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Reduced size composition and fecundity related to fishery and invasion history in the introduced red king crab (*Paralithodes camtschaticus*) in Norwegian waters

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ABSTRACT

The introduced red king crab (*Paralithodes camtschaticus*) in the Barents Sea is abundant in the coastal waters of eastern Finnmark and supports a valuable fishery. In this paper we look at the development in size span among ovigerous females in the period between 1995 and 2010. We identify variations in individual fecundity in three fjords in Finnmark from 2000 to 2007. All the analyses were performed using regression and general linear models. We found that the size range decreased during this period. A decline in individual fecundity was observed. Individual egg weight (IEW) varied among fjords and years, and displayed a tendency to decline during the period of investigation, but the IEW was not affected by crab size. Increased fishing pressure on large males may have caused both a decline in size range of ovigerous females as well as a decline in fecundity. Reduced IEW however is likely to be due to limited available food. We attempted to compare individual fecundity in the invasive crab with fecundity results from populations in native areas. This comparison was inconclusive, due to differences in sampling season, size range and the methods employed.

1. Introduction

The red king crab (*Paralithodes camtschaticus*), which was deliberately introduced to the Barents Sea by Russian scientists in the 1960s, has increased in abundance over the past 40 years, and the population is now regarded as self-sustaining (Kuzmin et al., 1996). Its success may be generally due to high ecosystem productivity in the new region and to its escape from co-evolving predators or parasites in its native areas. Life history traits such as size at maturity, number and size of offspring, and reproductive lifespan affect the population growth rate of invasive species (Tibbets et al., 2010). During the initial period of establishment of the population, fishing pressure was low, due to strict regulations. A male-only fishery for the crab has been carried out in Norwegian waters since 1994, and this species is now a valuable fishery resource (Falk-Petersen et al., 2011). Until recently a "3S" (sex, size and season) (Otto, 1986; Kruse, 1993) regime was applied as a management tool; only males with a carapace length (CL) greater than 137 mm could be legally harvested during the autumn fishing season. All females and undersized males were to be returned to the water (Otto, 1986; Dew, 2008). In 2008, the Norwegian authorities (Ministry of Fisheries and Coastal Affairs) permitted catch of females larger than 137 mm CL.

The reproductive strategies of a species play a major role in population dynamics (Ramirez-Llodra, 2002). Fecundity is defined as the number of eggs produced by a female, and is directly related to life-history traits such as size and age at maturity, life-span and egg size (Stearns, 1992; Ramirez-Llodra, 2002). In the red king crab population in Norwegian waters, female size at maturity, that is the size at which 50% of the females carry eggs, is 109–111 mm CL, depending on sampling area, and this is larger than in other populations in their native areas (Hjelset et al., 2009). The red king crab reproduces annually and incubates the eggs for 10–12 months (Stevens and Swiney, 2007a). In crustaceans, egg size is directly related to the maternal investment in reproduction, and is the result of a trade-off between the size of the egg and the number of eggs produced (Ramirez-Llodra, 2002). The quality and quantity of food available to a female crab may also influence the size of her eggs (Sastry, 1983; Ramirez-Llodra, 2002). The many variables required to adequately describe the fecundity of a species or population can make comparisons across stocks somewhat complex (Sastry, 1983).

The fecundity of a population may decline because of reduced abundance of spawners but may also be due to a skewed sex ratio (Murua et al., 2003). The fishery for many valuable crustaceans alters the population demographic structure, because only large males are harvested (Wahle, 2003). The reproductive success of the red king crab depends on males and females being on the mat-

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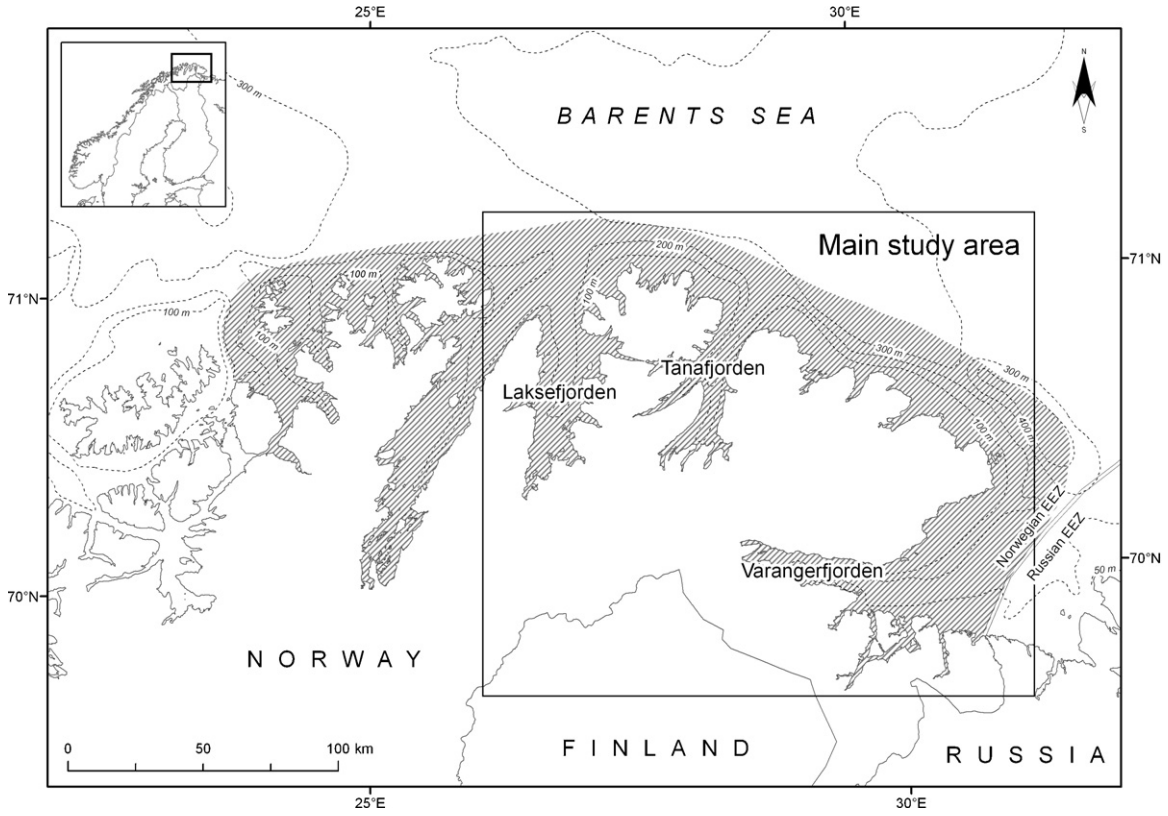

Fig. 1. Map of our study area in county of Finnmark, situated in northern Norway, shaded area represent current distribution of red king crab (*Paralithodes camtschaticus*) in Norwegian waters.

ing grounds at the same time (Wallace et al., 1949; Powell et al., 1974). Male size is an important factor in mating efficiency, due to the handling and guarding behaviour exhibited by male crabs during mating (Paul and Paul, 1997). Large females, which produce the highest number of eggs, are most successfully fertilised by large males (Schmidt and Pengilly, 1990; Kruse, 1993). Females mating with small males with less sperm capacity have lower fertilisation success than females that mate with larger males (Paul and Paul, 1990a,b, 1997; Sato and Goshima, 2006). Other studies report that large females are sometimes observed without broods or with reduced brood sizes (Powell et al., 1973), which may be due to unsuccessful mating with smaller males. Adult males that moult before a mating season do not participate in that mating season (Rodin, 1990). This may further reduce the number of large males present on spawning grounds (Dew and McConnaughey, 2005).

Since the male-only harvest may skew the sex ratio in the population and thereby reduce the reproductive potential of females (McMullen, 1969), it is important to monitor fecundity at population level. Stock–recruitment relationships are poorly understood for most commercially important crab and lobster species (Wahle, 2003), but it is well known that egg production plays a critical role in crustacean population dynamics and recruitment (Botsford, 1991). A general shortcoming of previous studies is that long-term data on fecundity are scarce. Information regarding how fecundity in an introduced species evolves after settling and spreading in a new geographic area has not been previously presented.

In this study we investigated individual fecundity in red king crab in three large Norwegian fjords during an eight-year period, beginning 34 years after the species was first recorded in the region (Orlov and Ivanov, 1978). We studied spatial and temporal variations in the size structure of ovigerous females, and individual fecundity, including egg size, in the Norwegian red king crab stock, and compared our findings on fecundity with studies performed in the species' native areas.

2. Materials and methods

2.1. Data collection and sampling area

A total of 12,117 ovigerous female king crabs with carapace lengths (CL) ranging from 74 mm to 192 mm were caught in the course of autumn scientific cruises in northern Norway between 1995 and 2010. The crabs were collected using baited traps and a beam trawl, at depths that ranged from 25 to 400 m. Egg samples from 905 female crabs were collected from three large inlet fjords; Varangerfjorden (first invaded), Tanafjorden and Laksefjorden (last invaded), from 2000 until 2007. During the sampling period, the distribution area of the species has increased as the crab has spread westward along the coast of Finnmark in northern Norway (Fig. 1).

The CL of all the females caught was measured to the nearest 1.0 mm. Clutches were collected from between one and ten individuals in each 10 mm size group in order to ensure a representative selection from the available range of sizes (93–186 mm CL) in each year and fjord. Sampling was restricted to females with full clutches, and we avoided sampling females with lost or reduced legs, or showing signs of stress or egg loss. All samples were collected from females that had spawned during the previous reproductive season, since the red king crab reproductive cycle (hatching, moulting, extrusion and fertilization) is synchronous and lasts for about 12 months (Marukawa, 1933; Stevens and Swiney, 2007a). No estimates of clutch fullness were made, as we assumed that the crabs would not suffered any significant reduction in egg masses due to factors related to the mating event. In order to