ASPECTS OF THE LIFE HISTORY OF THE
BLUE KING CRAB (PARALITHODICES PLATYPU S) IN ALASKA

by

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D.A. Somerton and R.A. MacIntosh

INTRODUCTION

The blue king crab, Paralithodes platypus, is similar in size and general morphology to the better known and commercially more important red king crab, P. camtschatica. Unlike the red king crab, which is generally distributed in coastal Alaska waters, blue king crab occur in isolated populations. Principal fisheries for blue king crab occur in the eastern Bering Sea, where most populations are associated with offshore islands. Minor, but locally important fisheries occur south of the Alaska Peninsula in a number of widely scattered, enclosed bays.

The National Marine Fisheries Service (NMFS) has conducted annual trawl surveys within the range of the Pribilof Islands population of blue king crab since 1974, and the range of the St. Matthew Island population since 1978. Examination of females from these populations suggested that their reproductive cycle was fundamentally different from that of the red king crab. Barren mature females were regularly found in summer (Otto et al. 1979) when almost all red king crab would have had external eggs. A sample of 61 mature females collected in the Pribilof Islands in October, 1981 also contained a high percentage (67%) of barren females. Sasakawa (1973, 1975a) similarly found barren blue king crab females in the western Bering Sea. He attributed high incidences of non-ovigerous females to a 2 year reproductive cycle; 19 months of which is spent incubating eggs and 5 months of which is spent in a barren condition (old shell and having empty egg cases on the setae of the pleopods).
In order to test Sasakawa's findings and study other aspects of the life history of blue king crab, the NMFS initiated a study of a small population of blue king crab occurring in Olga Bay, at the south end of Kodiak Island. The accessibility of this population allowed quarterly sampling that was not feasible in the eastern Bering Sea. This paper summarizes Olga Bay data and compares them to data collected from Prince William Sound and the eastern Bering Sea populations. Locations of these populations are shown in Figure 1. Histological studies of Olga Bay blue king crab tissues indicated that about 50% of the adult female population was infected by a rhizocephalan parasite. The implications of this finding are also discussed.
MATERIALS AND METHODS

Olga bay is 31 km long, 5.6 km in width, and has a maximum depth of 159 m. It is separated from the Gulf of Alaska by a shallow sill that is 185 m across and 9 m deep. Blue king crab were sampled at roughly three month intervals: 25 March - 2 April, 16-26 June, 3-10 October, 1980, and 8-15 January, 1981. Crab were captured by SCUBA diving and in ring nets at depths less than 50 m. Crab were in deep (>30 m) water during the October sampling period and could not be taken by divers.

Data from the Pribilof Islands and St. Matthew Island were collected between the years 1974 and 1980 during NMFS resource assessment trawl surveys and crab tagging cruises. Prince William Sound samples were taken in 1979 and 1980 from the commercial catch and during research surveys conducted by the Alaska Department of Fish and Game.

Carapace length on all specimens captured was measured to the nearest mm and shell condition was subjectively scored from 1 (exoskeleton still soft) to 4 (crab presumably skipped two successive molts). External egg clutches were rated by size, color of eggs, and presence or absence of eye spots. Presence or absence of empty egg cases on non-ovigerous females was also noted. Pleopods (with or without eggs attached) and ovaries were collected from females >70 mm in Olga Bay, and the occurrence of grasping pairs (males holding females in a pre-copulatory embrace) was also noted. Chela heights (see Wallace et al. 1949) were measured on male crab in all four areas, and total body weights of males were taken in all but Prince William Sound.

External egg clutches were collected in June and July of 1978 and 1979 in the Pribilof Islands for the determination of fecundity. All six pleopods were removed from the crab and placed in 10% formalin. Egg masses were later air dried and the pleopods and setae removed. Two subsamples of approximately 250 eggs were
counted and weighed to the nearest 0.1 mg on an analytical balance. Total number of eggs was extrapolated from the count and weight of each subsample, then the two estimates were averaged. Olga Bay external egg samples were handled in the same manner.

RESULTS AND DISCUSSION

Reproduction

In the four sampling periods at Olga Bay, 759 blue king crab and 301 red king crab were captured (Table 1). Of the blues, 422 were male and 337 were female. One hundred and eighty crab were juveniles (<90 mm carapace length).

Grasping pairs of blue king crab were observed in January and March when adults occurred in water as shallow as 3 m. Such pairs were usually found near a prominent objects (pilings, large rocks, or oil drums) and rarely with other crab on open soft bottom. In January, four of 10 grasped females were primiparous and five were multiparous (one was immature); while in March, all grasping females (n=7) were multiparous. The average length of grasping males was smaller (134 mm) in January than in March (143 mm; t test, df=14, P < .05). Since the sizes of grasping males and females are correlated (rank correlation coefficient = 48, df=14, P < .05), it appears that small males mate early in the breeding season with primiparous females.

Egg hatching was observed only in the January and March sampling periods. Two females in January and 8 in March were clearly in the process of hatching out eggs. Five of the March females were being grasped by males while hatching was in progress. Ovary weights of females collected during January and March ranged from 1-94 gms. Grasping females, however, had ovaries that were consistently heavier than those of most non-grasppers (Fig. 2).

The duration of grasping, molting, egg extrusion and fertilization in blue king crab is probably similar to that of red king crab. Female red king crab are
grasped, molt, and extrude eggs that are immediately fertilized, all within a period of about a week (Powell and Nickerson 1965). The fact that all 9 mature grasper taken in January were in the pre-molt condition as determined by histological examination (Dr. P. Johnson, NMFS, Oxford, MD 21654, pers. comm.) suggests similar timing and sequence of mating events for the two species.

The 19 month incubation period and five month barren period hypothesized by Sasakawa (1973, 1975a) for western Bering Sea crab does not fit the Olga Bay data. The fact that grasping and egg hatching were found in both January and March and that five of the March grasped females were still hatching out eggs, strongly suggests a twelve month reproductive cycle. The large number of barren females in the population indicates that many females have active (egg bearing) and inactive (barren) phases during their mature life. Some females are, however, reproductively active for two years in a row.

Forty-three percent of the mature females (>90 mm) sampled from Olga Bay were barren. The percentages by season from January through the October sampling period were: 46, 52, 33, and 38% respectively. Presence of non-ovigerous females is hence a persistent feature of the population throughout the year. By contrast, more than 90% of mature females in red king crab populations would normally be ovigerous. The reproductive potential of blue king crab is apparently lower than that of red king crab.

The Rhizocephalan Parasite

The presence of a rhizocephalan parasite seriously complicates interpretation of Olga Bay reproductive data. The species of rhizocephalan is unknown and either lacks an externa or has an inconspicuous and ephemeral externa that was not detected in the field. Histological examination of tissues from 104 females collected in January showed that 51% (53) of adult females were parasitized (Dr. P. Johnson, NMFS, Oxford, MD 21654, pers. comm.). The highest rate of parasitism was among barren females.
Since rhizocephalans are known to interfere with reproduction in their hosts, it is possible that some or all breeding inactivity is due to the parasite. Unparasitized barren females that had small ovaries were, however, observed during the breeding period. This suggests that the effects of rhizocephalan parasites are superimposed on the reproductive patterns described above. Reproductively inactive females are also regularly found in the Pribilof and St. Matthew Islands populations (where tissue samples have recently been collected for examination for the parasite) and in the western Bering Sea (Sasakawa 1973). We think it is unlikely that the rhizocephalan is entirely responsible for this phenomenon throughout this broad range.

**Fecundity**

The relationship between fecundity and size was examined using two Olga Bay samples (October, N=28; January, N=25) and one Pribilof Island sample (N=145). Preliminary plots of the Pribilof Island data suggested that fecundity might increase with size at a diminishing rate. Such a curvilinear relation was previously reported by Sasakawa (1975b). Curvilinearity was tested by fitting a quadratic equation to fecundity and size data. Analysis of variance showed that the coefficient of the squared term was significant (P < .05). For predictive purposes, however, a relationship proposed by Somerton (1981) was used instead. This relationship is expressed as \( E = E_\infty - A \exp(-Bx) \), where \( E \) is fecundity at size \( x \), and \( E_\infty, A \) and \( B \) are parameters. Weighted nonlinear regression was used to fit this equation to Pribilof Islands fecundity and size data. The estimated parameter values are:

\[
E_\infty = 241629 \\
A = 2632606 \\
B = .028023
\]

This equation predicts (Fig. 3) that the average fecundity ranges from approximately 50,000 at 93 mm to 200,000 at 155 mm.
To determine if fecundity differs between seasons, the October Olga Bay sample was compared to the January sample (excluding females with new uneyed eggs) using analysis of covariance. The slopes of the fecundity-size relationships were not significantly different (P=.28), but the intercepts were significantly different (P=.0004). Since the mean fecundity at each size was higher in October than January, blue king crab apparently experience a significant egg loss with time.

To determine if fecundity differs between areas, the Olga Bay sample was compared to the Pribilof Islands sample. Potential differences in fecundity due to differences in the time of sampling were minimized by excluding the January Olga Bay sample from the comparison. The statistical comparison of the two populations consisted of: 1) dividing the size axes into a number of equal size intervals; 2) using the Wilcoxon signed rank statistic to calculate a one-tail probability of a population difference within each interval; and, 3) using Fisher's method (Sokal and Rohlf 1969, chap. 17) to combine probabilities over all intervals. Pribilof Island crabs had a significantly higher fecundity (P=.0001) than Olga Bay crabs.

Size at Sexual Maturity

Female and male size at maturity was estimated for four blue king crab populations: St. Matthew Island, Pribilof Islands, Olga Bay, and Prince William Sound. A detailed description of this aspect of the study is provided in Somerton and MacIntosh (In press a). Female maturity was based on the presence of eggs or egg remnants on the pleopods setae or by the relative length of the pleopod setae. The size of 50% maturity was estimated by fitting a logistic equation to percent mature by size, using methods described in Somerton (1980), then evaluating the fitted equation to find the size corresponding to 50% mature. Estimates of the size of 50% maturity and their variances are shown in Table 2. The percentage of mature females as a function of length and fitted logistic equations are shown in Fig. 4.
The average size of maturity for males was estimated by analyzing the allometric relationship between chela height and carapace length. When chela height is plotted against carapace length on log-log axis, the data assume a pattern consisting of two intersecting straight lines. The average size at maturity, which corresponds to the intersection point, was estimated using an iterative computer technique described in Somerton and MacIntosh (In press a). Average sizes at maturity and their variances are shown in Table 2. Chela height and carapace length and the fitted straight lines are shown in Fig. 5.

For both female and male blue king crab, the size at sexual maturity is smallest at St. Matthew Island, largest at the Pribilof Islands and intermediate between these extremes at Olga Bay and Prince William Sound.

Weight-Length Relationship

Weight-length relationships of male blue king crab were determined for three populations: St. Matthew Island, Pribilof Islands, and Olga Bay. A detailed description of this analysis is presented in Somerton and MacIntosh (In press b). Weight was assumed to be proportional to carapace length raised to a power, that is, \( W = AL^B \) where \( W \) is weight (grams), \( L \) is carapace length (mm), and \( A \) and \( B \) are parameters. The two parameters were estimated by fitting a straight line to the natural logarithms of weight and length. The estimated parameters are shown in Table 3. Weight-length data and the fitted curves are shown in Fig. 6.

Equality of the weight-length relationships between populations was tested using analysis of covariance. The slopes (B) of the weight-size relationships did not differ (\( P = .3279 \)) between populations, but the intercepts (logA), assuming a common slope, differed significantly (\( P < .0001 \)). Pairwise comparisons of the intercepts (Bonferroni t test; Miller 1966) showed that St. Matthew Island and Pribilof Islands did not differ (\( P > .1372 \)) but that Olga Bay differed significantly (\( P < .0001 \)) from each of the Bering Sea populations. Since the intercepts rather than the slopes of the
weight-length relationships differ between Olga Bay and each of the Bering Sea populations, the ratio of the weight of an Olga Bay crab to the weight of an equal size Bering Sea crab is a constant. Olga Bay blue king crab are therefore roughly 8-9% heavier at all lengths than either St. Matthew Island or Pribilof Islands crabs.
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camtschatica Tilesius). U.S. Fish. and Wildl. Serv., Fish.
Table 1.—Numbers of male and female blue and red king crab caught in the four sampling periods at Olga Bay, Kodiak Island, 1980 - 1981.

<table>
<thead>
<tr>
<th></th>
<th>JAN.</th>
<th>MAR.</th>
<th>JUNE</th>
<th>OCT.</th>
<th>TOTAL</th>
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<td>Blue King</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>♂</td>
<td>121</td>
<td>95</td>
<td>132</td>
<td>74</td>
<td>422</td>
</tr>
<tr>
<td>♀</td>
<td>108</td>
<td>95</td>
<td>53</td>
<td>81</td>
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<tr>
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<td>229</td>
<td>190</td>
<td>185</td>
<td>155</td>
<td>759</td>
</tr>
<tr>
<td>Red King</td>
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</tr>
<tr>
<td>♂</td>
<td>35</td>
<td>19</td>
<td>103</td>
<td>58</td>
<td>215</td>
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<tr>
<td>♀</td>
<td>13</td>
<td>5</td>
<td>20</td>
<td>48</td>
<td>86</td>
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<tr>
<td>Total</td>
<td>48</td>
<td>24</td>
<td>123</td>
<td>106</td>
<td>301</td>
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</table>
Table 2.—Female and male sizes at maturity and their 95% confidence intervals for each of the four populations studied.

<table>
<thead>
<tr>
<th>Area</th>
<th>Size at 50% Maturity</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Matthew Island</td>
<td>80.6</td>
<td>79.4 - 82.6</td>
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<tr>
<td>Pribilof Islands</td>
<td>96.3</td>
<td>95.7 - 96.9</td>
</tr>
<tr>
<td>Olga Bay</td>
<td>93.7</td>
<td>92.9 - 94.5</td>
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<tr>
<td>Prince William Sound</td>
<td>87.4</td>
<td>86.4 - 88.4</td>
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</table>

<table>
<thead>
<tr>
<th>Area</th>
<th>Average Size at Maturity</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Matthew Island</td>
<td>77.0</td>
<td>57.8 - 96.2</td>
</tr>
<tr>
<td>Pribilof Islands</td>
<td>108.0</td>
<td>82.9 - 133.1</td>
</tr>
<tr>
<td>Olga Bay</td>
<td>87.0</td>
<td>72.9 - 101.1</td>
</tr>
<tr>
<td>Prince William Sound</td>
<td>93.0</td>
<td>65.7 - 120.2</td>
</tr>
</tbody>
</table>
Table 3.—Estimated parameters of the fitted weight-length relationships for each of the three populations.

<table>
<thead>
<tr>
<th>Population</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
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<tr>
<td>St. Matthew Island</td>
<td>0.000329</td>
<td>3.175</td>
</tr>
<tr>
<td>Pribilof Islands</td>
<td>0.000470</td>
<td>3.103</td>
</tr>
<tr>
<td>Olga Bay</td>
<td>0.000475</td>
<td>3.115</td>
</tr>
</tbody>
</table>
Figure 1. -- Locations of blue king crab populations sampled for biological data.
Figure 2. -- Ovary weights of crabs captured in the March, 1980 and January, 1981 sampling periods at Olga Bay, Alaska.
Figure 3. -- Fecundity and carapace length data for female blue king crab from the Pribilof Island and the fitted curvilinear relationship.
Figure 4. -- Female percent mature as a function of size and the fitted logistic equation for each of four populations.
Figure 5. -- Male chela height and carapace length and the fitted straight lines for each of the four populations. The intersection point indicates the average size of maturity.
Figure 6. — Male weight and carapace length and the fitted curves for each of three populations.