Mem. Fac. Fish. Hokkaido Univ. [XXXXV,1

16. A Comparison of Year-class Variability of Red King Crabs and Tanner Crabs in the Eastern Bering Sea

Albert V. TYLER[1] and Gordon H. KRUSE[2]

[1] *School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Fairbanks, Alaska, USA. 99775-7220*
[2] *Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, 1255 W. 8th Street, Juneau, Alaska, USA. 99802-5526*

Abstract

Populations of red king and of Tanner crabs reside in the Bristol Bay area of the Eastern Bering Sea. Both stocks are at low levels of standing biomass and have had low rates year-class strength formation, though there is an indication that numbers of pre-recruits of red king crab are increasing. Recruitment time-series for the two stocks are not correlated. Process-related hypotheses are reviewed that explore likely sources of interannual variation in year-class strengths. The monotonic decline year-class strength of red king crabs through the late 1980s is significantly correlated with barometric pressure averaged over the area of the Aleutian Low pressure region. However many variables may be correlated with this simple trend and so statistical evidence could not be developed for specific process mechanisms. On the other hand, year-class strength of Tanner crabs is not correlated with barometric pressure, but with wind intensity from the NE and SW quadrants during May - June. The wind changes, while ultimately caused by shifts of both intensity and position of the Aleutian Low, are likely to have differential implications for larval survival for the two species. We discuss how differences in rates of year-class strength formation between the two species likely are generated by the differing geographic positions of the reproductive and early life history stages in relation to wind driven currents and mixing.

Introduction

Both red king crab (*Paralithodes camtschaticus*) and Tanner crab (*Chionoecetes bairdi*) stocks are currently depressed in the Bristol Bay area. Occasional periods of high productivity are the source of the biomass upon which the fishery of each species is based. Recently both stocks have had low rates year-class strength formation, though there is an indication that numbers of pre-recruits of red king crab are increasing (Zheng, Kruse and Murphy 1997). Factors contributing to this production are unknown. Our research goal is to understand the causes of bursts of increased, fishery-sustaining production. The primary objective is to develop a statistical model of relationships between physical and biological factors affecting population levels of red king crabs and Tanner crabs in the eastern Bering Sea. Step-by-step evaluations of possible effects of oceanographic variables on each stage of the species life history have lead to formation of hypotheses that can be expressed as mathematical functions that serve as the basis for a conceptual simulation model. At the present time we are carrying out statistical testing of physical oceanographic variables relating to our conceptual models of Tanner crabs. Later a multivariate modeling approach will provide the means to investigate these relationships further. This paper reviews progress to date, including several publications as well as new findings.

For both Tanner crabs and red king crabs in Bristol Bay seven years (give or take a year) separate hatching and recruitment. Knowledge about key factors that control year-class strength will yield information vital to fishery management. During long periods of poor recruitment, harvest rates should be lowered so that spawning stocks are not reduced to levels so low that the stock cannot recover. During periods of strong recruitment, increased harvests may be taken. It is critical to distinguish between the effects of the fishery and the environment on recruitment. Results from this project will be directly incorporated into analyses of alternative management strategies by state and federal agencies

Length-based models of year-class strength

Zheng et al. (1995) developed a length-based model for red king crabs of Bristol Bay that estimated the abundance of the crabs as they entered the surveyed population. The model used length and abundance data from the U. S. National Marine Fisheries Service research surveys. The authors were able to back calculate the abundances of females < 90 mm and males < 95 mm, and assign the estimated number of crabs in a brood to a particular year of fertilization, thus giving a time series of the formation of year-class strengths.

Zheng et al. (in press) developed a similar length-based model to the Tanner crabs of the Bristol Bay region. Changes in Tanner crab year-class strengths were not correlated to those of the red king crab (Zheng and Kruse 1997). Tanner crab year-class strengths decreased during the late 1960s and early 1970s, while king crab were remained high, then Tanner crab year classes increased in size following 1977, and decreased again during the mid 1980s. The Tanner stock decidedly has two periods of good year-class strength separated by a period of poor recruitment 1973 to 1978. Red king crab year-class strengths were high in the late 1960s and early 1970s, then decreased steadily through the late 1980s. There is an indication that numbers of pre-recruits of red king crab have increased during the early 1990s (Zheng, Kruse and Murphy 1997). For either species the two periods before and after 1976 or 1977 were different from each other in year-class strength trends.

From two regional workshops we developed a stage by stage table of life history events with ecological processes pertaining to survival rates for both species (Tyler and Kruse 1995, 1997). The information included the location and timing of life stages, along with the coincident physical oceanographic and biological factors that could influence the productivity and survival rate of the stages. The procedure has been termed the events-time process. Hypotheses in common to both species emerged relating survival to physical factors: a critical number of degree-days is necessary to bring on ovary maturation; after fertilization cool temperatures will delay hatching; high temperatures will increase embryo mortality; a high percentage of successful hatch is linked to an optimum temperature; timing of hatching depends on a water quality cue that is related to the abundance of a particular diatom; for the larval stages, water-mass mixing or else Ekman transport increases nutrients used in primary production and consequent larval growth and survival. Other hypotheses were related to predation and biological factors. These ecological relationships were redesigned as mathematical functions and set into the structure and logical flow of the conceptual aspects of a simulation model (Tyler and Kruse 1996). The conceptual model showed the simultaneous influence of particular factors on several life stage processes. Inferences are drawn for decadal period dynamics, implications for fishery management, and needs for at-sea research to clarify understanding.

Red king crabs and broad-scale ocean-atmosphere shifts

What were the broad-scale changes in the ocean that occurred during the decade of the 1970s? There is evidence that major changes in ocean weather occurred over the North Pacific during the mid-1970s. Trenberth and Hurrell (1994) and others have shown that strong barometric pressure changes occurred in 1976, and that this change continued through the decade. It was significantly, statistically correlated ($r = 0.596$, d.f. = 18) with the changes in the year-class strengths of the red king crabs (Tyler and Kruse, 1996). It is not clear at this point how the change in pressure translated into mechanisms that might have influenced the recruitment patterns of Tanner and red king crab in the Bristol Bay area. This barometric change would have brought about many other changes in ocean physics that could have acted on survival. Several species of fish also displayed changes in their recruitment and biomass estimates. Some of the biomasses increased while others decreased (Bakkala 1993). By no means were the late 1970s and early 1980s a period of generally low productivity (Beamish and Bouillon 1993).

Statistical hypothesis testing of Tanner crab data in relation to physical factors

The complex time-series of year-class strength of this species made it conducive to statistical hypothesis testing. Average May-June winds measured at St. Paul Island were expressed as vector-components for the period 1969 to 1987. May and June were chosen because these are the months during which the zoea of Tanner crabs are in the water column. There was a significant correlation ($r = 0.58$, d.f. = 17) between wind intensity and *C. bairdi* year-class strength for winds from the northeast (NE) and southwest (SW) quadrants (Rosenkranz et al. Unpublished MS). Winds from these quadrants were taken together as associated positive and negative anomalies from the opposite directions. There was no statistically significant relationship for cross winds from the NW and SE quadrants. Northeast winds likely affect the net movement of Bering Sea surface water and may prevent zoea from being advected to the northeast to the inner reaches of Bristol Bay, where habitat is rocky and apparently less suitable. Tanner crabs are found on the offshore mud sediments rather then the nearshore rocky bottom. Alternately winds from the NE flowing parallel to the Alaska Peninsula could bring about offshore Ekman transport along the north side of the Peninsula. As a hypothesis, this upwelling might cause increased primary and secondary production, and hence increased survival of zoea due to production of food. Because wind direction was critical to the significance of the correlation, we suggest that simple mixing by wind does not enhance survival but instead the factors involve either or both Ekman transport and alongshore advection (Rosenkranz et al. Unpublished MS).

Inter-species comparisons of processes affecting year-class strength

Because of the strong differences between the year-class strength time-series of the red king crabs and the Tanner crabs of the Bristol Bay area, it is anticipated that there would be some differences in the life history stages and the biophysical mechanisms that influence productivity and mortality rates for the two species. The two workshops on year-class strength of red king crabs and Tanner crabs, (Tyler and Kruse 1995, 1997), facilitate a comparison of the processes that influence the formation of year-class strength of these species, including a matching of hypotheses by stage, place and process for the two stocks in the eastern Bering Sea.

The stages of mating and hatching of the two species for the developed embryos show contrasts. Tanner crabs form mounds in deep water (150 m) in spring. It is during this time that the embryos hatch, and that younger females undergo their maturity molt and mate. There is evidence that some mature female Tanner crabs may molt again after their maturity molt. Red king crabs likely have a greater sensitivity to the sex ratio for the survival of molting females and also the fertilization of eggs. Female red king crabs must mate in the year that it carries fertilized eggs, whereas Tanner crab females can carry sperm from a single mating for several years, and use the sperm to fertilize eggs for more than one year. These processes of mating and hatching in the Tanner crab are carried out on mud sediments, further offshore than are the same processes for red king crabs. It is probable that bottom temperatures associated with the Bering Sea"cold pool" effect the egg and embryo development of Tanner crabs more than they effect those same processes of the red king crab. The cold pool is thought to be generated by the formation of sea ice, and so the interannual extent of sea ice might appear to effect Tanner crabs more than red king crabs.

The bulk of the Tanner crab larvae start in deeper, perhaps cooler water than do the king crab larvae. It is likely that the location is farther from shore than the same stages for red king crabs. Ekman upwelling might occur off the north shore of the Alaskan Peninsula (Rosenkranz *et al.* Unpublished MS), leading to the possibility that diatom production in the neighborhood of Tanner crab zoea is more likely to be influenced by the upwelled water than the production of diatoms occurring with larvae of red king crab. The cold, nutrient rich, upwelled water may not reach into the shallower, rocky habit preferred by the zoea and glaucothoe of the red king crab. Diatoms are consumed by the early-stage zoea and the copepod prey of the later-stage zoea.

Differences in habitat used for settling could also provide clues to the uncorrelated survival of the two species. Both species are likely to be influenced by alongshore advection, but the influence of this current on red king crab settlement of glaucothoe is likely to be a key factor for them. If alongshore currents are too strong the glaucothoe might be carried away from their obligatory, limited habitat. Red king crabs settle on rocky bottom-type with high-profile, sessile fauna. This habitat is critical for survival, consequently an increase in the strength of currents moving larvae away from this bottom type would likely increase mortality. Tanner crab megalopae settle on the more ubiquitous mud sediments offshore.

Both species possibly have density-dependent processes associated with larval and early post-larval stages. These stages of both species become cannibalistic as they age. Generally, cannibalism is known as a density-dependent predation process. For the red king crab the post-glaucothoe stages are particularly cannibalistic with survival being density dependent (Murphy and Blau 1997). The possible crowding on limited habitat will likely impart more density dependence in the dynamics of this stock than for Tanner crabs.

While both are cold water species, it seems possible to speculate that the juveniles of king crab live at slightly more elevated temperatures than do juveniles of Tanner crabs. If the two species have the same temperature preferences and tolerances, then an increase in ambient temperature may be more stressful to juvenile king crabs because any temperature increase may be more pronounced in the shallower regions.

Discussion

Future modeling will likely progress more rapidly for Tanner crabs than red king crabs because of the more complex time series of year-class strengths. Many variables will correlate with the monotonically decreasing recruitment series of the red king crab, presenting an opening for easy, spurious correlations. The complexities of the Tanner crab time series make it more difficult for spurious correlations to occur.

Biologists at the workshops emphasized contrasts between the species reproductive biology and larval life history as possible sources of the differing time trends in year-class strength. At this point in time, other differences between species among the older juveniles and adults cannot easily be tied to hypotheses that are likely to cause differences in year-class strength. Research is needed at sea and in the lab to investigate the more promising hypothetical relationships.

References

Bakkala, R.G. (1993). Structure and historical changes in the groundfish complex of the eastern Bering Sea. *NOAA Technical Report NMFS*, **114**, 1-91.

Beamish, R.J. and Bouillon, D.R. (1993). Pacific salmon production trends in relation to climate. *Can. J. Fish. Aquatic Sci.*, **50**, 1002-1016.

Murphy, M.C. and Blau, S.F. (1997). Postlarval red king crab density dependence in artificial collectors, Kodiak, Alaska, In, *High Latitude Crabs: Biology, Management and Economics.* Alaska Sea Grant College Program, Report No. 96-02, University of Alaska Fairbanks. pp. 545 - 547.

Rosenkranz, G.E., Tyler, A.V., Niebauer, H.J. and Kruse, G.H. (1997). Unpublished manuscript. Relationships between winds, sea surface temperature, and year-class strength of Tanner crabs in the southwestern Bering Sea. Presented at the November (1997) ; Annual Meeting, Alaska Chapter, American Fisheries Society.

Trenberth, K.E. and Hurrell, J.W. (1994). Decadal atmosphere-ocean variations in the Pacific. *Climate Dynamics* **9**, 303-319.

Tyler, A.V. and Kruse, G.H. (1995). A report on the modeling workshop on year-class strength formation of red king crab. *Alaska Department of Fish and Game, Regional Information Report* No. 5J95-11.

Tyler, A.V. and Kruse, G.H. (1996). Conceptual modeling of brood strength of red king crab in the Bristol Bay region of the Bering Sea. In, *High Latitude Crabs: Biology, Management and Economics.* Alaska Sea Grant College Program, Report No. 96-02, University of Alaska Fairbanks. pp. 511 - 543.

Tyler, A.V. and Kruse, G.H. (1997). Modeling workshop on year-class strength of Tanner crabs, *Chionoecetes bairdi. Regional Information Report* No. 5J97ñ02. Alaska Department of Fish and Game, Juneau. 46 pp.

Zheng, J., and Kruse, G.H. Unpublished MS. Recruitment patterns of Alaskan crabs and relationships to decadal shifts in climate and physical oceanography. *ICES Journal of Marine Science,* in review.

Zheng, J., Murphy, M.C. and Kruse, G.H. (1995). A length-based population model and stock-recruit relationship for red king crab, Paralithodes camtschaticus, in Bristol Bay, Alaska. *Can. J. of Fish Aquat. Sci.* **52**, 1229 - 1246.

Zheng, J., Kruse, G.H. and Murphy, M.C. (1997). Status of king crab stocks in the eastern Bering Sea in 1997. Alaska Department of Fish and Game, *Regional Information Report* 5J97-13, Juneau. 20 pp.

Zheng, J., Kruse, G.H. and Murphy, M.C. A length-based approach to estimate population abundance of Tanner crabs, *Chionoecetes bairdi*, in Bristol Bay Alaska. In G.S. Jamieson and A. Campbell, (eds.) *Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management, Can. Spec. Publ of Fish and Aqua. Sci.,* **125**.(In press)