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Optimizing release strategies for red king crab stock enhancement: Effects of release timing

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Highlights

- We performed a field experiment examining stock enhancement in red king crab.
- Crab were released at three different times/sizes and tracked post release.
- Crab survived best when released later and at a larger size.
- However, account for holding mortality, earlier release times are more effective.

Abstract

Red king crab, Paralithodes *camtschaticus*, was commercially important around Kodiak, Alaska, USA, in the 1960s and 1970s; however, the stock crashed in the late 1970 s and has remained closed since 1983. The lack of recovery inspired consideration of stock enhancement through the release of hatchery-reared juveniles as a means to bolster the wild population. We examined the effects of release timing on *in situ* survival of hatchery-reared red king crab by releasing juveniles in June, August, and September 2015 in Trident Basin, Kodiak. We monitored densities inside and outside of release plots for six months using quadrat counts to determine loss and emigration rates. Relative predation risk was determined using tethering experiments performed after each release, and predator densities were quantified using quadrat counts and predator transect counts. Initial mortality over the first 24 h was approximately 53%, and subsequent mortality rates decreased with month-of-release, likely due to a combination of larger size-at-release and seasonal changes in predation. Although predator density was consistent over time, relative predation risk of tethered crabs decreased with season, suggesting later releases may be beneficial. However, the extended hatchery rearing period needed for later releases presents other challenges, including cannibalism, and the potential for developing maladaptive traits. Stock enhancement programs must balance these trade-offs to maximize overall success. Early releases of small juveniles immediately after settlement may be optimal if large-scale hatchery communal rearing results in significant juvenile production loss and/or hatchery conditioning is impractical.

Introduction

Red king crab, *Paralithodes camtschaticus*, represented a major fishery species in Kodiak, Alaska, USA, during the 1960s and 70s, but the population crashed in the early 1980s (Bechtol and Kruse, 2010). The commercial fishery was closed in 1983 but the population has since failed to recover. The cause of the population crash is not fully understood, but it likely was due to a combination of climactic shifts, changes in the food web structure, recruitment failure, and overfishing (Bechtol and Kruse, 2009, Blau, 1986, Orensanz et al., 1998, Zheng and Kruse, 2000). The population crash and lack of a subsequent recovery, have spurred interest in using stock enhancement to supplement wild populations, with the hope of rebuilding local stocks to the point that sports or commercial fisheries would be viable again (Kron, 1992, Stevens, 2006, Stevens et al., 2014). Although large-scale hatchery production techniques have been developed for rearing red king crab from the larval to juvenile stages (Swingle et al., 2013) release strategies must be further developed to maximize post-release survival.

Red king crab are a long-lived crustacean with a complex life history (Fig. 1). Mature female red king crab brood between about 10,000 and 450,000 eggs annually before hatching in the spring (Stevens and Swiney, 2007, Swiney and Long, 2015, Swiney et al., 2012). Larvae pass through 4 zoeal stages prior to molting to the glaucothoe, or settling, stage; total larval duration is temperature-dependent, approximately 450 degree-day, which generally takes about 2–3 months *in situ* (Long, 2016, Shirley and Shirley, 1989). Glaucothoe seek complex habitats for settlement, and once they have found it, molt to the first crab stage (Stevens, 2003). Juvenile crab are highly cryptic (Daly and Long, 2014) and rely on complex habitat, such as hydroids, shell-hash, or rocky substrates (Loher and Armstrong, 2000, Sundberg and Clausen, 1979), to reduce predation (Long et al., 2012b, Long and Whitefleet-Smith, 2013, Stoner, 2009) for about the first 2 years of life. After the second year, when crab have become too large to effectively use crypsis to avoid predation, they undergo an ontogenetic behavioral shift, forming groups of crabs called pods (Powell and Nickerson, 1965), which forage at night, and form piles during the day, likely as a predator-avoidance strategy as they grow to maturity (Dew, 1990). Crabs reach sexual maturity at about 6 years of age (Stevens and Munk, 1989). Although hatchery techniques have developed for large scale rearing of juveniles, embryo and female biology do not offer much scope for varying the time of hatching more than a few months. The easiest way to achieve this is to vary holding temperatures during embryo development; however, red king crab embryos are primed to hatch in the spring and although holding temperature can alter hatch date to a small extent, by 2–3 months, lower temperatures lead to hatch failure and higher temperatures to hatched, but inviable larvae (Shirley et al., 1989).

Red king crab is likely a good candidate for stock enhancement. In addition to being a high-value species, mortality during the larval phase is believed to be high in the wild, with perhaps 1% survival from hatching to the glaucothoe stage (Shirley and Shirley, 1989), likely due to a combination of environmental factors such as high rates of predation, starvation, and failure to reach suitable settlement habitat, amongst others. *In situ* survival to the first crab stage is nearly impossible to estimate but is also likely low due to several factors. First, metamorphosis to the first crab stage is associated with high mortality even in the laboratory or hatchery (Persselin and Daly, 2010, Swingle et al., 2013). In addition, successful recruitment requires the glaucothoe to find suitable habitat to settle in, and it is unknown what proportion of them are able to do so. The development of large-scale hatchery rearing techniques has overcome these bottlenecks: survival to the first juvenile stage can exceed 60% (Persselin and Daly, 2010, Swingle et al., 2013), several orders of magnitude higher than *in situ* survival. The Kodiak area appears to be recruitment limited; a recent study in Trident Basin which was historically a nursery habitat for red king crab (Dew, 1991), found no evidence of wild recruitment (Long et al., 2018).

Post-release survival of hatchery-reared individuals can vary widely with a number of factors. Survival of hatchery-reared blue crab, *Callinecetes sapidus*, decreases with release density (Hines et al., 2008), likely because the predator functional response of the major predator of juvenile blue crab, larger blue crab (Hines and Ruiz, 1995), is a type III response, indicating a low-density refuge from predation (Long et al., 2012a). Size-at-release and release season can affect post-release survival as predation rates generally decrease with prey size (Johnson et al., 2008, Lebata et al., 2009) and predator densities (or predation rates) vary throughout the year (Johnson et al., 2008, van der Meeren, 2000). Because predator densities vary in space, release location is also an important consideration. In Chesapeake Bay both lower bay (near the mouth) and upper bay sites are under carrying capacity for juvenile blue crab; however, mortality rates are much higher in the lower bay, which is generally attributed to higher predator densities (Hines et al., 2008, Seitz et al., 2008). In systems where predator activity varies between night and day, the time of day of release may also be an important determinant of post-release mortality (Poh et al., 2018).

In this study, we released red king crab at three different times (release timing) to determine the optimal release strategy. This builds on previous research that demonstrated that release density (between 25 and 75 crab/m^2) of hatchery-reared red king crab did not affect post-release survival (Long et al., 2018). Because there is currently no way to control red king crab broodstock hatch timing (and thus the timing of hatchery rearing), later releases consisted of older, larger crabs. As such, we could not unambiguously distinguish between the effects of release date and size-at-release. However, our intent was to determine optimal release strategies for this species in realistic future enhancement scenarios. Throughout this manuscript, we will refer to our treatments as release timing or the time of release (relative to hatchery production) to differentiate it from the release date (the calendar day of release) and the size-at-release.

Section snippets

Methods

This study was designed to build on previous work on red king crab stock enhancement (Long et al., 2018). Except insofar as the two studies were designed to address different aspects of release strategies, all other pertinent aspects, including broodstock source, crab transportation and holding, hatchery procedures, release and monitoring locations and protocols, and modeling were the same between the two studies. This was done to maximize our ability to quantitatively compare the results from…

Results

Red king crab juveniles demonstrated highly cryptic behavior shortly after release: crabs were almost exclusively found under rocks or shells, or within kelp holdfasts. The best-fit model of movement and mortality was the most complex model fit, and none of the other models had any support whatsoever (Table 1). Both the diffusion term and mortality differed among the treatments, and mortality also decreased with time from release (Table 1, Fig. 3). Emigration (diffusion) rates were lowest in…

Discussion

When extended hatchery-rearing and post-release mortality are considered, releasing crabs soon after molting to the first crab stage is likely the best strategy for this species. We demonstrated that juvenile post-release survival increased from the June to the September releases. This is unsurprising, as later release dates corresponded with a larger release size, which likely decreased predation risk. We also found that crab migration rates were higher at later releases, also likely due to…

CRediT authorship contribution statement

Peter A. Cummiskey: Writing – review & editing, Investigation. **Benjamin J. Daly**: Writing – review & editing, Investigation. **William Christopher Long**: Writing – original draft, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.…

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: William C Long reports financial support was provided by NOAA Fisheries Office of Science and Technology.…

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References (67)

A.-L. Agnalt *et al.*

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Fish. Res. (2017)

B.F. Beal *et al.*

Survival and growth of hatchery-reared individuals of the European lobster, *Homarus gammarus* (L.), in field-based nursery cages on the Irish west coat

Aquaculture (2002)

W. Bechtol *et al.*

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

Fish. Res. (2009)

B. Daly *et al.*

Intra-guild predation among early benthic phase red and blue king crabs: Evidence for a habitat-mediated competitive advantage

J. Exp. Mar. Biol. Ecol. (2014)

B. Daly *et al.*

Effects of diet, stocking density, and substrate on survival and growth of hatchery-cultured red king crab (*Paralithodes camtschaticus*) juveniles in Alaska, USA

Aquaculture (2009)

B. Daly *et al.*

Predator-induced behavioral plasticity of juvenile red king crabs (*Paralithodes camtschaticus*)

J. Exp. Mar. Biol. Ecol. (2012)

B. Daly *et al.*

Increasing hatchery production of juvenile red king crabs (*Paralithodes camtschaticus*) through size grading

Aquaculture (2012)

G. van der Meeren

Out-of-water transportation effects on behaviour in newly released juvenile Atlantic lobsters *Homarus gammarus*

Aquacult. Eng. (1991)

E.G. Johnson *et al.*

Field comparison of survival and growth of hatchery-reared versus wild blue crabs, *Callinectes sapidus* Rathbun

J. Exp. Mar. Biol. Ecol. (2011)

T. Loher *et al.*

Effects of habitat complexity and relative larval supply on the establishment of early benthic phase red king crab (*Paralithodes camtschaticus* Tilesius, 1815) populations in Auke Bay, Alaska

J. Exp. Mar. Biol. Ecol. (2000)

W.C. Long *et al.*

Cannibalism in red king crab: habitat, ontogeny, and the predator functional response

J. Exp. Mar. Biol. Ecol. (2013)

W.C. Long *et al.*

Effects of anthropogenic shoreline hardening and invasion by *Phragmites australis* on habitat quality for juvenile blue crabs (*Callinectes sapidus*)

J. Exp. Mar. Biol. Ecol. (2011)

W.C. Long *et al.*

Cannibalism in red king crab, *Paralithodes camtschaticus* (Tilesius, 1815): Effects of habitat type and predator density on predator functional response

J. Exp. Mar. Biol. Ecol. (2012)

W.C. Long *et al.*
Habitat, predation, growth, and coexistence: Could interactions between juvenile red and blue king crabs limit blue king crab productivity?
J. Exp. Mar. Biol. Ecol. (2015)

B. Poh *et al.*
Estimating predation rates of restocked individuals: The influence of timing-of-release on metapenaeid survival
Fish. Res. (2018)

B.G. Stevens
Settlement, substratum preference, and survival of red king crab *Paralithodes camtschaticus* (Tilesius, 1815) glaucothoe on natural substrata in the laboratory
J. Exp. Mar. Biol. Ecol. (2003)

A.W. Stoner
Habitat-mediated survival of newly settled red king crab in the presence of a predatory fish: role of habitat complexity and heterogeneity
J. Exp. Mar. Biol. Ecol. (2009)

J.S. Swingle *et al.*
Temperature effects on larval survival, larval period, and health of hatchery-reared red king crab, *Paralithodes camtschaticus*
Aquaculture (2013)

S. Aspaas *et al.*
An enriched environment promotes shelter-seeking behaviour and survival of hatchery-produced juvenile European lobster (*Homarus gammarus*)
PLoS One (2016)

W.R. Bechtol *et al.*
Factors affecting historical red king crab recruitment around Kodiak Island, Alaska

Blau, S.F., 1986. Recent declines of red king crab (Paralithodes camtschatica) populations and reproductive conditions...

K.P. Burnham *et al.*
Model selection and multimodel inference: A practical information-theoretic approach (2002)

B. Daly *et al.*

Dietary astaxanthin supplementation for hatchery-cultured red king crab, *Paralithodes camtschaticus*, juveniles

Aquacult. Nutr. (2012)

B. Daly *et al.*

Predation of hatchery-cultured juvenile red king crabs (*Paralithodes camtschaticus*) in the wild

Can. J. Fish. Aquat. Sci. (2013)

B.J. Daly *et al.*

Moulding the ideal crab: implications of phenotypic plasticity for crustacean stock enhancement

ICES J. Mar. Sci. (2021)

J.L. Davis *et al.*

Assessing the potential for stock enhancement in the case of the Chesapeake Bay blue crab (*Callinectes sapidus*)

Can. J. Fish. Aquat. Sci. (2005)

J.L.D. Davis *et al.*

Differences between hatchery-raised and wild blue crabs: implications for stock enhancement potential

Trans. Am. Fish. Soc. (2004)

G.I. van der Meeren

Predation on hatchery-reared lobsters released in the wild

Can. J. Fish. Aquat. Sci. (2000)

G.I. van der Meeren

Effects of experience with shelter in hatchery-reared juvenile European lobsters *Homarus gammarus*

Mar. Freshw. Res. (2001)

C.B. Dew

Behavioral ecology of podding red king crab, *Paralithodes camtschatica*

Can. J. Fish. Aquat. Sci. (1990)

C.B. Dew

Characterization of preferred habitat for juvenile red king crab in three Kodiak bays

Final Rep. Kodiak Isl. Borough, Kodiak, Alsk. Contract (1991)

B. Hill

Effects of temperature on feeding and activity in the crab *Scylla serrata*

Mar. Biol. (1980)

J. Hinchcliffe *et al.*

European lobster *Homarus gammarus* aquaculture: Technical developments, opportunities and requirements

Rev. Aquac. (2022)

There are more references available in the full text version of this article.

Cited by (1)

Hitchhiking on drifting seaweed reduces predation risk in juveniles of the swimming crab Portunus tritberculatus ↗

2024, Hydrobiologia

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