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Reconstruction of historical abundance and recruitment of red king crab during 1960–2004 around Kodiak, Alaska

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ABSTRACT

Gulf of Alaska waters around Kodiak Island once supported the world's largest fishery for red king crab, *Paralithodes camtschaticus*. Fishery harvests occurred at low levels beginning in the 1930s, but increased rapidly in the 1960s to a peak harvest of 42,800 mt in 1965. However, stock abundance declined dramatically in the late 1960s, and again in the early 1980s. The history of the fishery included a variety of management measures, such as time and area closures and changes to minimum size limits. Despite these efforts, the stock was ultimately recognized as depleted, and a commercial fishery closure since 1983 has not resulted in a stock recovery. We developed a quantitative retrospective analysis to understand the conditions surrounding the rise, collapse, and continued depleted status of the red king crab stock around Kodiak Island, Alaska. Our approach used a population dynamics model to estimate abundance, recruitment, and fishing and natural mortality over time. The model included three male and four female "stages" and incorporated catch composition data from the fishery (1960–1982), a pot survey (1972–1986), and a trawl survey (1986–2004). Male abundance is estimated for 1960 to 2004, but the available data limit analysis of females to the years 1972 to 2004. During a critical time of fishery development in the late 1960s, a chance period of strong recruitment helped promote the capitalization of this fishery. Very high harvest rates in the late 1960s were not sustainable, likely due to reproductive failure associated with sex ratios skewed toward females following a recruit-driven fishing period in the 1970s. Environmental and ecological changes, associated with a climate regime shift, likely exacerbated these problems.

1. Introduction

Waters around Kodiak Island in the northern Gulf of Alaska (Fig. 1) once supported the world's largest fishery for red king crab, *Paralithodes camtschaticus*. A U.S. domestic fishery developed slowly during 1930s–1950s, as operators of purse seine vessels sought to supplement their summer salmon harvests by exploring crab fishing in the Kodiak area during winter (Gray et al., 1965; Spalinger, 1992). The lack of live tanks and small vessel size (i.e., <18 m overall length) limited the fishery to nearshore areas adjacent to seaports with processing facilities. Annual landings increased rapidly in the 1960s to a peak harvest of 42,800 mt in 1965, dropped sharply over the next few years, and then ranged from 4900 to 10,900 mt before another sharp decline in the early 1980s resulted in a fishery closure in 1983 (Fig. 2; Spalinger and Jackson, 1994). A variety of management actions, such as time and area closures and changes in minimum size limits, failed to stop the decline of this male-only fishery (Gray et al., 1965; Spalinger, 1992). Moreover, closure of the commercial fishery since 1983 has not resulted in recovery of this severely depleted stock.

We conducted a retrospective analysis to better understand the conditions surrounding the rise, collapse, and continued depressed status of the red king crab stock around Kodiak Island. Our analysis estimates king crab spawning stock abundance and recruitment during 1960–2004 by using a stock-synthesis approach to combine a variety of relative abundance and catch data (Methot, 1990). Previously, Collie and Kruse (1998) developed a two-stage (i.e., recruit, post-recruit) catch-survey analysis model (CSA) for male red king crab in both Kodiak and Bristol Bay, and Collie et al. (2005) developed a three-stage (i.e., pre-recruit, recruit, post-recruit) CSA for male blue king crab, *Paralithodes platypus,* in the eastern Bering Sea. Stage-based analyses are particularly useful when age determination is problematic, but a "recruit" stage can be identified. The CSA uses survey and commercial catch data to generate estimates of survey catchability coefficients, measurement errors, and absolute abundance. We extended these efforts by developing a CSA that uses three stages of male crab and four stages of female crab to estimate abundances for the Kodiak red king crab stock during 1972–2004. In addition, a time series of abundance estimates based on a catch-length analysis (CLA) of male

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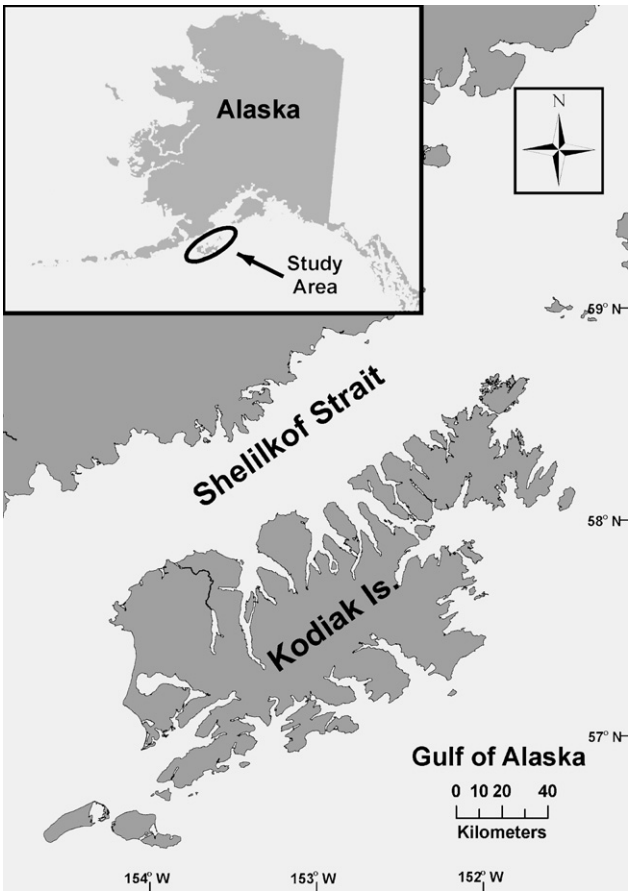

Fig. 1. Study area around Kodiak Island, Alaska.

red king crab (Zheng et al., 1996) over 1964–1982 was extended back to 1960 using dockside sample data (Blau, 1988). The CLA is a length-based analogue to the age-based virtual population (cohort) analysis (Gulland, 1965). Our stock-synthesis reconstruction of the Kodiak red king crab stock merged these CSA and CLA analyses by incorporating commercial catch records from the Alaska Department of Fish and Game (ADF&G) fish tickets, dockside samples of landed crab, and relative abundance data from annual pot (i.e., trap) and trawl assessment surveys. Zheng et al. (1998) incorporated pot and trawl surveys, subsistence harvests, and summer and winter commercial fisheries data into a similar length-based synthesis model for red king crab in Norton Sound, Alaska.

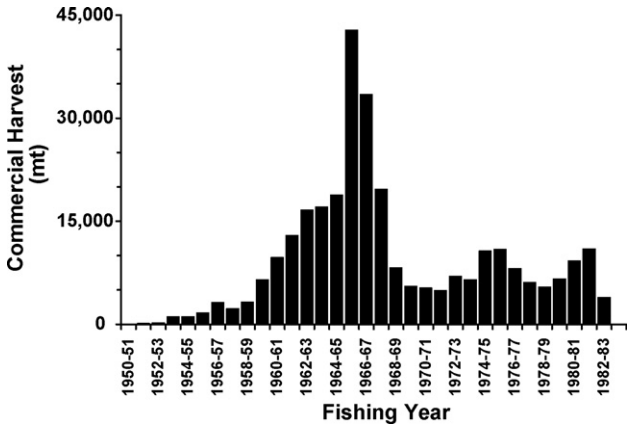

Fig. 2. Annual harvests (mt) of red king crab from the Kodiak Management Area during 1950–1982.

Our population estimation models were developed in consideration of some general features of red king crab life history around Kodiak Island (Tyler and Kruse, 1995; NPFMC, 1998; Zaklan, 2002; Donaldson and Byersdorfer, 2005). The annual reproductive cycle is closely linked to the female molt. Adult females molt annually, regardless of size, from March through April. After molting, females extrude 40,000–500,000 ova which are fertilized by sperm transferred from a grasping male partner (Otto et al., 1990). The male molting period lasts several months starting in December, but males begin to "skip molt" (i.e., do not molt annually) with increasing frequency upon reaching approximately 125 mm carapace length (CL). Male crab can copulate with multiple females during the mating season, but laboratory studies found reduced fertilization success associated with smaller males and with secondary or later matings by a given male (Paul and Paul, 1990, 1997). In the wild, mating success with multiple females may be further constrained by factors such as the availability of mates, synchrony of female molting, and the relatively short duration of the mating season. Embryos are incubated on the underside of the female's abdomen for approximately 300 d, then hatch during March through May, after which the annual female reproductive cycle is repeated. The pelagic larvae inhabit the water column at depths <100 m until settling into a benthic existence between May and July in Kodiak; preferred habitat is nearshore (<50 m depth), rocky substrate with attached high-profile sessile fauna (Powell and Nickerson, 1965; Armstrong et al., 1993; Loher, 2001).

Juvenile crab molt through a series of instars in which the growth increment for both sexes is a linear function of pre-molt length up to approximately 60 mm CL (McCaughran and Powell, 1977). Molt frequency declines with increased carapace size, from 7 to 8 molts the first year after settlement to 1–2 molts in the fourth year. Greater molt frequency and larger size at age may occur in years of warmer water temperatures (Stevens, 1990; Stevens and Monk, 1990). Females grow more slowly than males, particularly after achieving 70 mm pre-molt CL (McCaughran and Powell, 1977). As red king crab age and grow, their distribution extends to progressively deeper depths (Armstrong et al., 1993; Stone et al., 1993). After achieving sexual maturity, adult crab migrate annually to shallower water for mating. In the Kodiak area, male size at physiological maturity (75–85 mm CL) is smaller than size at functional maturity (>125 mm CL, i.e., size at which males have been observed in mating pairs). Mean age for male functional maturity is 7–8 years. Maximum red king crab age exceeds 20 years (Matsuura and Takeshita, 1990), and maximum reported male size is 227 mm CL and 11 kg (Powell and Nickerson, 1965).

2. Methods

2.1. Data

2.1.1. Fishery data

Fishery harvest data for 1960–1968 were primarily obtained from ADF&G published reports (e.g., Gray et al., 1965; Spalinger and Jackson, 1994; Cavin et al., 2005). Harvest data for 1969 through 1982 were obtained from the ADF&G TIX database (G. Smith and M. Plotnick, ADF&G, Juneau, pers. comm.). Although the Kodiak commercial fishery has been closed since 1983, limited king crab harvests have continued under subsistence fishing regulations. Commercial harvest data were pooled in accordance with State of Alaska guidelines to protect the confidentiality of individual landing records. Subsistence data are available for 1988 to present from