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Distribution of Larval Dungeness crabs in Glacier Bay, Southeastern Alaska

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Adult Dungeness crabs are restricted primarily in the lower part of Glacier Bay, Alaska, but the interaction of larval dispersion and adult distribution is unknown. To understand the larval occurrence in the upper part of Glacier Bay, Dungeness crab larvae, sea surface temperature (SST), and sea surface salinity (SSS) were collected at 16 near-shore and 12 mid-channel stations in Glacier Bay, southeastern Alaska during six sampling periods from March through August 2000. Each station was visited from one to five times during the entire sampling period. Geographic Information System (GIS) was used to contour SST and SSS distribution in Glacier Bay. Seven to 27 stations were visited during each sampling period. Most larvae (85% were zoeae I) occurred during May 31 to June 14, 2000. Larval density varied from none to 51.4 100 m^{-3} between stations. A few later stage larvae occurred during later sampling periods. Overall, no relationship between larval densities, and SSS, and SST existed. Larvae occurring in the upper bay were probably transported by tidal currents from the lower bay; adult Dungeness crabs in Glacier Bay have a relatively high density near the mouth of the bay but decrease sharply around 40 km north of the mouth. The lack of adult crabs in the upper 60 km of the bay may be related to lower salinity, resulting in sharp haloclines, or colder temperatures which are not conducive to survival or growth of either larvae or adults.

Key words: Dungeness crab, *Cancer magister*, Larval distribution, Glacier Bay, Larval ispersion

Introduction

Dungeness crab, *Cancer magister*, has a wide latitudinal range along the west coast of North America from the Aleutian Islands and Pribilof Islands, Alaska to Magdalena Bay, Mexico (Hart, 1982; Jensen, 1995). The northern Gulf of Alaska is the northern limit for commercial populations of Dungeness crabs, although small numbers of Dungeness crabs have been found in the Pribilof Island and the Aleutian Chains (MacKay 1943; Hart 1982; Orensanz et al., 1998). Dungeness crab larvae can be transported long distances by ocean currents (McCoughnauhey et al. 1992, 1994; Park et al., 2007). Tidal currents may help larval advection of Dungeness crabs in inland straits in southeastern Alaska (Park, 2007).

Glacier Bay is a recently deglaciated fjord estuarine system with a highly diverse oceanographic and topographic system within a relatively small area (Hooge and Hooge, 2002). Generally, water temperature in the mouth of the bay is warmer while that in the upper bay is colder (Taggart et al., 2003). The wide gradients of temperature from the upper bay to the lower bay may affect the reproductive biology of invertebrates and distribution of their larvae. The upper bay also has lower salinity than the lower bay (Hooge and Hooge, 2002; Ethrington et al., 2004). However, Glacier Bay is a stratified, deep basin estuary whose waters are tidally mixed (Hooge and Hooge, 2002). Strong tides in the bay may be responsible for changes of zooplankton and environments within the bay from the mouth to both arms.

Glacier Bay was an important area for Dungeness crab fishery before a fishery closure in 1999; the closure was prompted by legislation because the area is within a national park, Glacier Bay National Park and Preserve. Owing to the commercial importance of Dungeness crabs in Glacier Bay, the Multi-Agency Dungeness Study (MADS) has collected detailed bio-

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logical information, such as distribution, abundance, reproductive biology, appendage injuries, and fishing closure effects on adult crabs in the bay since 1992 (O'Clair et al., 1990; Leder et al., 1993; Schultz and Shirley, 1998; Scheding et al., 2001; Swiney et al., 2003; Taggart et al., 2004 a,b; Park, 2007). In the bay, most Dungeness crabs exist in the lower bay because the upper bay may not be suitable for the survival of the adults (Taggart et al., 2003). Abiotic factors such as cold water temperatures and low salinity were proposed as variables that might limit survival of crabs in the upper bay (Taggart et al., 2003) as prior studies had reported that ovigerous Dungeness crabs did not survive in cold water temperatures of 0°C (Shirley et al., 1987); however, the distribution and abundance of larvae in the upper bay was not examined

Water temperature affects reproductive events of invertebrates (Ebert et al., 1983; Hartnoll, 1982; Reed, 1969). Molt increment and intermolt period of crab larvae varies inversely with temperature at all stages (Shirley et al., 1987; Sulkin and McKeen, 1989, 1996; Kondzela and Shirley, 1993; Moloney et al., 1994). In addition, temperature can influence larval activity, swimming behavior, and larval survival (Reed, 1969; Sulkin, 1984; Shirley and Shirley, 1988, 1989; Jamieson and Phillips, 1993).

Alternately, salinity may have synergistic effects with temperature. Compared with the effects of temperature, the influence of salinity on the duration of development through individual stages is relatively weak or nonexistent (Kinne, 1971). However, the metabolic rate in euryhaline crab larvae increases under suboptimal salinity conditions while it decreeses in supraoptimal salinity (Kinne, 1971).

We investigated the distributional pattern of Dungeness crab larvae in relation to sea surface temperature (SST) and sea surface salinity (SSS) within Glacier Bay to ascertain whether Dungeness crab larvae were advected or retained within the bay, and to determine whether larvae are distributed in the upper portions of the bay.

Materials and methods

Zooplankton were sampled at 16 near-shore and 12 mid-channel stations from the R/V *David Gray* and R/V *Alaska Gyre* by the US Geological Survey. Samplings were conducted during six sampling periods from March to August 2000: March 17 to March 21 (period 1), May 10-11 (period 2), May 31 to June 14 (period 3), July 12 to July 20 (period 4), July 26 to August 9 (period 5), and August 12-22 (period 6). Each sampling station was visited from one to five times during the entire sampling period. Seven to 27 stations were visited at each sampling period. Salinity and temperature were collected at the sampling with a CTD sampler (Sea-Bird SBE 21); salinity is reported as practical salinity units (PSU). A 333 μm mesh net with a 60 cm diameter was hauled vertically from 50 m depth when possible, or from 2 m from the bottom in shallower stations. Samples were preserved in 4% formalin. Dungeness crab larvae were sorted and identified to stage.

A Chi-square test was performed to test whether larval occurrence was associated with hydrographical features such as salinity and temperature. Sea surface salinity (SSS) and temperature (SST) were categorized into six categories for SSS and five categories for SST and were compared with larval occurrence. The Wilcoxon rank sum test was used to compare larval abundances between the nearshore and mid-channel stations.

SST and SSS were contoured with a Radius Base Function in ArcGIS 9.1 (2001). Although there were insufficient data points to evaluate spatial autocorrelations for geostatistical interpolation, the Radius Base Function was used because oceanographic data were assumed to be continuous over the study areas and the function was deterministic.

Results

Among the six sampling periods, most larvae occurred during May 31 to June 14, 2000 and most larvae were zoea I (85%) and II (15%) (Fig. 1). Larval densities varied from none to 51.4 100 m^{-3} among stations. After this time period, only a few larvae occurred (Fig. 2, 3).

Overall, no relationship was evident between larval density and SSS and SST (Table 1). During May 31 to June 14, the primary season of larval hatching in southeastern Alaska, larval abundances at nearshore stations was significantly higher than those of mid-channel stations (Wilcoxon rank-sum test, $z = -2.98$, $p = 0.003$). No larvae were found during the first two sampling periods and the last sampling period.

Hydrographic features had a seasonal pattern and were less variable between stations in March to May, and strongly variable during the remaining summer months. SSS ranged from 29.7-31.0 during March 17 to 21, and 27.1-31.0 during May 10 to 11. During the summer, SSS fluctuated from 5.2 to 31.5. In general, SSS was relatively higher near the mouth of the bay and lower progressively up both arms (Fig. 4). However, SSS in some locations was sharply higher or lower than at neighboring locations.

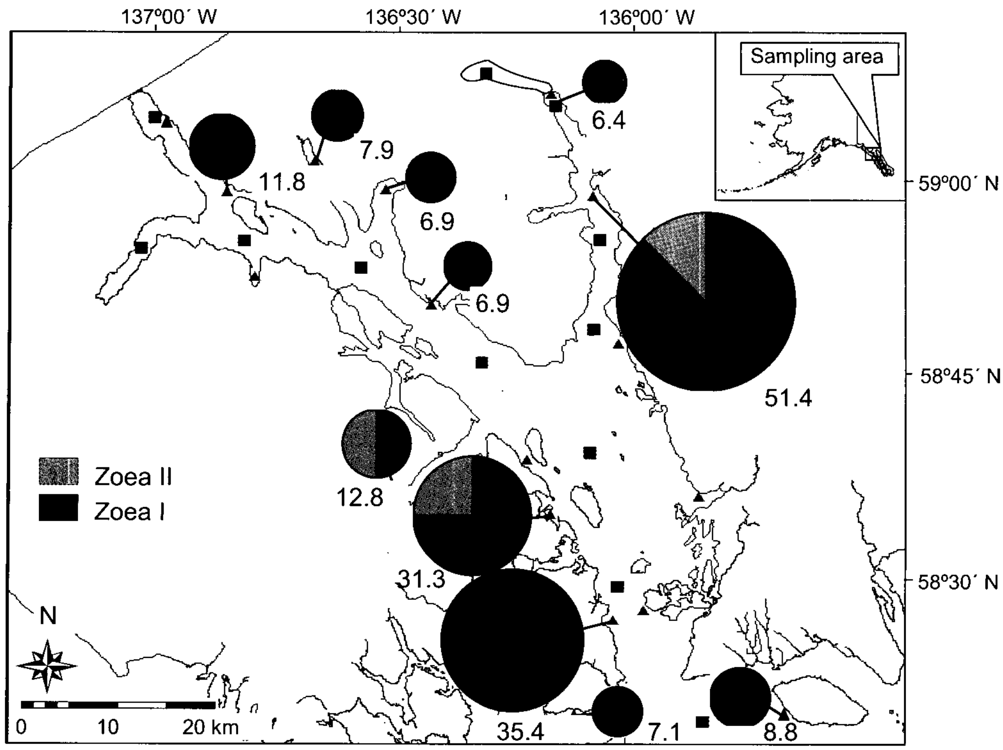

Fig. 1. Larval distribution of Dungeness crabs, *Cancer magister* in Glacier Bay, southeastern Alaska from May 31 to June 14, 2000. Dungeness crab larvae were collected from 27 stations. Squares indicate mid-channel stations and triangles denote nearshore stations. Numbers below each pie chart indicate larvae per 10 m^3.

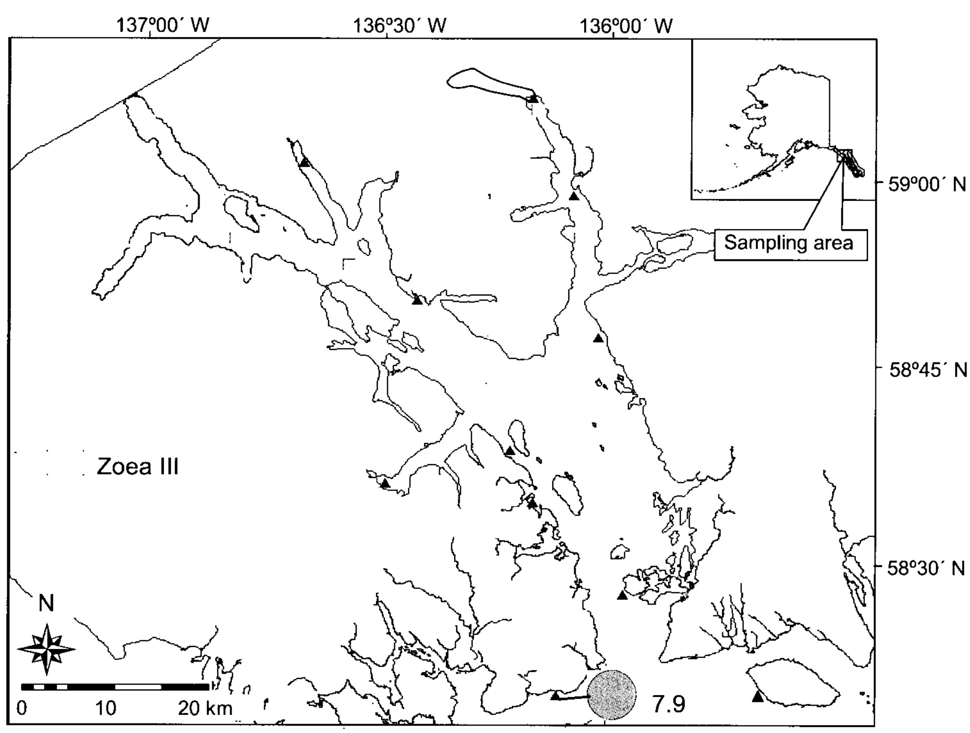

Fig. 2. Larval distribution of Dungeness crabs, *Cancer magister* in Glacier Bay, southeastern Alaska from July12 to 20, 2000. Dungeness crab larvae were collected from 11 stations. Triangles denote nearshore stations. Numbers below each pie chart indicate larvae per 10 m^3.

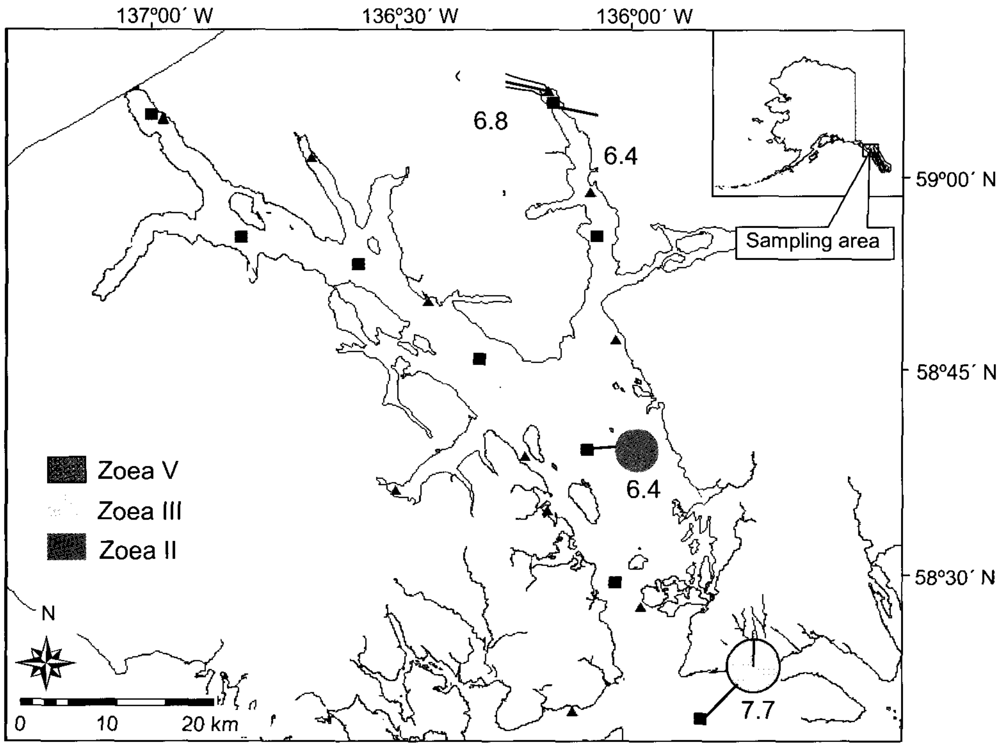

Fig. 3. Larval distribution of Dungeness crabs, *Cancer magister* in Glacier Bay, southeastern Alaska from July 26 to August 9, 2000. Dungeness crab larvae were collected from 21 stations. Squares indicate mid-channel stations and triangles denote nearshore stations. Numbers below each pie chart indicate larvae per 10 m^3.

Table 1. Chi square test summary comparing relationships between environmental variables and larval ccurrence of Dungeness crabs, *Cancer magister* in Glacier Bay, southeastern Alaska. Sea surface salinity (SSS) was sorted into six categories and sea surface temperatures were sorted into six categories. The entire sampling period is from March to August 2000 and the primary larval hatching period is from May 31 to June 14, 2000

	Df	χ^2	P value	χ^2 significance
SSS and larvae (entire sampling period)	5	2.21	0.9 <	11.07
SSS and larvae (main larval hatching period)	5	4.48	0.9 <	11.07
SST and larvae (entire sampling period)	4	7.52	0.2 <	9.49
SST and larvae (main larval hatching period)	4	3.80	0.9 <	9.49

In general, SST in the mouth of bay and both arms was colder than at mid bay stations, with strong geographical variations (Fig. 4). SST during March was coldest (3.4-4.9°C) and increased during the summer sampling periods (approximately 4.0-11.6°C).

Discussion

Dungeness crab larvae have diel vertical migration (Hobbs and Botsford, 1992; Park and Shirley, 2005), however zoeae I prefer shallower depths while later zoeal stages occupy deeper depths (Reilly, 1983). In our study, larvae were collected only in the upper 50 m depth, and any larvae at deeper depths might not have been collected. Larval densities we report here are lower than other studies conducted near the study area (Park, 2007), and conceivably could have resulted from our relatively shallow sampling depths. However, the larval collections in the current study were made in the areas of extremely low adult densities, where no ovigerous females were found (Taggart et al., 2003).

Dungeness crabs in Glacier Bay have relatively high abundance near the mouth of the bay and their abundance decreases sharply around 40 km north of the mouth (Taggart et al., 2003). In addition, most ovigerous female crabs aggregate at shallow depths from 2 to 5.5 m and most aggregations are less than

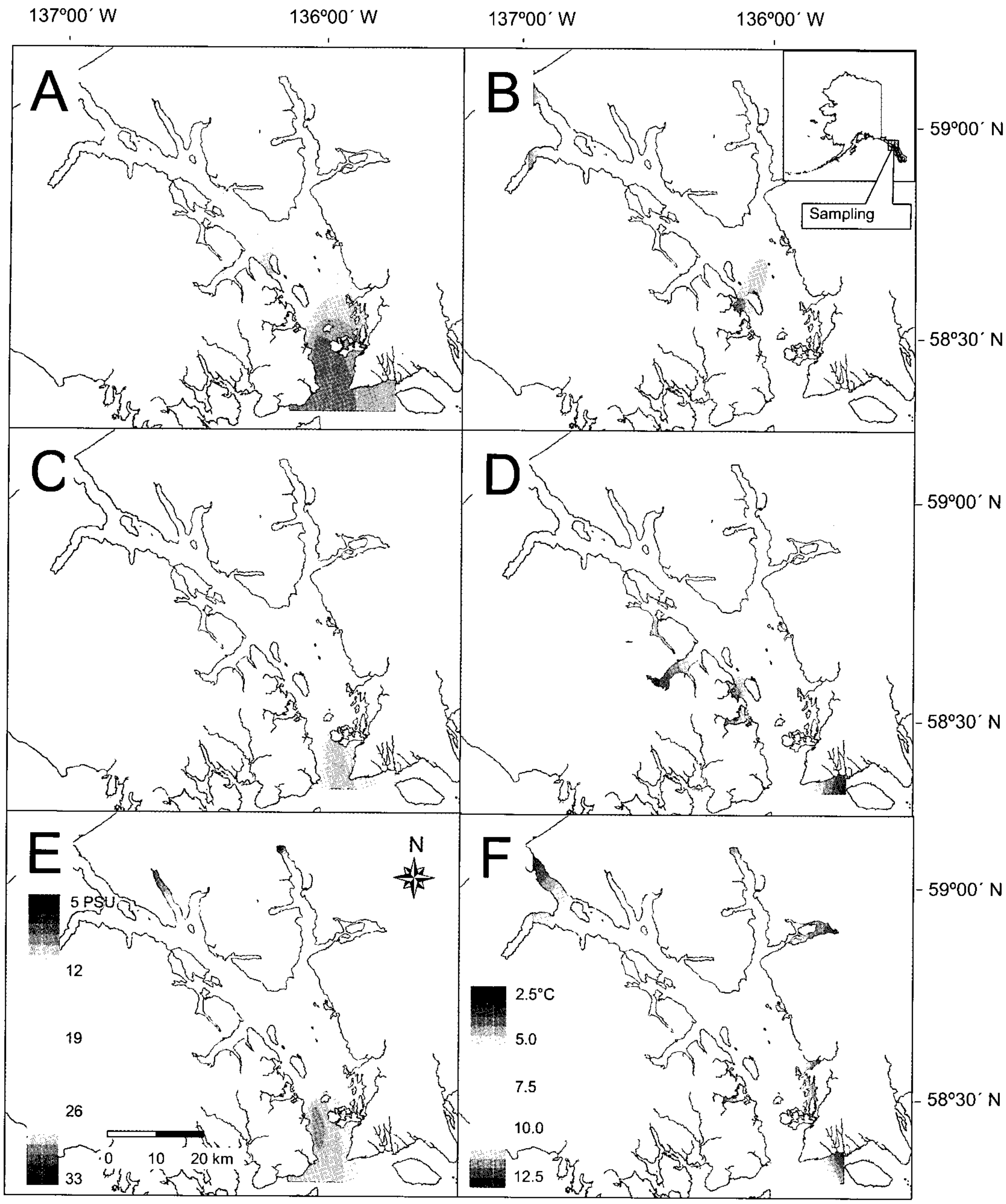

Fig. 4. Contour plots of hydrographic features measured at 1 m depth in 2000. Left column indicates sea surface salinity (SSS); Right column indicates sea surface temperature (SST). A and B were measured at 27 stations from May to June 14, 2000; C and D were measured at 11 stations from July 12 to 20, 2000; E and F were measured at 21 stations from July 26 to August 9, 2000.

10 m in depth near the mouth of the bay (Scheding et al., 2001). Only a few female crabs are found in the upper bay. Assuming that adult crabs occur mostly near the mouth of the bay, larvae found in the upper bay may have been transported from the lower bay. Zoeae I that occurred at the nearshore stations (Fig. 1) might have hatched at shallow depths where ovigerous female crabs were aggregated near the mouth of the bay and then may have been transported to the upper bays by tidal changes. Tidal changes and associated internal waves may have resulted in larval occurrence that was not related to hydrographic features in our study because tidal changes and associated internal waves may transport plankton and particles to their unexpected locations (Matthews, 1981; Hooge and Hooge, 2002).

Larval survival is influenced by hydrographic variables such as salinity and temperature (Reed, 1969; Sulkin and McKeen, 1989; Moloney et al., 1994). Rapid changes or persistent unfavorable hydrographic variables are lethal to Dungeness crab larvae (Reed, 1969). In Glacier Bay, water temperature throughout the year is below the optimal temperatures for larval survival of Dungeness crabs, but particularly in the upper bay (Taggart et al., 2003). Dungeness crab larvae have limited temperature ranges for their development. Survival of Dungeness crab larvae below 6°C is poor and may result in cessation of larval development (Reed, 1969, Jamieson and Phillips, 1993). The later stage larvae found during July and August were in approximately 4°C (SST), which is not suitable for larval survival of Dungeness crabs (Reed, 1969; Jamieson and Phillips, 1993). Accordingly, even if larvae had been found in the upper bay, we assume that they would not have survived or recruited. Larvae dispersed to the upper bay from the lower bay may have experienced suboptimal environments. Benthic stages of the crabs that recruit into populations of the upper bay barely survive in the extreme temperature and salinity (Taggart et al., 2003).

At salinities lower than 20, the duration of the prezoeal stage lasts about an hour and less than 50% survive, while at salinities higher than 21, and up to 32, molting takes only fifteen minutes and almost 100% of the prezoeae molt to the ZI (Buchanan and Milleman, 1969). Zoeae at salinities below 20 did not live more than a week (Reed, 1989). Among the four stations where larvae were found, two stations were below 10 PSU. This salinity does not provide suitable conditions for larval survival and development.

Overall, larvae probably hatched in the lower part of the bay where adult populations exist. Some portion of the larvae from those suitable habitats may have been transported to the unfavorable habitats in the upper bay and did not survive.

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