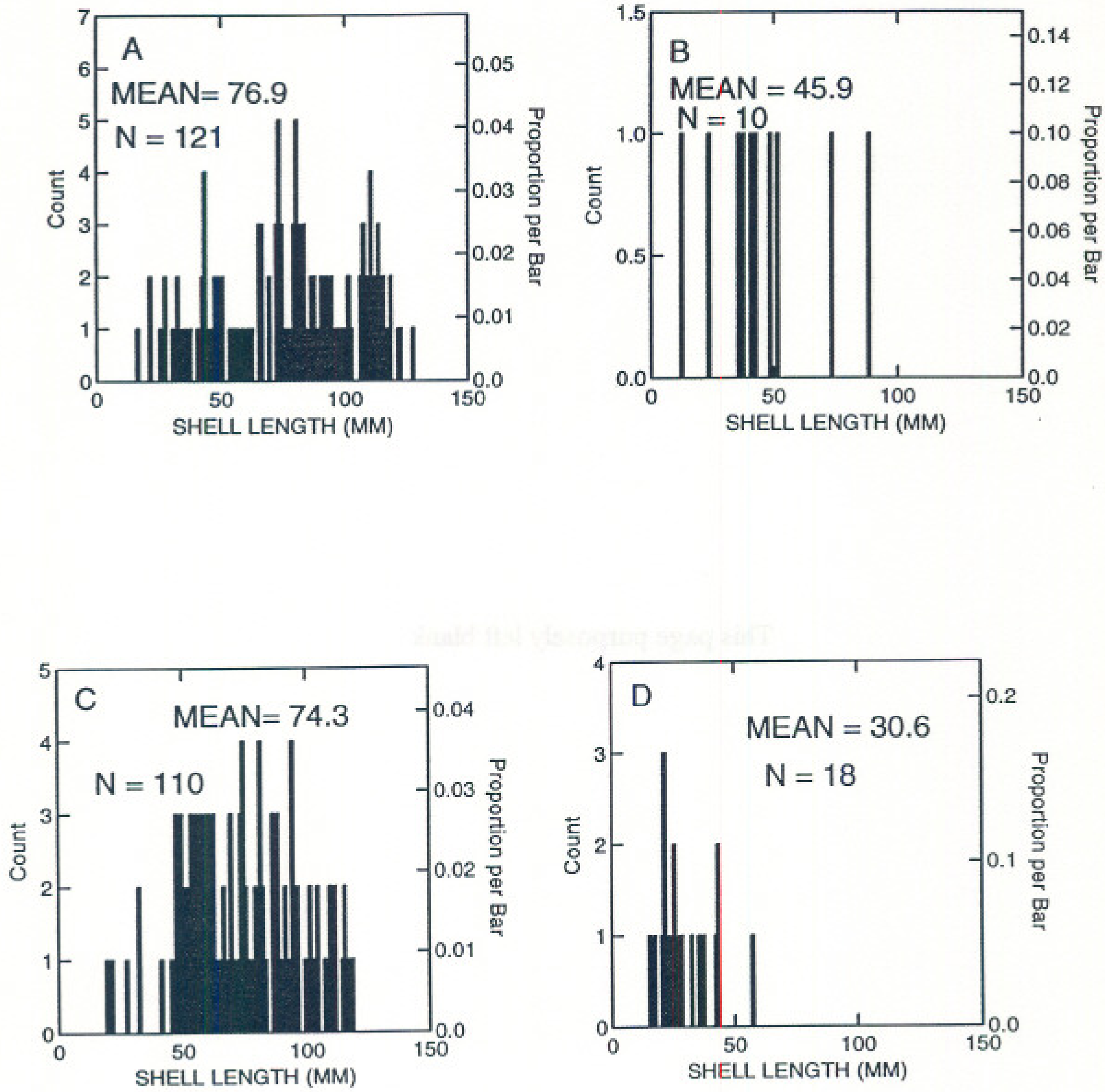

Fig. 5. Size frequencies of (A) exposed and (B) cryptic abalone from intensive samples at Dallain Point, May, 1995, and (C) exposed and (D) cryptic abalone from intensive samples at Higgins Pass, May, 1996.

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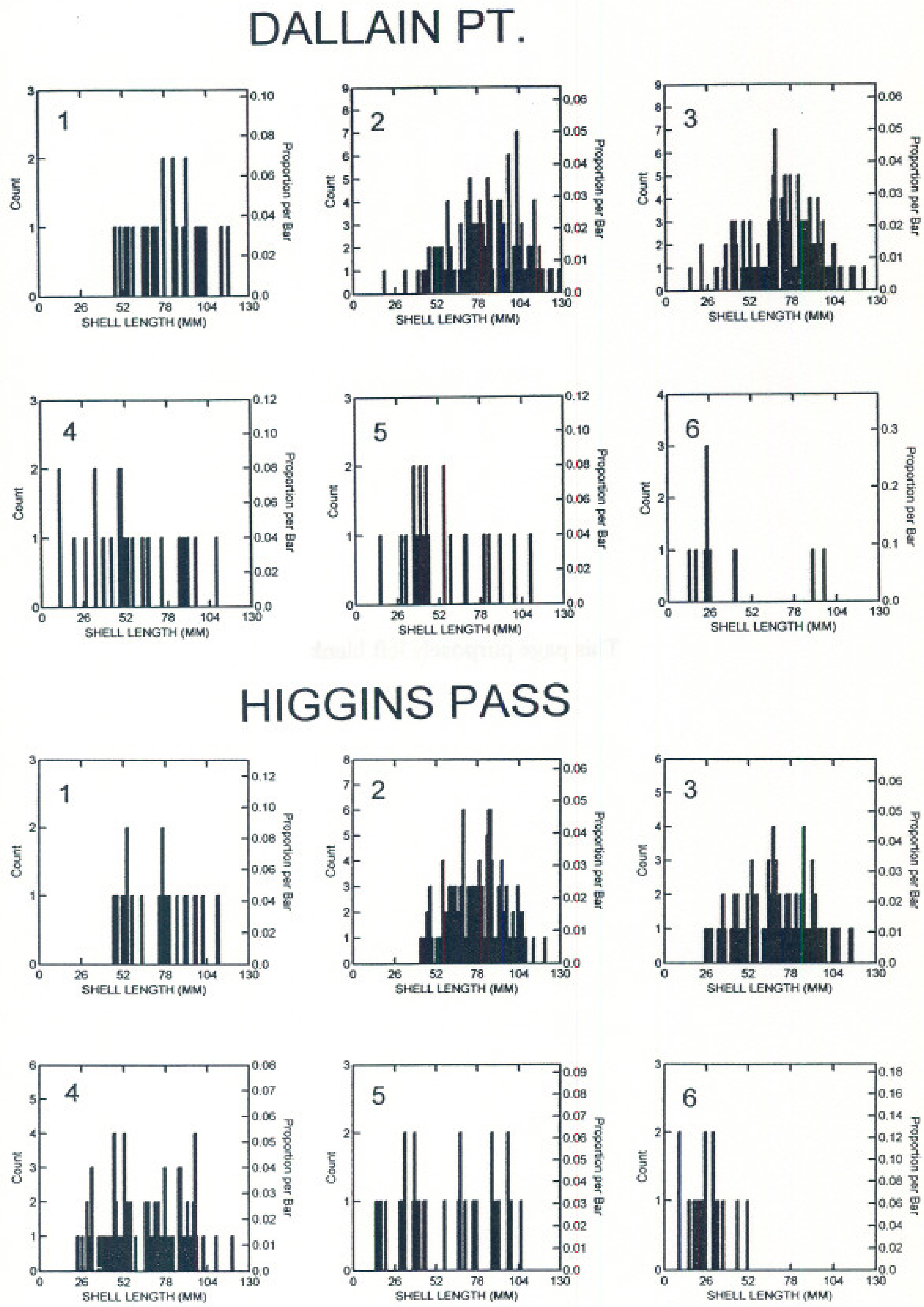

Fig. 6. Size frequencies by depth category of exposed abalone from Dallain Point, May, 1995, and Higgins Pass, May, 1996. Depth category (1) < 0 m, (2) 0 - 1.50 m, (3) 1.51 - 3.00 m, (4) 3.01 - 4.50 m, (5) 4.51 - 6.00 m, (6) 6.01 - 7.50 m.

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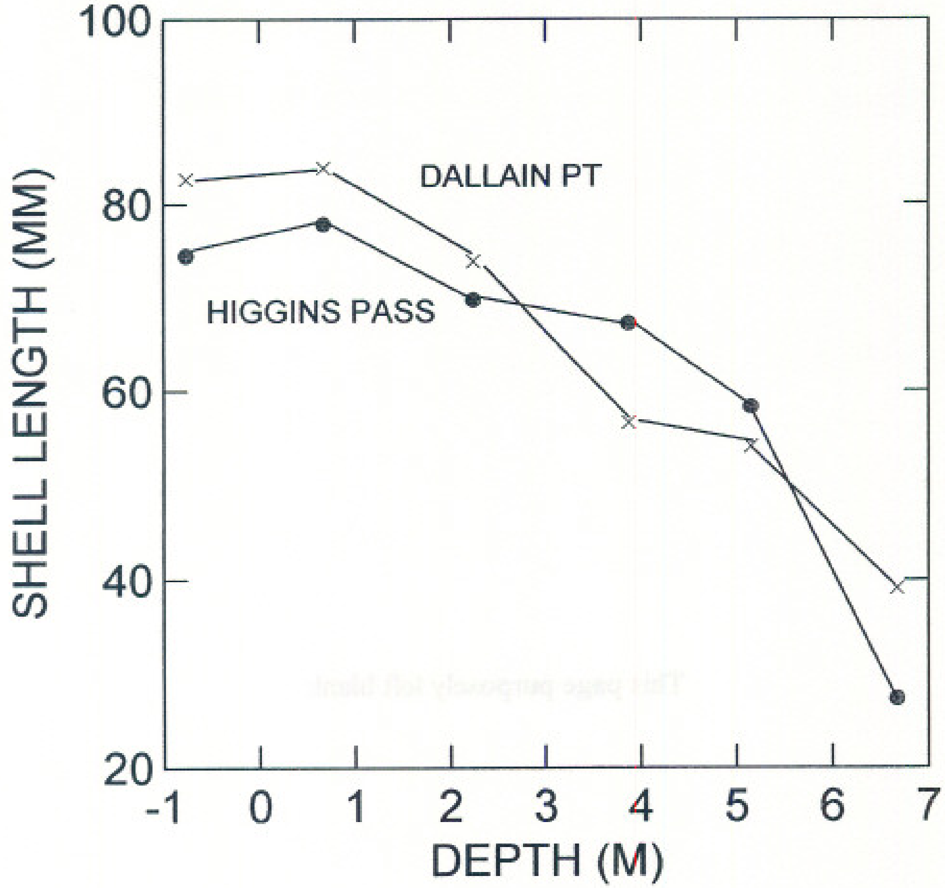

Fig. 7. Mean shell length of exposed abalone by depth from Dallain Point and Higgins Pass, May, 1995 and 1996, respectively.

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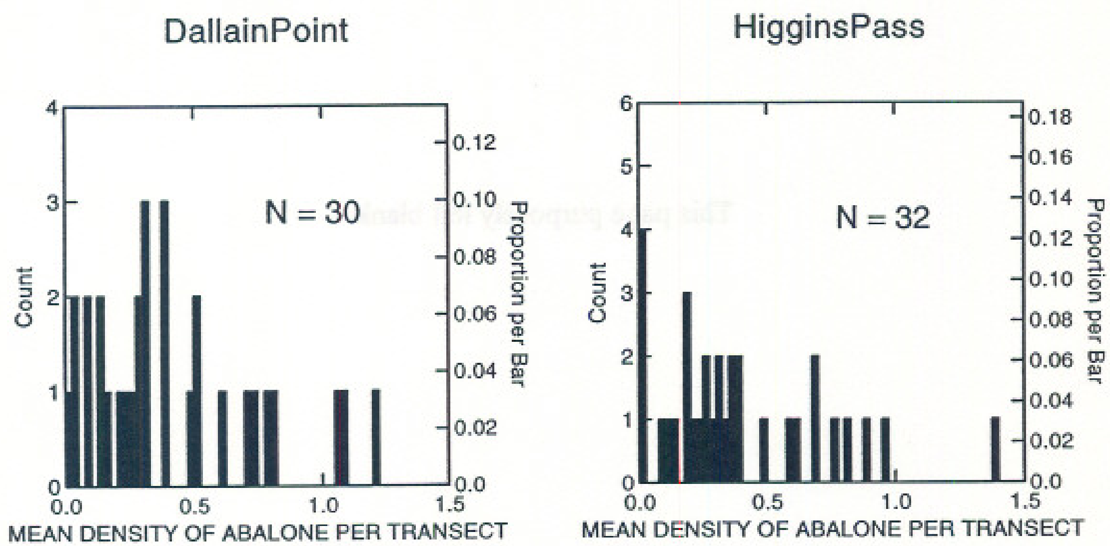

Fig. 8. Frequency distribution of mean densities (number per m^2) of exposed abalone per transect for all depths combined at Dallain Point and Higgins Pass, May, 1995 and 1996, respectively.

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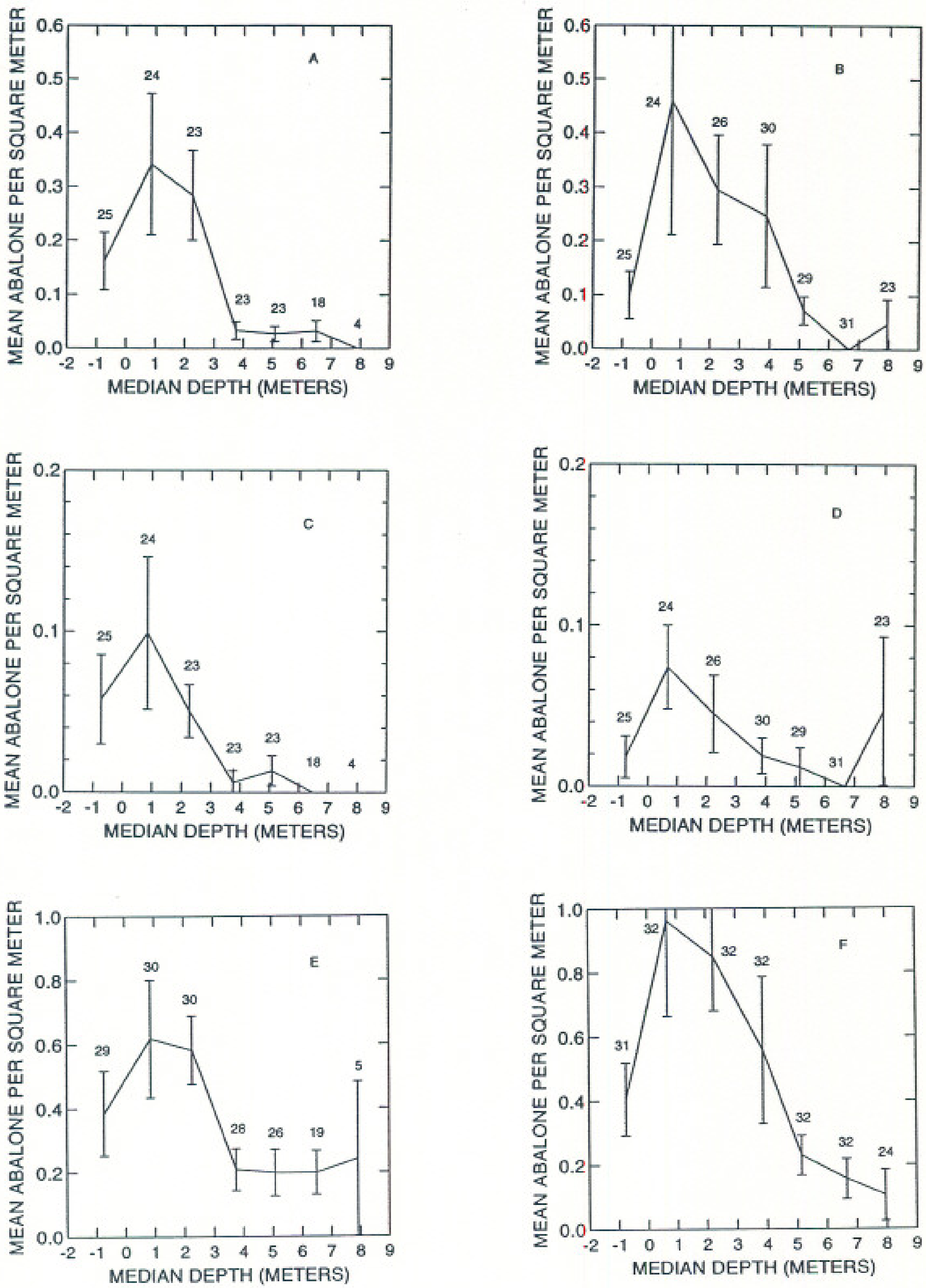

Fig. 9. Mean densities of exposed and cryptic abalone size group by depth (A) ≥ 70 mm SL for Dallain Point, (B) ≥ 70 mm SL for Higgins Pass, (C) ≥ 100 mm SL for Dallain Point, (D) ≥ 100 mm SL for Higgins Pass (E) all sizes for Dallain Point, and (F) all sizes for Higgins Pass. Vertical lines are ± 1 SE. Numbers are number of transects.

Fig. 9. Mean densities of exposed and cryptic abalone size group by depth (A) ≥ 70 mm SL for Dallain Point, (B) ≥ 70 mm SL for Higgins Pass, (C) ≥ 100 mm SL for Dallain Point, (D) ≥ 100 mm SL for Higgins Pass (E) all sizes for Dallain Point, and (F) all sizes for Higgins Pass. Vertical lines are ± 1 SE. Numbers are number of transects.