HABITAT USE AND SEASONAL CHANGES IN THE RELATIVE ABUNDANCE OF THE RED ROCK CRAB, *CANCER PRODUCTUS*, IN INDIAN ARM

Silvester Benny Pratasik

Ir. (Fish.), Sam Ratulangi University, Manado, Indonesia, 1983

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Examining Committee:

Chair: Dr. B.A. McKeown, Professor

Dr. E.B. Hartwick, Associate Professor, Senior Supervisor,
Department of Biological Sciences, SFU

Dr. A.S. Harestad, Associate Professor,
Department of Biological Sciences, SFU

Dr. B.D. Roitberg, Associate Professor,
Department of Biological Sciences, SFU

Dr. G.S. Jamieson, Head of Shellfish Section,
Department of Fisheries and Oceans,
Pacific Biological Station, Nanaimo, B.C.
Public Examiner

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Habitat use and Seasonal Changes in the relative abundance of the red rock crab, Cancer productus, in Indian Arm

Author: ______________________

(signature)

S.B. Pratunk

(name)

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ABSTRACT

My objectives were to determine habitat use and relative density of red rock crabs, *Cancer productus*, during different seasons with consideration of sex, size, behavior, migration and reproduction. My study was conducted at six sites in the shallow subtidal to depths of 12 m in Indian Arm, British Columbia. Data were collected by SCUBA using 2 m wide, 15 m long belt-transects randomly placed within four selected depth intervals. Crab samples were also collected using a 15-min random search technique. Five commercial crab traps were operated in areas deeper than 12 m.

My results showed that bottom sediment was mainly comprised of a mixture of coarse sand and shell fragments at five study sites and fine sand at the other site. Nine different habitat types were classified in this study. Red rock crabs mostly used coarse sand-sparse cobble habitat and rarely fine sand habitat. Habitat use changed over the seasons. Males and females preferred different habitat types in different seasons. The behavior, sex ratio and mean size of crabs also changed with seasons. These changes may be associated with the seasonal changes in temperature, sex segregation and migration.

Dedication

This work is dedicated to my wife, Siska, who provided encouragement and accompanied me in all the bad and good moments through all my study.

Acknowledgments

I would like to thank my senior supervisor, Dr. Brian Hartwick, for his patience, encouragement in developing my independent research through the increase in diving skills and criticisms in reviewing several drafts of my thesis.

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Financial support was provided by Eastern Indonesian University Development Project (EIUDP) during my study at Simon Fraser University.

Finally, I thank my wife, Siska, for her care, patience, understanding and mental support throughout my whole study at SFU.

Table of Contents

List of Tables

List of Figures

I. INTRODUCTION

The red rock crab, *Cancer productus*, (Brachyura) is distributed along the west coast of North America from Kodiak Island (Alaska) to San Diego (California). In British Columbia, this species is widespread and common (Hart, 1982). It occurs in two major types of habitats: bays and estuaries and protected rocky coast (Knudsen, 1964). Red rock crabs inhabit the low intertidal and subtidal zones to depths of 79 m, and are often observed half-buried in sand or under rocks (Morris *et al.*, 1980; Ricketts and Calvin, 1968; Hart, 1982). Previous reports document that red rock crabs occupy shallow water to 112 m deep (MacKay, 1943).

Characteristics of *Cancer productus* have been described by Ricketts and Calvin (1968) and Hart (1982). *C. productus* is a large crab and therefore useful for food; however, the species is not plentiful enough to be commercially important (Ricketts and Calvin, 1968). In British Columbia, the adults are taken in small numbers by fishermen for personal use, although this crab and three other *Cancer* species, *C. anthonyi*, *C. antennarius* and *C. gracilis* are commercially exploited in Mexico (Carvacho and Bonfil, 1989).

In British Columbia, the red rock crab is often a by-catch in traps for Dungeness crab, *C. magister*, and is often thrown back into the sea or left on shore to die (Dahlstrom and Wild, 1983). The average annual catch for the commercial Dungeness crab fisheries from 1980-1991 was 1431.35±135.53 tonnes which was a combined crab catch for Dungeness, tanner, king and red rock crabs (Joyce, 1992). In British Columbia, red rock crabs support a sport fishery; however, records of catches have not been kept for sport fishing (Dept. of Fisheries & Oceans, pers. comm.).

Cancer productus forms the prey of several predators, such as large rock fish (*Sebastes sp.*), octopus, herring gulls (*Larus sp.*), sea otters (*Enhydra lutris*), fishers (*Martes pennanti*), mink (*Mustela vison*), raccoons (*Procyon lotor*) and some shark species (Estes *et al*. 1981; VanBlaricom and Estes, 1988; Knudsen, 1964; Cowan and Guiguet, 1965; Morris *et al*., 1980; Talent, 1982). In fall and winter, the juveniles of *C. productus*, common in Southern California, are eaten in large number by sculpin (*Scorpaena guttata*), sand bass (*Paralabrax nebulifer*), and kelp bass (*P. clathratus*). Such predation might explain the nocturnal of activity of smaller individuals. Nevertheless, fishers and raccoons are nocturnal predators for intertidal *C. productus*.

Furthermore, in Elkhorn Slough, California, *C. productus* is an important food for gray smoothhound sharks (*Mustelus californicus*) and brown smoothhound sharks (*Mustelus henlei*) (Talent, 1982). They account for 54% of the total volume of food items of the gray smoothhounds, and are the most important crustacean preyed on by brown smoothhound sharks. *C. productus* was also one of the major prey of *Octopus dofleini*, and abundance of the predator was correlated to crab availability (Robinson and Hartwick, 1986).

Cancer productus is a carnivore and preys on molluscs. It also feeds on barnacles attached to pilings and on dead fish or other animal matter available in its habitat (Knudsen, 1964). Laboratory studies on both the adult and larva stage of red rock crabs have examined predatory aspects, the behavior, the capability of this crab to prey on some mollusc species, and prey selection (Spight, 1976; Zipser and Vermij, 1978; Boulding and Labarbera, 1986; Appleton and Palmer, 1988; Boulding and Hay, 1984; Shimek, 1983; Morris *et al.*, 1980; Rumrill *et al.*, 1985). Published field observations on red rock crabs are very limited. In some studies, abundance has been indirectly assessed (Hartwick *et al.*, 1981 and Robinson and Hartwick, 1986). Other studies have examined reproduction and foraging activities but have been limited to short studies in the intertidal area (Knudsen, 1964; Robles *et al.*, 1989; and Hines, 1991). In addition, preliminary diving surveys in several locations at Indian Arm (December 1990-April 1991) suggested a biased sex ratio with only male crabs being encountered (pers. obs.). Little information is available on other aspects of the natural history of this crab.

The distribution of a species may be limited by the behavior of individuals in actively selecting their habitat (Krebs, 1985). In fact, a good habitat is generally reflected by a higher abundance compared to a poor one. The importance of a habitat to an organism can be deduced from the species distribution over time and space and from the species demographic attributes (Begon *et al.*, 1990). In benthic communities, populations may be limited by the availability of suitable benthic habitat (Fogarty and Idoine, 1986). Thus, the characteristics of the sea bottom may be important in determining abundance. Relationships between benthic communities and particular ecological factors, e.g. substrate and depth, have been described (Jones, 1950; Tenore and Coull, 1980; McCall and Tevesz, 1982; Knott *et al.*, 1983; Long and Lewis, 1987). Habitat suitability is a surrogate measure of fitness because females produce more young in a more suitable habitat than they do in less suitable one. The suitability of a habitat is partly a function of the density of other individuals, because overcrowding can reduce the suitability (Krebs, 1985). In applied ecological studies, a habitat suitability index (HSI) is often used to estimate the quality of a habitat for particular species. This index generally includes information on environmental quality in relation to its carrying capacity, how well the habitat will meet the known physiological and behavioral needs of a species, such as food availability, physical factors (temperature, salinity, light, exposure to air and desiccation, oxygen content, nutrient, current, tides and characteristics of the substrate) and biological factors (predation and competition) (Jones, 1950 and Anonymous, 1980).

My study is intended to describe aspects of the natural history of *C. productus* and in particular to provide basic information on the density of red rock crab, *Cancer productus*, in relation to different physical habitat characteristics and seasons, in Indian Arm, British Columbia, Canada. My objectives were:

1) to describe the physical characteristics of crab habitats in Indian Arm;

2) to examine habitat preference of crabs during different seasons;

3) to estimate relative density of crabs and the sex ratio during different seasons; and

4) to describe crab behavior in relation to habitat types and seasons.

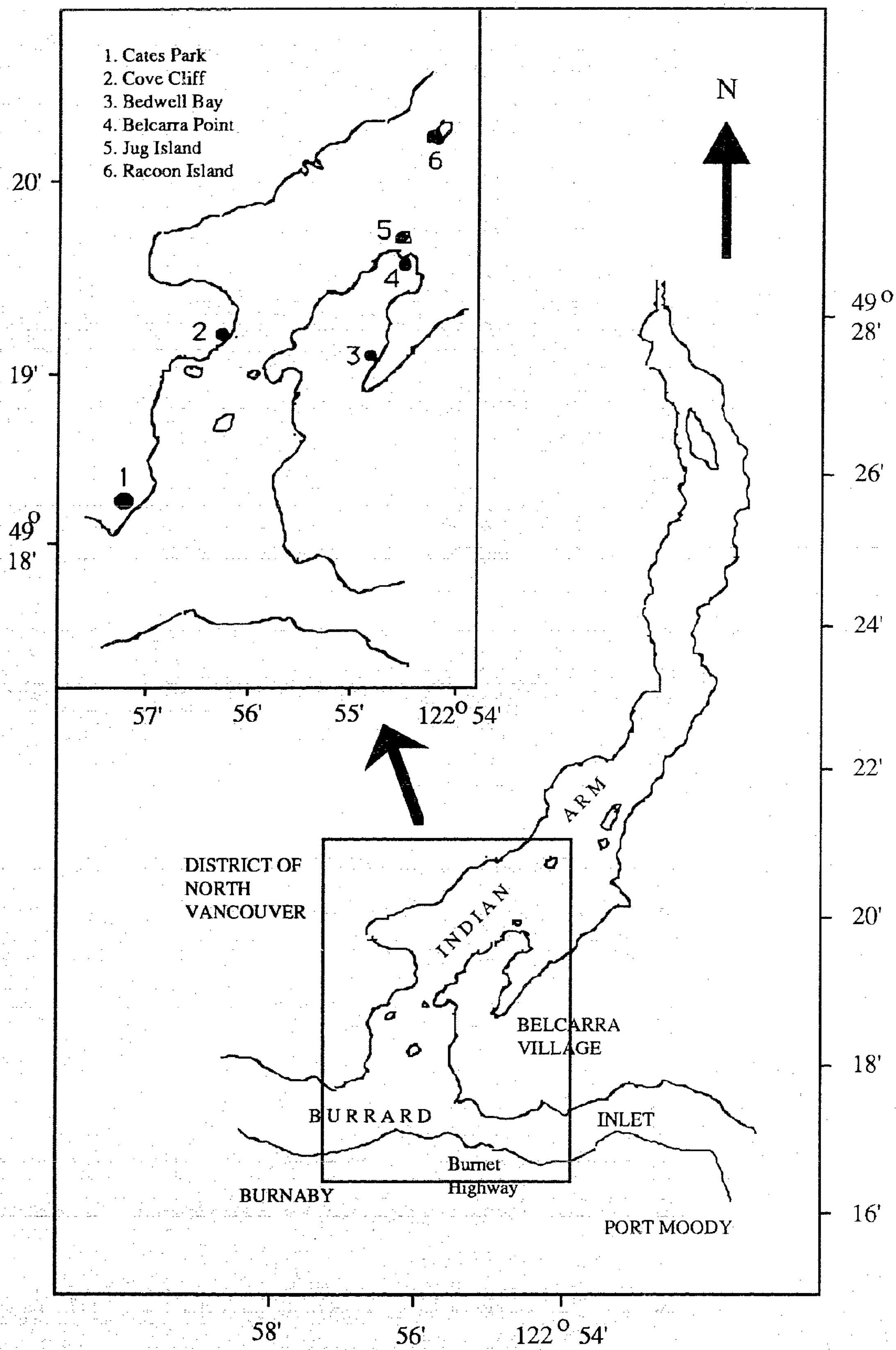
II. STUDY SITE DESCRIPTIONS

Indian arm is a south-north oriented fjord and is about 22.1 km long with an average width of 1.3 km. It joins Burrard Inlet at 49°18'10"N and 122°56'20"W (Gilmartin, 1962). Although crab densities played a role in selection of study sites, proximity to Burrard Inlet was also a factor because of economics of travel time. Study sites were also selected to ensure along-shore movements were detected. Six study sites were selected from the southern part of the arm: the mouth at Cates Park (49°18'17"N and 122°57"3"W), Belcarra Point (49°19'50"N and 122°55'13"W), Cove Cliff (49°19'18"N and 122°57'54"), west to north west of Racoon Island (49°20'30"N and 122°55'46"W), south east of Bedwell Bay (49°19'4"N and 122°55'W) and eastern Jug Island (49°19'52"N and 122°55'9"W) (Fig. 1).

These sites provide a number of different habitat types. Cates Park is mixture of sandy beach with rocky areas in which shallow subtidal is characterized by sand with dense cobble and occupied by some *Laminaria* sp. and eelgrass, *Zostera* sp.. The larger habitat components become sparser with depth leading finally to sand and shell bottom.

Belcarra Point is a part of the mainland that faces the north east of Jug Island. The upper intertidal is occupied by mussel beds, *Mytilus edulis*, and the low intertidal area

Fig. 1. Map of Indian Arm, British Columbia. Study sites are indicated by the numbered black dots.


1. Cates Park
2. Cove Cliff
3. Bedwell Bay
4. Belcarra Point
5. Jug Island
6. Racoon Island
1
2
3
4
5
6
20'
19'
49° 18'
57'
56'
55'
122° 54'
N
49° 28'
26'
24'
22'
20'
18'
16'
DISTRICT OF NORTH VANCOUVER
INDIAN
ARM
BELCARRA VILLAGE
BURRARD
INLET
Burnet Highway
BURNABY
PORT MOODY
58'
56'
122° 54'

and shallow subtidal predominantly by *Chlorella sp.* and *Laminaria sp.* This site is characterized by rock boulder followed by sandy areas with sparse small boulder, a rock outcrop with a thin layer of sand in the deeper site, and then flat sandy area. The area, close by to the south, is a flat sandy area with *Laminaria sp.* at the shallow part and a boulder area with a steep edge on the north.

Cove Cliff is characterized by rocky shores with an extensive mussel bed and *Laminaria sp.* in the intertidal. The subtidal zone starts with a shell-sand bottom with broken mussels followed by sand boulder and rock outcrop covered by a thin layer of sand, and flat sandy bottom in the deeper parts.

Racoon Island is an isolated island surrounded by deep water and characterized by a rocky shore with *Laminaria* sp. to about 3 m below 0 on the chart datum. This is followed by sand with dense cobble and some large boulders down to 10 m, and then a flat sandy bottom at depth dropping off to deep water.

Bedwell Bay has a rocky wall followed by sand-muddy bottom with a small area of eelgrass, *Zostera* sp., at 2 - 4 m below 0 on the chart datum, and then by *Gracillaria* sp. in the deeper areas. The eastern part is characterized by a compact sand bottom with large boulders inhabited by mussels, barnacles and seaweeds (*Fucus* sp.).

Jug Island is a small island close to Belcarra Point characterized by rock boulder shore with *Laminaria* sp. in the shallow water down to shell sand bottom. In the deeper parts, there is sand with sparse cobble. In the north, there are some boulders, a rocky area in the shallow water, and a sandy area with *Laminaria* sp. across to the mainland.

Selection of the study sites was based on spring 1991 crab densities estimated qualitatively by exploration SCUBA dives. Sites with high densities were identified and selected. At each site permanent shore level markers were established beginning at 0 on the chart datum and running at right angles to the shore. Cement blocks were placed along this line at depths of 0, 3, 6 and 9 m in which the distance between two cement blocks represented the depth intervals.

III. METHODS

1. Sediment analysis

Bottom samples were taken by SCUBA from the six study sites, Cates Park (CP), Belcarra Point (COP), Cove Cliff (CC), Racoon Island (RI), Bedwell Bay (BB) and Jug Island (JI). Using a one-liter plastic jar, sediment samples were taken at different depths within each of the 3 m depth intervals by hand scooping the bottom surface. These sample depths were previously randomly determined. Five samples were collected from Cates Park and Cove Cliff, three from Belcarra Point, Racoon Island and Jug Island, respectively, and only one from Bedwell Bay due to the similarity in sediment structure in that area. These samples were brought to the laboratory for analysis.

Dry sieving was used to analyze the sediment samples (Holme and McIntyre, 1984). Samples were dried in a drying oven at 60-70^{o}C and then weighed ($\pm$ 0.01 g). They were then screened through a series of sieves to do the scale grading of the particle sizes. Seven mesh sizes of sieves were used (Table 1). The sieves were nested in order of decreasing mesh size, placed in the Ro-Tap on a Fisher Whaler Shaker, and samples were shaken for 15 minutes. The particles retained on each screen were removed and weighed. Particles stuck in the screen meshes were removed by two sorts of brushes, a wire brush and a horse-haired brush, over

Table 1. Screen sizes used for sediment analysis.

U.S. Standard Sieve mesh	Mesh size (mm)	Description
6	3.36	pebble
8	2.38	granule
18	1.00	very coarse sand
35	0.50	coarse sand
50	0.30	medium sand
80	0.177	fine sand
140	0.105	fine sand
200	0.074	very fine sand
< 200	< 0.074	silt and clay

Source: Folk (1980)

a piece of paper. Particles passing through the smallest screen (No. 200) were treated as silt and clay. Large particles (> 3.36 mm) retained on screen no. 6 were not included in substrate description. Abundance of larger fractions (> 64 mm diameter) were qualitatively estimated in the field, and recorded as part of the elements that constitutes the habitat characteristics. Grain sizes included in sediment description were then graded according to Holme and McIntyre (1984). Samples weighed from each screen were expressed as percent of total weight.

2. Crab sampling

Crab sampling was utilized a permanent depth line marker laid on the bottom of each study site. Each vertical line, perpendicular to the shore, was divided into four parts which represented four 3 m depth intervals calculated from zero tide on the chart and passing through different habitat types. Data were collected between early summer 1991 to early summer 1992. Two study sites were visited every week, and therefore all study sites were visited in three weeks. Crabs were sampled by dives using two methods: a 2 m wide 15 m long transect line and a random collection. For the transects roughly parallel to the shoreline, four specific depths were randomly selected, one in each depth interval. Sampling was limited to four transects to avoid

Table 2. Wentworth grade classifications

Name		Grade Limits mm	µm
Boulder		> 256	
Cobble		256≥64	
Pebble		64≥4	
Granule		4≥2	
Very coarse sand		2≥1	2,000≥1,000
Coarse sand		1≥0.5	1,000≥500
Medium sand	Sand	0.5≥0.25	500≥250
Fine sand		0.25≥0.125	250≥125
Very fine sand		0.125≥0.062	125≥62
Silt		0.062≥0.004	62≥4
Clay		< 0.004	< 4

Source: Holme & McIntyre (1984)

repetitive dives and allow time for a random collection. At Bedwell Bay, only two transects were conducted on each trip due to the similarity of the habitat type. Two divers worked side by side along the transect starting from the permanent vertical line in the direction against the current to ensure good visibility in the water column. All crabs caught were put into a goody bag. Underwater lights were also used to illuminate crabs in crevices and between rocks in the rocky areas. During all dives, habitat types and crab positions were recorded. Three types of behavior were noted: crabs free on the bottom, crabs semi-buried and crabs buried. After completing the transects, a 15-min random dive was conducted, in which all encountered crabs were taken. Behaviors were again recorded to compare with the data from the transects. All crabs caught were brought to the boat for further examination.

The present habitat study was part of a larger research program which included the tag recapture of crabs (Basahi, pers. comm.). To ascertain if vertical movement occurred, five commercial traps were set overnight in deep sites (20-30 m) that were not surveyed by diving. Thus, an opportunity was available to use recapture data to determine movements of crabs.

3. Environmental parameters

The bottom temperature was recorded at 10 m below 0 depth on the chart datum using digital temperature readings on the diving equipment. Water samples were also collected using a 100 ml bottle but salinity records could not be taken. Instead, I used the salinity records taken by Vancouver Aquarium at 14 m in Burrard Inlet, about 13 km from the mouth of Indian Arm. These salinity values were adjusted for the southern part of Indian Arm using distributions of mean salinity with depths and the change rate of surface salinity with distance suggested by Gilmartin (1962).

4. Sample treatments

All crabs were sexed and measured. Sex was determined using a generally accepted technique by examining external physical characteristics; females have a wider abdomen than do males (Warner, 1977). Crab size was measured as spine to spine carapace width (Pineda Polo, 1986). In addition, reproductive status was assessed by recording numbers of mating pairs and ovigerous females.

5. Data analyses

Crab abundance and sex ratio data were grouped by seasons as follows: summer (June 21 to September 20), fall (September 21 to December 20), winter (December 21 to March 20), and spring (March 21 to June 20). To obtain size frequencies, carapace widths were grouped into 10 mm classes beginning with 20 mm carapace width. Data were analyzed using the statistical package SAS. Analysis of Variance (ANOVA) was used to examine relative abundance in relation to season, depth and tide. Habitat preferences were indicated as selectivity indices adopted from Ivlev's electivity index (Ivlev, 1961), in which values less than 1 indicate avoidance and those greater than 1 indicate preference. Chi-square tests were used to test for the agreement between the observed and expected habitat use, (Elliot, 1971). Differences in sex ratio were also examined using Chi-square tests. Bonferroni adjusted probability was used to determine significance levels.

IV. RESULTS

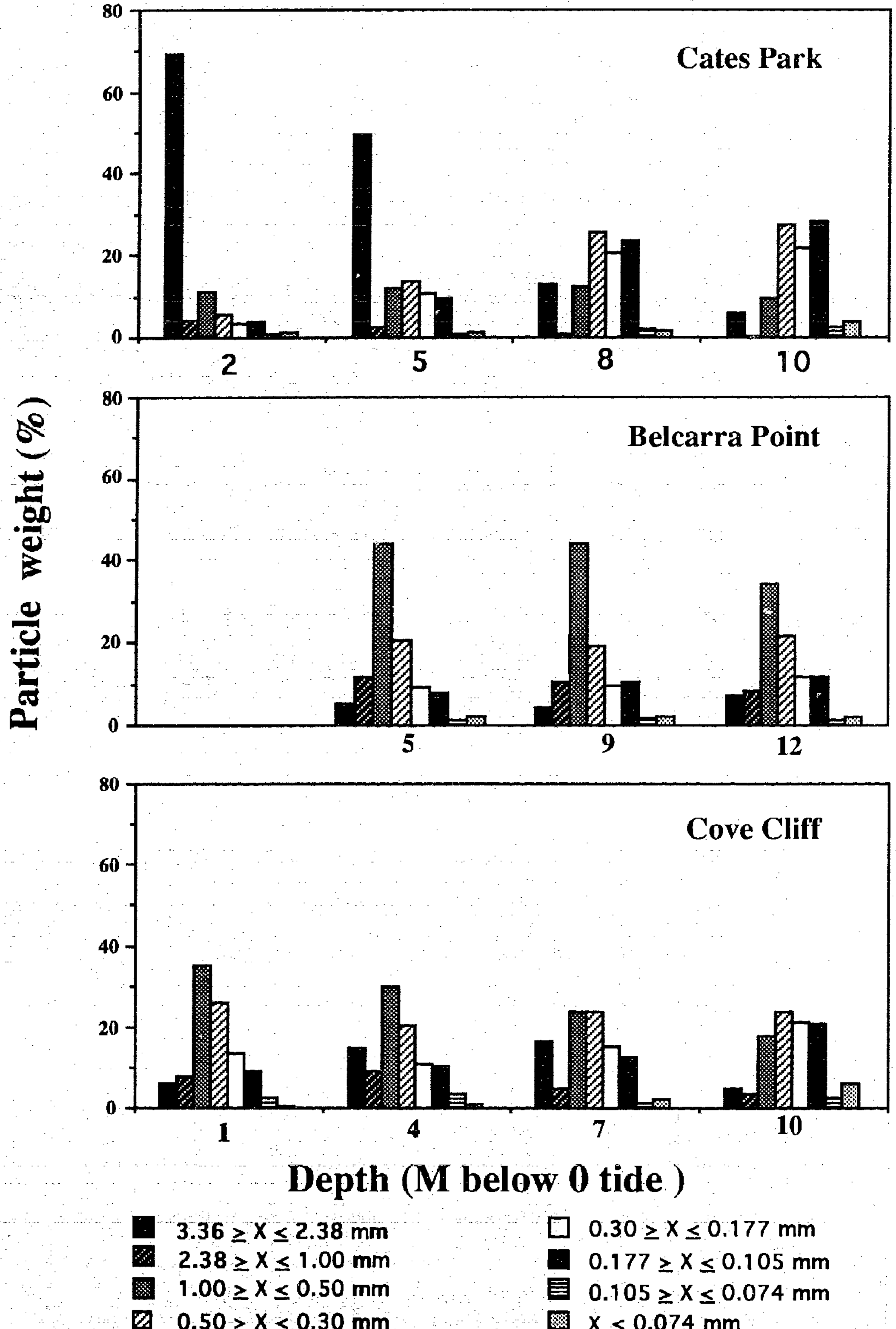
1. Habitat classification

Analyses showed that sediments at all study sites but Bedwell Bay were primarily particles of coarse sand and shell fragments. Particles of coarse sand comprised less than 15% of total weight of sediment. Clay and mud comprised only 2% of the total weight. In general, numbers of large fragments decreased and fine particles increased with depth (Fig. 2).

Using the Wentworth Grade classification, habitat types were classified based on major substrate components of the sea bottom. Locations of habitats were recorded in terms of depths below 0 tide on the chart datum to standardize the depth categories.

Distributions of habitat types in Indian Arm were not the same among the study sites and depths. As a whole, there were nine habitat types in my study (Table 3). Fine sand habitat was found only in Bedwell Bay at any depth. Coarse sand occurred at the other five study sites: Cates Park at depths deeper than 6 m, southern Belcarra Point at 3 m and deeper, Cove Cliff at 0 - 6 m, Racoon Island at deeper than 9 m and Jug Island at 3 - 4 m. Sand-sparse cobble habitats were recorded at 3 - 6 m at Cates Park and Cove Cliff, 6 - 9 m at Racoon Island and 6 - 12 m at Jug Island. Sand-dense cobble habitat were at 0 - 3 m and 3 - 6 m at Cates Park

Fig. 2a-b. Particle size frequency distribution of bottom sediment.


Cates Park
Belcarra Point
Cove Cliff
Particle weight (%)
0
20
40
60
80
2
5
8
10
9
12
1
4
7
Depth (M below 0 tide)
3.36 ≥ X ≤ 2.38 mm
2.38 ≥ X ≤ 1.00 mm
1.00 ≥ X ≤ 0.50 mm
0.50 ≥ X ≤ 0.30 mm
0.30 ≥ X ≤ 0.177 mm
0.177 ≥ X ≤ 0.105 mm
0.105 ≥ X ≤ 0.074 mm
X ≤ 0.074 mm

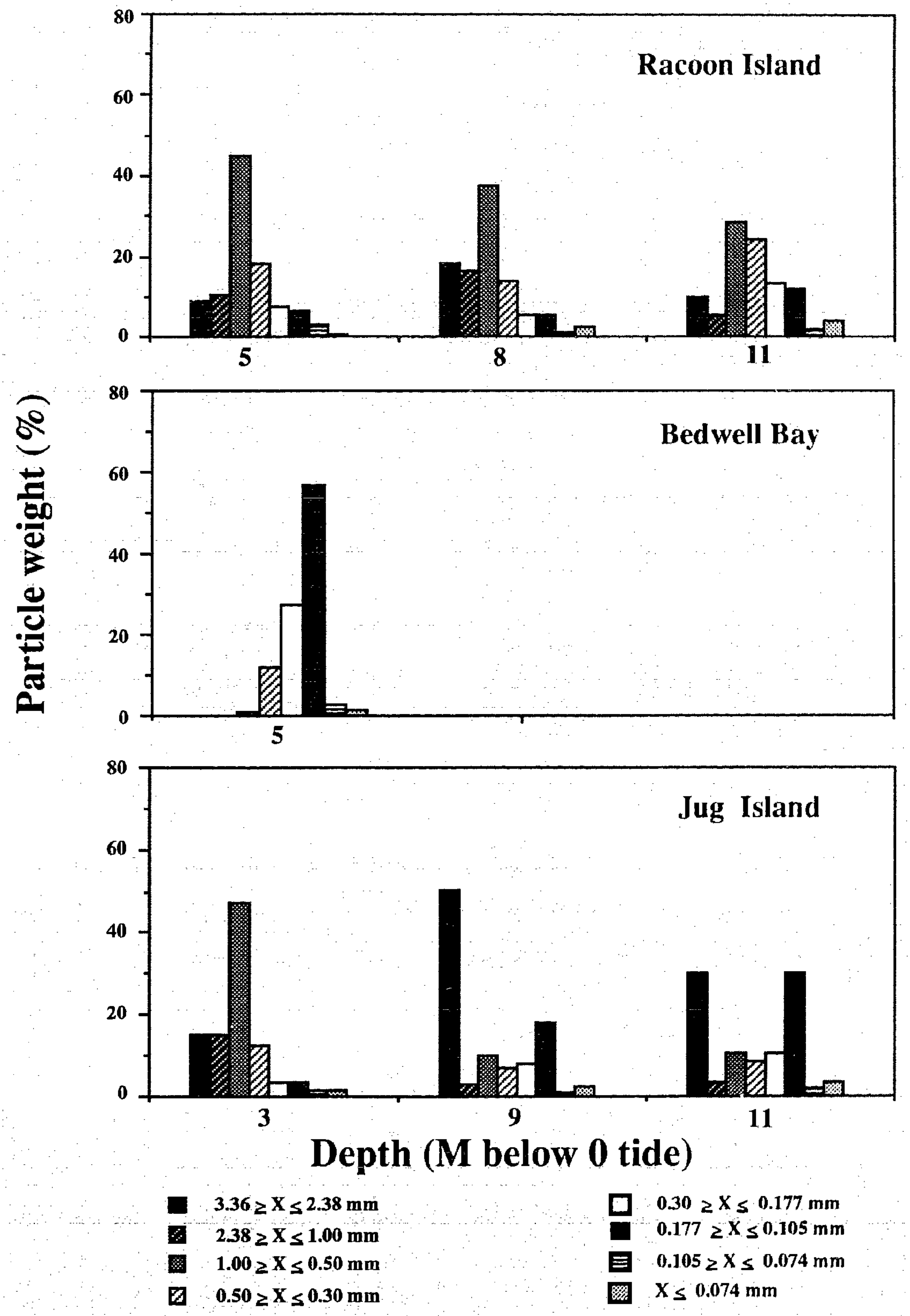

Racoon Island
Bedwell Bay
Jug Island
Particle weight (%)
0
20
40
60
80
5
8
11
3
9
Depth (M below 0 tide)
3.36 ≥ X ≤ 2.38 mm
2.38 ≥ X ≤ 1.00 mm
1.00 ≥ X ≤ 0.50 mm
0.50 ≥ X ≤ 0.30 mm
0.30 ≥ X ≤ 0.177 mm
0.177 ≥ X ≤ 0.105 mm
0.105 ≥ X ≤ 0.074 mm
X ≤ 0.074 mm

Table 3. Distribution of habitat types over six study sites in southern Indian Arm from subtidal to 12 m. 1= fine sand; 2= coarse sand; 3= coarse sand-sparse cobble; 4= coarse sand-dense cobble; 5= coarse sand-sparse cobble-boulder; 6= coarse sand-dense cobble-boulder; 7= coarse sand-boulder; 8= rock-boulder; 9= rock-outcrop.

Study sites	Habitat types
Cates Park	2, 3, 4, 8
Belcarra Point	2, 7, 8, 9
Cove Cliff	2, 3, 5, 7, 8, 9
Racoon Island	2, 3, 4, 5, 6, 7, 8
Bedwell Bay	1
Jug Island	2, 3, 4, 7, 8, 9

and Racoon Island, respectively. At Cates Park, this habitat was characterized by a patchy area of dense kelp, *Laminaria* sp. Sand-sparse cobble-boulder areas were at 3 - 6 m and 6 - 9 m at Cates Park and Racoon Island, respectively. Sand-dense cobble-boulder was only at Racoon Island at 3 - 6 m. Sand-boulder areas were at 3 - 6 m at Belcarra Point, Cove Cliff, Racoon Island and Jug Island. Rock-boulder areas were at the intertidal area to 3 m in Belcarra Point, Racoon Island and eastern Jug Island, and in the intertidal area only at Cove Cliff. Rock-outcrop areas were at 9 - 12 m at Belcarra Point and Cove Cliff, and at 0 - 25 m at Jug Island.

2. Environmental parameters

Seawater temperature and salinity at the study sites varied over the seasons. Temperatures at 10 m ranged from a maximum of 16.6^{o}C in summer to a minimum of 7.7^{o}C in winter (Fig. 3). Surface salinity ranged from a minimum of 15.9 ppt in spring to a maximum of 16.6 ppt in fall. At 10 m, the salinity ranged from a minimum of 24.8 ppt in spring to a maximum of 26.03 ppt in fall.

3. Effort and catches

Over the study period, 730 crabs were recorded on transects and 1622 crabs on random dives (Table 4). Sixty-

Fig. 3. Water temperature of southern Indian Arm. Data were recorded at 10 m from the first week of August 1991 to the third week of June 1992.

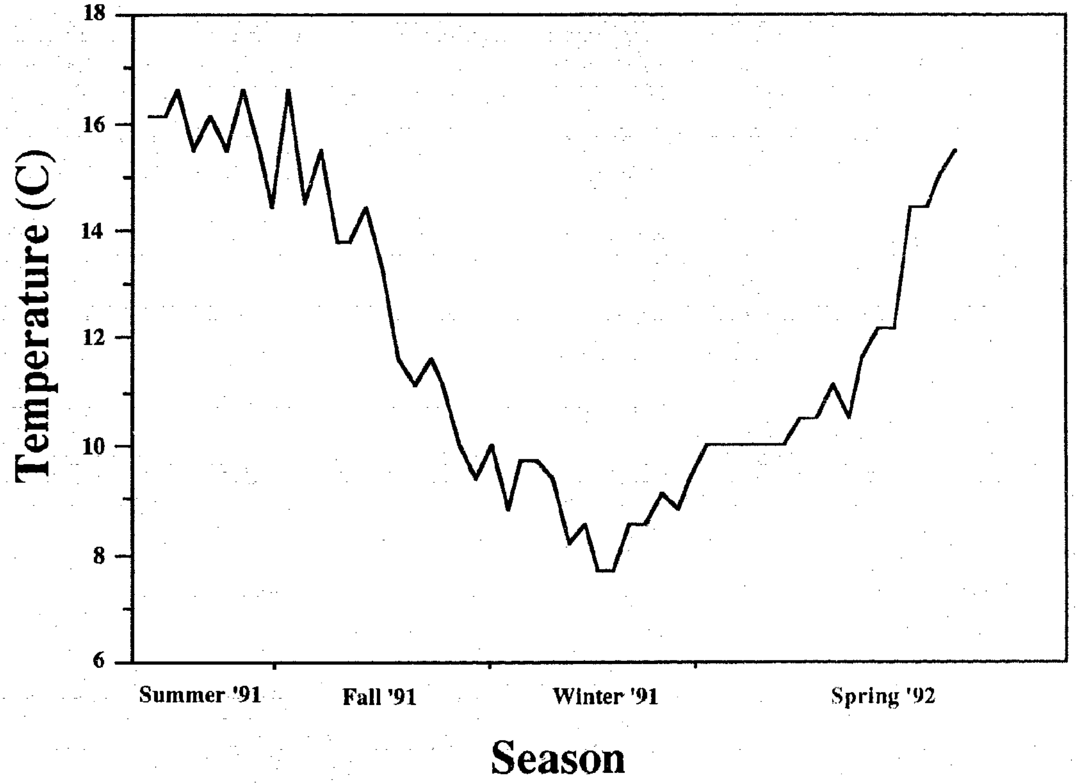
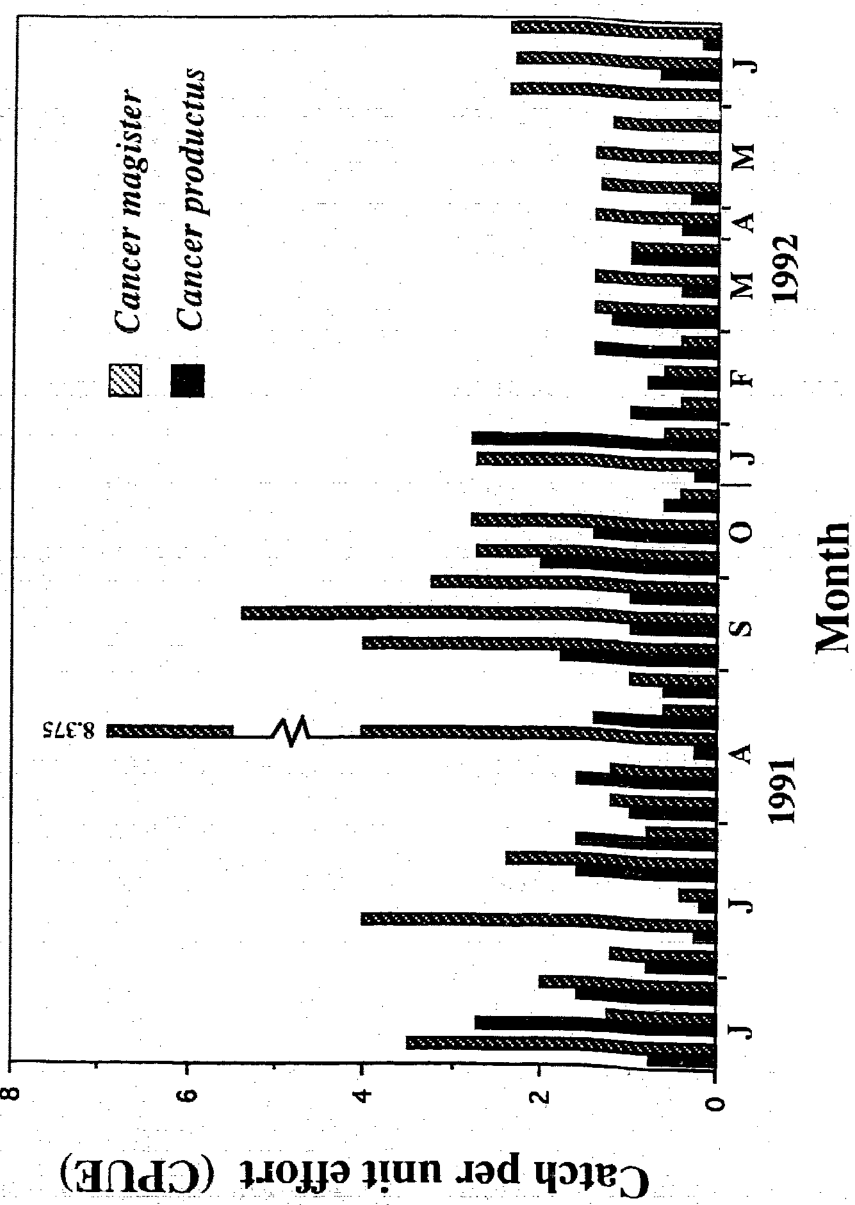

18
16
14
12
10
8
6
Temperature (C)
Summer '91
Fall '91
Winter '91
Spring '92
Season

Table 4. Sampling effort and number of crabs obtained over 12 months in the diving survey.

Site	Number of transects (15 m/transect)	Total crabs caught	Number of random dives (15 min/dives)	Total crabs caught
Cates Park	67	140	16	347
Belcarra Pt.	71	143	18	292
Cove Cliff	64	159	14	297
Racoon Island	71	135	22	433
Bedwell Bay	24	18	7	27
Jug Island	67	135	16	226
Total	364	730	93	1622

Fig. 4. Trap catches of crab in Indian Arm from June 1991 to June 1992. Catch per unit effort (CPUE) is the number of crabs caught per trap.


Catch per unit effort (CPUE)
0
2
4
6
8
8.375
Cancer magister
Cancer productus
J
J
A
S
O
J
F
M
A
M
J
1991
1992
Month

four crabs of the crabs were seen but not captured, hence they were not sexed or measured. The trap catch included both 154 red rock crabs (*C. productus*) and 338 dungeness crabs, (*C. magister*) (Fig. 4). Seventy-four tagged red rock crabs were recaptured by dives and 11 by commercial traps.

4. Sex ratio

Sex ratios were calculated from 2288 red rock crabs collected in the transects and random dives. For all crabs captured between 1991-1992 in Indian Arm, the sex ratio of red rock Crab, was significantly different from 1 : 1 ratio (df = 1, χ^2= 48.17, P < 0.001). All sites, but Cove Cliff had more males than females (Table 5). The sex ratio of crabs changed over the seasons (df = 3, χ^2= 81.64, P < 0.001) (Fig. 5). During summer, the sex ratio of *Cancer productus* was 1 : 1 for all study sites combined. The proportion of males, then, increased during fall (sex ratio 1.7 : 1, N = 324, df = 1, χ^2= 75.11, P < 0.001) and winter 2.8 : 1 (N = 455, df = 1, χ^2= 105.41, P < 0.001). The sex ratio then returned to 1 : 1 (N = 519, df = 1, P > 0.1) during spring 1992.

The seasonal proportion of males and females differed among the study sites (Fig. 6). Crabs at Bedwell Bay were excluded due to small sample size per season (N varied from 4 to 29 crabs), and they were only used for one-year

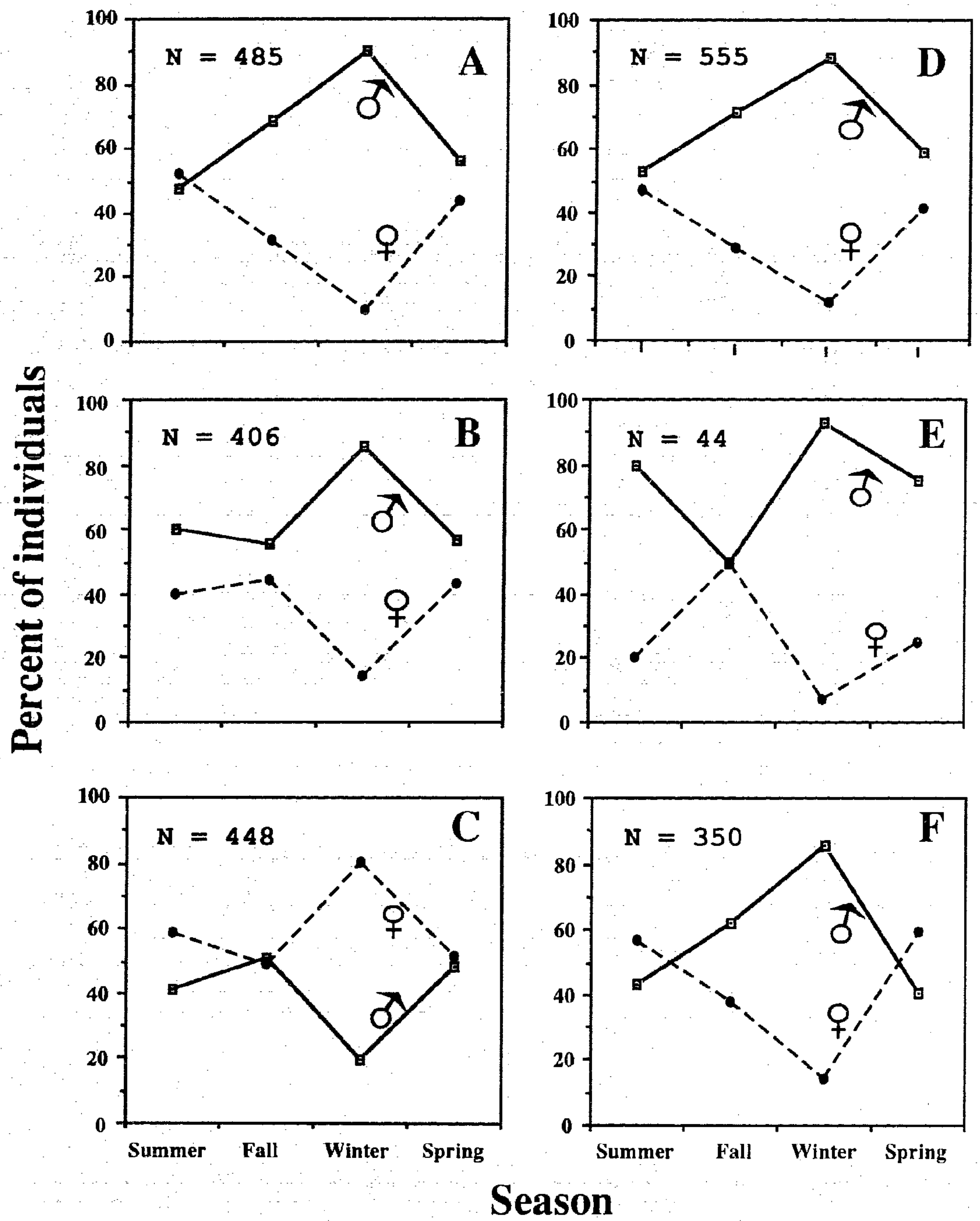
Table 5. Sex ratio of *Cancer productus* at six study sites in Indian Arm, British Columbia.

Sites	N	Males	Females	Sex ratio
Cates Park	485	286	199	1.4 : 1***
Belcarra Point	406	260	146	1.8 : 1***
Cove Cliff	448	181	267	1 : 1.5***
Racoon Island	555	345	210	1.6 : 1***
Bedwell Bay	44	37	7	5.3 : 1***
Jug Island	350	201	149	1.3 : 1**

Note: ** significantly different from 1 : 1 $P < 0.01$

*** significantly different from 1 : 1 $P < 0.001$

Fig. 5. Seasonal variations in proportion of male and female of the red rock crab, *C. productus*. A = Cates Park; B = Belcarra Point; C = Cove Cliff; D = Racoon Island; E = Bedwell Bay and F = Jug Island.


Percent of individuals
Season
Summer
Fall
Winter
Spring
0
20
40
60
80
100
N = 485
A
N = 406
B
N = 448
C
N = 555
D
N = 44
E
N = 350
F
♂
♀

samples. Three sites showed no difference in sex ratio during summer; Cates Park (N = 216, df = 1, χ^2= 0.46, P > 0.5), Racoon Island (N = 327, df = 1, χ^2= 1.35, P > 0.1), and Jug Island (N = 114, df = 1, χ^2= 2.25, P > 0.1). Belcarra Point and Cove Cliff exhibited a sex ratio significantly different from 1 : 1, 1 : 1.5 (N = 177, df = 1, χ^2= 7.73, P < 0.01) and 1 : 1.4 (N = 151, df = 1, χ^2= 4.83, P < 0.05), respectively. In fall 1991, sex ratios at only Cates Park and Racoon Island were significantly different from 1 : 1, 2.2 : 1 (N = 64, df = 1, χ^2= 9, P < 0.001) and 2.4 : 1 (N = 100, df = 1, χ^2= 17.64, P < 0.001), respectively. During winter, sex ratios were highly significantly different from 1 : 1 ratio for all five study sites. At four of these sites there were more males than females. Cove Cliff had a greater proportion of females (Fig. 6). By spring 1992, crabs at all study sites had sex ratios of 1 : 1.

5. Habitat use

Transect data were used to estimate habitat use by crabs. Because the number of visits to each habitat type was not the same for all habitat types, use was calculated based on equal effort (Table 6). The expected values were calculated as the ratio between number of visits in each habitat and total visits, multiplied by the total number of crabs observed.

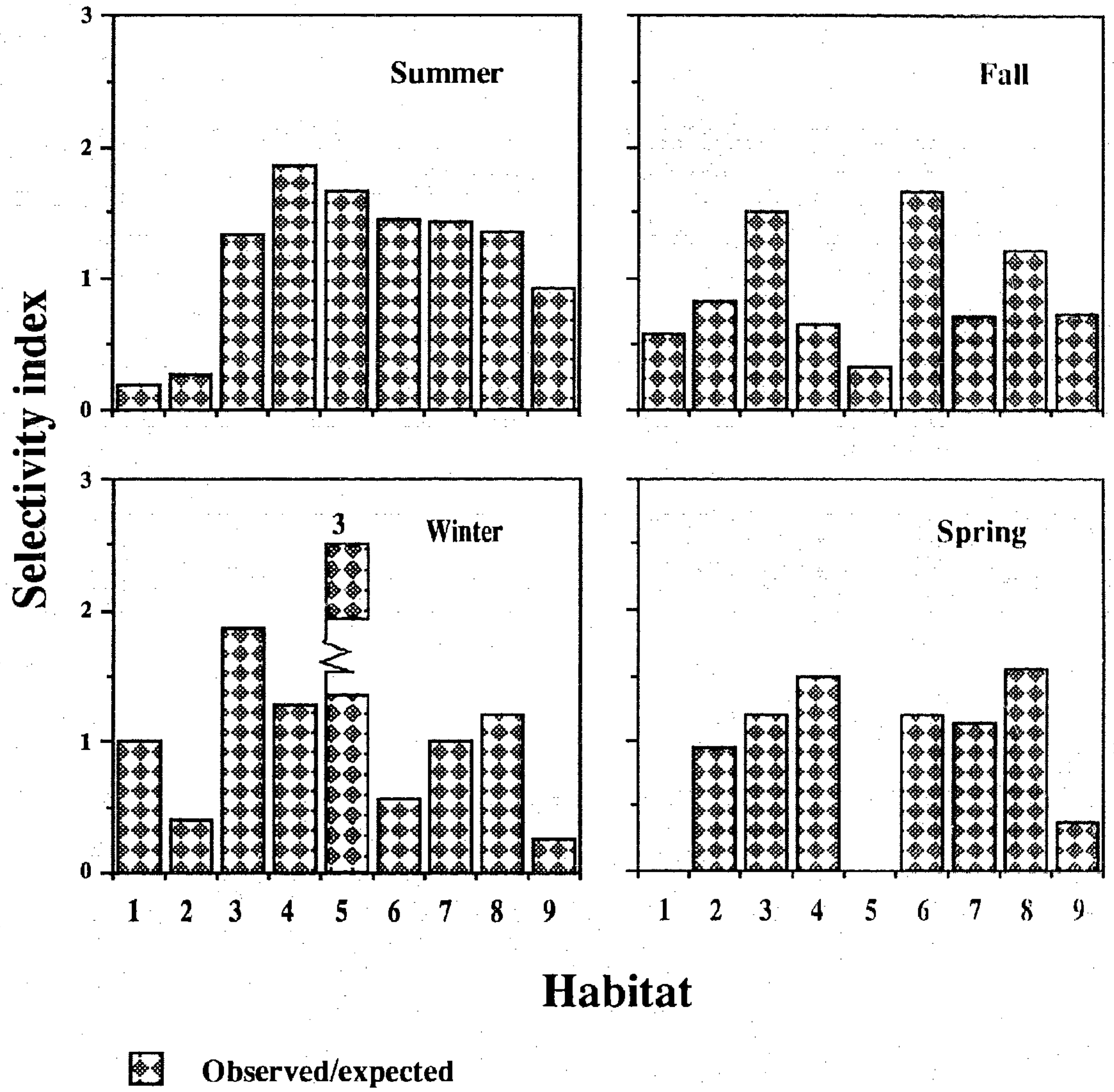
Table 6. Habitat selectivity of the red rock crab, *Cancer productus*, from transect observation, in Indian Arm. 1= fine sand; 2= coarse sand; 3= coarse sand-sparse cobble; 4= coarse sand-dense cobble; 5= coarse sand-sparse cobble-boulder; 6= coarse sand-dense cobble-boulder; 7= sand-boulder; 8= rock-boulder; 9= rock-outcrop.

Habitat	Number of visits	Observed number of crabs	Use (no. crabs/ visit)	Expected number of crabs	Observed/ Expected
1	24	18	0.75	48	0.375
2	77	74	0.96	154	0.48
3	68	196	2.88	136	1.44
4	25	79	3.16	50	1.58
5	4	9	2.24	8	1.12
6	18	47	2.60	36	1.30
7	34	82	2.40	68	1.20
8	58	150	2.58	116	1.29
9	56	75	1.34	112	0.67

Over the year, there were six habitat types preferred by the red rock crab: coarse sand-sparse cobble, rock-boulder, coarse sand-dense cobble, coarse sand-sparse cobble-boulder, coarse sand-boulder and coarse sand-dense cobble-boulder, with coarse sand-sparse cobble and coarse sand-dense cobble being the most preferred habitat.

Habitat selectivity varied among seasons (df = 24, χ^2= 95.31, P < 0.001) (Fig. 6). In summer, six habitat types were preferred, coarse sand-sparse cobble, coarse sand-dense cobble, coarse sand-sparse cobble-boulder, coarse sand-dense cobble-boulder, sand-boulder and rock boulder with the habitat of coarse sand-dense cobble and coarse sand-dense cobble boulder being the most preferred (N = 358, df = 7, χ^2= 109.1, P < 0.001). The coarse sand-sparse cobble-boulder habitat was excluded from inter-habitat comparison because I had only one observation. In fall, crabs preferred the coarse sand-sparse cobble, coarse sand-dense cobble-boulder and rock-boulder habitats (N = 123, df = 6, χ^2= 12.84, P < 0.05). Due to having only two observations, coarse sand-dense cobble-boulder habitat was not included in inter-habitat comparisons. In winter, four habitats were preferred, coarse sand-sparse cobble, coarse sand-dense cobble, coarse sand-sparse cobble- boulder and rock-boulder with the most preferred being coarse sand-sparse cobble (N = 125, df = 7, χ^2= 46.83, P < 0.001). Since there was only one observation for coarse sand-sparse cobble-boulder habitat,

Fig. 6. Habitat use of the red rock crab, *C. productus*, in different seasons. 1= fine sand; 2= coarse sand; 3= coarse sand-sparse cobble; 4= coarse sand-dense cobble; 5= coarse sand-sparse cobble boulder; 6= coarse sand-dense cobble-boulder; 7= coarse sand-boulder; 8= rock-boulder; 9= rock outcrop.


Summer
Fall
Winter
Spring
3
Selectivity index
0
1
2
3
1 2 3 4 5 6 7 8 9
Habitat
Observed/expected

this habitat was excluded from inter-habitat comparisons. During spring, the crabs preferred rock-boulder and coarse sand-dense cobble habitats, although coarse sand-sparse cobble and sand-boulder habitats were also inhabited (N = 110, df = 7, χ^2= 24.42, P < 0.01). In this season, the coarse sand-sparse cobble-boulder habitat was not visited (Fig. 6).

Habitat use varied with sex (N = 666, df = 8, χ^2= 39.83, P < 0.001). Males were more often found on fine sand (N = 17, M/F = 3.25, df = 1, χ^2= 4.76, P < 0.05), coarse sand-dense cobble-boulder (N = 40, M/F = 2.07, df = 1, χ^2= 4.90, P < 0.05) and rock-boulder habitats (N = 126, M/F = 1.52, df = 1, χ^2= 5.36, P < 0.05), whereas females were more often found on flat coarse sand (N = 71, M/F = 0.45, df = 1, χ^2= 10.26, P < 0.005) and rock-outcrop (N = 77, M/F = 0.39, df = 1, χ^2= 4.69, P < 0.05) habitats. Other habitats were shared by both sexes.

6. Relative abundance

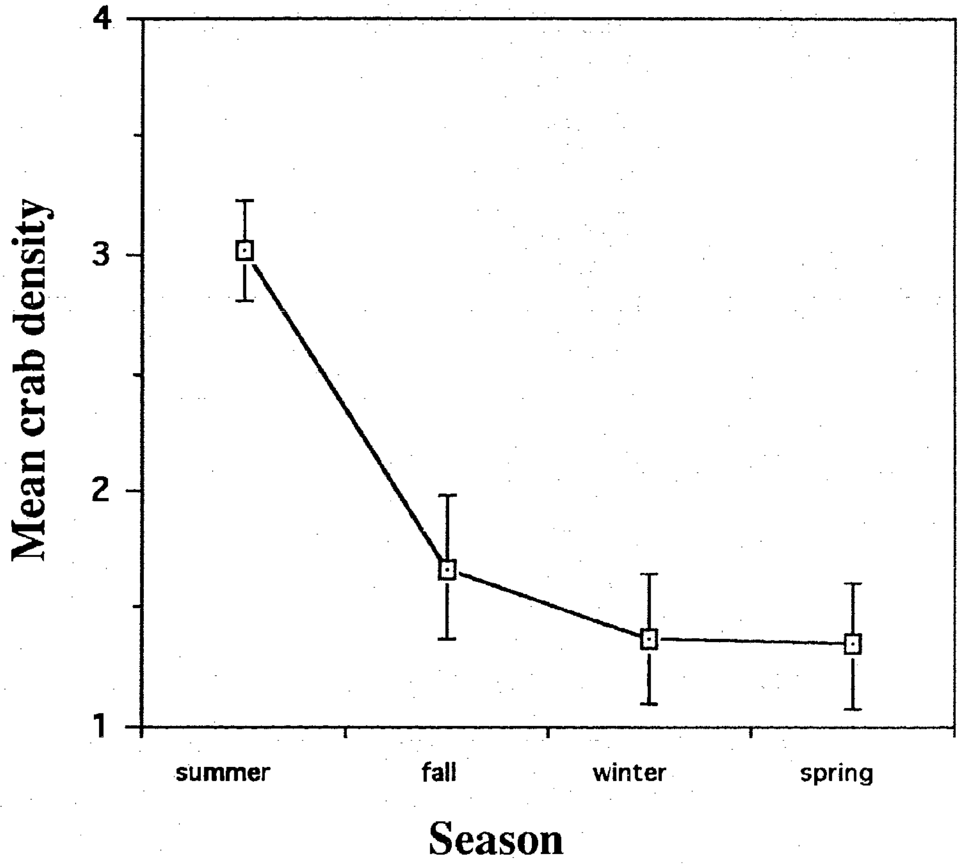
Across seasons, transect data revealed that summer had the greatest abundance of crabs, 3.02/transect (30 m^2) (P ≤ 0.002). The density then decreased over fall, winter and spring months (1.35 - 1.67 per transect). No significant differences in density were found among these three seasons (Fig. 7).

Relative density of crabs varied significantly with depth (Table 7). Figure 8 shows that *Cancer productus* were

Table 7. Analysis of variance (ANOVA) for the comparisons of the relative density of the red rock crab with seasons, depths and tides.

Source	DF	SS	MS	F-value	P > F
Season	3	172.88	57.63	11.30	0.0001
Depth	3	176.69	58.89	11.55	0.0001
Tide	3	8.40	2.80	0.55	0.65

Fig. 7. Mean relative density and standard error of the red rock crab, *C. productus*, during different seasons.

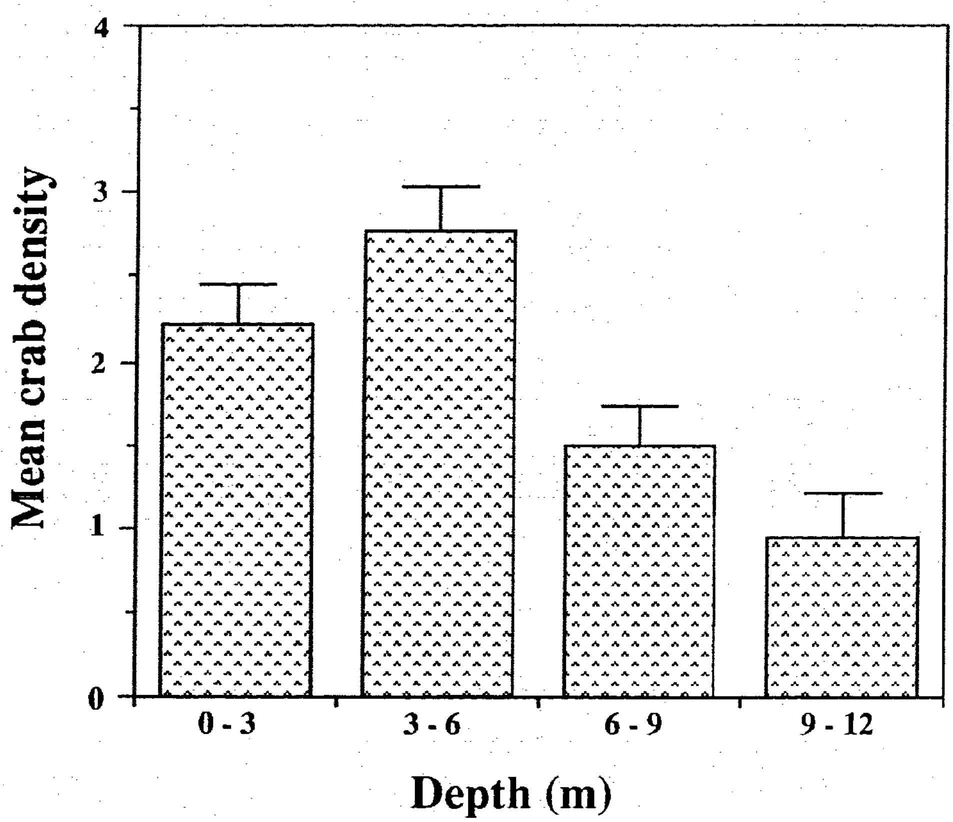

4
3
2
1
Mean crab density
summer
fall
winter
spring
Season

mostly concentrated at the depth interval of 0 - 6 m below 0 on the datum chart. The crab densities were 2.21 and 2.78/transect (30 m^2) at the 0 - 3 m and 3 - 6 m depth intervals below 0 on the datum chart, respectively. The crab density at the 0 - 3 m depth interval was not different from that at the 6 - 9 m depth interval. The crab density at the 3 - 6 m depth interval was significantly greater than that at 6 - 9 m and 9 - 12 m depth intervals ($P \leq 0.0004$). The density at 6 - 9 m depth interval was also not different from that at the 9 - 12 m depth interval. The crab density at 0 - 3 m depth interval was greater than that at 9 - 12 m depth interval ($P \leq 0.0008$). During spring through summer, crabs tended to broaden their distribution and I found them at all depth intervals along the transects. There was no effect of tides on the relative density of crabs in the shallow subtidal (Table 7). During the whole year, I only observed a few crabs foraging in the intertidal.

7. Crab size

Data from 15 min random collection were used to analyze the crab sizes in relation to season, study site and habitat type. Over the study period, most crabs found were at sizes bigger than 110 mm for males and bigger than 100 mm for females. Above and below these sizes represented legal and sublegal sizes. Males were predominant at sizes bigger than 119 mm and females outnumbered males at sizes smaller than

Fig. 8. Mean relative density and standard error of the red rock crab, *C. productus*, at different depth intervals. Those depth ranges were 0-3, 3-6, 6-9, and 9-12 m below 0 on the chart datum.



Mean crab density
0
1
2
3
4
0 - 3
3 - 6
6 - 9
9 - 12
Depth (m)

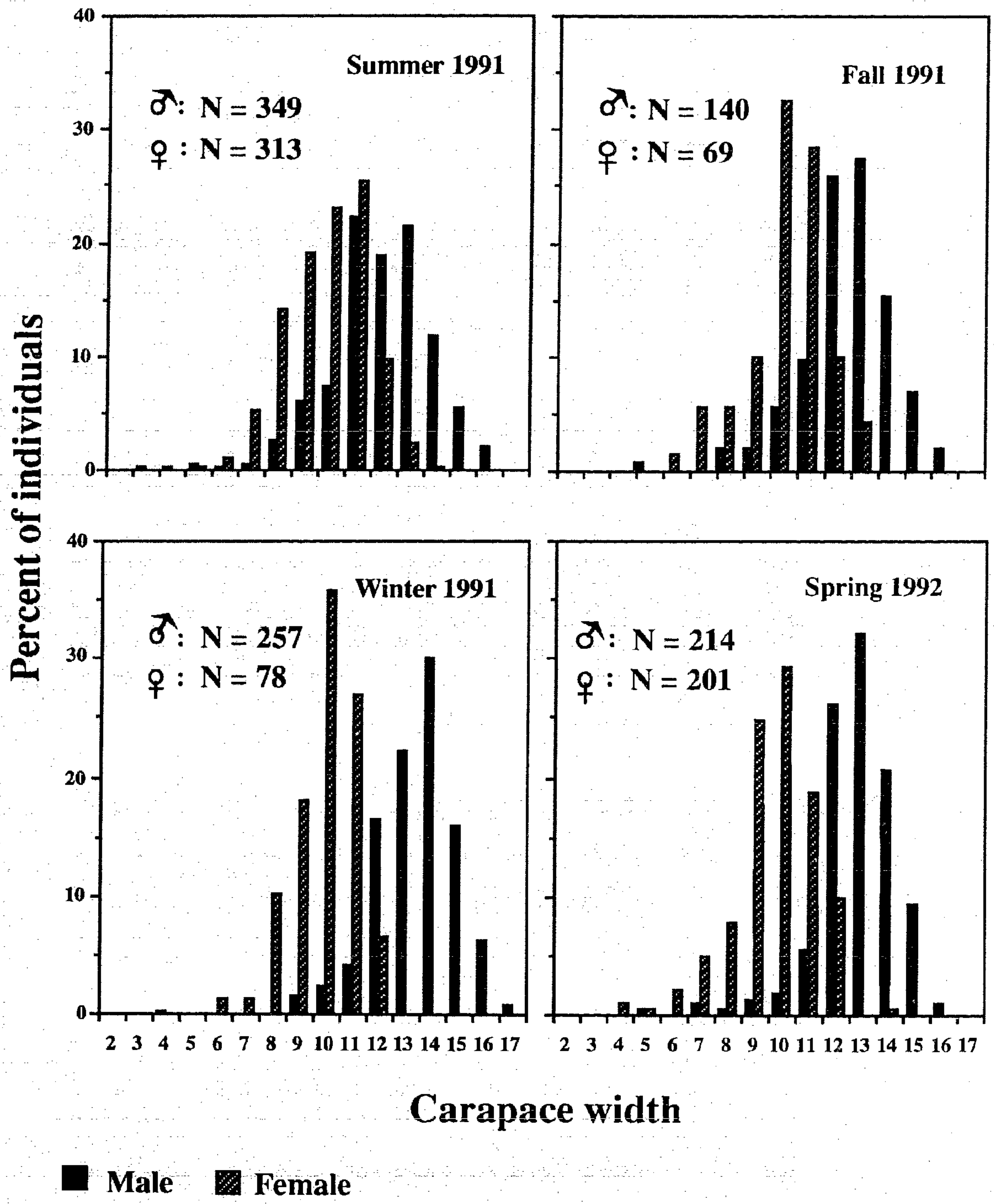
120 mm. Size frequency distribution indicated a bimodal distribution in summer, winter 1991 and spring 1992 and a single mode in fall 1991 for male crabs. Female crabs had a unimodal size distribution during summer, fall and winter 1991 and bimodal size distribution during spring 1992. Despite different sample sizes, the size frequency distribution exhibited a shift in modes for both males and females. Sizes bigger than 110 mm made up 81.95% of summer, 89.29% of fall, 95.72% of winter and 94.86% of spring male catch. Females at size bigger than 100 mm made up 60.38% of summer, 76.81% of fall, 69.23% of winter and 50.71% of spring. Only one female was caught at the size ≥ 140 mm. This modal shift caused changes in mean crab size during different seasons (Table 8).

In Cates Park, male size bigger than 110 mm made up 76.35% of total male catch and female size bigger than 100 mm covered 30.77% of total female catch. In Belcarra Point, 90.36% of male crabs were bigger than 110 mm and 69.47% of female crabs were bigger than 100 mm. In Cove Cliff, 92.09% represented male crabs at sizes bigger than 110 mm and 67.09% female crabs at sizes bigger than 100 mm. Racoon Island had 96.25% of male catch at sizes bigger than 110 mm and 76.51% of female crabs at sizes bigger than 100 mm. In Bedwell Bay, 91.67% represented male catch at sizes bigger than 115 mm and all females caught were bigger than 100 mm Fig. 10). Male crabs at Cates Park had the widest size range with the smallest minimum individual size, whereas Racoon

Table 8. Mean and ranges of body size of the red rock crab, *C. productus*, during different seasons.

Season	Male		Female	
	N	Mean CW (mm) (min.-max.)	N	Mean CW (mm) (min.-max.)
Summer 1991	349	121.55 (39-160)	313	102.89 (52-141)
Fall 1991	140	127.76 (56-164)	69	104.92 (67-136)
Winter 1991	257	137.2 (40-173)	78	103.12 (69-122)
Spring 1992	214	135.06 (53-165)	201	103.05 (49-144)

Fig. 9. Carapace width frequency distribution of the red rock crab, *C. productus*, during different seasons. Number 2-17 indicate size classes of 10 mm interval that start from the minimum of 20 mm CW.


Summer 1991
♂: N = 349
♀ : N = 313
Fall 1991
♂: N = 140
♀ : N = 69
Winter 1991
♂: N = 257
♀ : N = 78
Spring 1992
♂: N = 214
♀ : N = 201
Percent of individuals
0
10
20
30
40
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Carapace width
Male
Female

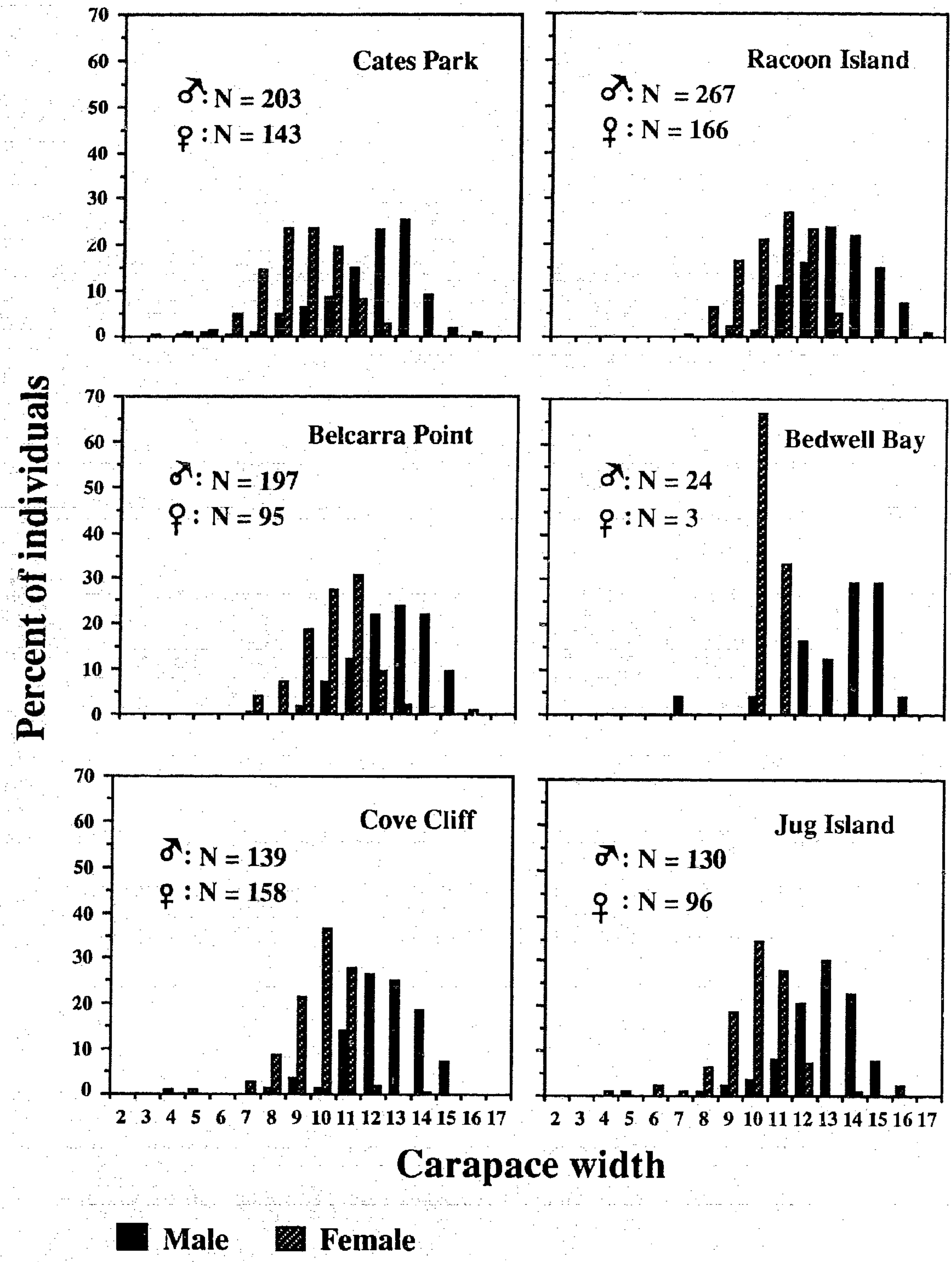
Island had the smallest size range with the biggest minimum size. Therefore, both study sites showed the smallest and the biggest mean crab size, respectively (Table 9).

Size frequency distribution indicated that sizes bigger than 115 mm made up 84.6% of male catch in the habitat of fine sand. Only 4 females were caught in this habitat, two of which had sizes bigger than 100 mm. In coarse sand habitat, male crabs at sizes bigger than 110 mm made up 95.4% of male catch and 59.2% of females caught in this habitat were at sizes bigger than 100 mm. In this habitat, only adult crabs were found. Coarse sand-sparse cobble had the widest size range for males (Table 10). Eighty-two percent of male catch was at the size bigger than 110 mm and the rest were below this size. In this habitat, all females caught were adult, but only 53.5% of female catch were at the size bigger than 100 mm. In coarse sand-dense cobble habitat, 89.2% of male catch were at the size bigger than 110 mm and 51.6% female catch were at the size bigger than 100 mm. In this habitat, some females below this size were caught. In the habitat of coarse sand-sparse cobble-boulder, all male crabs caught were at the size bigger than 110 mm and 85.7% of female catch were at the size bigger than 100 mm. Because this habitat was visited only four times during the study period, it had a very small sample size and the smallest size range. In coarse sand-dense cobble-boulder habitat, males at the size bigger than 110 mm made up 85.2% of male catch and females at the size bigger than 100 mm

Table 9. Mean and ranges of body size of the red rock crab, *C. productus*, at different study sites.

Sites	Male		Female	
	N	Mean CW (mm) (min.-max.)	N	Mean CW (mm) (min.-max.)
Cates Park	203	121.61 (39-160)	143	91.41 (40-126)
Belcarra Point	197	131.38 (74-164)	95	105.31 (74-131)
Cove Cliff	139	128.45 (40-157)	158	103.27 (76-141)
Racoon Is.	267	139.93 (93-171)	166	110.18 (78-136)
Bedwell Bay	24	131.9 (76-166)	3	106.13 (101-114)
Jug Is.	130	129.66 (56-165)	96	104.69 (48-143)

Fig. 10. Carapace width frequency distribution of the red rock crab, *C. productus*, at different study sites. Number 2-17 indicate size classes of 10 mm interval that start from the minimum of 20 mm CW.


Cates Park
♂: N = 203
♀: N = 143
Racoon Island
♂: N = 267
♀: N = 166
Belcarra Point
♂: N = 197
♀: N = 95
Bedwell Bay
♂: N = 24
♀: N = 3
Cove Cliff
♂: N = 139
♀: N = 158
Jug Island
♂: N = 130
♀: N = 96
Percent of individuals
0 10 20 30 40 50 60 70
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Carapace width
Male
Female

formed 84.7% of female catch. In the habitat of coarse sand boulder, 87.8% of the male catch were at the size bigger than 110 mm and 82.1% of female catch were at the size bigger than 100 mm. There were some females smaller than 100 mm and some sublegal-sized males were also found in this habitat. In the habitat of rock boulder, 92% of male catch had size bigger than 110 mm and 60% of female catch had size bigger than 100 mm. In rock outcrop habitat, 73.7% of male catch were at the size bigger than 110 mm and 61% of female catch were at the size bigger than 100 mm. All females in this habitat were bigger than 70 mm at which size they were observed mating, and only one small male was caught in this habitat (Fig. 11).

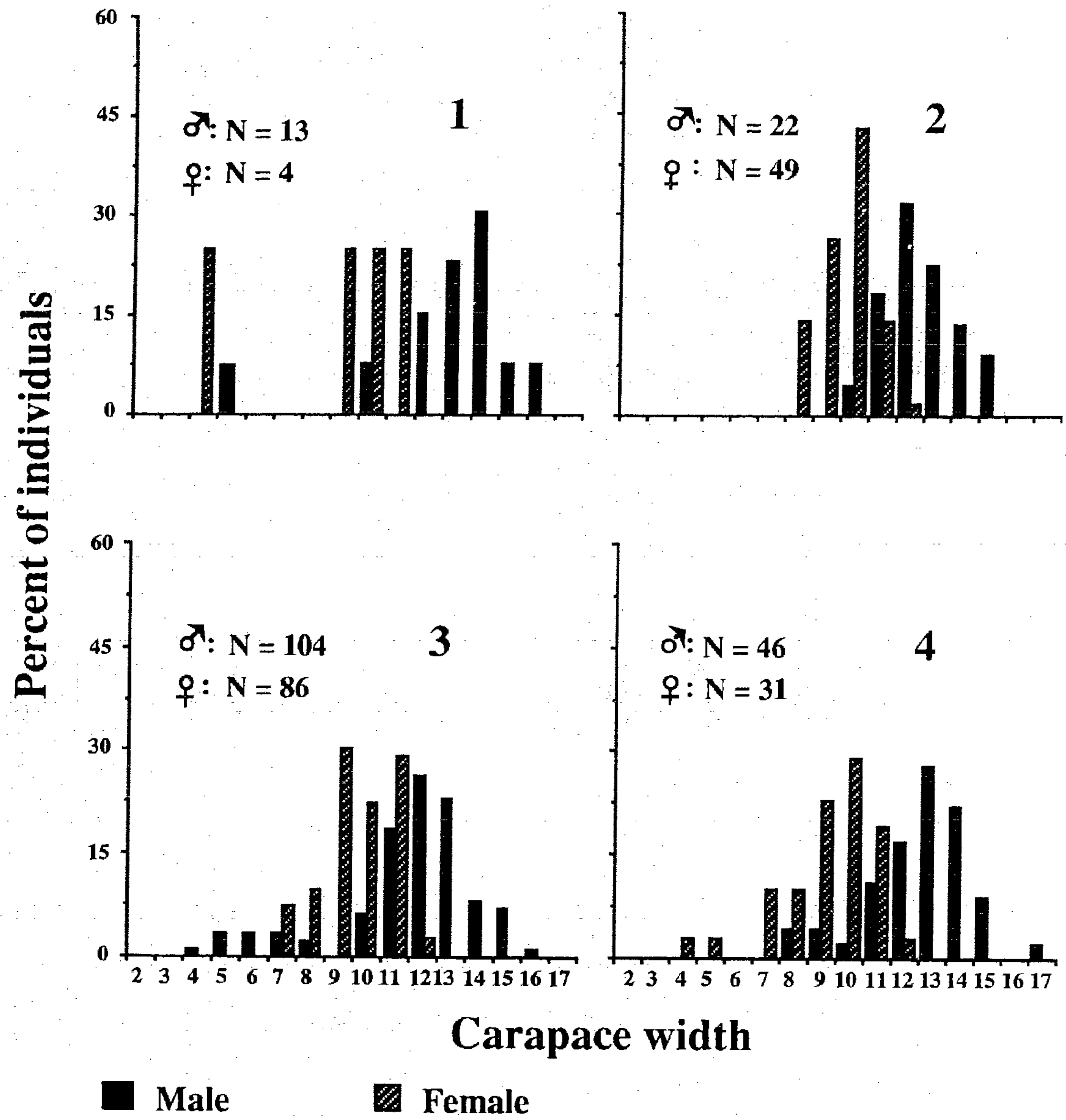
8. Reproduction

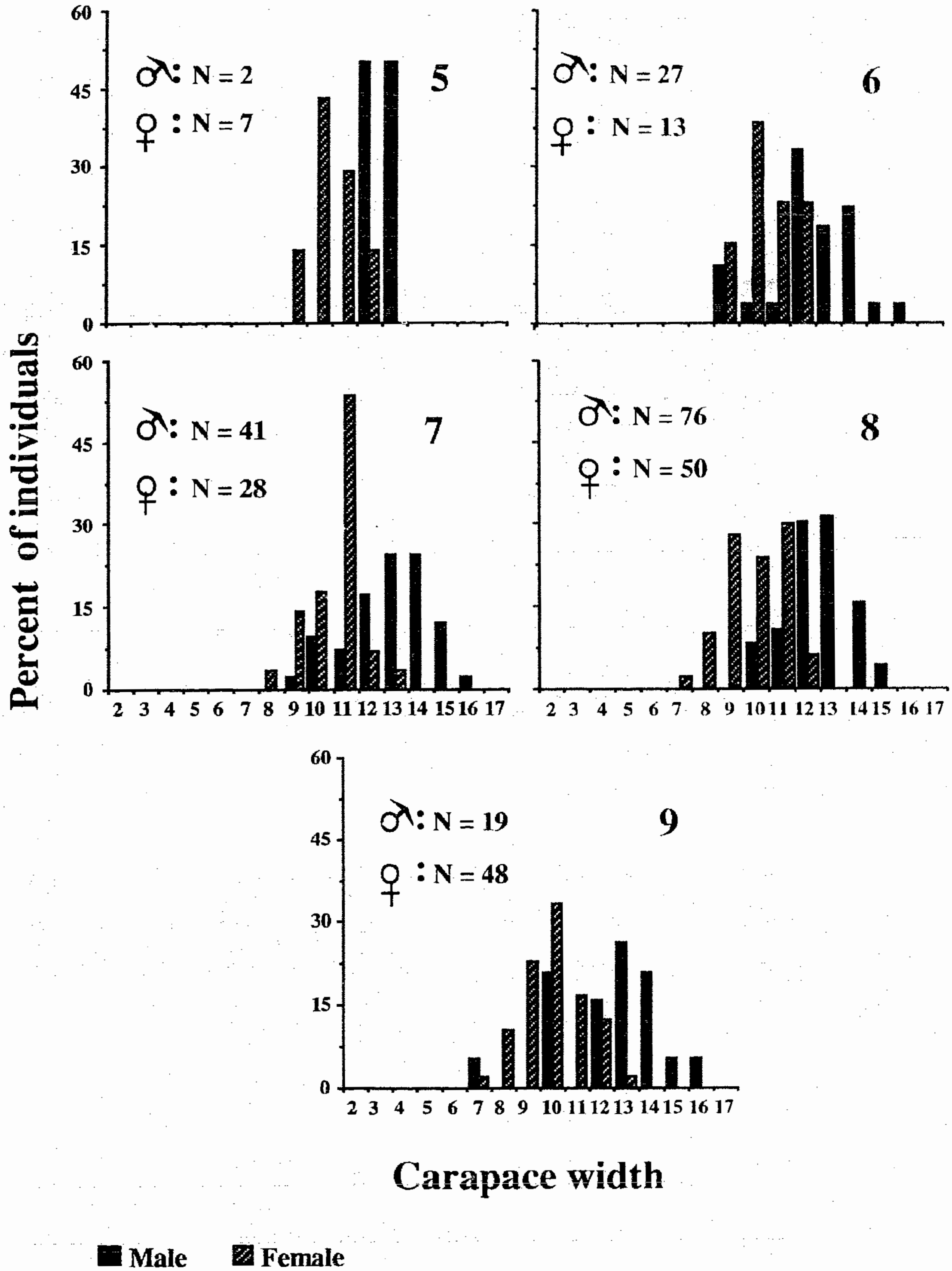
Cancer productus mates in the warmer months. My data indicate that there was variation in the breeding period. Figure 12 showed that in 1991 mating pairs were encountered in two successive months, June and July. In 1992 the mating activity was observed earlier in Indian Arm in the year than that in 1991 with a peak in June. Only two mating pairs were observed after that, one in July and one in October. Ovigerous females were recorded from October 1991 to May 1992 with a peak in March 1992 (Fig. 13).

Table 10. Mean and ranges of body size of the red rock crab, *C. productus*, at different habitat types.

Habitat	Male		Female	
	N	Mean CW (mm) (min.-max.)	N	Mean CW (mm) (min.-max.)
1	13	131.0 (54-161)	4	83.33 (41-117)
2	22	129.27 (106-157)	49	100.73 (81-122)
3	104	121.23 (49-167)	86	100.63 (71-121)
4	46	130.43 (83-175)	31	96.90 (47-122)
5	2	130.5 (126-135)	7	113.37 (90-122)
6	27	128.52 (94-165)	13	105.58 (97-123)
7	41	132.58 (94-167)	28	109.25 (88-130)
8	76	129.76 (101-154)	50	103.26 (73-121)
9	19	128.31 (74-160)	48	103.83 (76-132)

Fig. 11. Carapace width frequency distribution of the red rock crab, *C. productus*, at different habitat types. Number 2-17 in the X-axis indicate size interval of 10 mm that start from the minimum of 20 mm CW. Habitat types 1-9 are as previously described.


Percent of individuals
60
45
30
15
0
♂: N = 13
♀: N = 4
1
♂: N = 22
♀ : N = 49
2
♂: N = 104
♀: N = 86
3
♂: N = 46
♀: N = 31
4
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Carapace width
Male
Female



Percent of individuals
♂: N = 2
♀: N = 7
5
♂: N = 27
♀: N = 13
6
♂: N = 41
♀: N = 28
7
♂: N = 76
♀: N = 50
8
♂: N = 19
♀: N = 48
9
0 15 30 45 60
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Carapace width
Male
Female

Fig. 12. Mating pairs encountered from May 1991 - June 1992. The number of crabs observed (N) was given at the top of the figure.

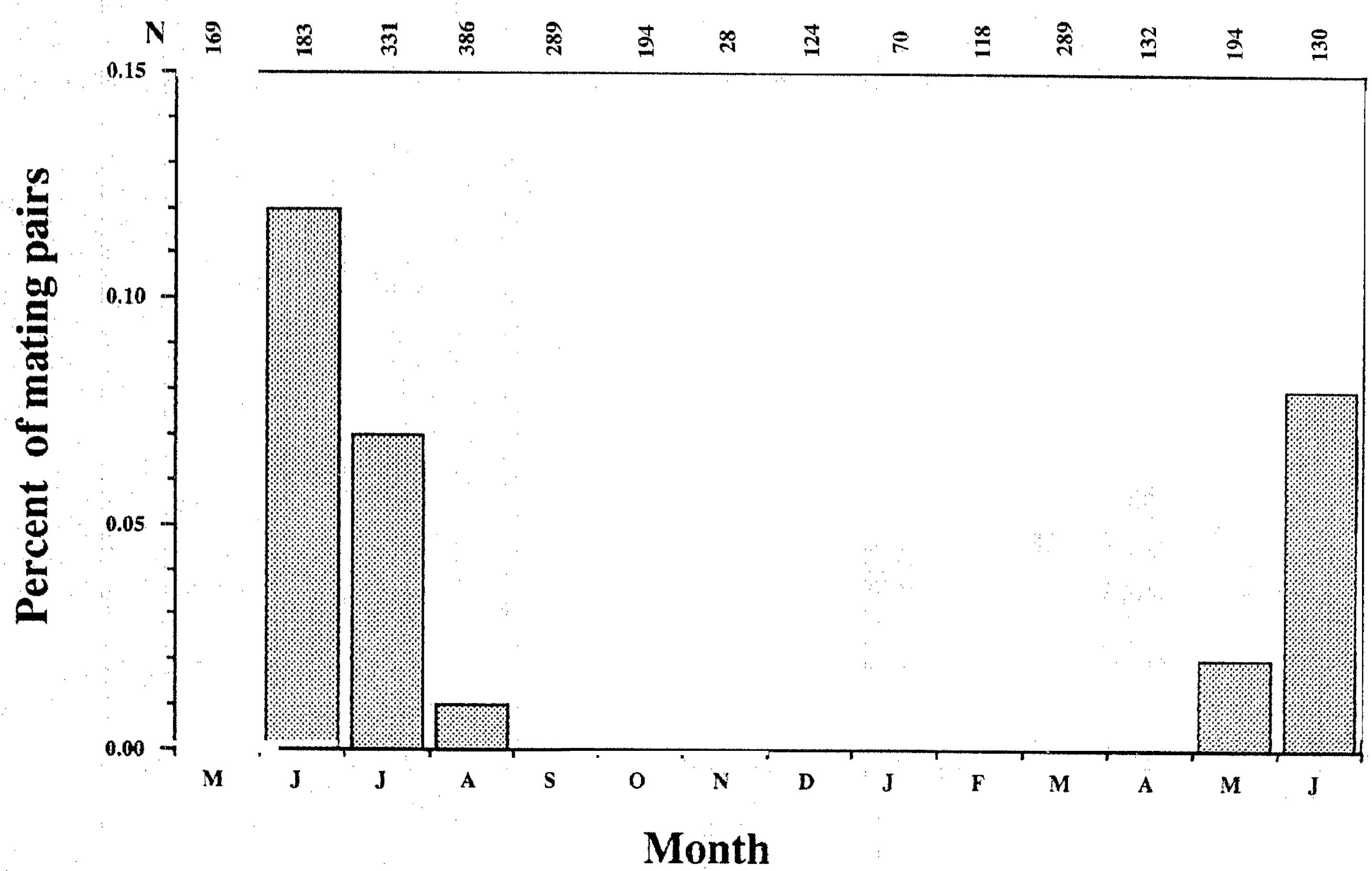
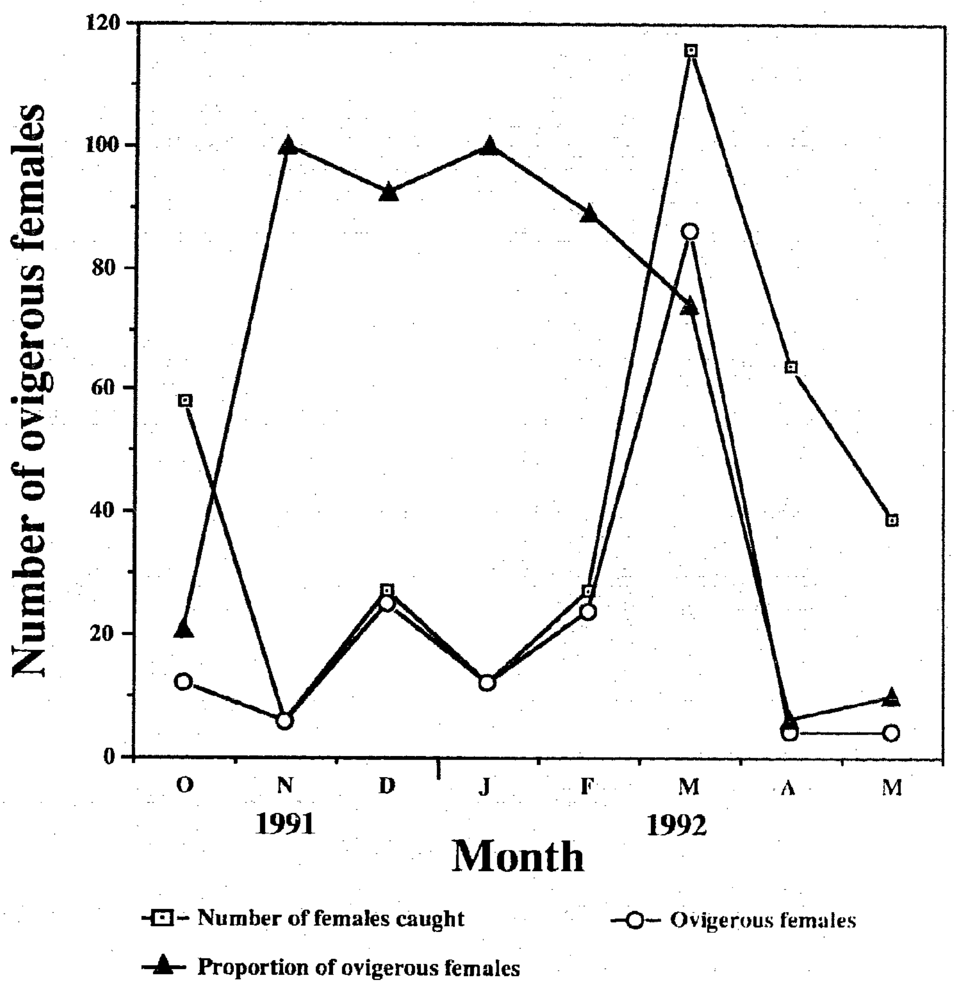

N
169
183
331
386
289
194
28
124
70
118
289
132
194
130
0.15
0.10
0.05
0.00
Percent of mating pairs
M
J
J
A
S
O
N
D
J
F
M
A
M
J
Month

Fig. 13. Frequency distribution of ovigerous female red rock crab, *C. productus*, after the mating season.

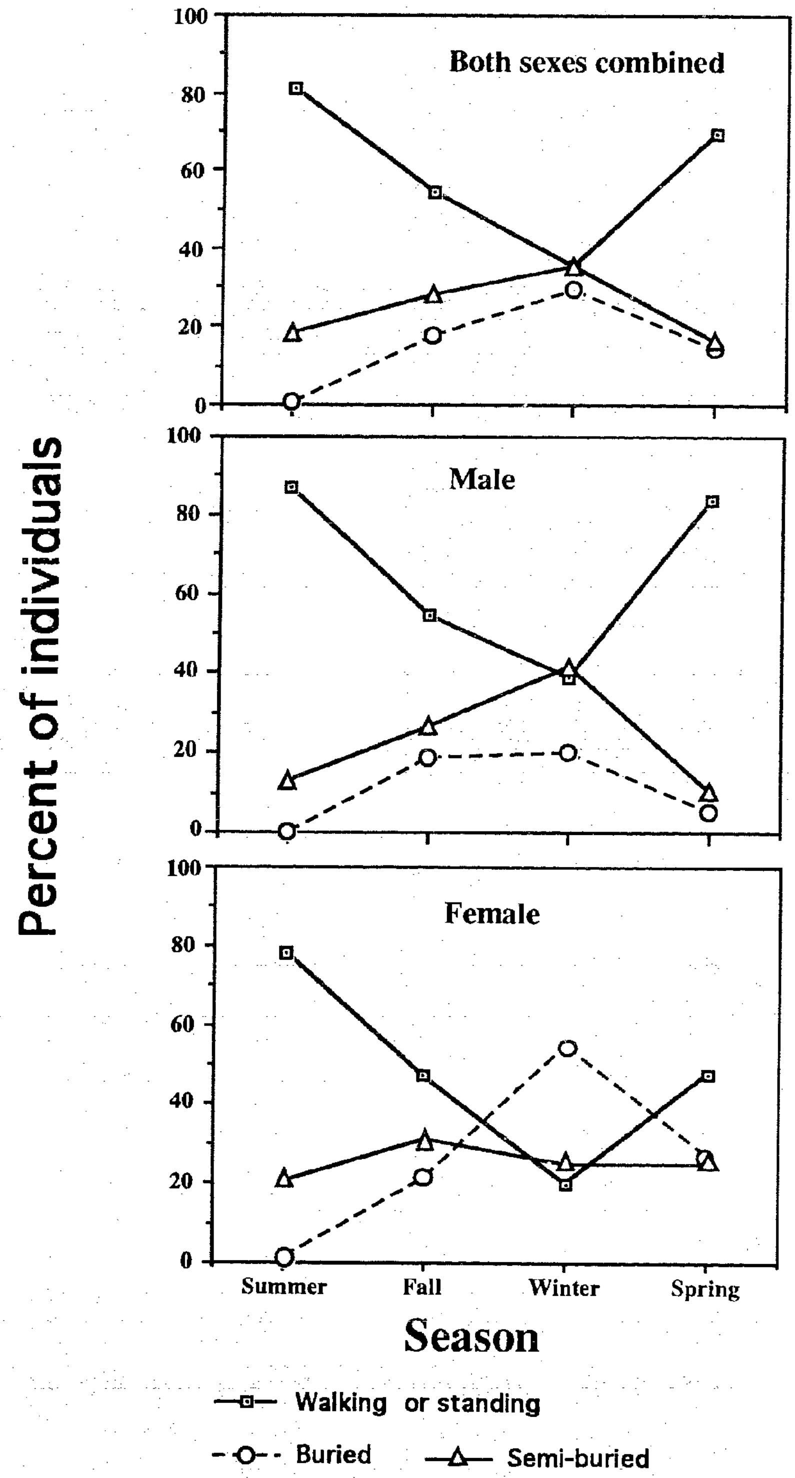


120
100
80
60
40
20
0
Number of ovigerous females
O
N
D
J
F
M
A
M
1991
1992
Month
Number of females caught
Ovigerous females
Proportion of ovigerous females

9. Crab behavior

Behavior was observed in the following categories: 1) crabs free on the bottom,i.e. those that were either walking and standing on the bottom or in crevices; 2) buried crabs, i.e. those whose carapaces were totally covered by sand, eyestalk outside, two claws were covered or only small portion of mouth part was outside; 3) semi-buried crabs, i.e. those whose carapaces were half-covered or claws were outside. The proportion of crab behavior engaged in these activities varied with season ($N = 664$, $df = 6$, $P < 0.001$) (Fig. 14). Over the year, 66.44 % of total catch by transect were free on the bottom, 10.96% and 22.6% were buried and half-buried, respectively. In summer, the crabs were mostly observed free on the bottom (80.99%), and the rest were buried and semi- buried, 0.83% and 18.18%, respectively. The number of walking crabs decreased drastically during fall and winter to 54.26% and 35.16%, respectively, while the proportion of buried and half-buried ones increased to 17.83% and 27.91%, respectively, in the fall and to 29.69% and 35.16%, respectively, in the winter. Crab behavior, then, changed during spring wherein the proportion of walking crabs increased.

Fig. 14. Seasonal changes in crab behavior, *C. productus*, in Indian Arm.


Both sexes combined
Male
Female
Percent of individuals
100
80
60
40
20
0
Summer
Fall
Winter
Spring
Season
Walking or standing
Buried
Semi-buried

V. DISCUSSION

In Indian Arm, the abundance of the red rock crab in subtidal areas differs with respect to habitat type. The influence of bottom type on abundance of crabs was suggested by Wenner *et al.* (1987). In the present study, on an annual basis, coarse sand-sparse cobble habitat was used more intensively by the red rock crab then were other habitats. Other habitats used by the red rock crab were rock-boulder, coarse sand-dense cobble, coarse sand-boulder and coarse sand-dense cobble-boulder. Shelter is one of the main requirements for the survival of many species; it is self-evident that some sort of retreat from predators and adverse environmental conditions help to ensure the survival of the individual (Cobb, 1971). A shelter-providing habitat is often a necessary prerequisite for recruitment to the benthos (Caddy, 1986; Fogarty and Idoine, 1986). I observed *C. productus* using larger bottom elements, such as cobble and boulder, for protection from predators. When red rock crabs were in rock-boulder areas, they often used the space between rocks or boulders as refuges. During my sampling, 64 crabs were not sexed and measured because they were in crevices and inaccessible. Similar observations were reported by Robles *et al.*(1989). *C. productus* also are often buried or half-buried into the sand next to rocks or beneath boulders or any other large objects available on the bottom, such as kelp, *Laminaria sp.*, logs, tires etc.

Sheridan (1992) suggested that in the intertidal, vegetated habitats provide greater densities of food and greater degrees of protection than do non-vegetated habitats, and thus should attract mobile organisms as these habitats become available. This habitat affinity is exhibited by other *Cancer* sp.. *Cancer irroratus* preferred to seek protection under natural shelters or to burrow into sediment next to the rocks (Fogarty, 1976), and when natural shelters were absent, it attempted to protect itself by quickly burying into sediment (Hudon and Lamarche, 1989). Jonah crabs, *C. borealis*, often dug into the substrates partially or completely burying themselves if fish attacked or approached repeatedly (Richard and Cobb, 1986). *C. borealis* hid beneath stones and fought only when directly confronted by a predator by displaying its large claw; *C. irroratus* that are buried will run when disturbed (Jeffries, 1966). In similar situations, the red rock crab is apparently willing to defend itself. On one occasion, I observed a red rock crab repeatedly waving its big claw when a rock fish passed by in front of it.

In Indian Arm, three habitat types were rarely used by the red rock crab, fine sand, coarse sand and rock-outcrop. Although these habitats lack refuges, sand could function as a partial refuge from predators at low prey density (Lipcius and Hines, 1986). Fine sand habitat was rarely used by the red rock crab. In this habitat, Dungeness crabs, *C.*

magister, are common (Knudsen, 1964; pers. obs.). According to Rickett and Calvin (1968), *C. productus* lacks structures for straining the fine debris encountered on mud or sand bottoms out of its respiratory water. Previous studies on lobsters suggested that low densities on soft bottoms could result from differential habitat selection at settlement and/or a heavier post settlement predation than that on rocky bottoms (Hudon and Lamarche, 1989).

I also found evidence of a strong seasonality in habitat use and this affects the site specific abundance of the red rock crab. My finding supports previous observations by Robinson and Hartwick (1981) on the west coast who reported seasonal variations in the relative abundance of the red rock crab. This seasonal variation could result from shifts of crab populations to particular habitats in different seasons. The use of particular habitat types in summer may also reflect mating activity. In Indian Arm, crabs appear to move to shallow areas to find mates. In Cates Park, they move into coarse sand-dense cobble habitats and at other sites into rock-boulder habitats. Mating occurred when females were soft-shelled, especially in summer. *C. productus* males were observed carrying soft-shelled females pressed to their ventral surfaces for several days while moulting and copulation were completed (Morris et al., 1980). In Puget Sound, mating activities occurred mainly in summer and fall; starting in June and continuing on through July and August, at which time mating pairs were encountered regularly (Knudsen, 1964). The four seasons over which I observed red rock crabs in Indian Arm, from early summer 1991 to early summer 1992, showed that there may be variation in the breeding period for the species. In 1991, mating activity at least in the study sitesoccurred from early June to early August, and no mating pairs were observed after this date. In 1992, the crabs were observed mating in the third week of May, continued through June. During weekly exploratory dives until late fall, only two additional mating pairs were observed, one in mid-July and one in mid-October. Such differences in the mating season if real might result from differences in temperature that affect the rate of development. Nevertheless, the number of degree days required may be the same.

Both sexes inhabit coarse sand-sparse cobble, coarse sand-dense cobble, coarse sand-dense cobble-boulder, sand-boulder and rock-boulder habitats with the greatest use in coarse sand-dense cobble habitat. More females were, however, caught in flat coarse sand and rock-outcrop habitats. Crabs were found walking around on the bottom and distributed over a broad area of sea bottom in all depth intervals of the transects; nevertheless, they were especially abundant in the shallow subtidal where they mated.

In fall, the habitat of coarse sand-sparse cobble is the most preferred habitat for red rock crabs. Males and females shared all habitats, although more males than females were found. In winter, both males and females shared flat coarse sand, coarse sand-dense cobble, and rock-boulder habitats, while more males were found in fine sand, coarse sand-sparse-cobble and sand-boulder habitat and females in rock-outcrop habitat. The 15-min random dives indicated that during these seasons, most crabs were captured in both coarse sand-sparse cobble and soft bottom of coarse sand habitats. The crabs were found buried or half buried and typically in an obvious clumped pattern.

Ovigerous female crabs were mostly found in coarse sand habitat. This behaviour might be associated with the cold temperature in the fall and winter months in general or the egg maturation for the ovigerous females in particular. In spring 1992, rock-boulder and coarse sand-dense cobble habitats were preferred by red rock crabs. Other habitats shared by both sexes are coarse sand-sparse cobble, coarse sand-dense cobble, coarse sand-dense cobble-boulder, sand-boulder and rock-outcrop. At this time, more males were found in rock-boulder habitat and more females in flat coarse sand habitat. The use of coarse sand by female crabs was associated with high occurrence of ovigerous females which needed soft substrate to bury in. Crabs were not observed in fine sand and coarse sand-sparse cobble-boulder habitats. The water temperature at this time approached summer temperature, and the crabs changed their behaviour from burying to walking. This was also the period during which crabs began mating.

Ovigerous females were observed from late September 1991 to the end of May 1992. According to Morris *et al.*(1980), ovigerous females occurred from October to June (especially December to March) in Puget Sound, and from January to August (especially April to June) in southern California. From late September to late October, only a small proportion of females were ovigerous. The number of ovigerous females increased from November 1991 to January 1992 to a maximum of 95% of females encourtered and then decreased to 77.7% and 71.2% in February and March 1992, respectively. This number rapidly decreased by April 1992 due to egg releases. In May 1992, few ovigerous females were observed; the same situation was also observed in early May 1991 (pers. obs.). Previous findings (Knudsen, 1964) showed that most females extruded eggs by December or January and most eggs hatched by March or early April.

Seasonal variations in sex ratio obtained in this study are different from that previously described (Knudsen, 1964). Knudsen (1964) found that in Puget Sound males are predominant in the intertidal from January through May and females are almost totally absent. Females predominated from summer months through to early October, and both sexes were equally distributed in numbers from the end of May on into June and then again equal in numbers during November and December. However, using the same categories of seasonal groupings, my study shows that sex ratios of summer 1991 and spring 1992 were 1 : 1, while males predominated in the fall and winter months. Equality in male-female ratio in summer is likely associated with breeding activity, in which males and females move to the shallow areas and mate. On a monthly basis, 1 : 1 sex ratios were observed in August 1991, March, April and June 1992. Females predominated only in September 1991, but in other months, males were more often found. Uneven sex ratios were also found for rock crabs, *C. irroratus*, in which there is an absence of females in winter populations (Shotten and Van Engel, 1971).

The differences between results of my study and those of Knudsen (1964) may relate to his use of only surface observations and the limitation of his study to the intertidal area. Such limited observations likely could result in bias. Surface observations do not sample the depths where the crabs are mostly abundant. Using SCUBA diving techniques, I found that the crabs are mostly abundant at 3-6 m deep below 0 tide. The limitations of these two methods of observation were described by Heggeness *et al.*(1990).

Variation in sex ratio among different study sites in Indian Arm may be due to the availability of suitable habitat types. Cove Cliff is characterized by soft sandy bottom and supports more females than males. This substrate consists of coarse sand covered with a thick layer of shell fragments which enables the crab, especially ovigerous females, to bury themselves. After the spawning season, the male crabs leave this habitat, and 47.5% and 16.25% of total winter catches indicate migration to areas of coarse sand-sparse cobble and rock-boulder, respectively. Only 3.75% of winter catches were found in the flat coarse sand area. On the other hand, the females move to coarse sand-sparse cobble (37.5%) and flat coarse sand (20%) and sand boulder (20%) habitats. The 20% of the total catch in flat coarse sand habitat represents only a small number of crabs (8 crabs). This may reflect the lack of replications for this habitat type. Nevertheless, 15-min random collections confirmed these findings by a high catch of female crabs in this habitat. In addition, this higher catch of female crabs relative to males was also detected in Cove Cliff, a site that has this habitat.

Sizes of the red rock crab most frequently captured in my study were between 100 - 150 mm CW for males and between 80 - 110 mm CW for females. Mature males of red rock crabs are bigger than females. This finding agrees with other previous studies on *Cancer* sp. (Phillips, 1939; Morris *et al.* 1980). Cleaver (1949) who observed the growth rate of the female Dungeness (*C. magister*) of the Pacific coast found that its growth rate slowed down with the onset of maturity. Members of Spider crab family are known to terminate molting at maturity. In my study, the smallest size of mating females was 61 mm (Basahi, pers. com.). Only three males were larger than 170 mm CW and one female was larger than 140 mm CW. These maximum sizes are bigger for males and smaller for females than those recorded by MacKay

(1931) and Morris *et al.*(1980), but smaller than those reported by Hart (1982) for both sexes. Lack of red rock crabs at these sizes could be caused by either natural or fishing mortality. During the study periods, few small crabs (less than 100 mm for males and less than 70 mm for females) were found. This size segregation could result from cannibalism by bigger crabs, movement by small crabs toward deeper site or different habitat requirement for small crabs.

A bimodal or polymodal size frequency distribution of male crabs represents several age groups. A single modal size frequency distribution of female crabs could also represents several age groups due to the wide range of size classes. In the present study, however, the age classes can not be detected because molting frequency and growth rate of the species were not followed. The smallest crab mean size is found in summer and the biggest ones in winter and spring. Shift in size modes during different seasons could reflect growth, mortality and movement of the species. Besides these processes, there is a tendency for larger crabs to migrate inshore and smaller ones move offshore. Eleven recaptures of tagged crabs (Basahi, pers. com.) by traps in deeper water are consistent with Cleaver (1949) who reported that the red rock crab migrate off-shore in the cold months. The seasonal migration of large crabs to and from shore has been associated with molting activity or egg maturation and hatching (Scarratt and Lowe, 1972). The lack of smaller males at the shallow depths in cold months could also reflect competition with bigger males occupying the shallow depths. In spring 1992, mature males of different sizes moved inshore to mate. My study showed that seasonal migration of red rock crabs is also associated with breeding activity. My results, therefore, confirm those of previous studies (Cleaver, 1949; Prasad and Tampi, 1951; Knudsen, 1964; Haefner, 1976, and Robles *et al.*, 1989) in that there is size segregation in *Cancer* sp. over a broad bathymetric and seasonal scale.

The biggest and smallest mean crab sizes were observed at Racoon Island and Cates Park, respectively; crabs of Belcarra Point, Cove Cliff, Bedwell Bay and Jug Island had similar size distributions. Cates Park also had the smallest crab mean size for females and Racoon Island had the largest one although there was no significant difference from those at Bedwell Bay. This situation might be associated with the availability of particular habitat types. Cates Park, Cove Cliff and souther Jug Island have coarse sand-sparse cobble habitat that supports small sized crabs. A similar situation is also found in northern Jug Island. On one exploratory dive at northern Jug Island, a number of juveniles were noted on coarse sand-sparse cobble habitat. Each individual crab occupied sand area close to cobble. In addition, coarse sand-dense cobble habitat with *Laminaria* sp. might be important for juvenile red rock crabs although this habitat was not monitored regularly. Other study sites with sand boulder habitat do not appear to be selected by small sized red rock crabs. The size of particle size may also be important for crabs of particular sizes.

Studies of other *Cancer* sp. and lobsters have suggested that temperature fluctuations may increase or decrease their activity (Jeffries, 1966; Thomas, 1968 and Cooper *et al.*, 1975). Although the distribution of animals is influenced by a number of biotic processes or factors, their occurrence or behavior should reflect the influence of abiotic factors. This process may be apparent in red rock crabs with regard to their different behaviors or migration. In summer when the bottom temperature at 10 m ranged from 14.4°C-16.6°C, they tend to stay on the bottom, often under the kelp, *Laminaria* sp., or walked about. The crabs were mostly collected at this temperature range. In the fall and winter months when the temperature dropped from 15.5° to 7.7°C, the crabs reduced their activity by burying themselves in the sand or left shallow sites and moved to deeper sites. The depths affected by temperature fluctuations ranged from 0 - 30 m (Gilmartin, 1965). Lobsters tend to avoid this depth range and inhabit deeper sites or were buried in areas at depths less than 4 m (*Cooper et al.*, 1975). Fluctuations in the trap catch that I observed for red rock crabs may reflect the use of particular depth ranges by Dungeness crabs. The low catch of red rock crabs in the warmer months may be due to the high abundance of the dungeness crabs. In the cold months, vertical shifts of red rock crabs into deeper waters may be coincident with similar movements of the Dungeness crabs migrating even deeper, and hence, more red rock crabs were captured. During the diving program, 79 tagged crabs were caught. The duration between release and first recapture of the tagged crabs varied from 2 days to over one month. Moreover, 5 crabs were recaptured twice and the duration of the second recapture varies from four days to approximately six weeks after the first recapture. Because all tagged crabs were recaptured at the same sites where they were tagged (Basahi, pers. comm.), there was no evidence in along-shore movements. A daily vertical migration of the red rock crab was reported by Robles *et al.* (1989). However, my results were inconsistent with Robles *et al.* (1989) because very few crabs were found in the intertidal during my study period. Moreover, the use of the food resources available in subtidal area by the red rock crab (pers. obs.) indicated that foraging migration to the intertidal area may not be crucial for red rock crabs at least in Indian Arm. However, no attempt was made to minitor nocturnal activities which may have occurred in the intertidal. In fact, the emphasis in the present study was on subtidal habitat so that little sampling was done above 0 tide.

Water salinity of Indian Arm is influenced by the intrusion of freshwater from Indian River and saline water from Burrard Inlet. This situation creates horizontal and vertical gradients in salinity. My study indicates that the mean surface salinity ranged from 15.9 to 16.6 ppt, about 1 ppt higher than that of in 1957 to 1959 (Gilmartin, 1962). At 10 m the mean salinity ranged from 24.8 ppt to 26 ppt and 25.3 ppt to 26.5 at 20 m in spring and fall, respectively. Because crabs were caught at all these depth ranges and there was low salinity fluctuation with seasons, salinity may have little effect on red rock crab distribution in Indian Arm at least in these study sites. No sampling was carried out farther north in Indian Arm closer to the Indian River.

Diving is useful and a reliable technique for underwater study. Direct counts and measurement can provide high quality data (Malatesta *et al.*, 1992). In this study, diving allowed me to regularly count crabs and record their positions. However, this technique could produce some bias when the water visibility is poor, especially in Indian Arm. Besides this limitation, the diving technique is generally limited by depth constraints and available bottom time. For sediment sampling, there are many ways to obtain bottom sediment depending upon the objective of the study. In this study, I collected the sediment sample from the first few centimeters of the bottom surface. I only sampled this depth because red rock crabs were generally buried close to the surface.

Selection of study sites likely introduced some biases because habitat types could not be replicated at different study sites. As I mentioned before, coarse sand habitat favors ovigerous females. However, ovigerous females were mostly caught at this habitat in Cove Cliff, whereas there was a lack of ovigerous females in similar habitat at Belcarra Point. Therefore, other factors may determine this pattern. Nevertheless, my study has provided information about habitat selectivity by red rock crabs. My study is limited in regard to information about crab size and selectivity of habitat because some habitats had very small sample sizes. My study also does not provide much information about habitat use by juvenile red rock crabs. Previous studies have revealed that eelgrass beds are important nursery habitat for blue crabs and other decapod crustaceans (Heck and Orth, 1980; Heck and Thoman, 1984; Orth and Van Montfrans, 1987). Thayer and Phillips (1977) noted that eelgrass beds are important for small red rock and Dungeness crabs. Two transect records from Tofino in summer 1991 (pers. obs.) agree with Thayer and Phillips (1977). I did not observe this association in Indian Arm. In Bedwell Bay (that has a sparse eelgrass bed), I only found Dungeness crabs. This lack of red rock crabs may occur because the bottom substrate of fine sand in this eelgrass bed may be unable to support red rock crabs. In Indian Arm, clumped kelp, *Laminaria sp.*, may be more important than eelgrass beds for small red rock crabs. The habitat relationships of red rock crabs needs further study over a broader range of study sites.

VI. CONCLUSION

My results agree in part with previous studies (Knudsen, 1964; Hartwick and Robinson, 1981 and Robles *et al.*, 1989) and have provided more information on the natural history of the red rock crabs. Red rock crabs use a variety of habitat types but overall they prefer a mixture of coarse sand and sparse cobble. Depending on seasons, habitat use may be associated with the biological cycle of the species, such as breeding, egg maturation, or avoiding unfavorable environmental conditions. Males and females have different habitat preferences in particular seasons. In summer, males and females share a variety of habitat types and become active to find mates. From the middle of fall through spring, when sex segregation occurs, males are predominant in coarse sand-sparse cobble areas but ovigerous females were found primarily in coarse sand and rock-outcrop. The high catch of crabs in summer and the low catch in the other three seasons suggest that the high relative abundance of the crabs occurs only in mating seasons due to habitat sharing by both sexes. Size variation with seasons is due to both sex segregation and size changes in male crabs. Racoon Island and Cates Park had the biggest and the smallest crabs, respectively. Some size variation also occurs in relation to season, study site and habitat type because of habitat selectivity and size segregation in the red rock crab. Vertical movements occur with seasons but there was no evidence for alongshore movement.

Although my study contributed to a greater understanding of the natural history of red rock crabs, the following studies should be conducted:

1. The presence of preferences for habitat types by sex and size classes of red rock crabs suggests that Habitat Suitability Index (HSI) approach would be useful to define the quality of certain habitat types. In particular,a study is needed that examines reproduction success of female crabs in different habitat types.

2. During my study, very few juveniles were caught and thus their habitats are unknown. Therefore, a study on the ecology of juvenile crabs is needed. This study should also examine adult-juvenile interactions to determine if social behaviour is the reason that few juveniles occur in the habitats occupied by adult crabs.

3. The low catch of the red rock crab and high catch of Dungeness that I observe in traps could be the result of negative interaction between the species. Interspecific behavior should be examined and may be important ifa crab fishery is developed.

4. Size differences of red rock crabs between study sites but I do not know why these differences occur. A study is needed to determine which ecological or genetic factors are involved.

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