Title: Population Connectivity via Larval Drift of Pribilof Islands Blue King Crab in the Eastern Bering Sea

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Background

Blue king crab (BKC, *Paralithodes platypus*) stocks in the eastern Bering Sea (EBS) have historically supported important commercial fisheries that benefit local coastal communities in Alaska. The two crab stocks managed within the federal Fishery Management Plan (FMP) for Bering Sea and Aleutian Islands (BSAI), King and Tanner Crabs, are located around the Pribilof Islands and St. Matthew Island (Fig. 1).

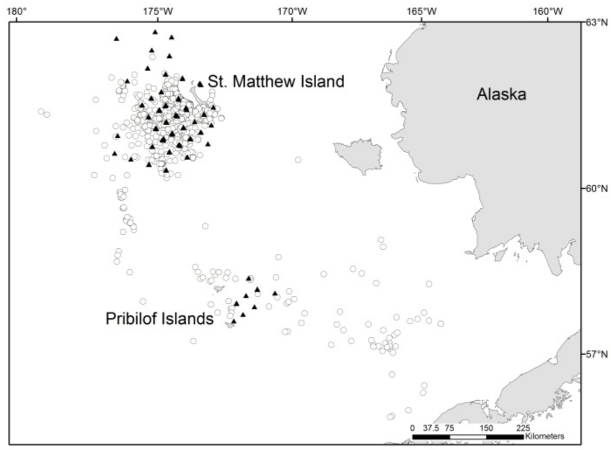

Figure 1. Distribution of BKC observed in eastern Bering Sea bottom trawl surveys (triangles) and during groundfish fisheries (circles) between 2007 and 2011.

While the St. Matthew Island BKC stock has increased in abundance in recent years after collapsing in the 1990s, the Pribilof Islands stock has remained depressed, with mature male biomass declining from 30,000 t in the late 1970s to a low of 412 t in 2011 (Chilton et al., 2011). Although the mechanisms of the collapse are not known, substantial measures implemented to reduce the impacts of fisheries have not resulted in the rebounding of the stock. As such, it is imperative that other factors such as the role of environmental variability on the distribution, abundance, and interaction of this stock with the St. Matthew BKC stock be assessed before considerable restrictions are placed on coastal communities.

The BKC fisheries are cooperatively managed by the State of Alaska and the National Marine Fisheries Service. The Pribilof Islands BKC male-only fishery took place from 1973 to 1989 and from 1995 to 1999. The fishery began in 1973 with a reported catch of 590 t and increased to 5,000 t in the 1980/81 season (Foy, 2011). The guideline harvest levels were 10 percent of the mature male abundance or 20 percent of the legal male abundance (ADF&G, 2006). In 1995, Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area which prohibits the year round use of trawl gear around the Pribilof Islands to protect crab habitat. Declines subsequent to the smaller 1995-1999 catches resulted in a fishery closure from 1999 to the present, with bycatch levels remaining below the overfishing level. Pribilof Islands BKC are caught incidentally in the snow crab (*Chionoecetes opilio*), Tanner crab (*Chionoecetes bairdi*), Pribilof Islands red king crab (*Paralithodes camtschaticus*), flatfish, and Pacific cod (*Gadus macrocephalus*) fisheries. In September, 2003 the Pribilof Islands stock was declared overfished by the Secretary of Commerce and the North Pacific Fisheries Management Council. To comply with section 304(e)(7) of the Magnuson-Stevens Act and due to insufficient progress towards rebuilding, additional measures to protect the stock will be implemented by 2014.

BKC are anomurans in the family Lithodidae and occur off Hokkaido in Japan, and with distinct and separate populations occurring in the Sea of Okhotsk and along the Siberian coast to the Bering Straits. In North America, they occur from the Diomede Islands, Point Hope, outer Kotzebue Sound, King Island, and the outer parts of Norton Sound. They are found in the waters off St. Matthew Island and the Pribilof Islands in the EBS. In southeastern Alaska in the Gulf of

Alaska, BKCs are found in widely-separated populations that are frequently associated with fjord-like bays. The distribution of distinct and separate populations is potentially the result of increases in water temperature during post-glacial periods that have limited the distribution of this cold-water adapted species (Somerton 1985). Factors that may be directly responsible for limiting the distribution include the physiological requirements for reproduction, competition with the more warm-water adapted red king crab, exclusion by warm-water predators, or habitat requirements for settlement of larvae (Somerton 1985; Armstrong et al 1985, 1987).

Stock structure of BKCs in the EBS is largely unknown. Population trends are very different between the Pribilof Islands regions and the St. Matthew region. However, there are no apparent barriers to adult dispersal between the regions yet they are infrequently taken in NMFS trawl surveys between those islands suggesting limited post-settlement dispersal as adults.

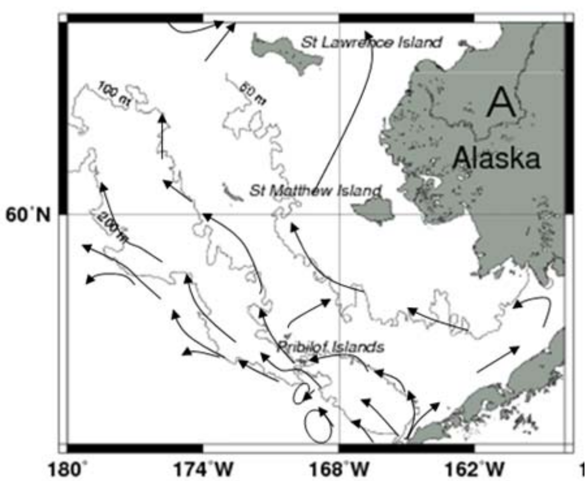

Figure 2. General currents in the eastern Bering Sea.

General current structure in the EBS (Fig. 2) suggests that there may be a possible source-sink relationship between planktonic larvae released in the Pribilof Islands region that could settle in the St. Matthew region, but also potential retention in the area around the Pribilofs (Parada et al. 2010). Survey data revealed that the distribution of BKC in the EBS averaged over the past decade stretches from southeast of the Pribilof Islands to northwest of St. Matthew Islands with obvious clusters of biomass around the Islands (Fig. 1). Additional data based on observed bycatch during groundfish fisheries suggests that the distribution extends even farther to the southeastern portions of the EBS. The mechanisms or proportion of interactions that occur among these regions is unknown and may be driven by spatially variable environmental conditions such as currents or bottom temperature. Historically the EBS had high year to year variability in temperature. Since 2000, it has entered a period of multiyear variability (2001-2005: warm, 2007-2012: cold). The EBS is influenced by many factors such as flow through the Aleutian passes, variable winds and ice. Currents also differ in warm vs. cold years, with stronger westward flow in cold and weaker westward flow in warm years (Stabeno et al. 2012).

Reproductive life history: Female BKC molt, mate, and extrude their clutches in late March through mid-April (Armstrong et al. 1987). BKC are typically biennial spawners with average sized (1.2 mm) embryos developing internally for between 11-12 months (Armstrong et al. 1985, 1987, Stevens 2006a) and 14-15 months (Somerton and MacIntosh 1985). Prey availability or reduced feeding activity due to cold water may limit ovary development, growth, and egg extrusion preventing annual mating (Armstrong et al. 1987, Jensen and Armstrong 1989). BKC fecundity increases with size, from approximately 100,000 embryos for a 100-110 mm (carapace length, CL) female to approximately 200,000 for a female >140-mm CL (Somerton and MacIntosh 1985). Each female hatches an average of 110,033 larvae over an average of 29 days between February and April (Stevens 2006b). The biennial reproductive cycle of individual crab means that only about half the mature female population extrudes eggs or hatches larvae in a given year, which obviously constrains total annual production.

Larvae are pelagic through four zoeal stages during 2.5 to 4 months; each stage lasting about 10 days, each dependent on temperature (Armstrong et al. 1987, Stevens et al 2008). Stage I zoeae must find food within 60 hours as starvation reduces their ability to capture prey (Paul and Paul 1980) and successfully molt. Zoeae consume phytoplankton, preferably the diatom *Thalassiosira* spp., and zooplankton. The fifth larval stage (glaucothoes) is a non-feeding highly mobile swimming stage that begins to search for suitable benthic habitat to select for settlement and metamorphosis to the first juvenile instar from July to early September (Stevens et al. 2008). Given long pelagic duration and yet apparent need to settle close to islands affording suitable refuge habitat, the mechanism employed and consequence otherwise of long distance advection are central issues in this FATE proposal.

The objectives of the FATE project are to adapt a biophysical individual-based model (IBM) to determine connectivity between larval release and benthic settlement areas for EBS BKC populations. The study will determine the likelihood of exchange via larval drift among populations of BKC in different regions of the EBS, from near the Alaska Peninsula, the Pribilof Islands and St Matthew Island. Connectivity, or the lack of it between these regions can shed light on populations structure of BKC in the Bering Sea.

<u>Approach</u>

We propose to adapt an existing IBM of larval drift that has been used for snow crab research in the EBS (Parada et al. 2010, Parada et al. In Revision) for BKC. This model has been used to demonstrate connectivity patterns for snow crab across the EBS. The IBM is forced by annually varying ROMS hydrodynamic model output (Shchepetkin and McWilliams, 2005; Haidvogel et al., 2008) for the Bering Sea. A time series (1970-2009) of ROMS model output on a ~10 km grid (NEP) will be available by the beginning of this project (July, 2013) in a 60-layer version (BSNEP-60). If the completion of that time series is delayed, another time series for a 10-layer version (BSNEP-10) is complete at this time (G. Gibson, pers. comm., K. Aydin, pers. comm.) and could be used. The 60-layer version is preferable, as higher resolution in the vertical dimension leads to more accurate renditions of the currents around the islands, however both versions (10 and 60-layer) reproduce the currents and temperatures in the EBS well (Danielson et al, 2011, Hermann et al, 2012).

<u>Model Configuration</u>: The IBM will be adapted from the Bering Sea snow crab model (Parada et al. 2010). The IBM will be run for each of the chosen years, between March and late fall. Spatial conditions for release of larvae will be explored based on BKC mature female distribution, which will allow us to generate spatially-explicit reproductive potential indices. The reproductive potential indices will be generated as a function of female fecundity, female abundance, size-at-maturity and bienniality, as available information allows. The EBS will be spatially discretized into strata – for larval release areas and for settlement areas, similar to what was done for snow crab but modified for blue king crab. Larval blue king crab will be released in March and April, around the Pribilof Islands and St Matthew Island and in other locations where blue king crab have been observed. The spatial initial condition scenarios explored for blue king crab will be integrated for all data available, and for different time periods as the data allows.

Larvae released in spring (March-April), will be followed through the 4 zoeal pelagic larval stages, to the glaucothoe stage when settlement occurs (July-early September). Individual larvae will be released at the bottom and most likely rise to the mixed layer where it is likely to be retained. Whether larval stages of blue king crab use active behaviors such as Selective Tidal Stream Transport (STST) or movement to deeper parts of the water column (below the mixed layer) to enable retention in preferred habitats is an open question. If tidally resolved output from the ROMS simulation are available, or a method becomes available to superimpose tidal cycles on daily or weekly averaged ROMS output, we will be able to examine STST in the IBM. Non-tidal, active behaviors can be compared, in any case, to examine whether they affect retention.

Temperature dependent growth through the larval stages will be modeled, as well as settlement mechanisms. In general, settlement occurs in areas of shell hash where, due to their light color, the settlers are camouflaged (Armstrong et al. 1985, Palacios et al. 1985, Armstrong et al. 1987). We will define settlement habitat based on the following information: i) Data sets on larval timing and settlement habitat for early benthic stages (Armstrong, pers. commun.), ii) fine scale side scan sonar data from the nearshore Pribilofs (Armstrong, pers. commun.) and iii) larger scale maps of sediment types available for the EBS, including Smith and Mcconnaughy (1999), and other sources of sediment data that include shells. We will investigate these sources to characterize settlement habitat which will be selected by larval crab in the IBM. BKC are believed to have a lower survival on non-preferred habitat (Stevens, 2003). In the model, we will increase the mortality rate on individuals if they settle on non-preferred habitat. A settlement criteria will also be defined where if a larva does not find appropriate settlement habitat within 1 to 2 weeks after transitioning into the glaucothoe stage, the larva will die, otherwise it will be counted as a settled survivor.

<u>Model Output and Products</u>: Output of the IBM will consist of records of larval release location, locations each day (ie. larval spatial trajectories), and various individual characteristics such as age, stage, and settlement location. The model will be run initially to test the algorithms in the model. Runs may be done for validation purposes using data on the smallest sizes of BKC encountered in the surveys (20 cm juveniles), however these data are very uncertain due to low sample size and poor trawl performance at that size. Methods for testing the relationship between species spatial distributions from models and data, as described by Hinckley et al, (In prep) will be utilized. These include an overlap index, a difference index and the Syrjala method (Syrjala, 1996).

A set of model runs will be done for a different contrasting years (such as warm/cold, PDO contrasts, before/after the crash). Connectivity between release areas and settlement areas will be studied using connectivity matrices. These matrices are composed of the probabilities of being transported to any given settlement strata from any release strata, as derived from the larval trajectories, using larval release and settlement locations. Retention, ie. the probability of staying in the release area through to settlement, is also represented in these matrices.

Connectivity maps will be useful in helping to define the potential separation of populations of BKC in the Bering Sea. Connectivity matrices can also be used with genetics studies of BKC using seascape genetics models (Galindo et al., 2006, Galindo et al. 2010, Selkoe et al., 2008) to predict the likelihood of genetic separation between settlers in different locations (not included in this proposal). These results can be compared to genetic markers on different populations which are presently being developed by D. Tallmon (UA Southeast), to identify stock structure to BKC in the EBS.

<u>Benefits</u>

The results of this study will directly inform the assessment and management of the Pribilof Islands and St. Matthew BKC stocks. Currently, stock boundaries are established based on geographical features and fishing practices without any information on stock overlap or connectivity. Information on larval drift and likely impacts of environmental conditions and habitat availability on settling locations may inform the management boundaries. This would affect the estimation of biomass, determination of removals, and subsequent definitions of stock status. An extreme yet possible outcome of the changes in boundary definitions might lead to the aggregation of the Pribilof Islands and St. Matthew stocks for overfishing determinations. This would obviously have dramatic impacts on the overfishing status of BKC in the EBS and have potentially lasting impacts on the Pribilof Islands ecosystem. Additionally, results from this research that suggest that the crab observed as bycatch in the groundfish fisheries in the southeastern portion of the eastern Bering Sea are directly connected to the Pribilof Islands BKC stock would substantially increase the amount of bycatch that currently accrues against the overfishing levels set annually.

Statement of Work

Work Activities**:** The first part of this work will consist of (1) designing a conceptual model for the BKC IBM based on a review of life history information, (2) deriving parameters for the BKC model, (3) defining spatial and temporal initial conditions (initial larval release sites and timing) for the IBM from various sources of data including AFSC surveys, and (4) adapting the snow crab IBM code for BKC. Then, (5) simulations will be performed to assess the different algorithms in the model. (6) Data will be gathered for use in comparing BKC distributions from the field and those derived from the model, where such data are available. (7) Connectivity simulations will be performed, for an appropriate suite of years. (8) Analysis of the connectivity results via connectivity matrices will be performed. We will hold frequent (at least monthly, probably more) meetings to check on three main topics: model building and testing, model validation, and assessment of final results. We will hold a face-to-face meeting in Seattle early in the project (summer or fall of 2013).

Timeline*:* Project start – 1 July, 2013

Activity	Time Period
1. Designing conceptual IBM for BKC	July-October, 2013
2. Deriving parameters for the IBM	July-October, 2013
3. Defining Initial Conditions	July-October, 2013
4. Adapting the snow crab IBM for BKC	July-October, 2013
5. Testing model algorithms	November-December, 2013
6. Model validation	January, 2014
7. Connectivity simulations	February-March, 2014
8. Connectivity analyses	April-June, 2014

Deliverables

- Analysis (with maps) of likely particle (larvae) connectivity in various regions of the EBS so that managers can consider the lines drawn to define stocks.
- Publication of results from this study in peer reviewed scientific journals.
- Analyses for direct incorporation into the Stock Assessment and Fisheries Evaluation for Pribilof Islands BKC in the eastern Bering Sea.
- Presentations may be made, at the Alaska Marine Science Symposium, the North Pacific Fishery Management Council, or the Alaska Crab coalition.

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