MARKETABILITY TESTING OF TANNER CRAB (*CHIONOECETES BAIRDI*) INFECTED BY A *HEMATODINIUM*-LIKE DINOFLAGELLATE, THE PROBABLE CAUSE OF BITTER CRAB SYNDROME

by

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

This project was conducted to study the relationship between market grading, organoleptic evaluation, and hematological rating of Tanner crabs infected with the Bitter Crab Syndrome (BCS) through the biologically acceptable harvest period from September through February. The goal was to determine whether there might be an optimum period during these months when infection rate and intensity were low enough to justify changes to the fishing season and minimize economic losses attributable to BCS.

Tanner crabs for this study were collected from the vicinity of Sullivan Island, in Lynn Canal, northern Southeast Alaska. Size and shell condition data were noted for all captured crabs. Ovigerity and egg maturity information was collected from female crabs. The first 100 Tanner crabs captured during each sampling period were sampled for hemolymph, and the first 40 legal-sized males were retained for market grading and organoleptic testing.

Market testing was conducted by Sitka Sound Seafoods in Sitka, organoleptic testing by the Fisheries Industrial and Technology Center in Kodiak, and hematological grading by the ADF&G Pathology Laboratory in Juneau. Live crabs from the September sampling were accidentally killed by fresh water entrainment into their holding tank, thus market grading and organoleptic sampling could not be conducted for them. Samples from October through January were successfully processed through all facilities and complete sets of data were available for analysis.

Sixty-five percent of legal males (carapace width $\geq$ 140 mm) were infected. There were good correlations between hematological grading and organoleptic testing. Market grading rejected all but the most lightly infected crabs and was also correlated to taste testing and hematological grading results. In general, microscopic examination of blood smears is the least costly and destructive means of gauging presence and intensity of infection, and it can accurately predict both marketability and palatability of infected Tanner crabs.

No statistically significant trends in intensity or incidence of the infection were detected over the September through January period. These findings were inconsistent with other research conducted on crabs from Auke Bay and indicate the need for more study to determine possible variability in seasonal trends by area.

INTRODUCTION

The Tanner crab (*Chionoecetes bairdi*) is a brachyuran crab that ranges from northern California to the Bering Sea (Slizkin 1989). In some areas of Southeast Alaska, it is infected by an organism closely resembling the parasitic dinoflagellate *Hematodinium perezi* in blue and cancrid crabs on the east coast of North America as described by Newman and Johnson (1975). A similar parasite has also been identified in snow crabs (*C. opilio*) in the Bering Sea. In both crab species, infection by the presumed *Hematodinium sp.* imparts an astringent, bitter taste to the crab meat, compromises the reproductive viability of the crab, and usually kills the host between one and one and one-half years after initial infection.

The disease problem was first formally identified in 1985 after processors started reporting that something was affecting the taste of Tanner crabs taken in certain areas of Southeast Alaska such as Lynn Canal (Meyers et al. 1987, Meyers 1987). Reports from crab markets indicated crab lots which contained significant amounts of bitter, off-taste, or otherwise unpalatable crab meat. The bitter taste was associated with a milky condition of the crab's hemolymph (blood) and crabs were initially sorted at the sectioning line by inspecting each crab's hemolymph. Subsequently, it was discovered that crabs with milky hemolymph could also be sorted on the basis of associated external symptoms, e.g., bright pink abdominal coloration and abnormal streaking and coloration of the ventral surfaces of the walking legs. Unacceptable crabs were jettisoned at the dock or off the decks of tenders.

The Alaska Department of Fish and Game (ADF&G) began collecting slide smear samples of Tanner crab blood in 1985. These initial samples clearly indicated that the bitter crabs were infected with a parasitic organism. It was apparent that the bitter taste was associated more with this infection than a previously assumed premolt condition. Further samples were collected from crabs caught in Lynn Canal and elsewhere in Southeast Alaska. Protocols were developed for taking the samples, preparing the samples for microscopic examination, and for grading infection intensity. Crab processors were informed that bitter crab syndrome was most likely caused by a disease organism rather than a premolt mobilization of mineral salts as had been originally assumed.

Any threat to the biological or economic viability of Tanner and snow crabs is of concern because Alaskan fisheries for these species are worth over $100,000,000 per year. For example, total reported 1989/90 landings of combined Tanner and snow crab landings were about 192,000,000 lbs (worth about $132,000,000 exvessel) harvested mostly from the Bering Sea, Kodiak, and Southeast Alaska fishing grounds (ADF&G Board Report 1990). The possible spread of *Hematodinium sp.* in Alaskan crabs has prompted studies on species specificity (Love 1991), mode of infection (Love 1991; Eaton et al. 1991), seasonality of incidence and intensity (Meyers et al. 1990; Eaton et al. 1991; Love 1991), life history (Love 1991; Meyers et al. 1987), distribution (Meyers et al. 1987), and the collection of information from commercial fishermen on areas of high disease incidence (unpublished data from ADF&G port sampling program 1985-1993).

Meyers (1993) presented a synthesis of circumstantial evidence and research results which suggests various infection pathways and developmental scenarios for this organism. He summarized observations of the evident seasonal chronology in the development of the pathogenic organism within the host crab. This chronology seems to include development of a free-swimming, possibly infective, spore phase in late summer, infection at some point around the major crab molting and mating event in late spring, and increasingly severe systemic development of vegetative stages within the crab through the subsequent summer. Crab death upon sporulation of the parasite in late summer completes the cycle. The details in the timing of these stages are not well understood, there is potential for overlaps between stages, and discrepancies exist in the data and most proposed scenarios. However, some of these may be explained by the possible slow replication of vegetative stages which could delay full systemic involvement for 15 to 18 months.

From a management standpoint, there are few things that can be done to minimize the spread of this infection. Until the mode and seasonality of infection is determined, one management action would be to harvest crabs at some period between September and late March when it would be both biologically acceptable and maximize the utilization of infected crabs. The biological harvest window is a period during which molting, mating, and egg hatching is minimal and meat recovery is acceptable to industry. The current mid-February season date evolved during the past decade to discourage effort by larger vessels, to avoid conflicts with other fisheries, socio-cultural considerations, assumed maximum meat recovery, and other factors. The best harvest opportunity relative to utilization of infected crabs would be as early in the infective cycle as possible, within the biological window.

OBJECTIVE

This research project was intended to better define an optimum harvest period when infected crab stocks could be harvested for human consumption. Criteria for an optimum harvest period included maximizing the meat recovery from healthy crabs, as well as infected crabs, while minimizing the discard or rejection of infected crabs by processors.

METHODS

Field Sampling

Tanner crab sampling was conducted from the R/V Sundance and the R/V Polaris off the southwest shore of Sullivan Island, upper Lynn Canal (Figure 1), on September 24-25, October 22-23, November 24-25, December 17-18, 1991 and January 22-23, 1992. The Sullivan Island area was chosen for this study because its relatively isolated population of Tanner crabs consistently exhibited high incidences of infection through a number of sampling seasons.

Crabs were caught in pyramidal, top-loading king crab pots, 1.8 M square at the base, 1.2 M square at the top, and 0.6 M in height. Each pot had a fiberglass tunnel tapering from a 0.9 M by 0.9 M square entry to a 0.6 M by 0.6 M square mouth. The 15 cm stretched mesh treated nylon webbing covering the pot was hung with a major diagonal measurement of 12.5 cm. Chopped herring (*Clupea harengus*) was used as the standard bait. Pots were set at depths between 65 M and 102 M and were fished overnight through at least two tide changes. Location, depth, and times of setting and pulling were noted for each pot. The sex, shell condition, and carapace width were recorded for each Tanner crab caught. Sexual maturity, ovigerity, egg mass age, clutch size, and egg mass condition were noted for the few females that were captured.

Laboratory Sampling

Hemolymph samples were taken from the first 100 Tanner crabs caught on each trip regardless of sex or size. These 100 crabs included the 40 legal (> 140 mm carapace width) male crabs retained for market grading and taste testing. Hemolymph was extracted with a hypodermic syringe inserted into the intersegmental membrane between the coxa and merus of the third right walking leg. If this leg was missing or damaged, the third left walking leg was used. Other legs were used if the need arose. Hemolymph samples were smeared on glass slides and air dried for transport to Juneau. The dried slides were stained with Dif-Quik (Dade Diagnostics, Inc., Aguada, Puerto Rico, 00602) in the ADF&G Pathology Laboratory. Slides were read and graded by staff of the Pathology Laboratory using methods and criteria developed by Meyers et al. (1987).

The infection intensity or level was determined by microscopic examination of dried and stained hemolymph samples. Infection levels ranged from an intensity of 0 for uninfected crabs and 1 through 5 for progressively more heavily infected crabs. Grading was somewhat subjective, as the disease does not exhibit distinct stages during much of its life history and morphological changes to both the parasite and host occur gradually during the duration of the infection. Infection rate was estimated as the

proportion of crabs in the 100 sampled for hemolymph that were infected, regardless of level of intensity.

Market Grading

The first 40 legal-sized male Tanner crabs caught during each trip were retained for market grading. Sample size was limited to 40 because of staff and time limitations at Sitka Sound Seafoods (SSS) in Sitka, which participated on a voluntary basis. These crabs were individually identified with serially numbered cinch tags attached around the base of the third right walking leg. Crabs with more than two missing major appendages were not retained because recovery weights would be biased. Missing limbs were noted for all Tanner crabs retained for market testing.

Crabs were transported from Sullivan Island in live tanks aboard the vessels to the National Marine Fisheries Service Auke Bay Laboratory in Juneau, where they were transferred to a holding tank, pending air shipment to Sitka Sound Seafood's processing plant in Sitka. During transport after the September sampling, fresh water was entrained in the water supply to the ship's holding tank and killed all but two of the crabs died. In October, a deep water suction hose was used to pump water from 100 feet to assure sufficient salinity to prevent deadloss. Also during the October trip, a small subsample of crabs was transported "dry" in an insulated tote under absorbent cloth sheeting saturated with sea water. There was no mortality with either method for the 4-5 hours required for transport to Juneau. Crabs on the November, December, and January trips were transported "dry" to their temporary holding tank at the NMFS laboratory.

As soon as flight schedules and weather permitted, crabs were removed from the NMFS holding tank, packed into wetlap shipping boxes, and air-freighted to Sitka Sound Seafoods for grading, weighing, sectioning, cleaning, rinsing and blast freezing. All shipments arrived in Sitka without any deadloss.

At SSS, the crabs were prepared as they would have been for the Japanese market, except for the long rinse noted below. Quality control specialists at SSS first sorted the live crabs as: clean, healthy, shell-of-the-year or clean skip molts acceptable for live shipment or frozen sections (Market Grade 1); worn or dirty shell, skipmolt shell acceptable for meat pack (Market Grade 2); or sick, shell-of-the-year crabs exhibiting one or more symptoms of bitter crab syndrome that would normally not be purchased from fishermen (Market Grade 3).

Crabs were then sent to the sectioning line where their hemolymph and internal organs were examined to confirm the external grading. During the processing, ADF&G staff weighed the whole crabs and the sections for meat recovery information. After rinsing overnight in running seawater to clear the sections of hemolymph, the sections were blast frozen. The long rinse was a departure from standard procedure which uses a quick chemical dip to prevent blackening of raw crab meat by hemolymph oxidation. The anti-oxidant used to prevent meat discoloration for the Japanese market is not cleared by the U.S. Food

and Drug Administration for domestic use and could not be used in the project because the taste testing was being conducted in the United States.

Taste Testing

After processing at SSS, frozen sections were air-shipped from Sitka to the Fisheries Industrial and Technology Center (FITC) in Kodiak for cooking and taste testing. Frozen sections were thawed at room temperature. During initial cooking trials, small subsamples in various concentrations of salt were prepared to develop a standard to optimize crab flavor (Babbit, personal communication). Using the preferred standard of 3% NaCl by weight, FITC then cooked the rest of the sections and conducted double blind taste testing for each crab. Both flavor and texture were evaluated by the taste panel and three general classifications were established. Meat with firm texture and pleasant, sweet flavor was good (Taste Grade 1), meat with either a softer texture or more bland taste was borderline (Taste Grade 2), and meat with soft, chalky texture or notably bitter taste was rejected (Taste Grade 3).

Statistical Analysis

The general linear model (GLM), categorical model (CATMOD), and regression procedures of SAS (1990) were used to test for significant differences between months for infection intensities, market grading, carapace widths, and section weights of the samples. Significance of relationships between infection intensity, market grading, and sensory grading were also tested.

RESULTS

Infection Rate and Intensity

Nearly two-thirds (65.2%) of all legal males (carapace width $\geq$ 140mm) were infected. There was no apparent relationship between infection and crab sex ($p = 0.166$, Chi-square = 1.92; Table 2). However, there were only 11 females among the total 503 crabs tested for infection, so that the results are inconclusive (power of the test for detecting true differences as great as those observed is 0.29 at $\alpha = 0.05$, Agresti 1990, p. 241).

Crabs that had molted within the preceding twelve months (new shell crabs) were much more likely to be infected than were old shell crabs that had skipped their recent molt cycle ($p < 0.0001$, Chi-square = 78.2; Table 3). Among the new shell male crabs, the larger crabs were more likely to be infected ($p < 0.0001$, logistic regression; Figure 2).

Time trends in infection rate and intensity were analyzed by size and age classes of males. In Southeast Alaska these classes are defined according to the year of recruitment to the commercial fishery, which occurs when crabs molt to a size ≥ 140 mm carapace width. The classes are prerecruit (carapace width < 140 mm), recruit (crabs with new shells having a carapace width ≥ 140 mm and < 165 mm), and postrecruit (crabs with old shells having a carapace width ≥ 140 mm or any crabs having a carapace width ≥ 165 mm).

Recruit crabs, which typically make up the majority of legal crabs in the fishery, show no significant difference in infection rate across months ($p = 0.48$, GLM; Figure 3). In contrast, the infection rate among prerecruit crabs increased across months ($p < 0.0004$, logistic regression), with the predicted probability of infection ranging from 0.31 in September to 0.69 in January. There was a marginally significant difference in infection rates among months for postrecruit crabs ($p = 0.047$, GLM), but there was no significant trend through time ($p = 0.118$, logistic regression).

Results for infection intensities were similar to those for infection rates (Figure 4). No significant differences were detected between average infection intensities across months in recruit crabs (GLM, $p = 0.481$). There were marginally significant differences for postrecruits (GLM, $p = 0.049$), but there was no significant trend (simple linear regression, $p = 0.071$). There were highly significant differences among months for prerecruit crabs (GLM, $p < 0.0001$), and there was a significant linear increase in infection intensities across months (intensity = 0.16 + 0.22 x month [September = 1 through January = 5], simple linear regression, $p < 0.0001$).

Repetitive readings of multiple smears from a small subsample of crabs suggested that while infection rates of 0 and 1 are consistently detectable and read, rates between 2 and 3 are frequently and variably read as between 1 and 4. Rates of 4 and 5 are fairly consistently read (Meyers, personal communication). This preliminary finding suggests that criteria for identification of stages zero (uninfected), one, four, and possibly five are well defined while criteria for stages two and three are not as clear. Additional refinement of the current grading system is advisable.

Market Grading

All externally graded crabs were confirmed as correctly graded at the sectioning table, with the exception of a single crab that was externally graded as 1 before being sectioned and regraded as 3 based on internal symptoms of infection. This was an error rate of about 0.6 percent. This level of accuracy should be

assumed as the best case because sorting was conducted under controlled lighting conditions and each crab was carefully examined.

Market grades were highly correlated with infection intensity ($p < 0.0001$, CATMOD; Figure 5). Over two-thirds of the uninfected crabs were graded as 1, and infected crabs were likely to be graded as 3, particularly if they were heavily infected. Crabs graded as 2 were principally uninfected old shell crabs (11 of 12). The average market grade from October to January was 2.1, and there was no significant difference between months ($p = 0.98$, GLM).

Taste Testing

Sensory grades were also highly correlated with infection intensities ($p < 0.0001$, CATMOD; Figure 6), with uninfected crabs almost always graded as 1 (sweet flavor). Crabs infected at intensities from 1 to 4 were often assigned a taste grade of 2 (borderline taste; Figure 7), which is in contrast to market grading, for which most crabs with borderline taste were graded as unacceptable (market grade 3).

Crab Sizes and Weights

Average crab size (carapace width) increased significantly across sampling periods ($p<0.0001$, simple linear regression), due primarily to a drop in the catch of smaller crabs (Figure 8). Among the legal male crabs graded at SSS, there was no significant difference in average size between months ($p = 0.47$, GLM), nor was there a significant difference in weight ($p = 0.41$, GLM). Crab weights, adjusted for size (by dividing weight by width), showed no significant differences between months ($p = 0.18$, GLM), indicating no significant change in meat fullness over the sample period.

DISCUSSION

Infection Rate and Intensity

Significance in the relationship of shell condition and infection corroborates more general field observations of higher infection rates among crabs which have molted within the last year or so. This suggests that the likelihood of infection may be associated with some aspect of the molting process and supports the assumption that infected crabs die within a year, before they would either be observed as skip

molts or undergo another molt. However, it is difficult to explain the higher likelihood of infection among larger new shell males than smaller males. Possibly, the infection is transmitted between mating crabs (Meyers, 1993). Larger crabs may mate with more partners, increasing their risk of contracting a sexually transmitted infection. Infection rate and intensity data from Meyers, et al., (1987) and Eaton, et al., (1991) indicate that *Hematodinium sp* is not host size nor sex specific. There are some differences in sample collecting, seasonal effects, and areas sampled for these studies that may help explain the different conclusions they reached regarding size and infection rate.

Microscopic examination of crab hemolymph can definitely predict marketability of crabs and to a lesser extent, the probability of sensory acceptability. Thus, blood samples taken from various populations of Tanner crabs should be able to accurately predict the proportion of the catch that would be acceptable for market, as well as generally predict what proportion of the infected crabs may be amenable to alternate processing. This has some economic implications because general conclusions about marketability could be made without recourse to quality control testing by industry or formal sensory evaluation under laboratory conditions.

Infection intensity, measured by hemolymph grading of the level or stage of infection, and rate, the percent of crabs infected, both indicated increasing trends through the sampling period. However, neither trend is statistically significant. As a result, there seems to be little compelling economic incentive to change the starting date of the season from February 15.

Market Grading

It was obvious from observations of the market grading process that grade 1 crabs were asymptomatic, without more than two missing limbs, with fully hardened shell-of-the-year or in very early stages of skip-molt with minimum growth of encrusting organisms on the shell. Skip and multiple skip molt crabs with heavy encrusting growth were graded as market grade 2, primarily based on shell condition. Infected crabs showing external or internal symptoms of BCS were graded as market grade 3. In effect, the only two grades of interest for this study were limited to grades 1 and 3 because grade 2 (acceptable for meat pack) was based solely on shell condition.

Most of the determinations of market grades were by examination for external symptoms. It is evident from the data (Figure 5) that a trained sorter can detect infection rates as low as level 1 about 50 percent of the time. At blood smear infection rate level 2, sorters can detect infected crabs about 80 percent of the time. The success rate rises to nearly 100 percent at blood smear infection rate level 4. This means that the market rejects 50 percent of the crabs at infection level 1 and that most crabs at and above level 2 would be detected and rejected during the primary sort, which usually occurs aboard tenders or at dockside. As a result, the average market grade does not change much between October and January as sorters cull infected crabs at a consistently high rate regardless of blood smear infection level during this

period. This also agrees with the finding of no significant differences in infection rate during the entire sampling period for crabs selected for market grading.

Taste Testing

Correlations between sensory grade and blood smear infection level indicated that taste testers were able to detect infected crabs consistently from the early stages of infection as low as blood smear infection level 1. However, there was also a high likelihood that even a heavily infected crabs (determined by microscopic examination of blood smear) could be assessed to be of borderline, though acceptable taste. This finding suggests that some fraction of infected crabs, currently rejected by industry, might be used in an alternate product, such as crab surimi, dried flavor flakes or dips if a means of sorting out the worst tasting crabs could be developed. It clearly demonstrates that there is an opportunity to utilize many of the infected crabs that are currently an economic liability for fishermen and processors.

Crab Sizes and Weights

The statistically significant changes in the width frequencies of all male crabs caught between September and January suggest that the sampling area was too limited and slightly different segments of the local population were sampled through the sampling period. It is probable that observed changes in average size were due to seasonal migratory patterns and aggregative behavior. For example, fishermen have often reported taking larger male crabs from progressively shallower depths as the molting and mating period approaches in late winter and early spring. The lack of a corresponding significant change in average size of crabs shipped to SSS for market grading was not surprising, as the crabs selected were generally the first legal-sized, and therefore larger, males caught during each sampling period.

SUMMARY AND RECOMMENDATIONS

Although this study established broad correlations between blood smear, visual, and organoleptic grading of Tanner crabs infected by BCS, it also raised many questions and suggested many avenues for further research.

Based on the data collected at Sullivan Island, the meat to total section weight ratios do not change during the October to January period. These findings by themselves do not support a change in the commercial fishing season.

It is apparent that blood smear grading is a cost-effective method of evaluating the marketability of Tanner crabs; i.e., it is not necessary to conduct market grading or taste testing to evaluate probable marketability. Organoleptic results strongly suggest that some crabs, correctly market graded as infected crabs, could be acceptable for alternate processing or other products if criteria for more selective sorting could be developed. This study did not provide sufficient data to determine the infection levels at which market acceptability for alternate processing might occur. Development of more discrete grading criteria may result in the use of lightly-infected crabs that are currently rejected by processors.

As noted under the methods section, the extended 12-hour seawater rinse of the crab sections departs from the usual anti-oxidant treatment for raw sections exported to primary markets in the Orient. It was suggested that extended flushing may reduce some of the bitterness of infected crab meat. FITC found that at least some of the loss of flavor associated with the extended seawater flushing could be reconstituted by use of low levels of salt (about three percent by weight) in the cook water. The effects of extended flushing on the taste of uninfected and infected crab meat should be evaluated.

One of the objectives of the study was to better characterize the seasonality of infection rate and intensity. Results were inconclusive, sometimes contrary to conclusions reached by other studies, and limitations of sampling design do not permit further analysis of the available data. A well-designed study in the general area of Sullivan Island and another site, possibly Auke Bay, may better define seasonal variability and timing in disease-host relationships.

There is still a critical need to establish the mode and seasonal timing of infection. Both have serious implications for the continuing viability of the Tanner and snow crab resources in Alaska. Until they are better understood, the effectiveness of management policies and strategies for control of BCS will be questionable. There will continue to be unassessed long-term risks associated with permitted industry practices for processing and handling of infected crabs.

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Table 1. Numbers of male and female crabs captured, and numbers of crab sampled by month for hemolymph, market grading, and taste testing.

Dates	Males	Females	Hemolymph samples	Market grade samples	Taste test samples
Sept. 24-25, 1991	109	8	105	0	0
Oct. 22-23, 1991	147	3	100	40	40
Nov. 24-25, 1991	125	2	100	40	40
Dec. 17-18, 1991	112	2	97	40	39
Jan. 22-23, 1992	218	2	97	42	42
Totals	711	17	499	162	161

Table 2. Frequencies of infection by sex. Data are for samples collected September 1991 to January 1992.

	Infection		
Sex	No	Yes	Total
male	254	238	492
female	8	3	11
Total	262	241	503

Chi square = 1.92, p = 0.166.

Table 3. Frequencies of infection of male crabs by shell condition. Data are for samples collected September 1991 to January 1992.

Shell Condition	Infection: No	Infection: Yes	Total
New	171	233	404
Old	83	5	88
Total	254	238	492

Chi square = 78.2, $p < 0.0001$.

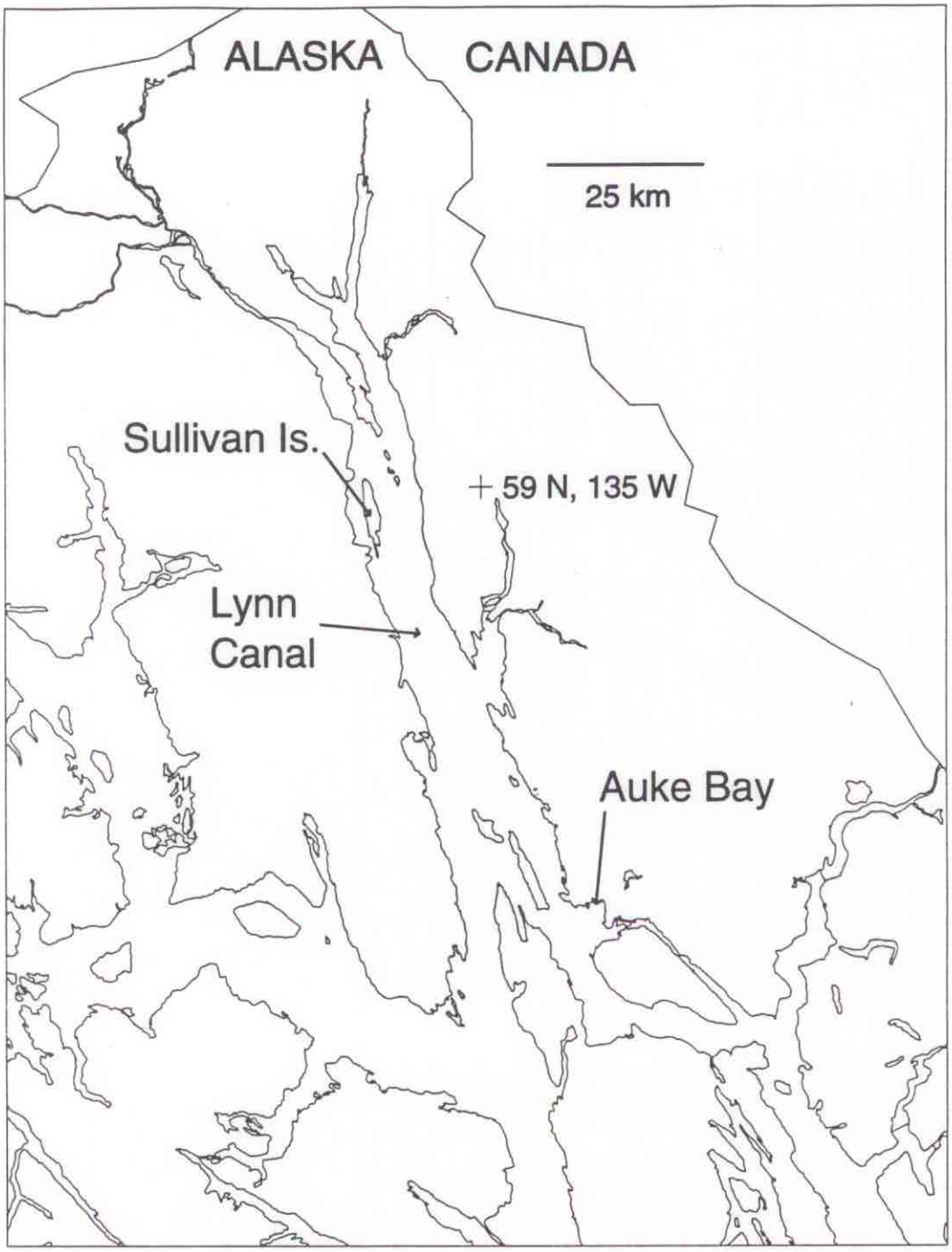

Figure 1. Map of Lynn Canal showing the sampling location near Sullivan Island.

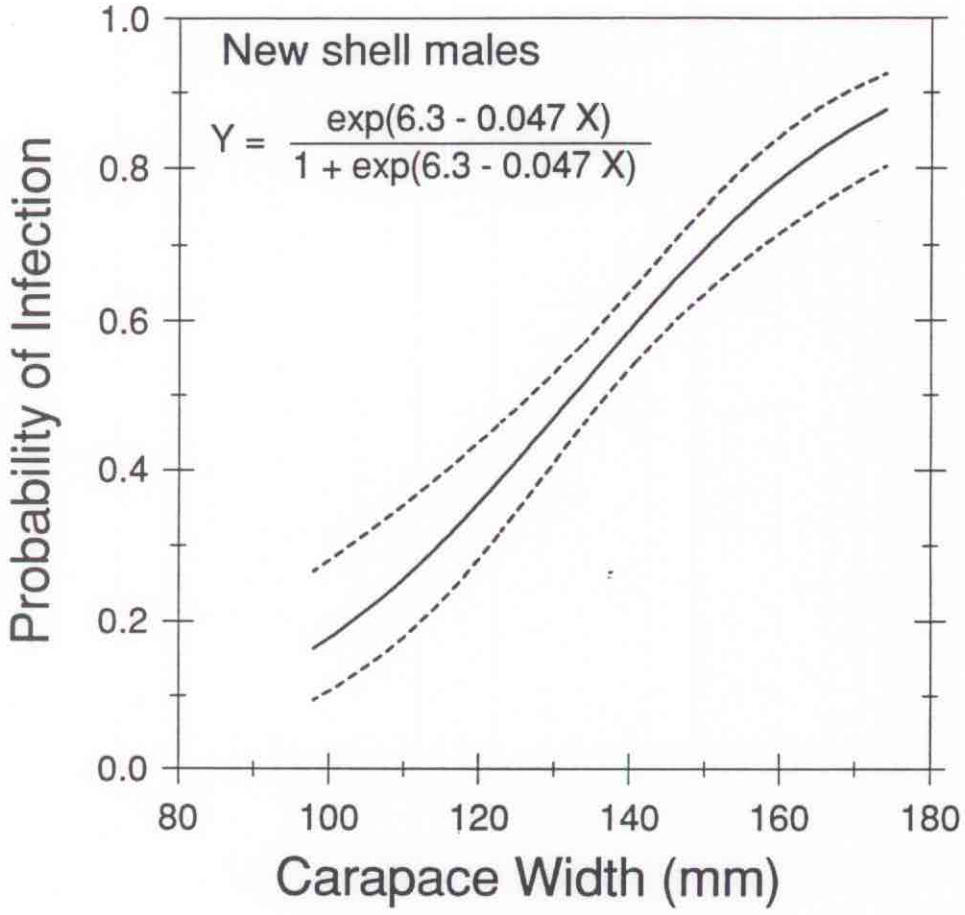

Figure 2. Probabilitity of infection as a function of carapace width for new shell male Tanner crabs. Data are derived from a logistic regression for crabs sampled from September 1991 to January 1992. Dashed line indicate upper and lower 95% confidence bounds for the sample data.

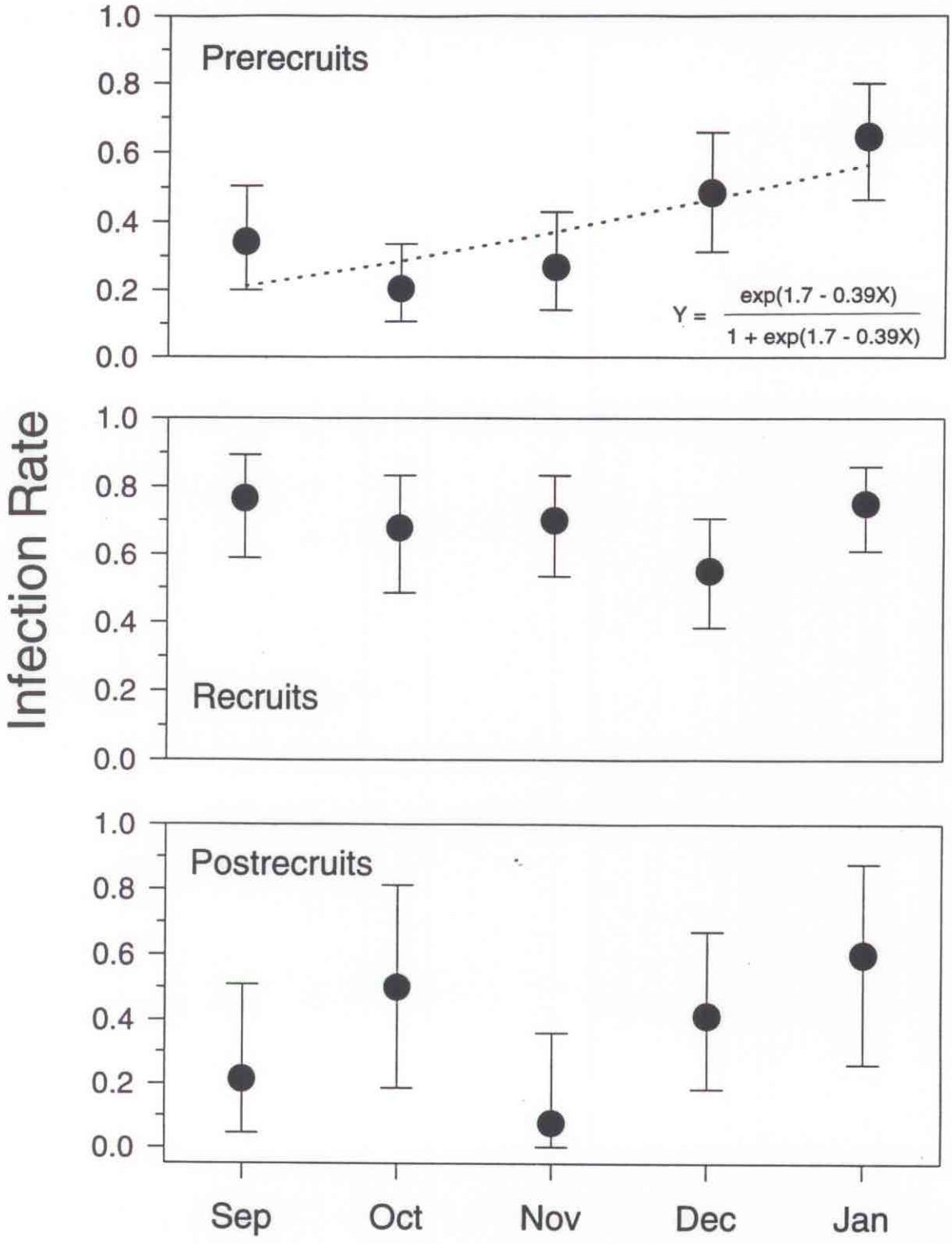

Figure 3. Infection rate by month for prerecruit, recruit, and postrecruit male Tanner crabs (carapace width < 140 mm). Error bars show 95% confidence intervals for each month's sample and are calculated using the F distribution method of Zar (1984, p. 378). A logistic regression line and equation is shown for prerecruits (slope significant at p = 0.0004).

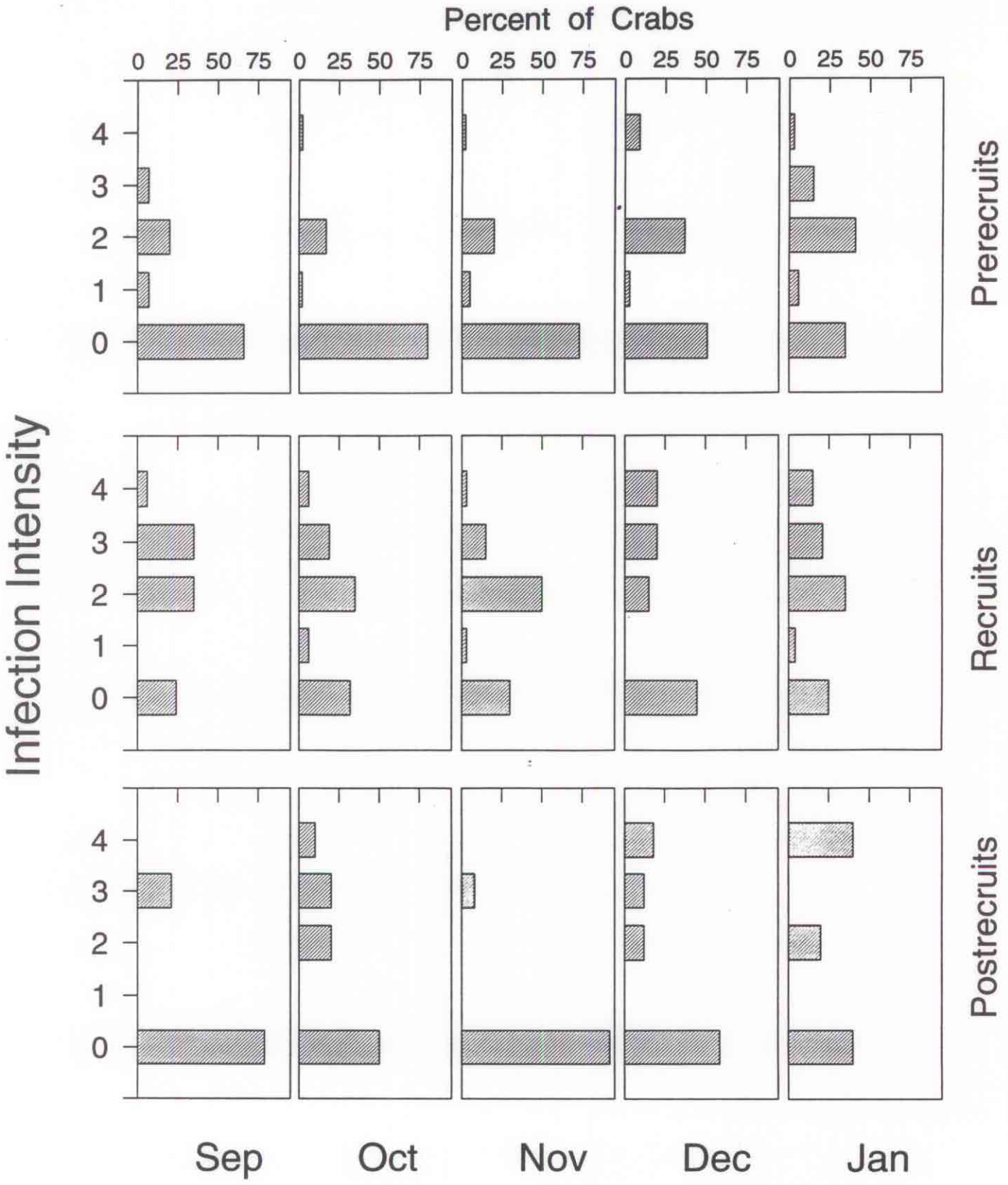

Figure 4. Distribution of infection intensity scores across months for prerecruit, recruit, and postrecruit male Tanner crabs.

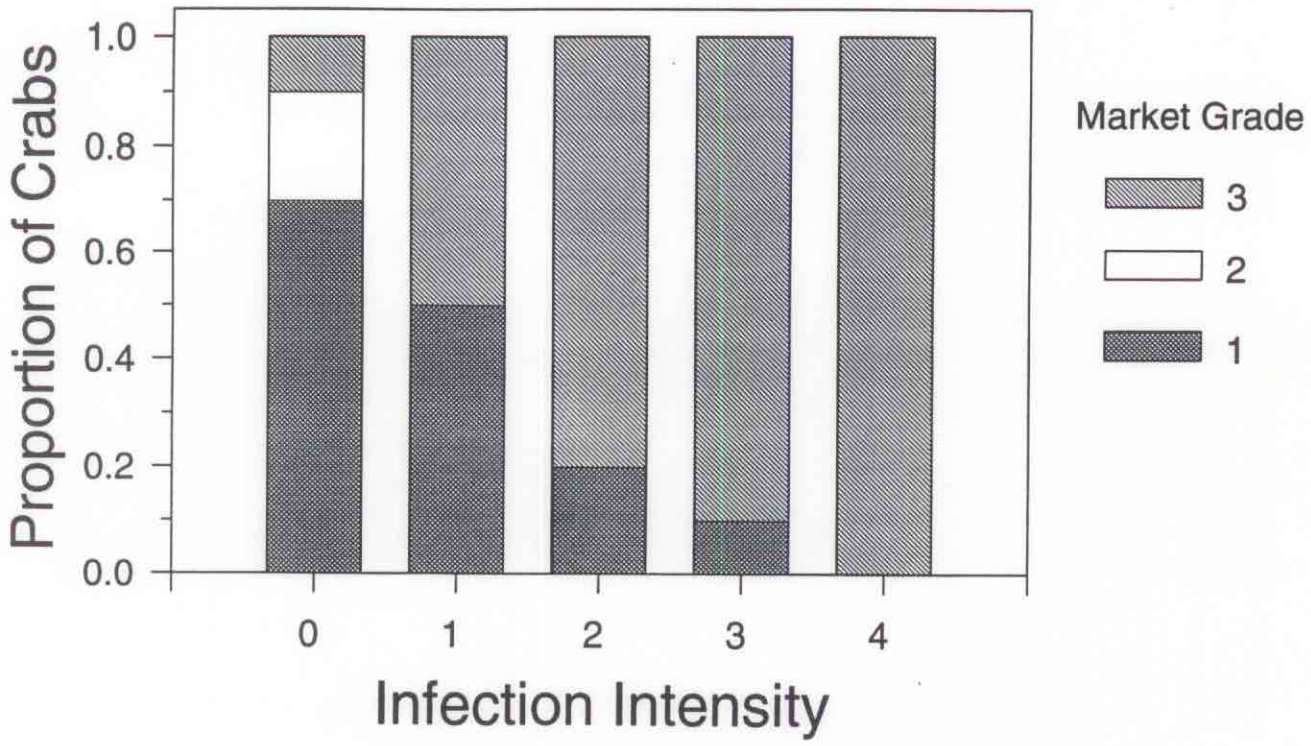

Figure 5. Proportion of legal male Tanner crabs in each market grade grouped by infection intensity scores. Data are for October 1991 to January 1992.

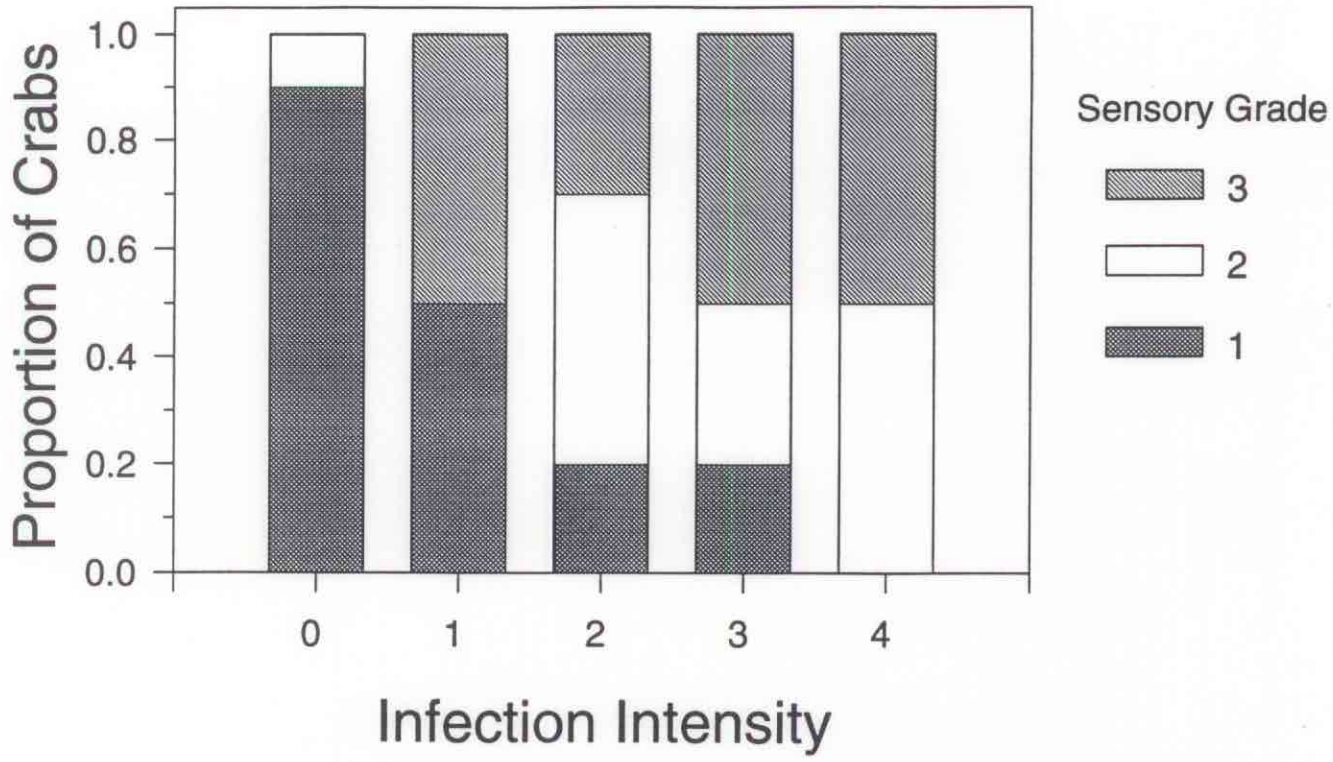

Figure 6. Proportion of legal male Tanner crabs in each sensory grade grouped by infection intensity scores. Data are for October 1991 to January 1992.

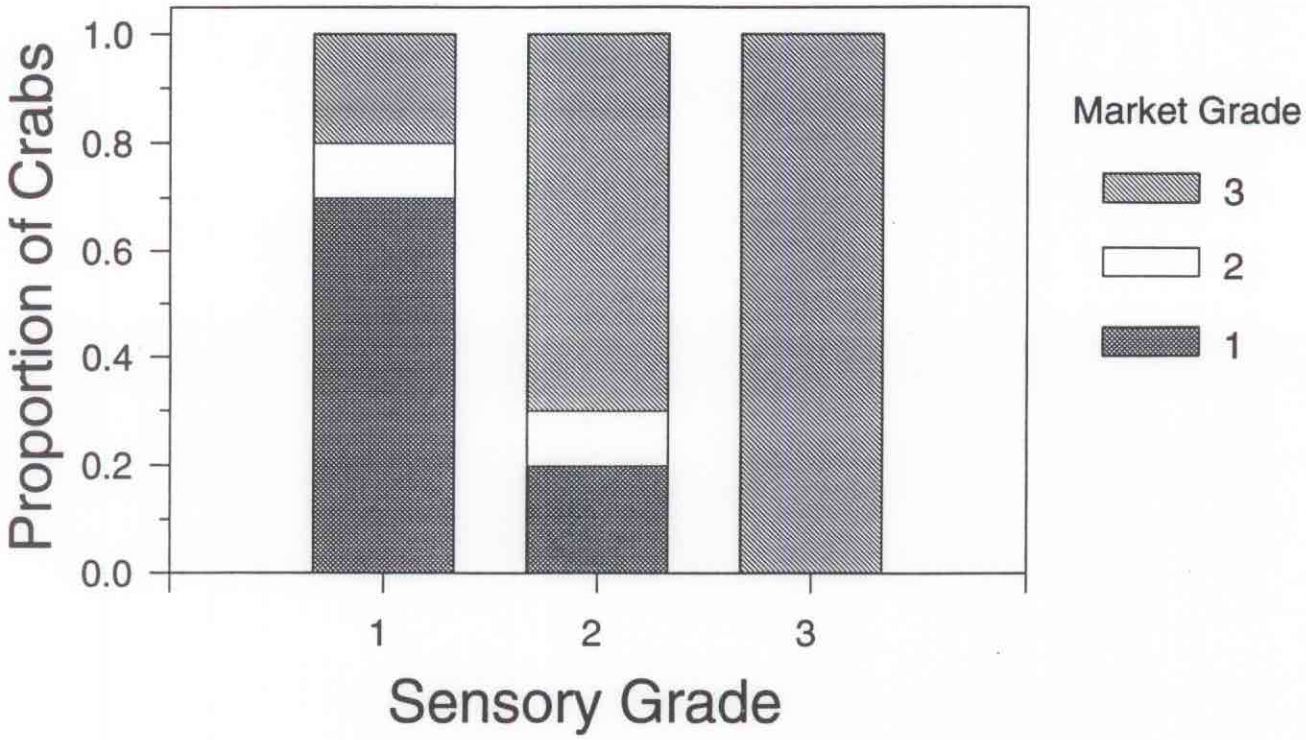

Figure 7. Proportion of legal male Tanner crabs in each market grade grouped by sensory grades. Data are for October 1991 to January 1992.

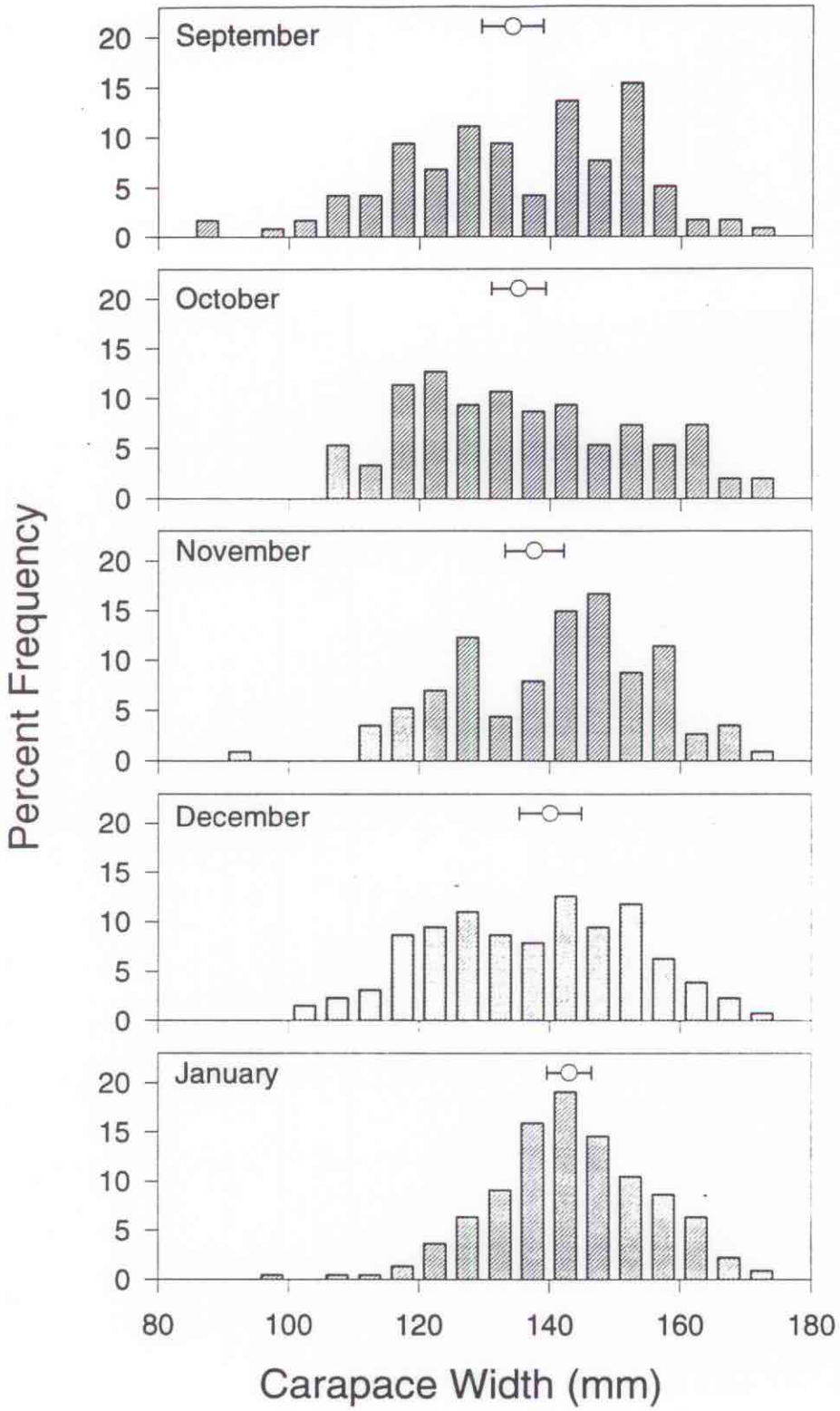

Figure 8. Size distribution of Tanner crab sampled at Sullivan Island, September 1991 to January 1992. Average width is indicated by a circle for each month with error bars showing 95% confidence intervals.

APPENDIX

Appendix 1. Data on individual crabs sampled for market grading and taste testing.

Month	Carapace width (mm)	Shell condition[a]	Weight (kg)	Infection intensity[b]	Market grade[c]	Taste[d]
Oct. 1991	140	1	0.81	2	3	3
	140	1	0.83	0	1	1
	141	1	0.79	3	3	2
	141	1	0.88	0	1	1
	142	1	0.80	2	1	2
	142	1	0.90	0	1	1
	142	3	0.81	0	2	2
	144	1	0.75	0	1	1
	144	1	0.84	3	3	2
	144	1	0.85	2	3	2
	144	1	0.85	3	3	3
	145	1	0.80	0	1	1
	145	1	0.80	0	1	1
	145	1	0.82	1	1	1
	150	1	0.96	2	3	3
	150	3	0.99	0	2	2
	152	1	0.91	2	3	3
	152	1	0.96	3	3	1
	152	1	0.97	2	3	2
	153	1	1.04	1	3	3
	153	3	1.30	0	2	2
	155	1	1.09	2	1	2
	157	1	0.93	4	3	3
	157	1	1.33	0	1	1
	158	1	1.30	0	1	1
	159	1	1.20	2	3	2
	159	1	1.27	2	3	3
	160	1	1.13	0	2	1
	160	1	1.30	0	1	1
	161	3	1.35	0	2	1
	162	1	1.19	3	1	2
	163	1	1.11	2	3	2
	163	1	1.14	3	1	3
	163	1	1.17	4	3	3
	164	1	1.17	3	3	2
	166	1	1.34	2	3	2
	167	1	1.12	4	3	3
	169	1	1.28	3	3	3
	171	1	1.43	0	3	1
	174	1	1.35	2	3	3
Nov. 1991	140	1	0.78	2	3	2
	140	1	0.82	2	3	2

Month	Carapace width (mm)	Shell condition[a]	Weight (kg)	Infection intensity[b]	Market grade[c]	Taste[d]
	141	1	0.79	3	3	3
	141	3	0.91	0	2	1
	142	2	0.92	0	1	1
	142	2	0.92	0	1	1
	143	1	0.87	0	1	1
	143	1	0.90	0	1	1
	145	1	0.87	2	3	
	145	1	0.91	3	3	3
	147	1	0.81	1	3	3
	147	3	0.98	0	2	1
	148	1	0.97	2	3	3
	148	2	1.08	0	1	1
	148	2	1.11	0	1	1
	149	1	1.06	0	1	1
	150	1	1.06	0	3	1
	150	1	1.15	2	3	1
	151	1	1.03	4	3	3
	151	1	1.05	2	3	2
	152	1	1.04	0	1	1
	152	1	1.05	2	3	1
	152	1	1.19	0	1	2
	153	1	1.07	2	3	2
	153	1	1.16	0	1	1
	153	2	1.26	0	1	1
	154	1	1.02	2	3	
	154	1	1.18	3	3	3
	154	3	1.18	0	2	
	155	1	0.99	2	3	2
	155	1	1.13	2	3	3
	156	1	1.13	0	1	1
	157	1	1.35	0	1	1
	159	3	1.16	0	2	1
	161	1	1.28	0	1	
	162	1	1.27	2	3	
	162	1	1.29	2	3	3
	166	1	1.33	0	3	3
	166	1	1.55	0	1	1
	169	1	1.49	0	1	1
Dec. 1991	141	1	0.71	3	3	3
	142	1	0.71	3	3	3
	142	1	0.86	0	1	1
	142	2	0.86	2	3	3
	142	2	0.92	0	1	1
	143	1	0.72	2	3	2
	143	1	0.82	2	3	2

Month	Carapace width (mm)	Shell condition[a]	Weight (kg)	Infection intensity[b]	Market grade[c]	Taste[d]
	143	2	0.98	0	2	1
	144	1	0.79	0	3	1
	145	1	0.52	0	3	3
	145	1	0.75	2	3	2
	146	3	1.04	0	2	1
	147	1	0.93	3	3	3
	147	1	0.96	0	1	1
	147	1	1.02	0	1	1
	147	3	0.98	0	1	1
	148	1	0.81	0	3	1
	150	1	1.03	0	3	1
	150	1	1.10	0	1	1
	150	1	1.13	0	1	1
	150	1	1.17	0	1	
	151	3	1.09	0	2	1
	152	1	1.08	0	1	1
	153	1	0.93	4	3	2
	153	1	1.08	3	3	3
	156	1	1.07	4	3	2
	156	1	1.10	0	1	1
	157	1	1.13	2	1	2
	157	3	1.24	0	1	1
	159	1	1.09	4	3	3
	159	1	1.10	4	3	3
	159	1	1.15	3	3	3
	159	2	1.41	0	1	1
	160	1	1.14	4	3	3
	163	2	1.48	2	1	1
	164	1	1.25	4	3	2
	166	1	1.25	4	3	2
	167	1	1.30	4	3	2
	167	1	1.40	3	3	3
	170	2	1.60	0	1	1
Jan. 1992	140	1	0.66	4	3	2
	140	1	0.70	1	1	1
	140	1	0.87	0	1	1
	141	1	0.76	2	1	1
	141	1	0.86	2	3	2
	142	1	0.79	3	3	2
	143	1	0.79	3	3	1
	143	3	0.91	0	1	1
	144	1	0.76	0	3	1
	144	1	0.77		3	1
	144	1	1.04	0	1	1
	145	1	0.68	2	3	2

Month	Carapace width (mm)	Shell condition[a]	Weight (kg)	Infection intensity[b]	Market grade[c]	Taste[d]
	145	1	0.69	2	3	2
	145	1	0.86	3	3	1
	146	1	0.86	2	1	1
	146	1	0.91	4	3	2
	147	1	0.86	3	3	3
	148	1	0.86	3	3	1
	148	1	0.93	0	1	1
	148	1	0.95	2	3	3
	148	1	0.96	2	3	3
	149	1	0.93	2	3	1
	150	1	0.89	2	3	3
	150	1	0.93	2	1	2
	151	1	1.12	0	1	1
	151	1	1.13	0	1	1
	152	1	0.88	0	1	1
	152	1	1.00	4	3	3
	154	1	1.18	0	1	1
	156	1	1.05	3	3	1
	157	1	1.09	3	1	2
	157	1	1.18	2	3	1
	158	1	1.10	2	1	1
	159	1	1.10	0	1	2
	159	2	1.34	2	1	1
	160	1	1.25	4	3	3
	161	1	1.65	0	1	1
	164	2	1.31	0	1	1
	166	1	1.27	4	3	2
	166	1	1.40	4	3	2
	167	1	1.37	2	3	3
	171	1	1.33	4	3	3

[a] Shell conditions: 1 = new shell (molting occurred within the past year), 2=old shell (molting occurred between 1 and 2 years ago), 3 = very old shell (molting occurred more than 2 years ago).

[b] Infection intensity: 0 = no infection, 1 to 5 for progressively more heavily infected crab.

[c] Market grade: 1 = healthy new shell crab, 2 = old or very old shell crab suitable for meat pack, and 3 = new shell crab exhibiting one or more symptoms of bitter crab disease.

[d] Taste testing: 1 = sweet flavored firm meat, 2 = softer texture and more bland than category 1, and 3 = soft, chalky-textured meat with a notably bitter taste.

Appendix 2. Data on individual crabs, including females, not included in Appendix 1.*

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
Males	Sept. 1991	107	1	4
		108	2	0
		110	1	
		110	1	0
		112	1	0
		114	1	0
		114	1	0
		115	1	0
		115	1	0
		115	1	2
		116	1	1
		116	1	
		117	1	3
		117	1	0
		117	1	0
		117	1	0
		118	1	2
		119	1	0
		121	3	
		121	1	1
		122	1	2
		122	1	2
		123	1	2
		123	1	0
		123	1	2
		123	1	0
		125	3	
		125	2	0
		127	2	0
		127	1	1
		127	1	2
		127	1	0
		127	3	0
		127	3	0
		127	1	0
		128	1	2
		128	2	0
		128	3	0
		129	1	3
		130	3	0
		131	1	0
		131	1	0

* These individuals were not sampled for market grading and taste testing. Data area grouped by sex and month, and includes histological infection intensity level, if available.

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		131	1	0
		131	2	0
		131	3	0
		132	3	
		132	3	0
		133	1	0
		133	1	3
		134	1	0
		135	3	0
		137	3	0
		137	1	0
		138	1	2
		138	1	0
		140	1	4
		140	1	2
		140	1	3
		140	1	3
		141	1	2
		141	1	0
		141	3	0
		141	3	0
		141	1	3
		141	1	2
		142	1	0
		142	1	
		143	1	3
		143	1	0
		143	1	3
		144	3	0
		145	1	2
		145	1	0
		145	1	4
		145	1	2
		147	1	
		147	1	
		148	1	3
		148	1	0
		149	3	0
		150	1	3
		150	1	2
		150	1	
		150	2	0
		150	3	
		150	3	0
		151	1	

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		151	3	0
		151	3	0
		152	1	2
		152	3	0
		152	1	0
		152	1	3
		153	1	3
		153	1	0
		154	1	3
		154	1	3
		154	1	0
		155	3	0
		157	1	2
		158	1	2
		159	3	0
		159	1	2
		159	1	3
		160	1	2
		162	1	2
		165	1	3
		166	1	3
		170	1	3
	Oct. 1991	107	1	
		108	1	1
		108	1	0
		109	1	
		109	1	
		109	2	0
		110	1	0
		112	1	
		112	1	
		112	1	0
		115	1	
		115	1	
		115	1	
		116	3	0
		116	1	0
		117	1	0
		117	1	0
		117	1	
		117	1	0
		118	1	2
		118	2	0
		119	1	0
		119	1	2

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		119	1	0
		119	3	
		119	1	0
		119	1	0
		120	1	0
		120	1	0
		120	1	0
		121	1	
		121	1	
		121	1	0
		122	1	
		122	3	0
		122	1	0
		122	1	
		122	1	
		122	1	0
		122	1	0
		123	1	
		123	2	0
		124	1	2
		124	1	0
		124	1	
		124	3	0
		125	1	
		125	1	2
		126	1	
		126	3	
		126	1	0
		127	1	
		127	1	0
		127	1	0
		128	1	0
		128	1	2
		128	1	0
		129	1	0
		129	1	
		129	3	0
		130	1	0
		130	3	0
		130	1	0
		131	1	0
		131	1	
		131	1	
		131	1	0
		133	1	2

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		133	2	
		133	3	0
		133	1	0
		133	1	0
		134	1	0
		134	1	
		134	3	
		134	1	0
		135	3	0
		135	1	0
		135	1	4
		135	1	1
		136	1	
		136	3	0
		136	1	0
		136	1	0
		137	1	2
		137	2	
		137	1	2
		138	1	2
		138	1	
		140	1	
		141	3	
		143	1	2
		145	1	
		146	1	
		149	3	
		149	1	
		149	3	
		150	1	
		150	1	
		151	1	
		151	1	
		155	1	
		158	1	
		162	1	
		163	1	
		163	1	
		170	2	
	Nov. 1991	101	1	0
		107	3	
		108	1	0
		109	1	0
		110	1	0
		110	1	0

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		113	3	
		115	1	
		115	1	0
		116	1	
		117	1	0
		117	1	0
		118	1	1
		118	1	0
		119	1	2
		119	2	
		119	3	0
		119	2	0
		120	1	0
		120	1	
		121	1	
		122	3	0
		122	2	0
		122	1	
		122	1	
		122	1	2
		122	1	2
		123	1	
		124	3	
		124	1	0
		125	1	0
		125	1	0
		125	2	4
		126	1	0
		126	1	
		126	3	
		126	1	2
		127	3	
		127	1	
		129	1	0
		129	1	0
		129	1	0
		129	1	2
		129	3	0
		130	2	0
		130	2	0
		131	1	2
		132	2	0
		133	1	
		133	1	0
		133	1	0

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		133	1	2
		133	1	2
		134	2	0
		134	2	0
		135	3	0
		135	1	0
		137	2	0
		137	1	1
		138	1	0
		138	1	0
		138	3	0
		139	1	0
		139	1	
		139	2	
		140	1	2
		140	1	
		140	1	
		141	1	0
		142	4	
		143	2	
		144	1	2
		144	2	
		145	1	3
		145	1	3
		146	1	
		147	1	2
		150	1	0
		152	1	2
		155	1	2
		155	1	2
		156	1	2
		161	1	
		162	1	3
		172	1	3
	Dec. 1991	112	1	0
		112	1	2
		114	1	0
		115	1	0
		115	1	1
		116	1	2
		118	1	
		118	1	0
		119	1	
		121	1	0
		121	1	0

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		122	1	2
		123	1	0
		123	1	0
		124	1	0
		124	1	0
		124	1	2
		125	1	4
		125	1	0
		125	1	4
		125	1	2
		125	1	0
		126	1	1
		126	1	0
		127	3	0
		127	1	0
		128	3	
		128	1	
		128	1	0
		129	1	2
		129	2	0
		130	1	2
		131	1	0
		132	1	2
		132	1	0
		134	1	4
		135	1	2
		135	2	0
		136	3	
		137	1	2
		138	1	2
		139	1	2
		139	1	2
		139	1	2
		139	1	0
		140	2	0
		140	1	0
		140	1	
		140	1	0
		140	4	2
		143	2	0
		143	3	
		143	1	
		145	3	
		145	1	4
		145	1	

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		146	3	
		146	1	
		146	1	3
		147	1	
		148	1	0
		148	1	0
		149	1	4
		149	1	
		153	1	2
		154	1	0
		155	1	0
		156	1	4
		156	1	3
		158	1	3
		159	1	
		167	1	3
	Jan. 1992	98	1	0
		117	1	
		117	1	0
		118	1	
		121	1	
		121	1	
		122	1	
		122	1	
		123	1	0
		123	1	
		123	1	2
		124	1	2
		125	1	
		125	1	0
		125	2	0
		126	3	0
		127	1	
		127	1	2
		127	1	3
		128	1	
		128	1	
		128	1	1
		128	1	3
		128	3	0
		129	1	0
		129	1	
		130	1	
		130	1	2
		131	1	

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		132	1	
		132	1	
		132	1	
		132	1	
		132	1	
		132	1	0
		132	3	0
		133	1	
		133	1	
		133	1	
		134	1	
		134	1	2
		134	1	
		134	1	
		134	1	
		134	1	4
		134	3	0
		135	1	
		135	1	
		135	1	
		135	1	
		135	2	2
		136	3	
		136	1	
		136	1	2
		136	1	3
		136	1	1
		137	1	
		137	1	2
		137	1	
		137	2	
		137	2	
		137	2	
		137	1	2
		137	1	2
		137	1	2
		137	1	0
		138	1	
		138	1	
		138	1	3
		138	1	
		138	1	
		138	3	
		138	1	
		138	1	0

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		138	1	3
		139	1	
		139	3	
		139	3	
		139	1	2
		139	1	2
		139	1	2
		140	1	
		140	1	
		140	3	
		140	1	
		140	1	
		140	3	0
		140	1	1
		141	1	
		141	1	
		141	1	
		141	1	3
		142	1	
		142	1	
		142	1	
		142	1	
		142	1	
		142	2	
		143	1	3
		143	1	
		143	2	
		143	1	
		143	1	
		143	1	
		143	1	
		143	1	2
		144	1	
		144	2	
		144	1	2
		144	1	
		144	1	
		144	1	0
		145	1	2
		145	1	
		145	2	
		145	1	
		145	1	2
		146	1	
		146	1	

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		146	2	
		147	1	
		147	1	
		147	1	
		148	1	
		148	1	
		148	2	
		148	1	0
		148	1	
		148	1	
		148	1	
		148	1	
		149	1	
		149	1	
		150	1	2
		151	1	
		151	1	
		151	3	0
		151	1	
		151	1	
		152	1	
		152	3	
		153	1	0
		153	1	
		154	1	
		154	1	
		154	1	2
		154	1	
		154	1	
		154	1	
		155	1	
		155	1	
		155	1	
		156	1	
		156	1	
		157	1	
		157	1	
		157	1	4
		158	1	
		158	1	
		159	1	
		159	1	
		159	1	4
		160	1	3
		160	1	3

Sex	Month	Carapace width (mm)	Shell condition[a]	Infection intensity[b]
		160	2	
		161	1	
		161	1	4
		162	1	4
		162	1	
		162	1	
		162	1	
		163	1	
		164	1	
		165	1	
		166	1	
		174	1	4
Females	Sept. 1991	86	2	0
		89	1	3
		99	3	
		101	1	0
		103	2	0
		106	3	0
		107	3	0
		107	3	0
	Oct. 1991	106	1	
		108	1	
		110	3	
	Nov. 1991	104	3	
		111	3	
	Dec. 1991	94	3	0
		114	3	2
	Jan. 1992	107	1	0
		110	1	5

[a] Shell conditions: 1 = new shell (molting occurred within the past year), 2=old shell (molting occurred between 1 and 2 years ago), 3 = very old shell (molting occurred more than 2 years ago).

[b] Infection intensity: 0 = no infection, 1 to 5 for progressively more heavily infected crab.

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