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Effects of changes in female size on relative egg production of northern shrimp stocks (*Pandalus borealis*)

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ABSTRACT

Length is one of the main factors determining fecundity of shrimp. Therefore, changes in length distribution where larger individuals disappear from the stock may affect the relative egg production (REP) of the stock. The main objective of this study was to use fecundity of shrimp to estimate changes in REP of four inshore shrimp stocks in the period between 1990 and 2016, and estimate how changes in length at sex change (L_{50}) and maximum size (L_{max}) impact the REP of the stocks. The results show that the REP of the shrimp stocks reduced considerably with lowering of L_{50} and L_{max}. However, the relationship between REP and recruitment was in general poor.

1. Introduction

The evaluation of the reproductive and recruitment potential has become increasingly important in studies of population dynamics (Hutchings, 2005). Year class strength in marine populations is highly variable and is thought to be determined during the first year of life. However, the population dynamics during the first years are often poorly known. Recruitment is driven by the biological and physical variability of the environment whereas key factors and processes influencing reproduction and recruitment success have been difficult to identify (Chambers and Trippel, 1997; Cushing, 1996).

Knowledge of fecundity is essential for estimating the relative egg production of a population, but fecundity is directly related to energy allocation and trade-offs between fecundity and other life history traits, such as female size and age at maturation (Wootton, 1998). Fecundity is quantified by the number of eggs produced per female and is considered a good indication of the reproductive potential and future stock of crustacean populations (Bilgin and Samsun, 2006; Mori et al., 1998; Nazari et al., 2003). Fecundity is highly variable between species (Corey and Reid, 1991; Kapiris and Thessalou-Legaki, 2006) but also within species, where it may vary between seasons, years, and areas (Hannah et al., 1995; Parsons and Tucker, 1986).

Pandalid shrimps are generally protandrous hermaphrodites, which reproduce first as males, go through a transition phase and transform to females and spawn as such for the rest of their life (Bergström, 2000; Shumway et al., 1985). Northern shrimp (*Pandalus borealis* hereafter referred to as shrimp) spawn in late summer to early fall and the females carry the eggs until they hatch in early spring (Shumway et al., 1985). Shrimp fecundity was studied in various ecosystems in the North Atlantic in the 1950s to 1980s (Allen, 1959; Berenboim and Sheveleva, 1989; Haynes and Wigley, 1969; Horsted and Smidt, 1956; Parsons and Tucker, 1986; Rasmussen, 1953; Shumway et al., 1985; Skúladóttir et al., 1978) but has not been the focus of many studies in the past 30 years (Brillon et al., 2005). Like for many other marine species, fecundity of shrimp increases with increasing length (Parsons and Tucker, 1986; Shumway et al., 1985).

In the 1980s and 1990s, shrimp was one of the most important commercial species in Icelandic waters. Since 2000 the shrimp stocks have declined (Jónsdóttir et al., 2017) and three out of six fjords have been closed for shrimp fishing (Anonymous, 2015). A recent study showed declines in length at sex change (L_{50}) and maximum length (L_{max}) in fjords north-west and north of Iceland following reduced stock sizes and higher bottom temperature (Jónsdóttir et al., 2018). Length is the main factor determining fecundity (Parsons and Tucker, 1986; Shumway et al., 1985) and therefore variations in L_{50} and L_{max} can generate changes in the reproductive potential. Spawning stocks may have a lower reproductive potential in areas where large females are missing. The main objective of this study was to estimate changes in egg production of four inshore shrimp stocks in the time period between 1990 and 2016, and estimate how observed changes in length (with decreasing L_{50} and L_{max}) impact the relative egg production of the stocks.

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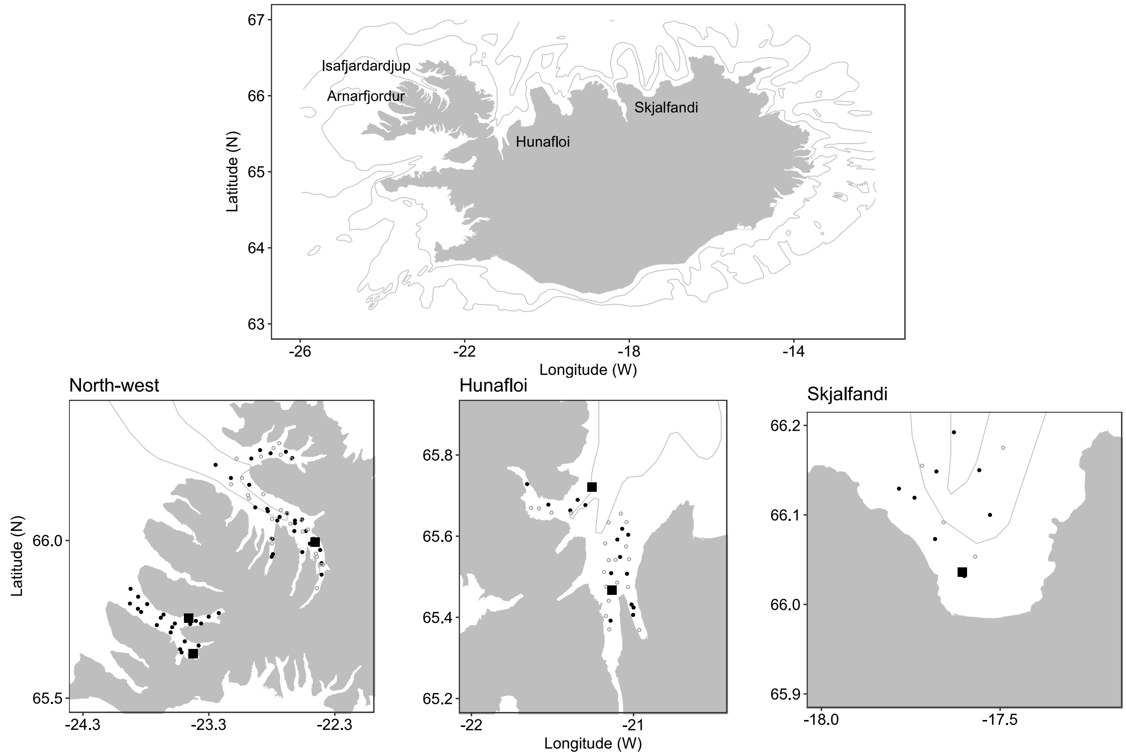

Fig. 1. Sampling locations in four inshore fjords in the annual shrimp survey in Iceland. Black filled symbols indicate stations sampled throughout the whole study period and gray open symbols indicate stations sampled until 2004. Squares indicate sampling of egg bearing females in September and October 2015. Depth contours at 100 and 200 m.

2. Material and methods

2.1. Sampling

Data were collected during the annual shrimp survey in four fjords in north-west (Arnarfjordur and Isafjardardjup) and north Iceland (Hunafloi and Skjalfandi) (Fig. 1). The purpose of the surveys was to provide an index of shrimp stock biomass to inform fishery management. The standardized surveys have been run every year since 1988, except for north of Iceland in 2004 and Skjalfandi in 2006. During September and October, the survey utilizes a standard shrimp bottom trawl of 1010 meshes in standard tows of 2 nautical miles, during daylight hours only, at a tow speed of 2.0 to 2.2 knots. The cod end has an open mesh size of 37 mm (42 mm whole mesh size). The distance between the wing ends is 14.7 m, and the mean ($\pm$ SD) vertical opening is 4.6 ± 0.3 m. The survey included 22, 54, 38 and 12 fixed stations in Arnarfjordur, Isafjardardjup, Hunafloi and Skjalfandi, respectively. From 2006, the sampling stations were reduced to 26 and 17 stations in Isafjardardjup and Hunafloi, respectively.

2.2. Shrimp length

At each station, the total shrimp catch was weighed, a subsample of approximately 250 individuals measured, and the subsample weight recorded. The carapace length was measured from the posterior edge of an eye socket to the distal edge of the carapace using sliding calipers and the individuals grouped in 0.5 mm carapace length intervals. Sex and maturity of all individuals was determined as described in Rasmussen (1953) and McCrary (1971). The sexual stages determined were later grouped into three categories: (i) males, (ii) transitionals and primiparous females, and (iii) multiparous females.

Length frequency distributions (LFDs) were analyzed within each fjord and year. Modal analysis of the LFDs was conducted using the Macdonald and Pitcher (1979) method, as implemented in the *mixdist* package in R (Macdonald and Du, 2012). Estimation of the total number of individuals in each of the three categories involved the following steps. The LFD of each category was converted to weight using two carapace length (mm)–weight (g) relationships, one for males, transitionals and primiparous females, $W = 0.00093^{*}CL^{2.875}$, and another for multiparous females, $W = 0.00089^{*}CL^{2.959}$ (unpublished data Marine and Freshwater Research Institute, Iceland). The number sampled in the three categories was then scaled to represent the catch per nautical mile in each tow. The scaled LFDs were then pooled within each fjord to estimate the average LFD within each fjord.

2.3. Indices

The shrimp biomass index was calculated using the sum of the mean biomass estimates per square kilometer, which was calculated for each area using the swept-area method described by Sparre and Venema (1989). The shrimp female biomass index was calculated by combining the weight of immature and mature females. The shrimp female biomass index is equivalent to the spawning stock biomass index. For the recruitment analysis, the mode of the LFD of two year old shrimp was used to estimate the index of the recruiting year class.

2.4. L_{50} and L_{max}

The length at which 50% of the shrimp were females was considered to be the length at sex change (L_{50}). A generalized linear model (GLM) with a logit link function was used to estimate L_{50} for each fjord and year. Model fitting was carried out using the *glm* function in R (RCoreTeam, 2014) with the logit link function to the equation:

$$p = \frac{1}{1 + e^{-k(CL - L_{50})}}$$