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SIZE OF MATURITY IN MALE GOLDEN KING CRAB, *LITHODES AEQUISPINUS* (ANOMURA: LITHODIDAE)

A. J. Paul and J. M. Paul

University of Alaska, Institute of Marine Science, Seward Marine Center Laboratory,
Post Office Box 730, Seward, Alaska 99664 U.S.A.
(e-mail: ffajp@uaf.edu)

ABSTRACT

Typically ≥90% of the eggs in clutches fertilized by hardshell Prince William Sound *Lithodes aequispinus* males ≥107 mm carapace length initiated division. Golden king crab males with only one chela and those with post-molt carapaces ≥11 days old were effective parents. Some test males had exclusive access to three ripe females. Their first and second mates all produced viable clutches with 81–100% of eggs exhibiting development. Not all males induced a third female to ovulate. The percentage of eggs initiating division in the clutches of their third potential female mates ranged from 56 to 100%.

The Alaskan fishery for *Lithodes aequispinus* Benedict, 1894, has increased dramatically in recent times as stocks of other crab species have declined. The life history of this species is poorly described, and the management plan for conserving golden king crab stocks was developed without much information on their reproductive capacity. Because they often live in deep water, typically on untrawlable bottoms in remote sites, field studies on the reproductive habits of this species are problematic. The fishery only harvests males, and they must have carapace lengths (CL) ≥ 140–180 mm depending on the geographical area they inhabit (Donaldson and Donaldson, 1992). The size regulations were set to allow males some opportunity to breed before they recruited to the fishery. However, prior to this study estimates for the size at maturity for male golden king crabs were based only on chela and carapace measurements (Jewett *et al.*, 1985; Somerton and Otto, 1986).

The size of maturity for males, the effect of their molt stage, their ability to breed more than one female, and the effect of chela loss on ability to fertilize females, was examined through laboratory breeding experiments. As a conservation measure the management program tries to leave enough males on the grounds to fertilize all females. Prior to this study there had been no experiments done that described the size and shell condition of males that were capable of breeding. The primary objective of these observations was to determine if males smaller than the size limit set by the fishery regulations were capable of fertilizing females. "Old-shelled" males missing chela have low market value and are often released by fishermen. The breeding tests with males missing a chela were done so fishery managers would know if these discarded males could be effective parents. Breeding tests using males that molted in captivity were done so resource managers could predict the impact on fertilization rates if "newshell" males were numerous.

MATERIALS AND METHODS

Crabs needed for the study were captured with crab pots fished at depths of 108 to 152 m on the western side of Prince William Sound, Alaska. After capture the specimens were transported to the Seward Marine Center Laboratory by floatplane. No moralities occurred during the transport process. Crab collections were made during 11–14 November 1996, 1 May 1997, and 10–20 October 1998, and observations of captives continued until September 1999.

The carapace length (CL) of all crabs was measured to the nearest mm, and they were tagged with a numbered plastic disk attached to the leg with a plastic cable tie. The chela height (CH) of males was measured at its widest point for the largest chela. Crabs were held in 800–1,000 l tanks with ten crabs of one sex in each tank. The sea water in tanks was exchanged ≥100% per h so its temperature was the same as the incoming sea water. The sea water came from 75-m depth in Resurrection Bay, Seward, Alaska. The temperature in the tanks followed the fjord's 75-m depth seasonal cycle ranging from 3.5 to 10°C. Females were isolated from test males until they molted. Females must molt prior to mating and have no ability to store sperm. Crabs were fed Mondays and

Table 1. The percentage of eggs dividing in clutches of *Lithodes aequispinus* mated to hardshell males of varying carapace length.

Test male CL (mm)	Female CL (mm)	Percentage eggs dividing with test male parent	Percentage eggs dividing with male 2 parent
95	126	–	100
99	135	–	71
101	133	71	
107	133	98	
107	148	94	
118	122	99	
121	138	98	
123	130	96	
123	130	100	
128	130	100	
130	130	99	
131	129	99	
132	121	100	
133	157	99	
133	135	100	
134	130	100	
136	149	100	
138	144	99	
138	137	100	
139	137	91	
141	136	96	
141	128	100	
144	126	99	
145	129	100	
146	138	98	
146	130	100	
147	129	100	
148	128	63	
148	129	99	
150	128	90	
153	141	99	
155	128	100	

Thursdays to excess with a repeating cycle of the following foods: whole Pacific herring *Clupea pallasi* Valenciennes, 1847, followed by fillet of coho salmon *Oncorhynchus kisutch* (Walbaum, 1792), then *Octopus dofleini* (Wulker, 1910) or whole squid (species unknown). Excess food was removed from tanks on Wednesday mornings and Friday afternoons.

There were four major categories of test males. The first was "hardshell" males that had been in captivity ≥12 months, and they were from 95 to 155 mm CL (n = 32). This group is referred to as "hardshell" males in this report. The next group of hardshell males had only one of their chela, CL ≥ 133–150 mm (n = 6). All of these hardshell "one-claw" males had been captive for at least 12 months before the tests. This group is referred to as "one-claw" males in the text. The third group of males had molted in the laboratory, so it was known how long after their molt they had access to a newly molted ripe female (n = 19). These males had molted between 1 and 71 d prior to being put into tanks with ripe females. This group of males is referred to as "newshell" males in this report. These newshell males had CL ≥ 115 mm. The fourth test group were males (n = 17) that were given access to three ripe females to see if they could fertilize more than one female. The length of time during which males had to fertilize all three females ranged from 1 to 41 d. This group of males is called "repeat breeders" in this manuscript.

Table 2. The percentage of eggs dividing in clutches of *Lithodes aequispinus* mated to hardshell males of varying carapace length that had only one right (R) or left (L) chela.

Male carapace length (mm)	Male chela height (mm)/right or left	Female carapace length (mm)	Percentage eggs dividing
133	12R	141	100
138	39R	152	100
139	22L	144	91
144	9R	126	99
148	23L	134	63
150	40R	134	90

In all breeding tests both parents were placed in a 0.5-m deep tank so the female brood pouch could be examined without separating grasping pairs. Then the pairs were watched for copulation, and the females were examined every 12 h afterward to see when a new clutch was extruded. If a male in any of the above observations failed to induce a female to extrude a clutch within 3 d after her molt, the test male was removed. Then another, larger hardshell male (CL ≥180 mm with both chelae) was put in with her to see if she would ovulate in the presence of an obviously mature male.

After ovulation, females were isolated and held until eggs reached ≥64-cell stage. Then a group of at least 100 eggs from each pleopod were randomly selected and examined under a microscope for cell division to determine if the male was fertile.

Results

Neither of the two smallest hardshell test males (95- and 99-mm CL) induced females to ovulate, although clutches were produced by those females when males ≥ 180-mm CL were put in their tanks (Table 1). The smallest hardshell male to fertilize an egg clutch was 101-mm CL with 71% of the eggs initiating division. Typically ≥90% of the eggs in clutches fertilized by hardshell males ≥107 mm CL initiated division (Table 1).

There were six males with only one chela that were put with ripe females. All the females they attended produced egg clutches with 63 to 100% eggs dividing (Table 2). Two of these males had only a small regenerating chela (9–12-mm CH).

Females were presented to 19 males that had molted between 1 and 71 days prior to the breeding test (Table 3). Three males that had molted between 1 and 8 days prior to the breeding experiment did not induce females to ovulate. All three females produced viable clutches with other hardshell males. The

Table 3. The percentage of eggs dividing in clutches of *Lithodes aequispinus* mated to recently molted newshell males.

Number of days after male molt breeding occurred	Male carapace length (mm)	Male chela height (mm)	Female carapace length (mm)	Percentage eggs dividing in clutch
1	133	30	135	No eggs*
4	117	28	149	No eggs*
7	141	30	136	96
8	162	42	139	No eggs*
11	161	47	148	99
15	163	45	123	99
16	148	23	128	63
19	157	37	132	100
20	164	44	141	100
21	153	41	141	99
23	127	27	141	100
23	148	38	143	99
26	145	34	129	100
31	124	29	144	100
32	141	31	128	100
42	151	36	140	99
55	119	26	138	100
57	115	27	145	99
71	129	29	142	99

* Indicates female produced a viable clutch with a different male.

clutch of a female bred by a male with a carapace 16 days old had only 63% of the eggs initiate division. However, the other males whose new carapaces were at least 11 days old fertilized females with ≥95% of the eggs in clutches dividing.

There were 17 males with exclusive access to three ripe females (Table 4). In all cases their first and second female mates produced viable clutches. In the clutches of females first to be bred, 81 to 100% of the eggs initiated division. The egg division rates for the second female mates were 78 to 100%. There were 11 second-to-be-bred females that were fertilized one day or less after the first female had been bred. In all 11 cases ≥91% of the eggs were dividing. Two of the females that were third possible mates did not extrude eggs in the presence of the test males, but they produced viable clutches with another male. The other 15 males bred their third mate, with 56 to 100% of the eggs in clutches dividing.

Table 4. The percentage of eggs dividing in clutches of *Lithodes aequispinus* mated to hardshell males with access to three newly molted adult females.

Days between breeding	Male carapace length (mm)	Male chela height (mm)	Female carapace length (mm)	Percentage eggs dividing in clutch
	151	36	140	99
<1			141	99
<1			139	99
	164	44	146	99
1			139	98
<1			128	98
	115	27	145	99
1			151	100
1			144	100
	119	26	138	100
1			136	100
1			126	93
	124	29	144	100
1			146	100
1			152	No eggs*
	127	24	141	100
1			144	98
1			132	No eggs*
	130	30	135	98
1			143	91
1			142	99
	137	30	135	100
1			148	95
1			137	98
	129	29	142	99
1			137	98
2			142	99
	142	24	116	100
2			139	99
1			134	100
	148	38	143	99
2			139	98
1			149	73
	117	28	151	81
1			141	97
3			145	99
	124	23	128	99
2			142	100
2			151	98
	127	29	143	91
3			144	96
1			145	56
	133	32	140	100
1			117	100
5			130	100
	128	30	138	97
10			142	78
2			138	89
	159	44	126	100
2			130	100
13			128	100

* Indicates female produced a viable clutch with a different male.

DISCUSSION

In Prince William Sound, where our golden king crabs were captured, males must have CL ≥ 178 mm to be legally marketed (Donaldson and Donaldson, 1992). All the males used in these breeding tests were smaller than that. Our results show that sublegal-size males ≥110-mm CL can be successful parents. In Prince William Sound a male golden king crab would undergo six or seven molts to grow from 110 to 170 mm (Paul and Paul, 2000), so they have more than one chance to breed prior to reaching a harvestable size. In British Columbia, Canada, male golden king crabs were thought to mature at ≈114-mm CL (Jewett *et al.,* 1985) vs. 130-mm CL in the Bering Sea (Somerton and Otto, 1986) based on chela morphometrics.

There were several instances of golden king crab males mating with females larger than themselves (Tables 1–4). Male red king crab *Paralithodes camtschaticus* (Tilesius, 1815) can also fertilize females that are larger than themselves (Paul and Paul, 1990). This is not unexpected because the females in both king crab species are softshell when mating occurs. Previous work demonstrated that for ten days after molting red king crab males are incapable of mating (Powell *et al.*, 1972), and our results show golden king crab have a similar recuperation period.

Our breeding experiments did not determine the maximum number of females a male could breed, but that may not be a major determining factor in golden king crab reproductive success. Red king crab breed synchronously in the spring (Paul and Paul, 1990, 1997), so the larvae can feed on the diatom bloom (Paul *et al.,* 1990). In red king crabs, having enough mature males on the breeding grounds during the brief mating period is important to insure all females produce clutches. However in this study, and in the Bering Sea (Somerton and Otto, 1986), golden king crab females hatched eggs, molted, and bred throughout the year. Hatching does not need to occur exclusively during the spring phytoplankton and zooplankton blooms because golden king crab larvae do not feed and can tolerate a wide range of temperatures (Shirley and Zhou, 1997; Paul and Paul, 1999). With a protracted breeding period individual males may be less likely to run out of sperm given their ability to fertilize two or three females in three days or less (Table 4). Of course, there have to be sufficient numbers of mature males on the breeding grounds, so all females get fertilized. There appears to be some migratory behavior in this species (Slone, 1985; Somerton and Otto, 1986) and how it relates to individual reproductive cycles is yet to be described.

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