Mass Molting of Tanner Crabs *Chionoecetes bairdi* in a Southeast Alaska Estuary

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ABSTRACT: A spring migration of Tanner crabs *Chionoecetes bairdi* into a shallow, glacially-influenced cove to molt en masse was studied in 1992 and 1993. An estimated 11,500 crabs molted in a 0.034 km^2 area of shallow (+0.6 m to -17.4 m) water in 1992. Over 2,400 carapaces from intact exuviae were collected by scuba divers in a 100 × 70 m section of the molting area. Molting in both years was restricted to a small area of the cove even though oceanographic conditions and habitat were similar throughout the cove. Crabs were 97% males and had probably molted within the previous year. Approximately 30% of the crabs would have recruited to the commercial fishery after this molt. Chelae measured from exuviae in spring 1993 indicated the migration consisted almost entirely of small-clawed crabs.

INTRODUCTION

The Tanner crab *Chionoecetes bairdi* on the North America coast ranges from Oregon (Hosie and Gaumer 1974) to the southeastern Bering Sea where it co-occurs and hybridizes (Karinen and Hoopes 1971) with the snow crab *Chionoecetes opilio* (Hart 1982). In Alaska, the Tanner crab currently supports a commercial fishery in Southeast Alaska only, but until recently it supported large-scale commercial fisheries throughout the Gulf of Alaska and the southeastern Bering Sea. Although much of the life history of this genus has been extensively studied, information is scarce on the timing, habitat requirements, and environmental factors influencing ecdysis in Tanner crabs.

Ecdysis is a critical stage for crustaceans. Growth, reproduction, and susceptibility to predation depend on the periodicity and timing of the molt cycle in crabs. Pubescent females (i.e., females about to undergo their molt to maturity) must molt before mating for the first time (Adams and Paul 1983). In the laboratory, male crabs are incapable of mating for at least 90 d after ecdysis (Paul et al. 1995). The molt cycle may also be an important factor in the dynamics of disease transmission and infection (Meyers et al. 1990).

Female *Chionoecetes* have determinate growth and become anecdysial when sexual maturity is attained (Hartnoll 1969; Hilsinger 1976). Male *Chionoecetes* are thought to exhibit indeterminate growth, but their growth pattern is subject to debate (Conan and Comeau 1986; Ennis et al. 1988; Donaldson and Johnson 1988; Conan et al. 1990; Dawe et al. 1991). A significant change in allometric growth occurs for some adult males; the chelae become disproportionately enlarged (Hartnoll 1963). Males that have attained differentiated chelae are referred to as large-clawed and may have competitive advantages over small-clawed crabs in mating and intraspecific agonistic interactions (Hooper 1986; Lee and Seed 1992; Stevens et al. 1993). Claw differentiation for male Tanner crabs occurs over a range of several size classes.

Only male Tanner crabs with a carapace width (CW) ≥140 mm including carapace spines (138 mm CW excluding spines) are commercially harvested in Southeast Alaska. Because male size at 50% sexual maturity is estimated at 113 mm CW (Brown and Powell 1972), a size limit of 138 mm would allow most male crabs to breed before harvest, thus preserving the stock's reproductive potential (Donaldson and Donaldson 1992). Crabs are not harvested during the molting period to minimize fishing mortality and maximize meat yield and market value. Colgate (1982) suggested that May is the peak molting period for male crabs in the western Gulf of Alaska, whereas Meyers

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et al. (1990) stated that Southeast Alaska Tanner crabs begin molting in mid March with peak activity occurring in April.

Tanner crabs were first observed molting en masse at the head of Fritz Cove on 6 April 1990, when numerous, large piles of exuviae were observed along and just above the slope at -1.8 m. Approximately 100 soft-shelled and actively-molting crabs were also found scattered in the area. All crabs and exuviae examined were males and comprised several size classes. Similar observations were made during the first week of April 1991. Field work during 1990 and 1991 were limited to these qualitative observations. The objective of this study was to quantitatively examine annual mass migration of Tanner crabs into shallow water to molt and to relate this event to the life history of the species.

METHODS

Spring migration, molting and reproduction of Tanner crabs were studied in Fritz Cove approximately 11 km northwest of Juneau, Alaska (Figure 1). Fritz Cove is

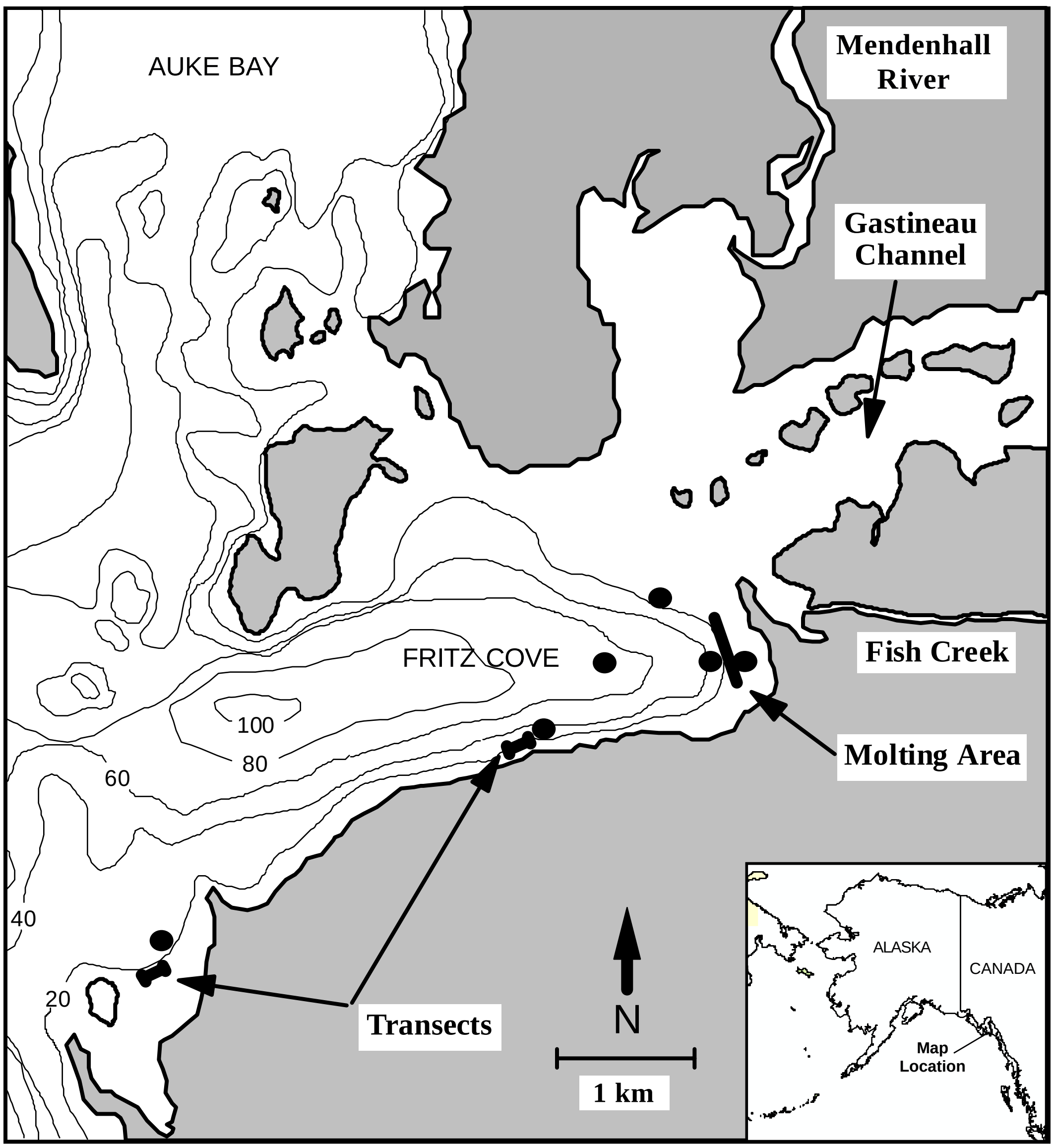

Figure 1. Study area at Fritz Cove near Juneau, Alaska where Tanner crabs were observed molting. Two additional 100-m transects were monitored weekly for the presence of molting crabs. Water temperature and salinity profiles were collected each week at locations denoted by solid circles. Depth contours are in meters.

a small estuary located off a system of large fjords. The cove is strongly influenced by freshwater from both the large, glacial Mendenhall River and the clearwater Fish Creek. Several watersheds empty into Gastineau Channel, a saltwater tidal slough that flows into Fritz Cove. Most of the subtidal area deeper than -5 m mean lower low water (MLLW) is covered with glacial silt.

A 100 × 70 m section (hereafter referred to as collection area) was delineated within the entire molting area; collections were initially made there and counts during the first week of collection indicated that exu-

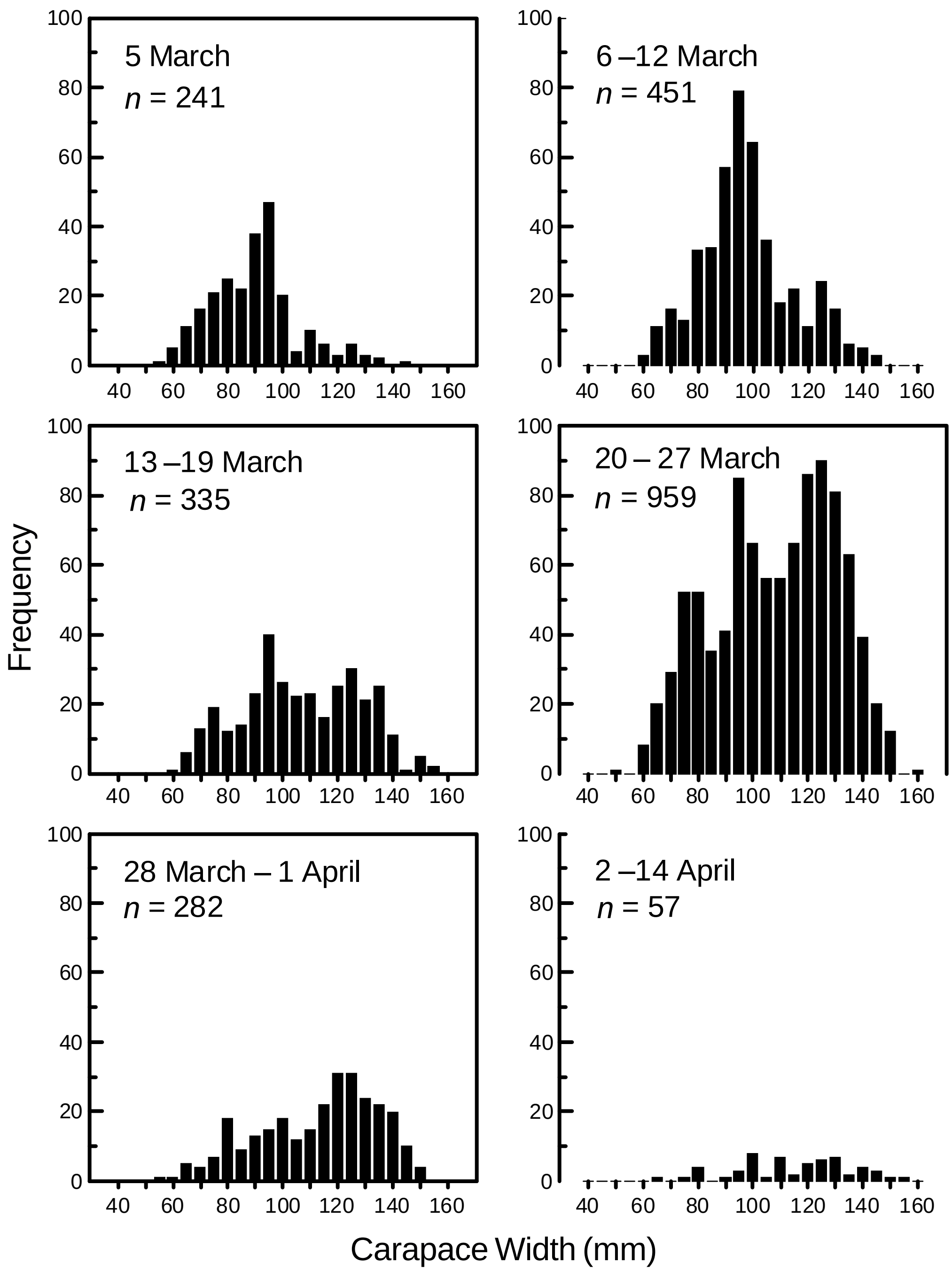

Figure 2. Carapace width frequencies of male Tanner crab exuviae collected during 6 time intervals between 5 March and 14 April 1992. Width intervals are 5 mm. No exuviae were found in the study area after 14 April.

viae were equally distributed in the molting area. The molting area consisted of 3 distinct homogeneous zones: (1) a low-gradient (2–7%), coarse sand flat extending from +0.6 m to a prominent shelf break at -1.8 m; (2) a mid-gradient (18–33%), fine sand slope from -1.8 m to -6.7 m; and (3) a high gradient (33–41%), fine sand and silt slope from -6.7 m to -17.4 m (all depths are reported relative to MLLW). All zones were devoid of boulder patches and associated macrophytes. All observations and collections were made by scuba divers. Depth was measured with a Suunto SME-ML[1] dive computer. Dive observations were made at least once per month in 1992 and 1993. Supporting observations made during several hundred scuba dives in and near the study area between 1990 and 1999 are incorporated into the discussion.

Carapaces of all exuviae (n = 2,407) within the collection area were collected every week during March and April 1992. Exuviae were collected on 18 different dates during this period. Dives were made each week to -30 m. Divers swam systematically throughout the collection area until all carapaces from exuviae had been collected. Gender of each exuvium was determined underwater, and carapaces were segregated by sex. Carapace width (i.e., straight line distance across the widest part of the carapace, excluding spines) of each exuvium was measured to the nearest 0.1 mm. Exoskeleton condition (EC), a subjective measure of exoskeleton age and approximate time since last molt, was recorded for each exuvium using the following criteria: (1) soft, brick red, pliable exoskeleton indicative of a recent molt, (2) hard, clean exoskeleton with limited epifauna and scratches indicative of a molt within one year, and (3) hard, worn exoskeleton with epifauna, discoloration and scratches indicating no molting within the past year. Excessive wear and epifauna on an exoskeleton would indicate several years had elapsed since the last molt.

On 10, 16, 26 March and 1 and 7 April 1993, intact exuviae were collected from the molting area. Exuviae of male crabs ≥85 mm CW (n = 189) were randomly collected, and CW, chelae height (CH), and EC were recorded for each exuvium. Chelae height was measured at the widest section of the propodus (spines excluded). Because Tanner crabs are homochelous, heights of both chelae were averaged if they differed by less than 1 mm, to exclude from analysis regenerated or damaged chelae. If they differed by more than 1 mm, the larger chela measurement was recorded as CH.

In 1993, 37 old-shell crabs (EC >2) were collected in or near Fritz Cove and held in flow-through aquaria in the laboratory throughout spring to determine if they

[1] Use of trade names does not imply endorsement by the National Marine Fisheries Service.

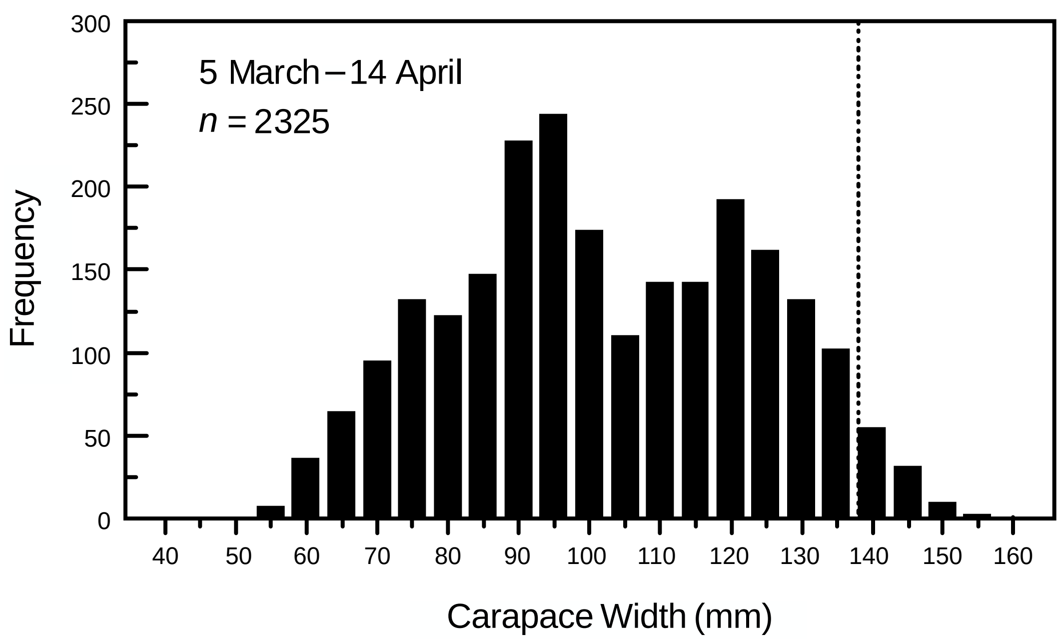

Figure 3. Carapace width frequencies of male Tanner crab exuviae collected between 5 March and 14 April 1992 in Fritz Cove, Alaska. Intervals are 5 mm. The dashed line at 138 mm indicates the minimum legal size for commercial harvest of Tanner crabs in Southeast Alaska.

molted. During both years, pre-mating pairs (n = 61) found within and near the study area were captured and held in the laboratory until molting or mating occurred. Aquaria were maintained at ambient (-30 m depth) temperature and salinity, and crabs were fed a mixed diet of blue mussels and squid twice weekly.

The relationship between chela height and carapace width was compared for non-molting crabs and exuviae collected in 1993. A linear regression line was fit to the natural-log transformed data for each group. The two fitted lines were then tested to determine if they were significantly different from each other (Neter and Wasserman 1977).

Profiles of water temperature and salinity were collected weekly in 1992 at 5 locations in Fritz Cove with a Seabird Electronics Seacat Profiler (Figure 1). Two additional transects (approximately 100 × 70 m) within the same depth range were established 1.5 km and 5.0 km from the molting area (Figure 1), and were monitored each week for molting activity.

RESULTS

Crabs moved into shallow water near the head of Fritz Cove to molt in early March 1992. Crabs molted within a 0.034 km^2 area (480 m × 70 m) at depths between +0.6 m and -17.4 m. A total of 2,407 Tanner crab exuviae were collected within the collection area between 5 March and 14 April. If exuviae were equally distributed throughout the entire molting area as initial observations indicated, an estimated 11,500 crabs at a density of 0.34 crabs per m^2 migrated to the head of Fritz Cove to molt. No exuviae were observed below -17.4 m.

Molting peaked between 20 and 27 March 1992 (n = 959, Figure 2). Only 57 exuviae were collected after 1 April, and none were collected after 14 April. An initial peak in molting occurred between 6 and 12 March when 451 crabs molted. Crabs migrating to the head of Fritz Cove to molt were mostly males (96.6%). Male exuviae ranged from 47.8 to 155.2 mm CW and comprised many size classes with modes at 95 and 120 mm CW (Figure 3). Crabs at 95 mm CW would require 2 molts and crabs at 120 mm CW would require 1 molt to reach legal size (Donaldson et al. 1981). Only 84 male exuviae (3.6%) were larger than the minimum legal size of 138 mm CW. Using the growth equation

$$\text{post-molt CW} = 1.07(\text{pre-molt CW}) + 15.75$$

derived for Kodiak Island area male crabs (Donaldson et al. 1981), crabs >114.3 mm CW before molting (698 crabs or 30%) would have recruited to the fishery. Larger males tended to molt later in spring than smaller males (Figure 4).

Exuviae from females and small juveniles were uncommon in Fritz Cove in 1992. Only 81 female exuviae were found in the collection area between 5 March and 1 April (Figure 5); none were found after 1 April. Only one small juvenile exuvium (30 mm CW) of indeterminate sex was collected.

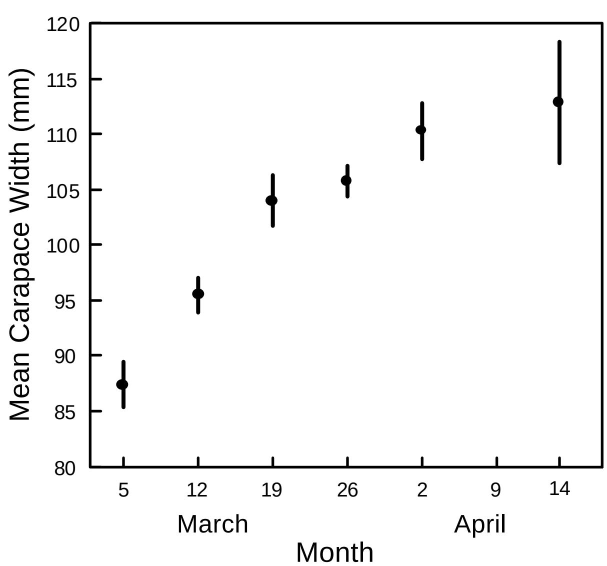

Figure 4. Mean carapace width (± 95% confidence limits) of male Tanner crab exuviae collected during 6 intervals between 5 March and 14 April 1992.

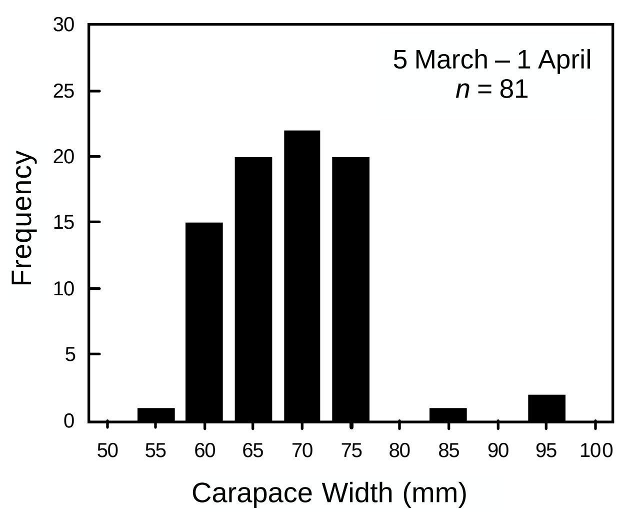

Figure 5. Carapace width frequencies of female Tanner crab exuviae collected between 5 March and 1 April 1992 in Fritz Cove, Alaska. Intervals are 5 mm. No female exuviae were found in the study area after 1 April.

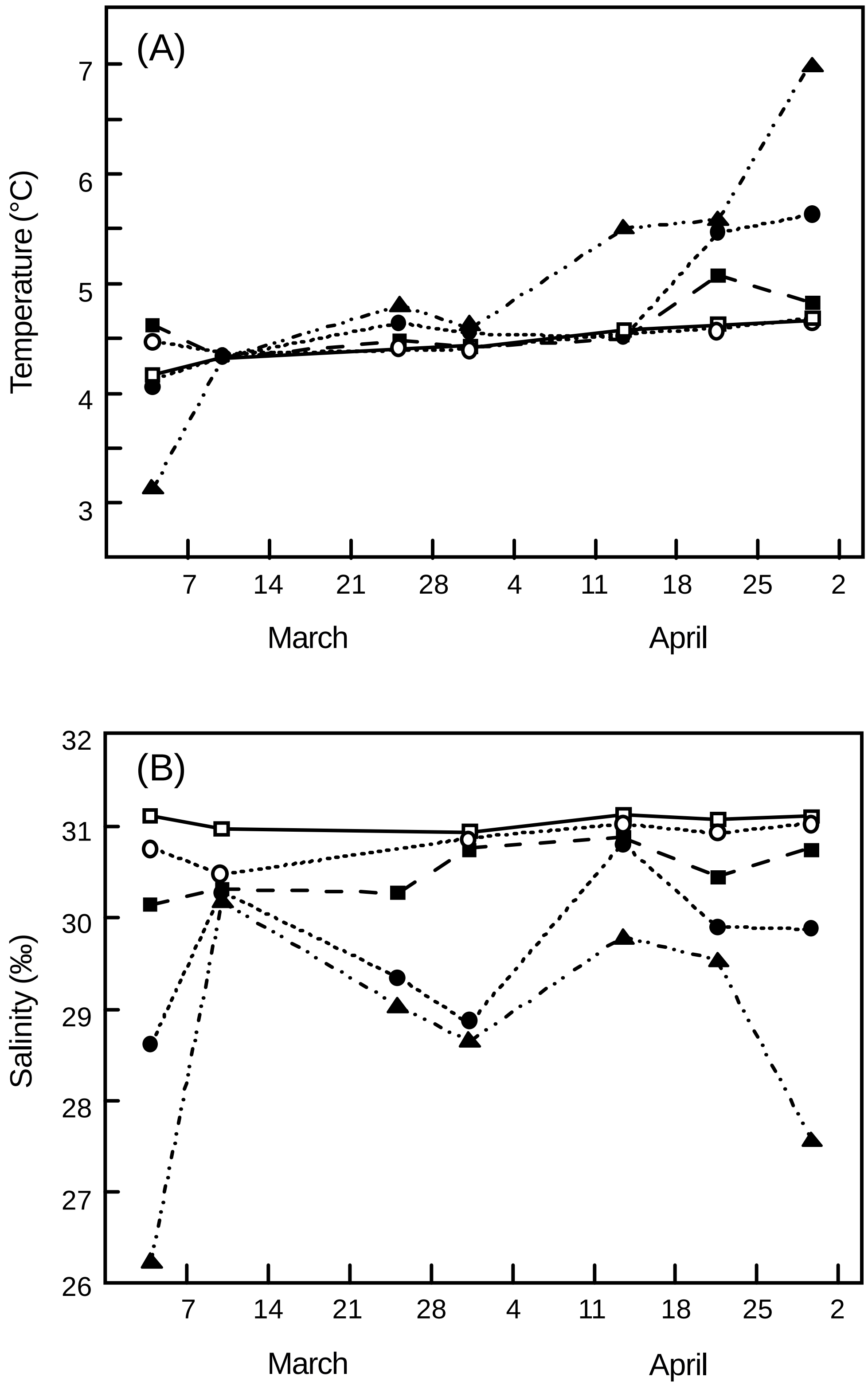

Figure 6. (A) Water temperature and (B) salinity at 0 m (solid triangles), 10 m (solid circles), 20 m (solid squares), 40 m (open circles), and 60 m (open squares) within the study area in Fritz Cove. The measurements at 40 m and 60 m were made at locations directly west of the molting area. Depths are relative to MLLW and measurements were made near the sediment-water interface.

Table 1. Means and ranges of morphometrics of female *Chionoecetes bairdi* from 61 mating pairs collected in shallow water in northern Southeast Alaska between 1992 and 1993. Growth = mean (± 1 SE).

Maturity Status	*n*	Pre-molt (mm)	Post-molt (mm)	Growth (mm)
Pubescent[a]	49	85.3 (72.9–98.3)	102.2 (87.2–115.9)	16.9 (0.3)
Multiparous[b]	12		95.4 (82.3–108.6)	

[a] Pubescent females were collected between 24 December and 17 June at depths between -4.3 and -19.2 m MLLW.
[b] Multiparous females were collected between 19 March and 23 April at depths between +0.3 and -7.6 m MLLW.

The water column was well-mixed with respect to temperature in Fritz Cove during the study period (5 March to 14 April), and ranged between 3.1°C and 5.5°C (Figure 6A). By late April, surface waters began to warm rapidly and a strong thermocline developed to about 30 m. Salinity was stable between 30.1‰ and 31.1‰ below 20 m during the study period (Figure 6B). Salinity at depths <20 m, however, was lower (26.2‰ to 30.9‰) and more variable (Figure 6B).

Only one exuvium and a few old-shelled males were observed in the 2 additional 100-m transects which were monitored weekly (Figure 1). Although the environmental conditions measured there and the habitat were similar at all sites, molting was restricted to the head of the cove.

Carapaces of all exuviae collected in this study in 1992 and 1993 were EC 2. The relationship between chela height and carapace width differed between non-

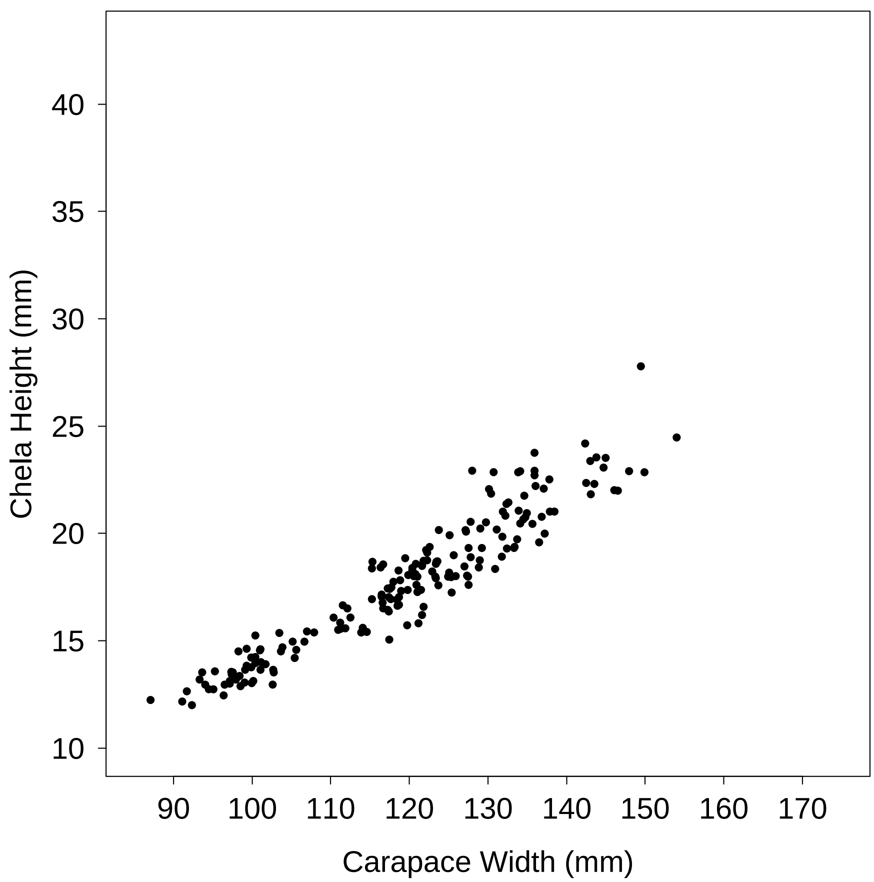

Figure 7. Allometric relationship between chela height and carapace width for non-molting male Tanner crabs (*n* = 37, open triangles) and exuviae (*n* = 189, solid circles) collected in 1993 in Fritz Cove, Alaska. A linear regression line was fit to the natural-log transformed data for each group. The 2 fitted lines are significantly different ($P < 0.001$). Non-molting male Tanner crabs had EC ≥3.

molting crabs and the exuviae collected in 1993 (Figure 7). The 2 fitted lines were significantly different ($P < 0.001$). Non-molting crabs had CH:CW ≥0.20, whereas all but 2 exuviae had CH:CW ≤17. Using the criteria developed by Stevens et al. (1993) for Kodiak Island area crabs, all non-molting crabs could be classified as large-clawed, and all but 2 exuviae could be classified as small-clawed.

DISCUSSION

Spring migration of Tanner crabs into shallow water to molt was noted by scuba divers during several consecutive years in the 1970s (John Karinen, National Marine Fisheries Service, Auke Bay Laboratory, Juneau, Alaska, personal communication). Mixed groups of males and females (<115 mm CW) and one group of exclusively large males were observed molting at 4 different locations in Auke Bay in March and April. These concentrations of crabs were estimated to number in the hundreds. Although I have observed small aggregations (<100 crabs) of molting male Tanner crabs at only 2 other locations in Southeast Alaska (8 and 21 km from Fritz Cove), mass molting of Tanner crabs is probably not unique to Fritz Cove. Numerous male Tanner crabs have been observed molting in the same area of Fritz Cove each spring between 1990 and 1999.

No other crab species has been reported to utilize the same area annually to molt en masse. Pubescent females and some male Tanner crabs migrate into shallow water to mate in spring (Stevens et al. 1993), but mass molting has not been reported. Spring breeding migrations of the snow crab *C. opilio* into shallow water have been reported along the eastern shore of Canada (Taylor et al. 1985; Hooper 1986). Predominantly small, but functionally mature male *C. opilio* (i.e., capable of successfully mating in situ in the presence of competition from larger males) may migrate into shallow water in the spring to molt (Sainte-Marie et al. 1988; Sainte-Marie and Hazel 1992).

The molt cycle of Tanner crabs is inextricably related to reproduction. All males that molted at Fritz Cove during 1992 may have been sexually mature; males as small as 45 mm CW produce spermatophores (Paul 1992), and males as small as 68 mm CW can successfully mate in the laboratory (Adams 1982). Males as small as 75 mm CW have been found in pre-mating pairs with pubescent females in situ at Kodiak Island (Paul et al. 1983). The smallest male found in a pre-mating pair with a pubescent female in my study was 92.7 mm CW. Most males (64%) examined in my study were larger than 92.7 mm CW and could have mated before molting. I observed pubescent females in pre-mating pairs in shallow water between late December and June (Table 1), with peak activity occurring in mid February. Over 90% of the pre-mating pubescent female pairs were collected before 1 April. These observations are consistent with those made near Kodiak Island (Donaldson 1975; Stevens et al. 1993). Multiparous females mate in deepwater aggregations during April and May (Stevens et al. 1993; Stevens et al. 1994) and to a lesser extent in shallow-water areas near mating pubescent females (Donaldson 1975; Stevens et al. 1993; Table 1). Size-related molt timing (Figure 4) may allow larger males to mate with more pubescent females before molting, but would probably preclude them from mating during most of the multiparous female mating period later in spring. Although in situ data are lacking, Paul et al. (1995) reported that recently molted males which were held in the laboratory for extended periods (up to 262 d) did not copulate with multiparous females up to 99 d after molting.

The relative absence of females during this annual migration into shallow water is puzzling. Only 81 female exuviae were collected in the study area. Twenty-two exuviae (27.2%) were larger than the smallest (72.9 mm CW) pubescent female collected from pre-mating pairs (Table 1). These may have been exuviae from pubescent females molting to maturity. Their presence probably was incidental to the molting event, because females mate only with males in the hard-shell condition (Hartnoll 1969). In contrast, 211 male exuviae (8.8% of total) with CW ≤72.9 mm were collected.

The frequency of ecdysis for small-clawed males is unknown. Donaldson et al. (1981) statistically predicted an intermolt period of 18 months for legal-size males. Donaldson (1980) tagged and released mature males ≥110 mm CW off Kodiak Island, Alaska, and concluded from recovery data that the intermolt period may exceed 3 years. However, chela morphometry was not measured by Donaldson (1980), so tag recoveries may have been large-clawed crabs which molt infrequently or were in terminal ecdysis. Zheng et al. (1997) analyzed historic trawl survey data from Bristol Bay and estimated molting probabilities which varied with time, possibly on a decadal scale. Intermolt periods exceeding 2 years have been recorded for mature males (both small- and large-clawed) held in the laboratory (Paul and Paul 1995). The synchronous nature of the molting event observed in this study indicated a one-year intermolt period for small-clawed males in situ. The absence of molting activity during any other time of year in shallow water at this site, and the consistent classification of exuviae as EC 2 support this hypothesis. No evidence exists in the literature that mature male Tanner crabs molt at depths greater than those observed in this study during any time of year. An in situ study designed to periodically observe crabs throughout an entire year is necessary to confirm the intermolt period for small-clawed male crabs.

Intensity and duration of light, temperature, and possibly salinity may affect molt initiation in crustaceans (Passano 1960). Rapid increases in light intensity and duration during early spring may initiate molting behavior in Tanner crabs. Differences in water temperature between 60 m and shallow water were small, and probably did not serve as cues to migratory behavior. Salinity was reduced at depths shallower than 20 m, however, and Tanner crabs might gain an osmotic advantage by molting in lower salinity water. *Callinectes sapidus* had greater incremental growth when molting in brackish water as a result of the favorable osmotic gradient (deFur et al. 1988). Previous measurements collected in the molting area in March and April 1990 showed increased levels of dissolved oxygen in shallow water (<20 m). Because oxygen uptake increases just before exuviation (Passano 1960), molting crabs may move into oxygen-rich waters to meet the high oxygen demands of molting.

Why Tanner crabs molt en masse in shallow water is unclear. Tanner crabs might migrate into shallow water to avoid predators. These shallow-water areas are practically devoid of predators; the only observed predation on a soft-shelled Tanner crab was by a hard-shelled Tanner crab and an adult female red king crab *Paralithodes camtschaticus*. By migrating to shallow water, crabs could separate themselves during ecdysis from deepwater predators such as large groundfish, other crab species, and the non-molting population of Tanner crabs.

Because large numbers of Tanner crabs use the same discrete area each year to accomplish an important life history requirement, the area should be considered essential habitat. Annual monitoring of extensive molting areas may be useful in predicting future recruitment trends.

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