Factors Leading to Stock Collapse of Kodiak Red King Crabs and their Failure to Recover

William R. Bechtol and Gordon H. Kruse
University of Alaska Fairbanks
School of Fisheries and Ocean Sciences, Juneau Center
Juneau, Alaska, U.S.A.
Kodiak Red King Crab Landings

Landings (thousands t)

Year

Fishery Closed

Kodiak Island

WATERS CLOSED TO NONPELAGIC TRAWL GEAR
Overall Research Goal

- Reconstruct the history of the Kodiak red king crab stock and fishery and understand the causes of the decline and failure to recover

Objectives

1. Conduct retrospective analysis of the king crab spawning stock abundance and recruitment over 1960 – 2004

2. Explore stock-recruit relationships

3. Analyze environmental and ecological factors affecting recruitment
Objective 1: Reconstruct spawning stock abundance and recruitment over 1960 – 2004

See:

Fishery Data

- Annual landings and dockside sampling since 1960

Photo: ADF&G
Pot Surveys
1972-1986

Trawl Surveys
1986-2004

Survey Data

Photos: ADF&G
Carapace Measurements

Carapace Length

Carapace Width
Shell Condition

From Donaldson and Byersdorfer 2005
Male Stages

- Pre-legal
  - 125-144 mm CL

- Legal-recruit
  - 145-164 mm CL newshell
    (145 mm CL ≈ 178 mm CW)

- Post-legal
  - 145-164 mm CL oldshell
  - >164 mm CL
Female Stages

- **Immature-small**
  - 88-101 mm CL immature

- **Immature-large**
  - >101 mm CL immature

- **Mature-small**
  - 88-101 mm CL mature

- **Mature-large**
  - >101 mm CL mature
Stock Dynamics Model

\[ N_{b,t+1} = \sum \left[ N_{a,t} e^{-M_t} - (C_{a,t} + D_{a,t} H) e^{-M_t(1-\tau_t)} \right] G_{a,b} + I_{t+1} \]

- \( N \) – Abundance
- \( a,b \) – Crab stages
- \( M \) – Inst. nat. mortality
- \( C \) – Catch
- \( D \) – Discard rate
- \( H \) – Handling mortality
- \( G \) – Growth probability
- \( I \) – Model recruits
- \( \tau \) – Time lag, survey to fishery
Estimation Years

- **Males:** 45 years of estimates - 1960-2004
  - 23 years of fishery data
  - 15 years of pot survey data
  - 19 years of trawl survey data

- **Females:** 33 years of estimates - 1972-2004
  - 15 years of pot survey data
  - 19 years of trawl survey data
Female Model Recruits

- Base model
- \( M = 0.1 \)
- \( M = 0.2 \)
- \( M = 0.3 \)
- \( M = 0.4 \)
Mature Females

Abundance (millions of crab)

Year


Base model

M = 0.1
M = 0.2
M = 0.3
M = 0.4
Fishing and Natural Mortality

Year

Mortality Rate

F Rate

M Rate
Sex Ratio
(mature females/total males)

Year

Females / Males

Objective 2: Explore a stock-recruit relationship

See:

S-R Models

- Standard Ricker
  \[ R_t = \alpha S_{t-k} e^{-\beta S_{t-k}} \]

- Autocorrelated Ricker
  \[ R_t = \alpha S_{t-k} e^{-\beta S_{t-k} + \nu_t} \]
  \[ \nu_t = \varphi \nu_{t-1} \]

- S-R lags \((k)\) of 5-8 yrs
  - Brood years 1960-1996 \((n = 37)\)

- Time-varying \(\alpha\) and \(\beta\) \(\rightarrow\) temporal shifts
Males used a proxy for S-R abundance

- Longer time series (1960 vs. 1972 for females)
- Males better represent contrast in population sizes
  - But, even males don’t capture S-R relationship during highest recruitment in early 1960s
S-R Plot
(lag-5)

Many points in 1980s & 1990s not shown

Standard Ricker

Autocorrelated Ricker

Spawners
(million males)

Male Recruits
(million crab)

0 5 10 15 20 25 30 35 40 45 50 55
S-R Residuals
(lag-5)

Residuals of ln(R/S)

- Standard Ricker
- Autocorrelated Ricker

Brood Year


Residuals of ln(R/S)

-4.5
-3.0
-1.5
-0.0
0.0
1.5
3.0
Autocorrelated Ricker lag 5, single and multiple $\alpha$

Spawners (million males)

Male Recruits (million crab)

- Single $\alpha$
- 1960–1974 $\alpha$
- 1975–1984 $\alpha$
- 1985–1996 $\alpha$
Residuals from one and three $\alpha$’s

Residuals of $\ln(R/S)$

- Single $\alpha$
- Multiple $\alpha$

Brood Year

But conflict between apparent moderate productivity yet no recovery since mid 1980s
Objective 3: Analysis of ecological factors affecting recruitment

# Some Early Life Factors

<table>
<thead>
<tr>
<th>Phase</th>
<th>Process</th>
<th>Data</th>
<th>Period</th>
<th>Timing (yr)</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reproduction</td>
<td>Fertilization</td>
<td>Sex ratio</td>
<td>Mar–Apr</td>
<td>0</td>
<td>Negative</td>
</tr>
<tr>
<td>Egg</td>
<td>Development</td>
<td>Water temp.</td>
<td>Jul–Feb</td>
<td>0</td>
<td>Dome-shape</td>
</tr>
<tr>
<td>Zoea</td>
<td>Growth</td>
<td>Water temp.</td>
<td>Mar–Jun</td>
<td>1</td>
<td>Positive</td>
</tr>
<tr>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
<td>1</td>
<td>Negative</td>
</tr>
<tr>
<td>&quot;</td>
<td>Stratification</td>
<td>Various</td>
<td>&quot;</td>
<td>1</td>
<td>Positive</td>
</tr>
<tr>
<td>&quot;</td>
<td>Advection</td>
<td>ACC Flow</td>
<td>&quot;</td>
<td>1</td>
<td>Negative</td>
</tr>
<tr>
<td>&quot;</td>
<td>Predation</td>
<td>Planktivores</td>
<td>&quot;</td>
<td>1</td>
<td>Negative</td>
</tr>
<tr>
<td>Glaucothoe</td>
<td>Advection</td>
<td>ACC Flow</td>
<td>May–Jul</td>
<td>1</td>
<td>Negative</td>
</tr>
<tr>
<td>&quot;</td>
<td>Predation</td>
<td>?</td>
<td>&quot;</td>
<td>1</td>
<td>Negative</td>
</tr>
<tr>
<td>Juvenile</td>
<td>Cannibalism</td>
<td>Other crab</td>
<td>Annual</td>
<td>1+</td>
<td>Negative</td>
</tr>
<tr>
<td>&quot;</td>
<td>Predation</td>
<td>?</td>
<td>&quot;</td>
<td>1+</td>
<td>Negative</td>
</tr>
</tbody>
</table>

Following Tyler and Kruse (1996a, 1996b)
### Factors Analyzed

<table>
<thead>
<tr>
<th>Data Series</th>
<th>Abbreviation</th>
<th>Data Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kodiak sea level pressure</td>
<td>SLP</td>
<td>1960–2004</td>
</tr>
<tr>
<td>Kodiak wind speed cubed</td>
<td>WS3</td>
<td>1960–2004</td>
</tr>
<tr>
<td>PDO</td>
<td>PDO</td>
<td>1960–2004</td>
</tr>
<tr>
<td>GOA freshwater discharge</td>
<td>DCG</td>
<td>1960–2004</td>
</tr>
<tr>
<td>Kodiak cloud cover</td>
<td>CLD</td>
<td>1960–2004</td>
</tr>
<tr>
<td>Kodiak sea surface temp.</td>
<td>SST</td>
<td>1960–2004</td>
</tr>
<tr>
<td>Pollock age 3+ fem. biom.</td>
<td>POL</td>
<td>1961–2004</td>
</tr>
<tr>
<td>Halibut age 10+ biom.</td>
<td>HAL</td>
<td>1960–2004</td>
</tr>
<tr>
<td>Pacific cod age 3+ biom.</td>
<td>COD</td>
<td>1964–2004</td>
</tr>
<tr>
<td>Arrowtooth age 3+ biom.</td>
<td>ATF</td>
<td>1961–2004</td>
</tr>
</tbody>
</table>
Modified Lag-5 Autocorrelated Ricker

\[ R_t = \alpha S_{t-k} e^{-\beta S_{t-k} + \nu_t + \theta_t} \]
\[ \nu_t = \varphi \nu_{t-1} \]
\[ \theta_t = \gamma_1 X_{1, t-k+j_1} + \cdots + \gamma_p X_{p, t-k+j_p} \]

- S-R lag (\( k \)) of 5 yrs
- \( X \) = time series of ecological anomalies
- \( \gamma \) = ecological coefficient
- Ecol. time lag (\( j \)) of 0 – 5 yrs from brood year
Reduced AIC<sub>c</sub> = 106.8

One Ecological Factor
(autocorrelated)

Factors:
- SLP
- WS3
- PDO
- DCG
- CLD
- SST
- POL
- HAL
- COD
- ATF

Legend:
- Green: Lowest AIC<sub>c</sub>
- Yellow: AIC<sub>c</sub> ≤ 2
- Red: 2 ≤ AIC<sub>c</sub> ≤ 4
- Orange: AIC<sub>c</sub> ≥ 4
Two Ecological Factors
(autocorrelated, COD-2 fixed)

Reduced $\text{AIC}_c = 98.9$

Factors:
- SLP
- WS3
- PDO
- DCG
- CLD
- SST
- POL
- HAL
- COD
- ATF

Factor Offset (years):
- $0$
- $1$
- $2$
- $3$
- $4$
- $5$

Legend:
- Green circle: Lowest $\text{AIC}_c$
- Yellow circle: $\text{AIC}_c \leq 2$
- Maroon circle: $2 \leq \text{AIC}_c \leq 4$
- Orange circle: $\text{AIC}_c \geq 4$
Pacific Cod Spatial Changes

Photo: NMFS

Pacific Cod
Pot Survey Catch
(# fish/pot-day)

- Orange: 1972 - 1976
- Purple: 1977 - 1981
- Red: 1982 - 1986
Conclusions

- Chance extremely high recruitment in early 1960s during fishery development led to:
  - Unrealistic expectations of productivity
  - Overcapitalization in fishery

- Once recruitment declined, excessive fishing effort caused:
  - High fishing mortality
  - High female/male sex ratios

- Skewed sex ratios compromised reproduction and caused recruitment failures

- Overfishing on declining stock in 1980s led to severe stock depletion
Conclusions

● Indications of density-dependent S-R relationship


● M increased since the mid 1980s

● Lack of stock recovery since fishery closure in 1980s may be due to:
  ● Predation mortality by cod (or other co-varying predatory species)
  ● Poor ocean conditions for larval survival indexed by cloud cover (likely poor feeding conditions)
Acknowledgments

- North Pacific Research Board
- Alaska Sea Grant
- Rasmuson Fisheries Research Center Fellowship
- NMFS AFSC Population Dynamics Fellowship