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

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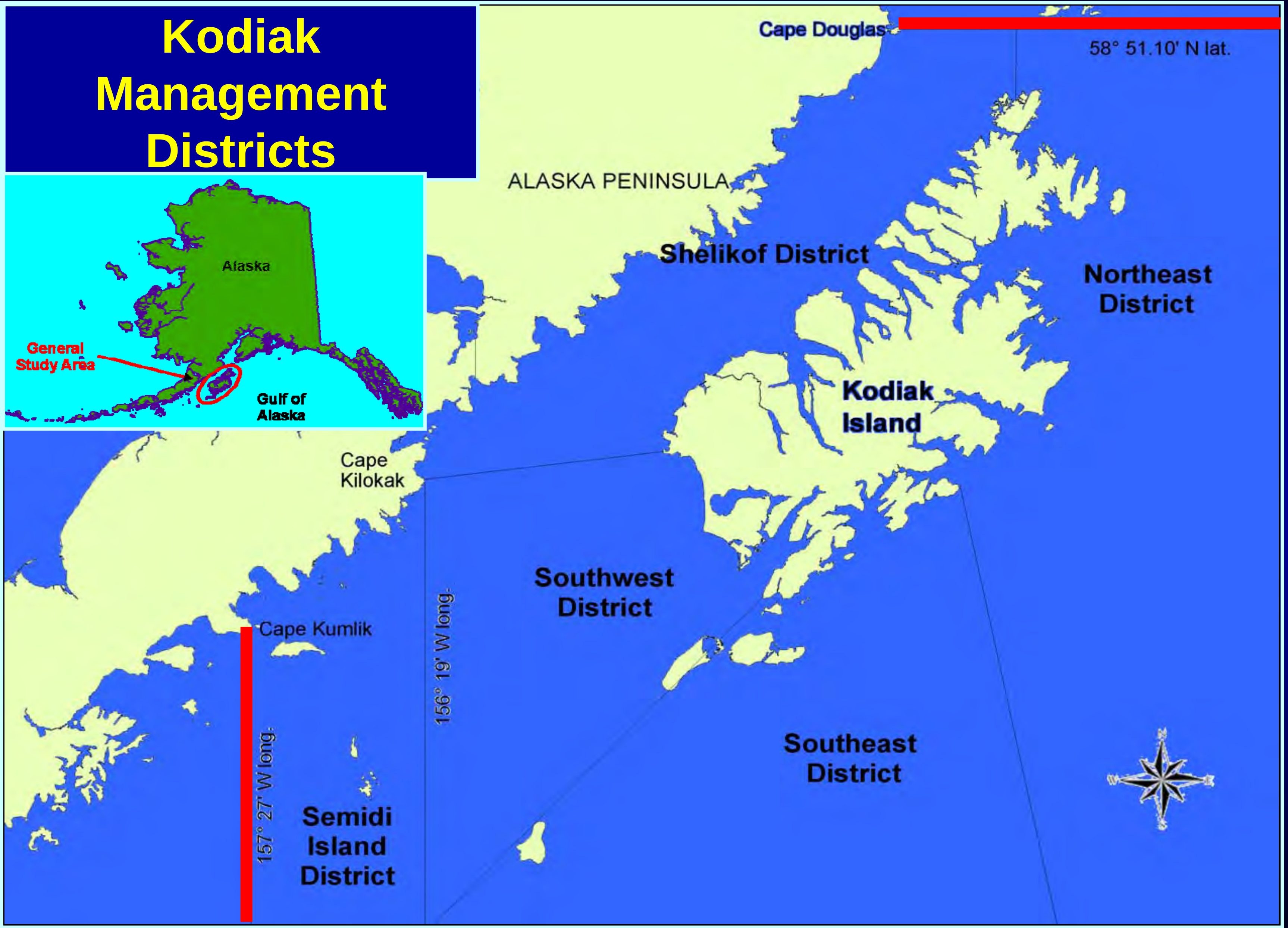
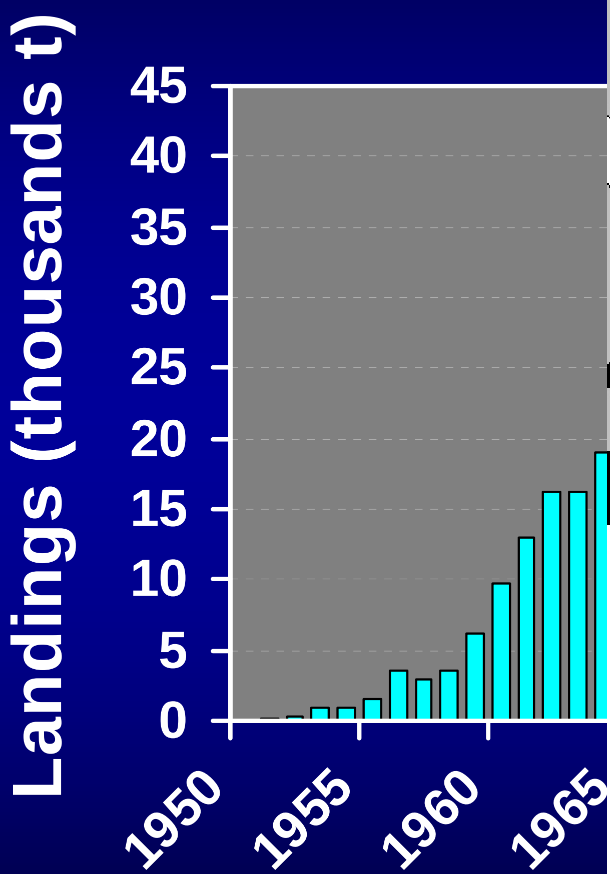
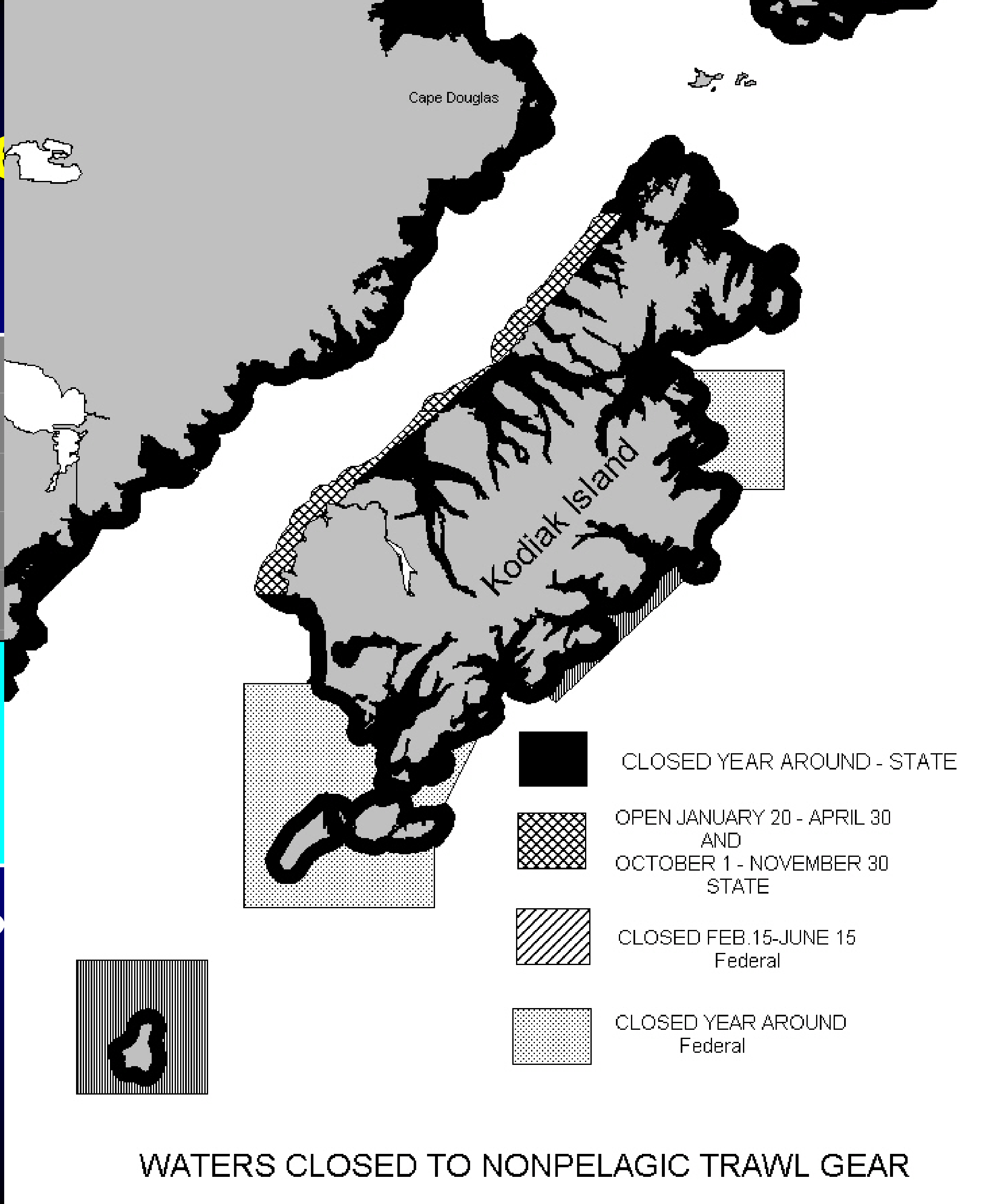
Kodiak Management Districts



King Crab Fishery

Kodiak Re


Landings (thousands t)
45
40
35
30
25
20
15
10
5
0
1950
1955
1960
1965


Cape Douglas
Kodiak Island
CLOSED YEAR AROUND - STATE
OPEN JANUARY 20 - APRIL 30
AND
OCTOBER 1 - NOVEMBER 30
STATE
CLOSED FEB.15-JUNE 15
Federal
CLOSED YEAR AROUND
Federal
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:

Bechtol, W. R., and G. H. Kruse. 2009. Reconstruction of historical abundance and recruitment of red king crab during 1960–2004 around Kodiak, Alaska. Fisheries Research 100: 86-98.

Fishery Data

- Annual landings and dockside sampling since 1960

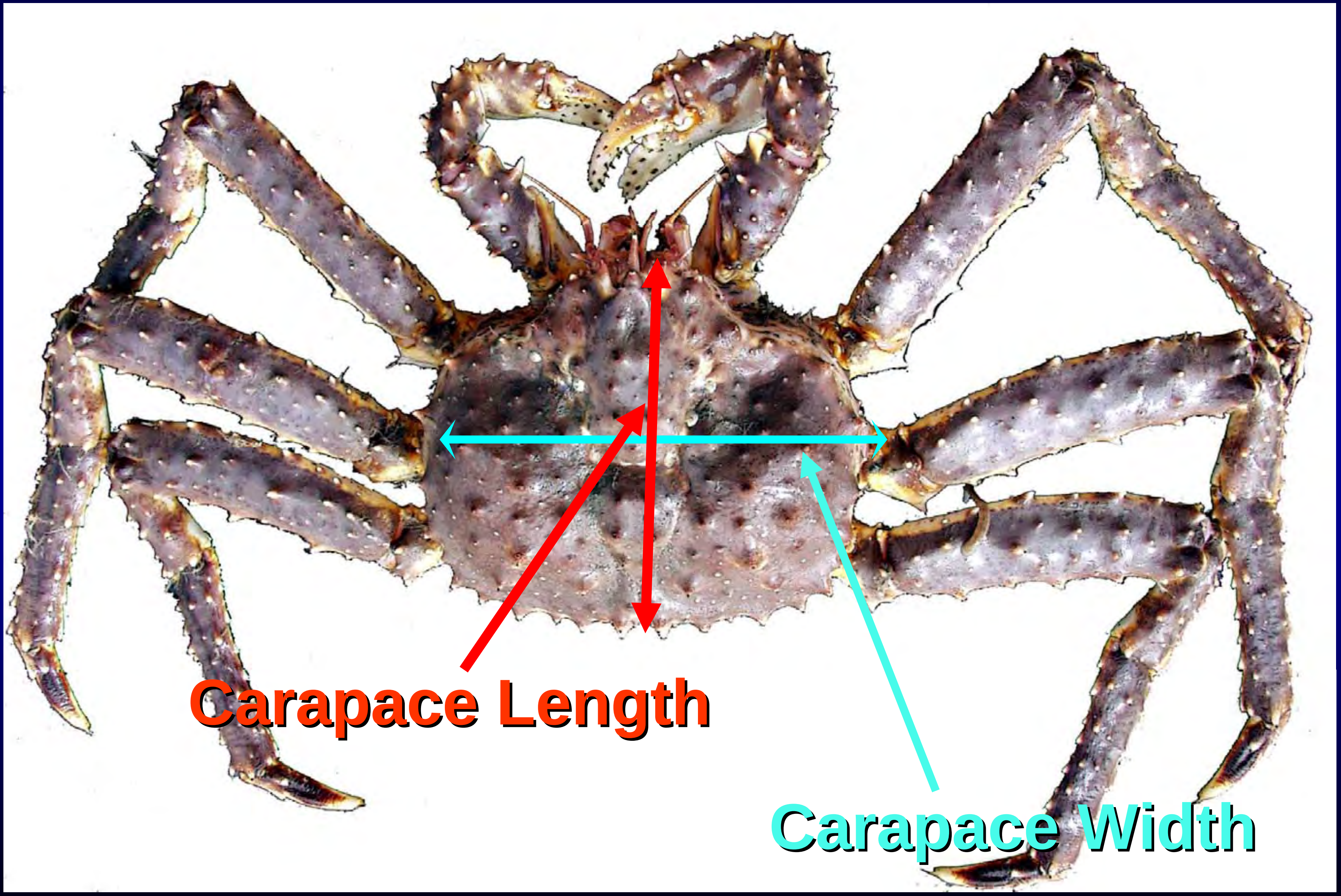
Survey Data

Pot Surveys
1972-1986

Trawl Surveys
1986-2004

Photos: ADF&G

Carapace Measurements

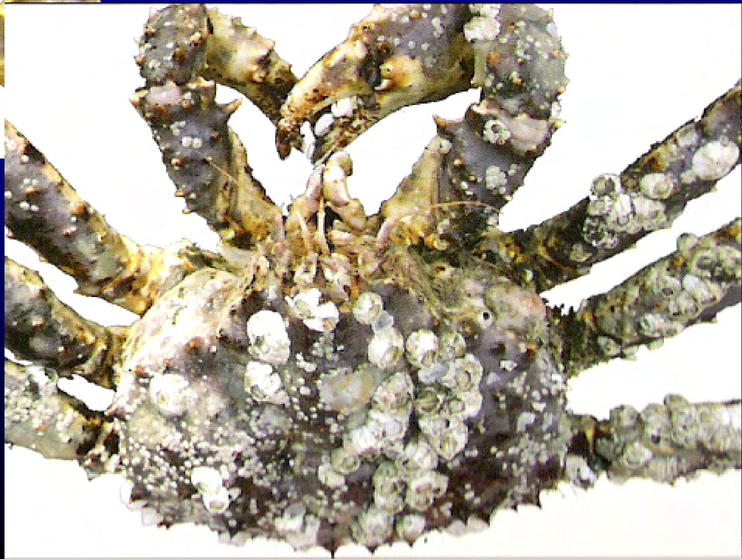


Shell Condition

New

Old

Very Old



From Donaldson and Byersdorfer 2005

Male Stages

All males

- 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

Legal males

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

Mature Females

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

M – Inst. nat. mortality

D – Discard rate

G – Growth probability

τ – Time lag, survey to fishery

a,b – Crab stages

C – Catch

H – Handling mortality

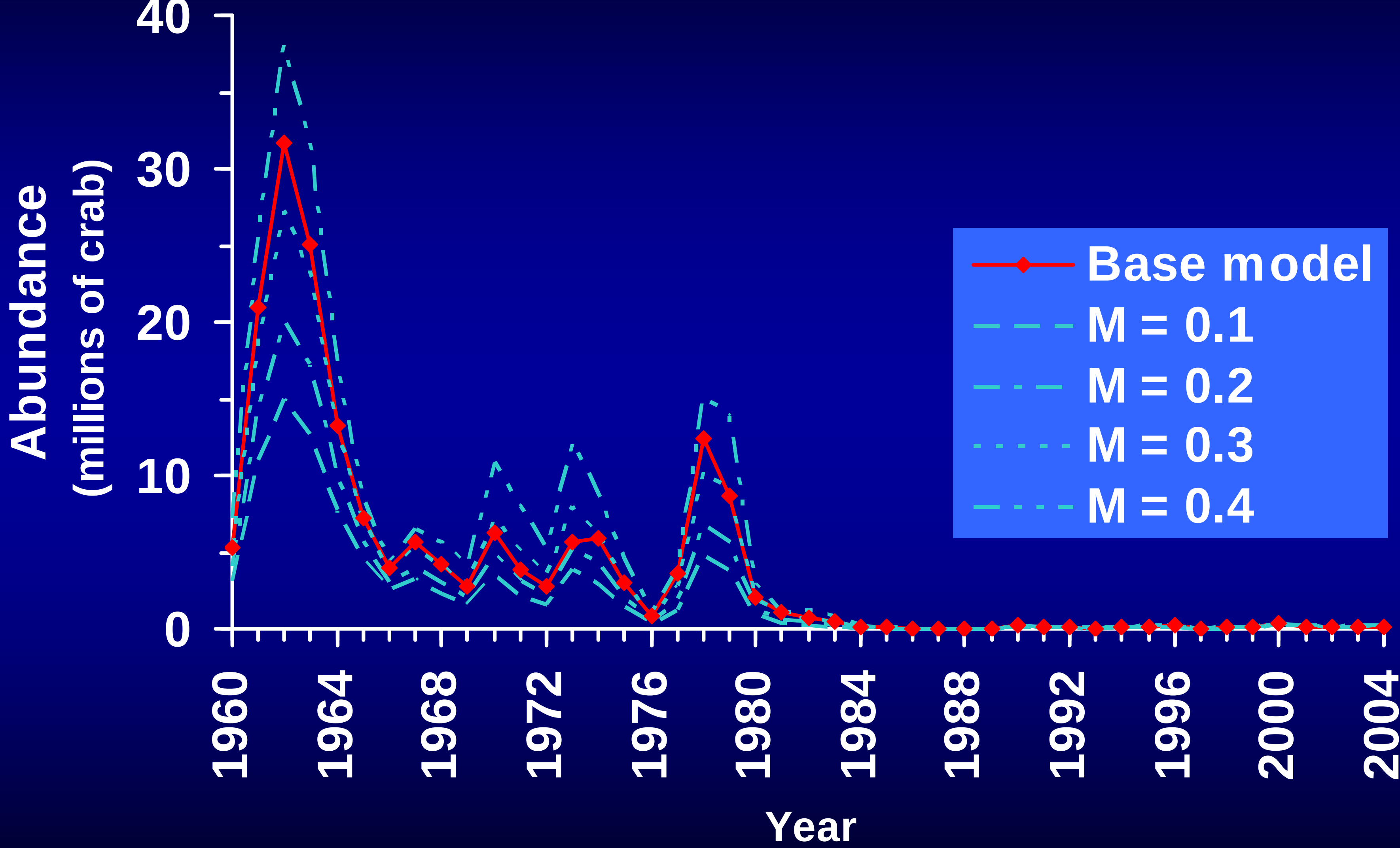
I – Model recruits

Estimation Years

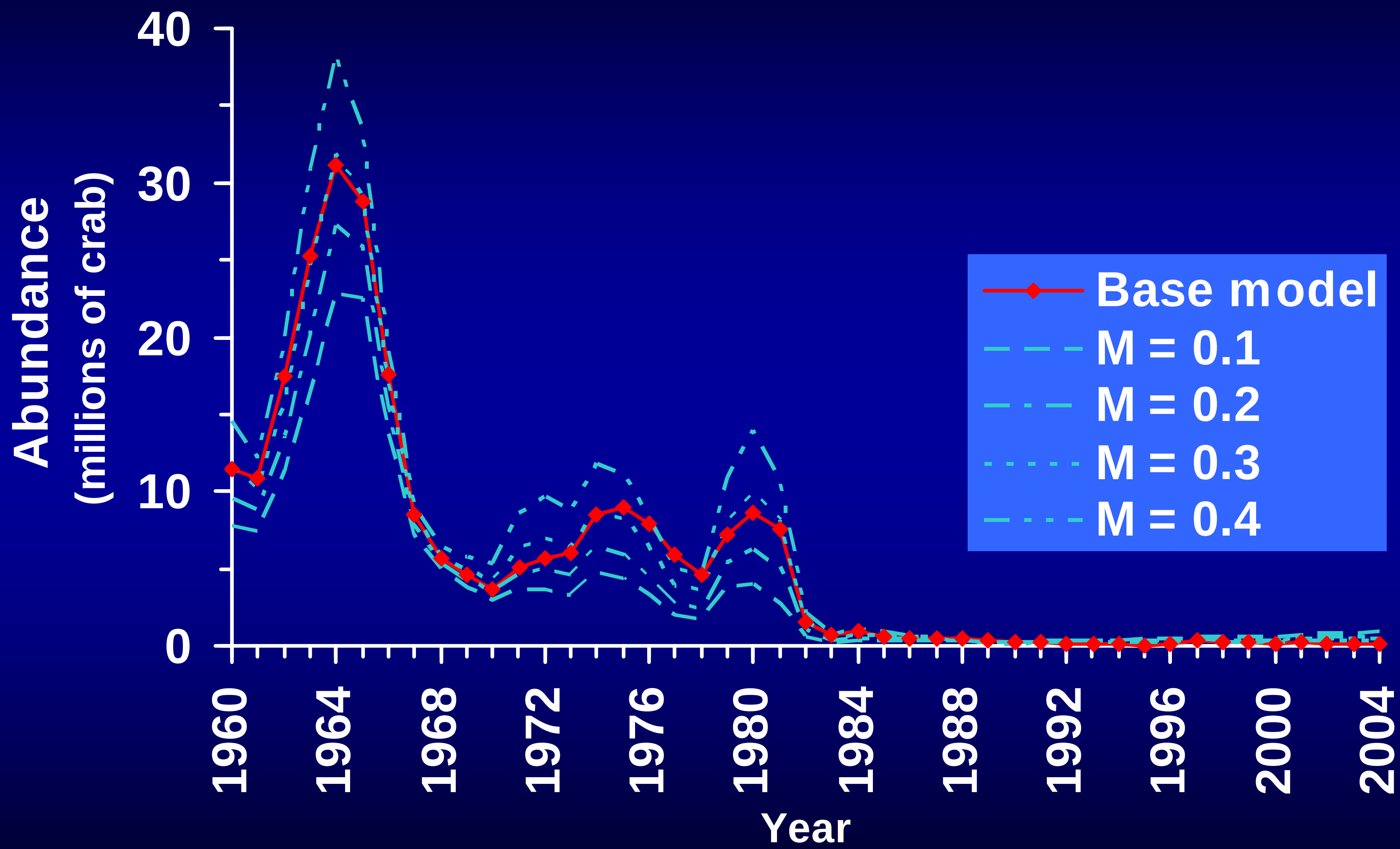
- Males: 45 years of estimates - 1960-2004
  - 23 years of fishery data
  - 15 years of pot survey data
  - 19 years of trawl survey data

- Females: 33 years of estimates - 1972-2004
  - 15 years of pot survey data
  - 19 years of trawl survey data

Male Model Recruits

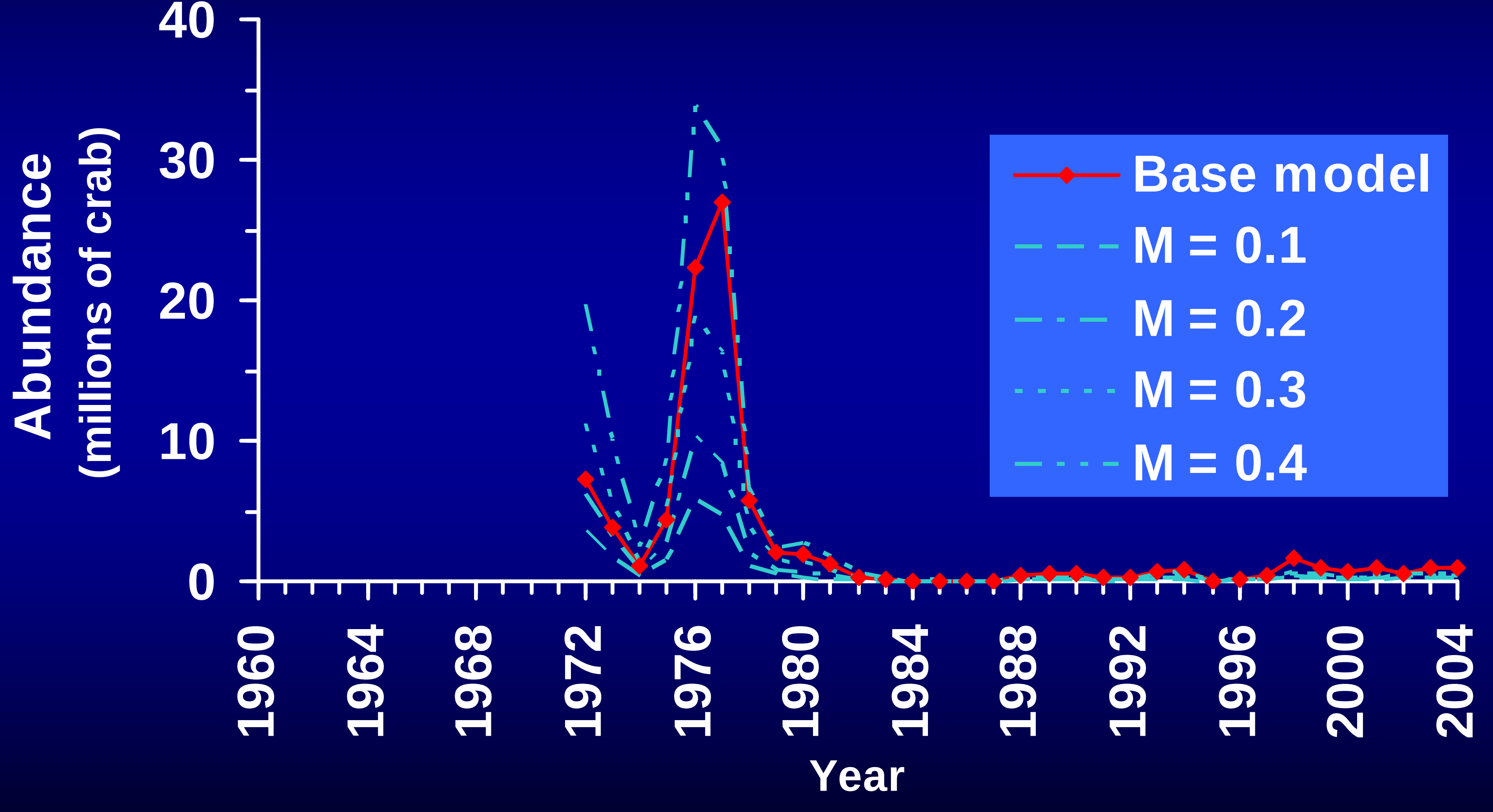


Legal Males

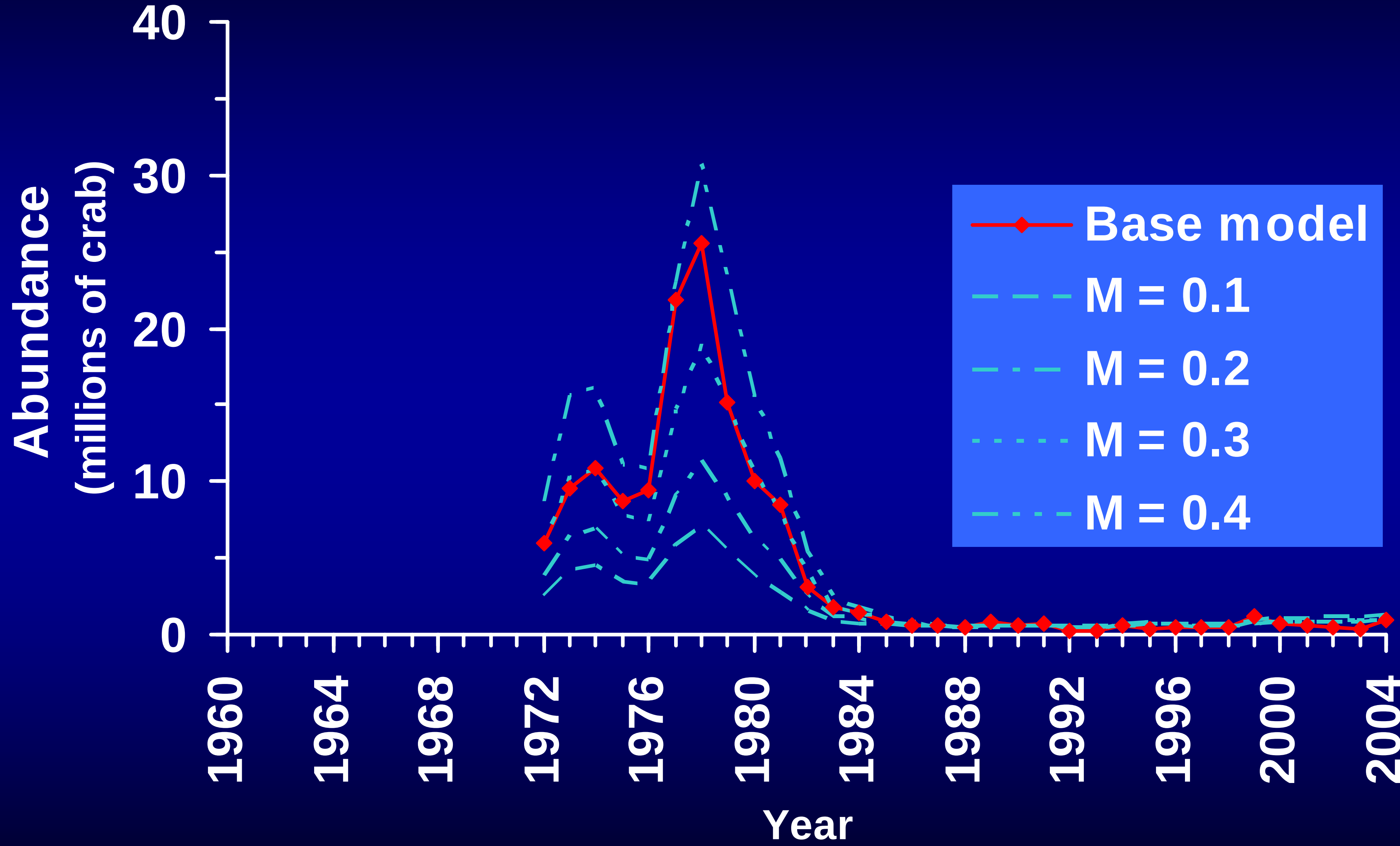


Abundance
(millions of crab)
40
30
20
10
0
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
Year
Base model
M = 0.1
M = 0.2
M = 0.3
M = 0.4

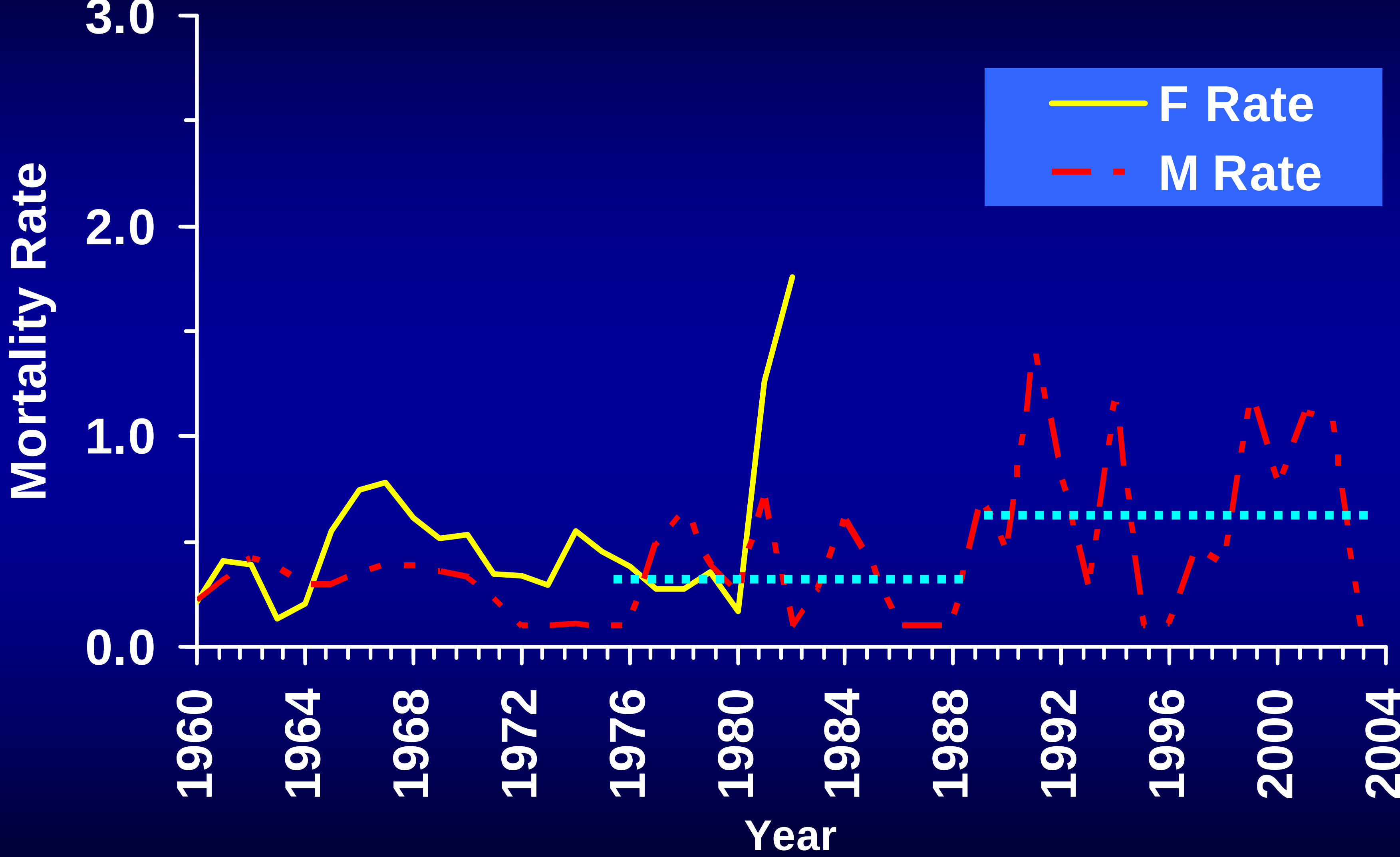
Female Model Recruits

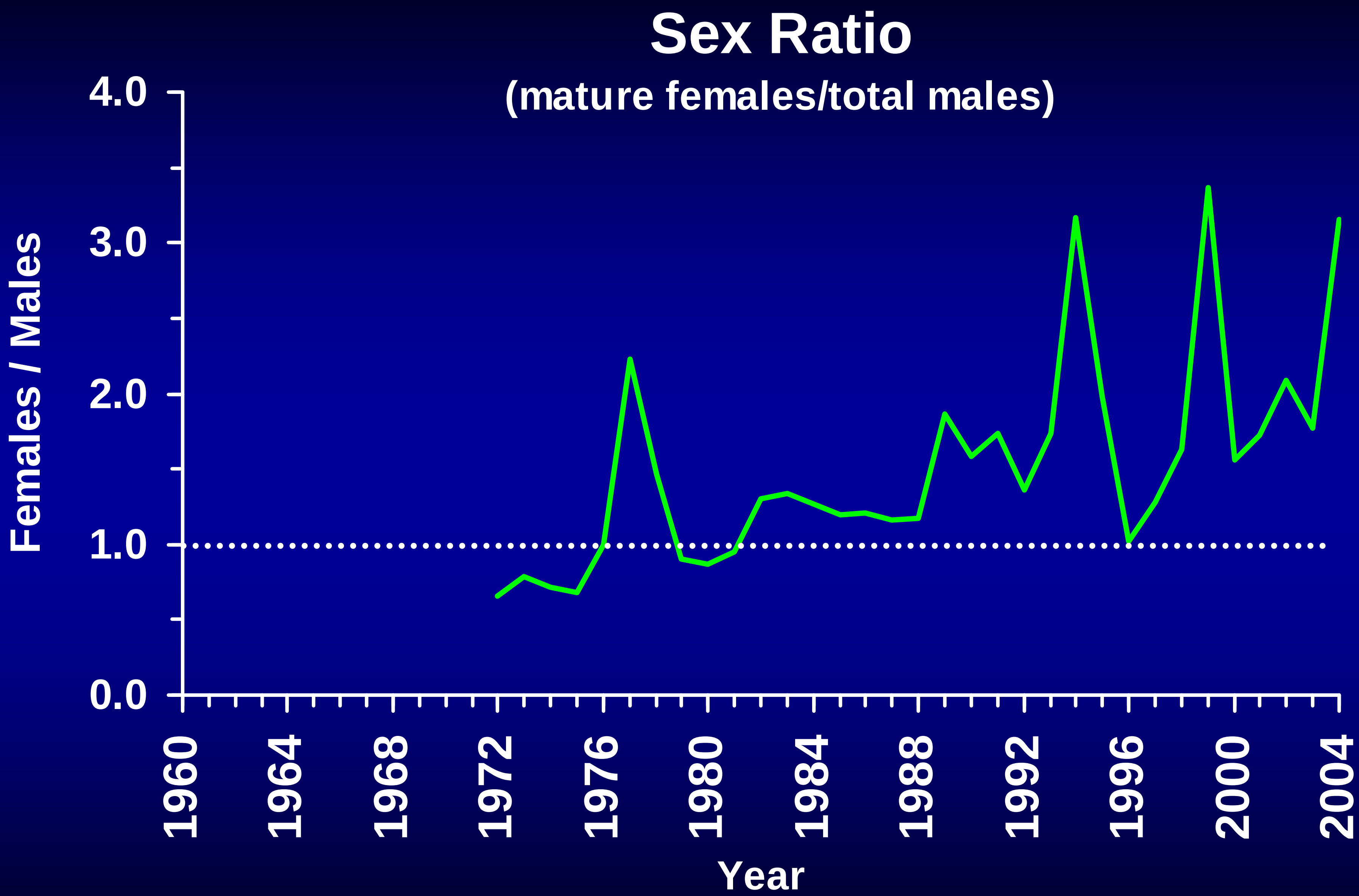


Mature Females



Fishing and Natural Mortality




Sex Ratio
(mature females/total males)
Females / Males
4.0
3.0
2.0
1.0
0.0
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
Year

Objective 2: Explore a stock-recruit relationship

See:

Bechtol, W.R., and G.H. Kruse. 2009. Analysis of a stock-recruit relationship for red king crab off Kodiak Island, Alaska. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1:29-44 .

S-R Models

- Standard Ricker $$R_t = \alpha S_{t-k} e^{-\beta S_{t-k}}$$
- Autocorrelated Ricker $$R_t = \alpha S_{t-k} e^{-\beta S_{t-k} + \nu_t}$$

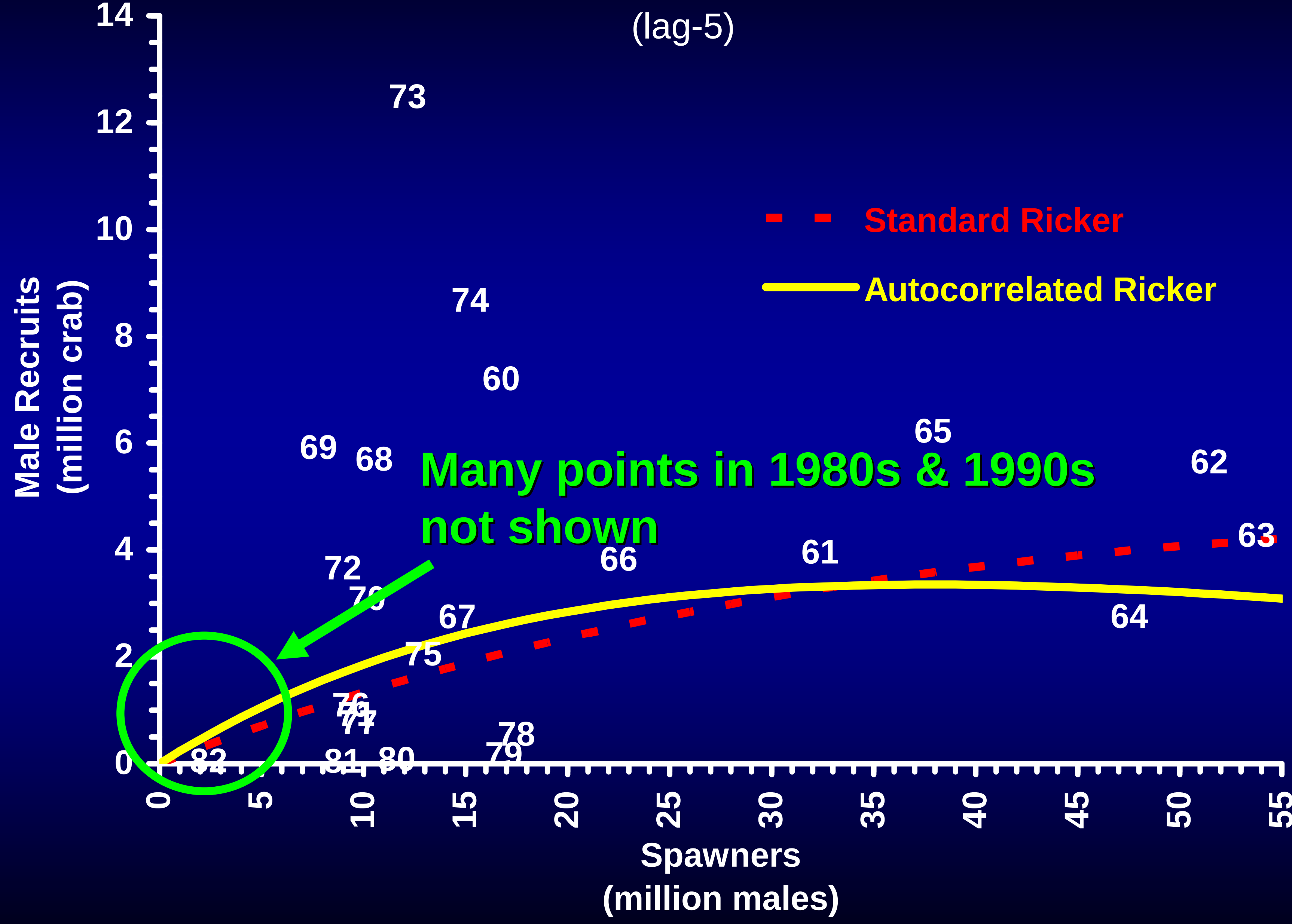
$$\nu_t = \varphi \nu_{t-1}$$

- S-R lags (*k*) of 5-8 yrs
  - Brood years 1960-1996 (n = 37)
- Time-varying *α* and *β* → 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

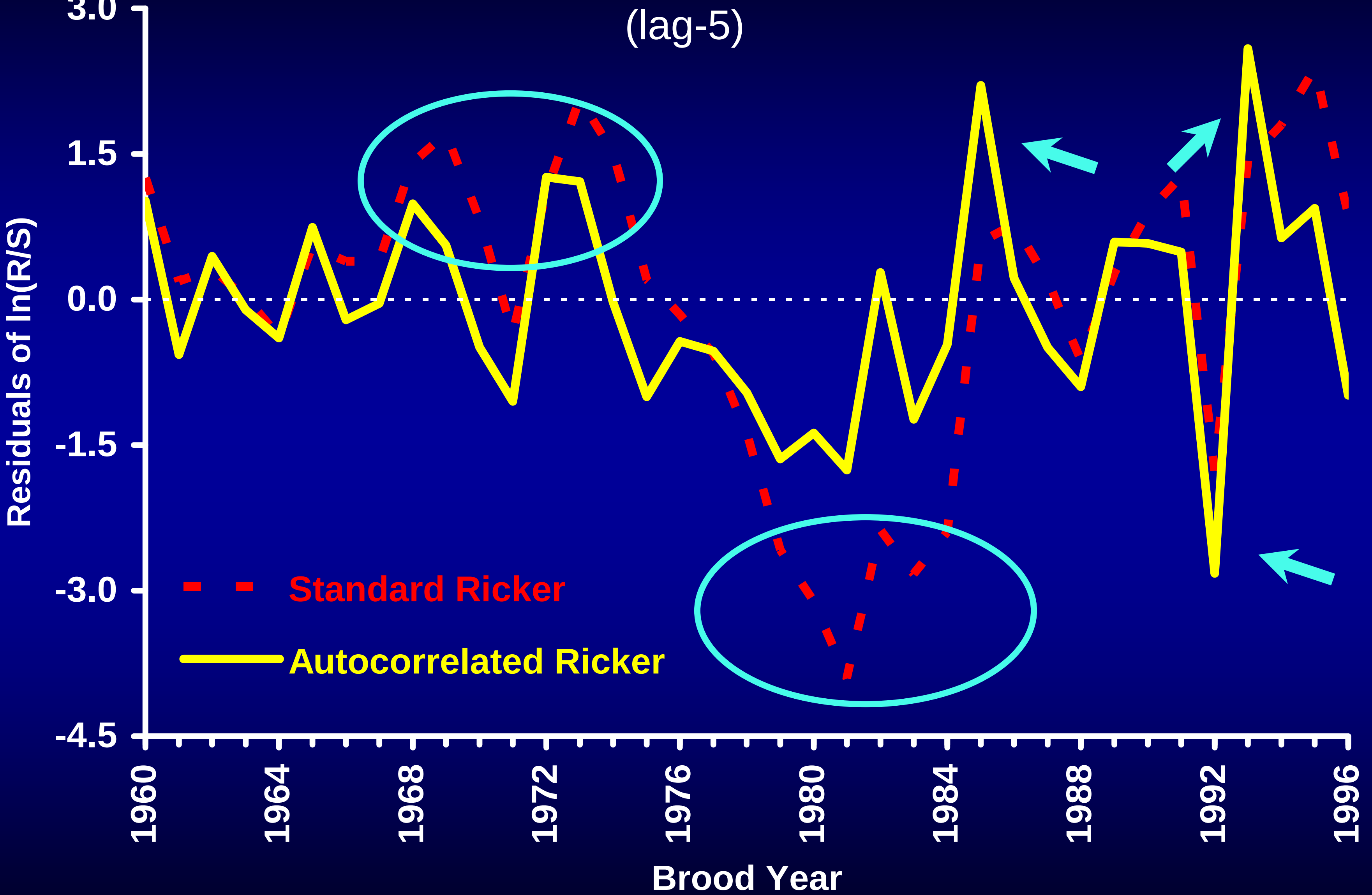
(lag-5)



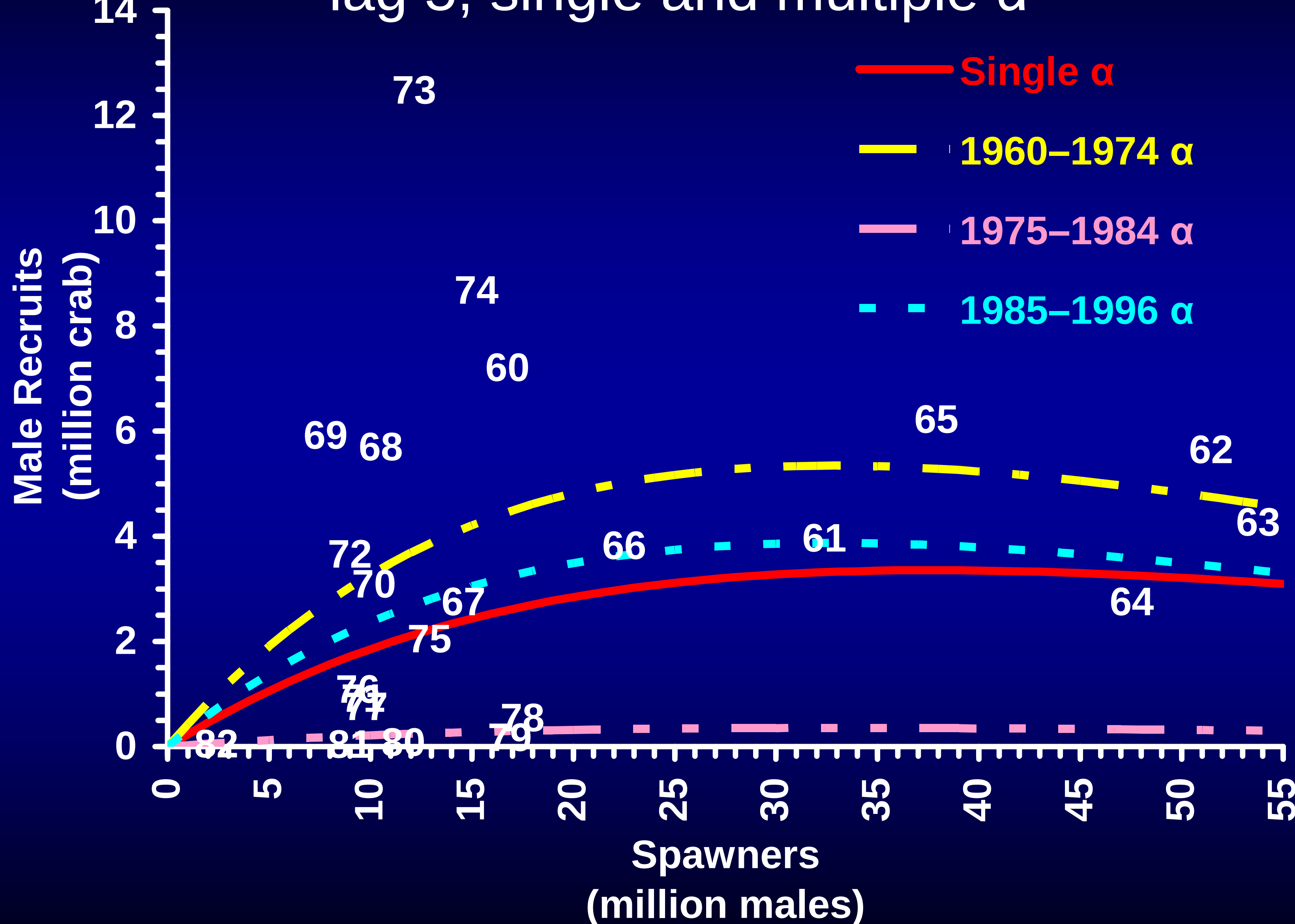
Male Recruits
(million crab)
14
12
10
8
6
4
2
0
Spawners
(million males)
0
5
10
15
20
25
30
35
40
45
50
55
Standard Ricker
Autocorrelated Ricker
Many points in 1980s & 1990s
not shown
73
74
60
65
62
69
68
63
66
61
72
67
64
75
76
77
78
79
82
81
80

S-R Residuals

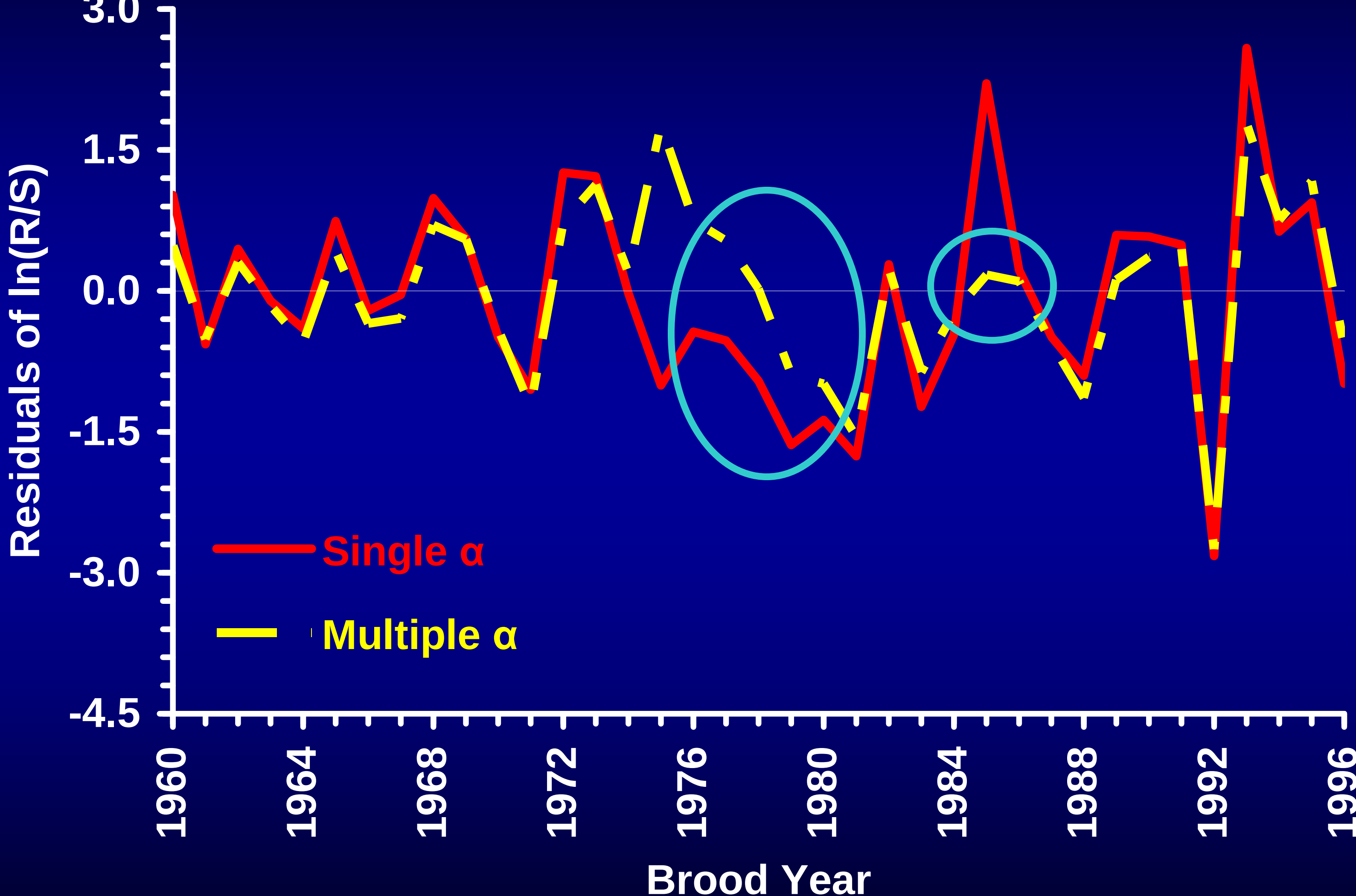
(lag-5)



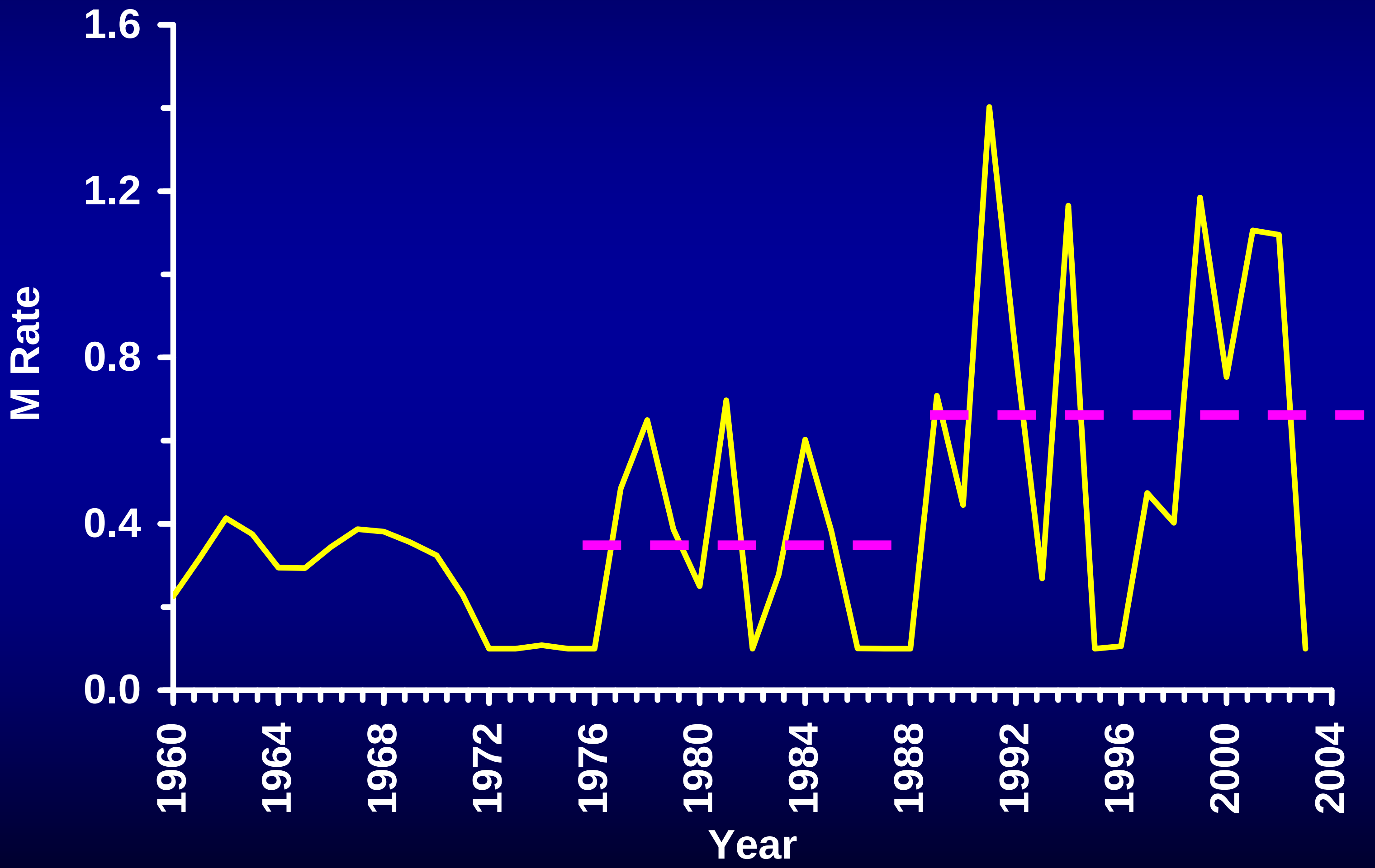
Autocorrelated Ricker
lag 5, single and multiple *α*



Residuals from one and three *α*'s



- **But conflict between apparent moderate productivity yet no recovery since mid 1980s**



Objective 3: Analysis of ecological factors affecting recruitment

Bechtol, W.R., and G.H. Kruse. MS. Factors affecting red king crab recruitment around Kodiak Island, Alaska. Proceedings of the International Symposium on Biology and Management of Exploited Crab Populations under Climate Change, submitted March 2009.

Some Early Life Factors

Phase	Process	Data	Period	Timing (yr)	Relationship
Reproduction	Fertilization	Sex ratio	Mar–Apr	0	Negative
Egg	Development	Water temp.	Jul–Feb	0	Dome-shape
Zoea	Growth	Water temp.	Mar–Jun	1	Positive
" "	Food	Water temp.	" "	1	Negative
" "	Stratification	Various	" "	1	Positive
" "	Advection	ACC Flow	" "	1	Negative
" "	Predation	Planktivores	" "	1	Negative
Glaucothoe	Advection	ACC Flow	May–Jul	1	Negative
" "	Predation	?	" "	1	Negative
Juvenile	Cannibalism	Other crab	Annual	1+	Negative
" "	Predation	?	" "	1+	Negative

Following Tyler and Kruse (1996a, 1996b)

Factors Analyzed

Data Series	Abbreviation	Data Years
Kodiak sea level pressure	SLP	1960–2004
Kodiak wind speed cubed	WS3	1960–2004
PDO	PDO	1960–2004
GOA freshwater discharge	DCG	1960–2004
Kodiak cloud cover	CLD	1960–2004
Kodiak sea surface temp.	SST	1960–2004
Pollock age 3+ fem. biom.	POL	1961–2004
Halibut age 10+ biom.	HAL	1960–2004
Pacific cod age 3+ biom.	COD	1964–2004
Arrowtooth age 3+ biom.	ATF	1961–2004

Modified Lag-5 Autocorrelated Ricker

$$R_t = \alpha S_{t-k} e^{-\beta S_{t-k} + \nu_t + \theta_t}$$

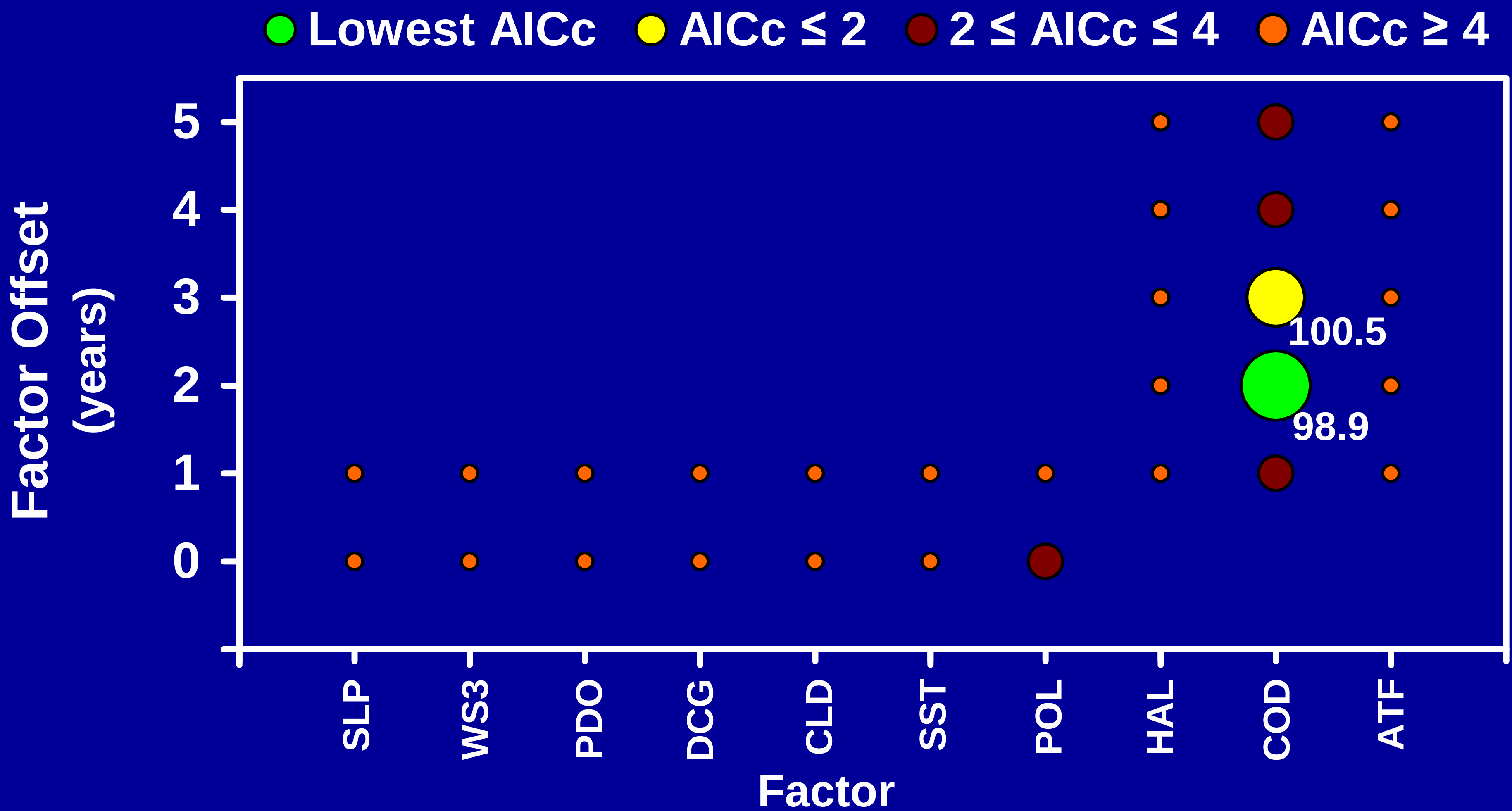
$$\nu_t = \varphi \nu_{t-1}$$

$$\theta_t = \gamma_{1_1} X_{1,t-k+j_1} + \cdots + \gamma_p X_{p,t-k+j_p}$$

- S-R lag (*k*) of 5 yrs
- X = time series of ecological anomalies
- γ = ecological coefficient
- Ecol. time lag (*j*) of 0 – 5 yrs from brood year

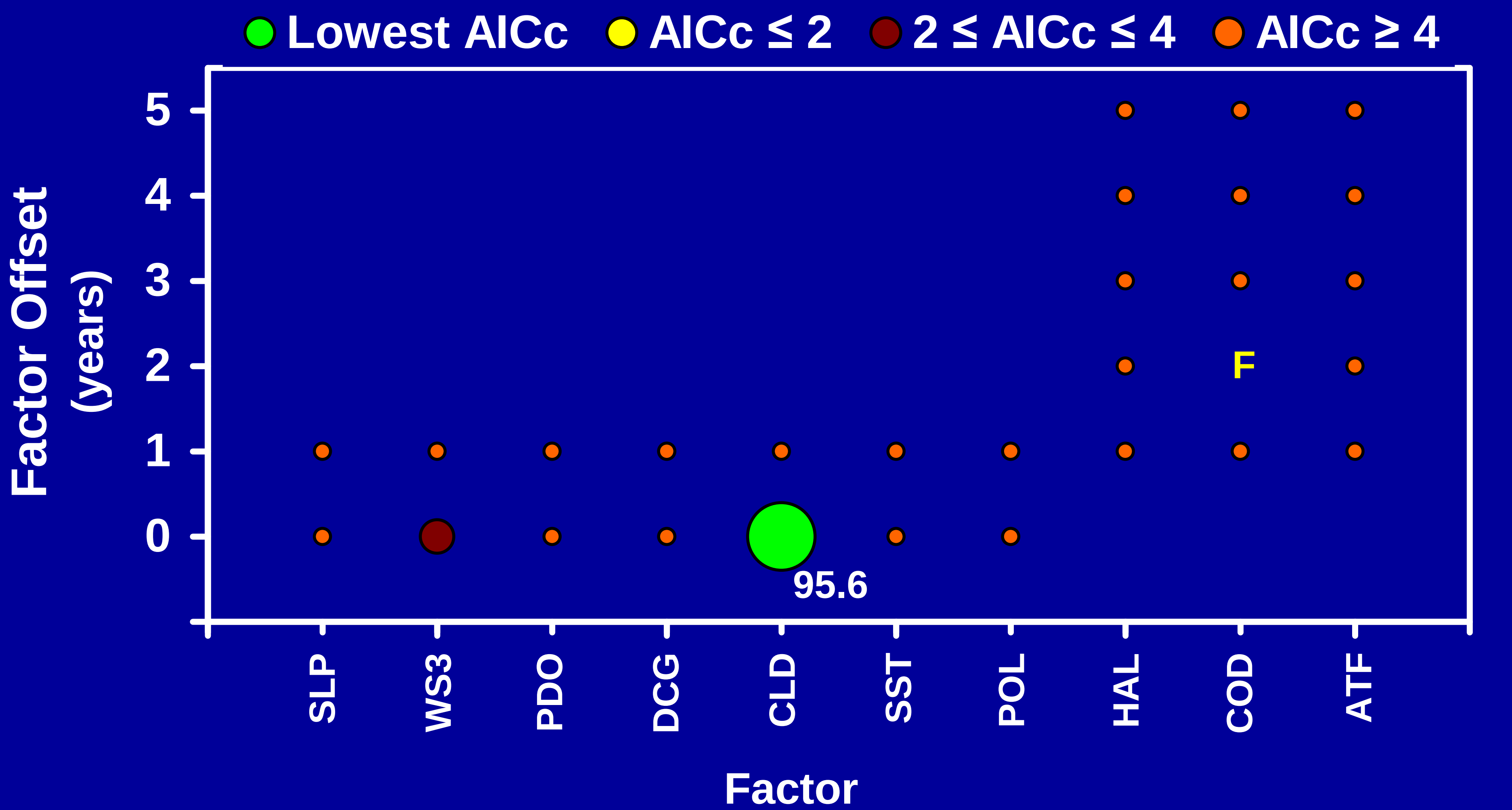
One Ecological Factor
(autocorrelated)

Reduced AIC_c = 106.8

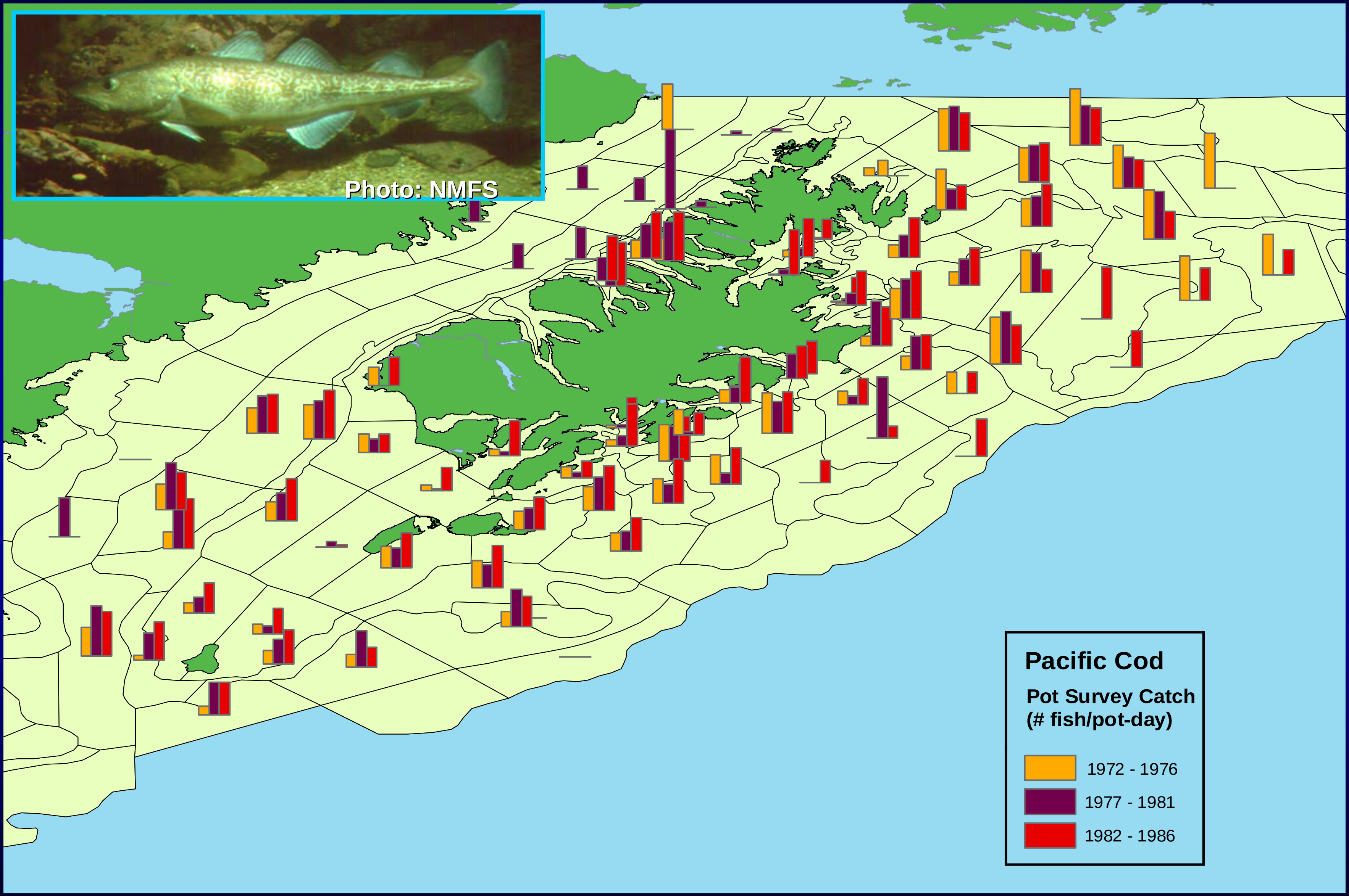


Two Ecological Factors
(autocorrelated, COD-2 fixed)

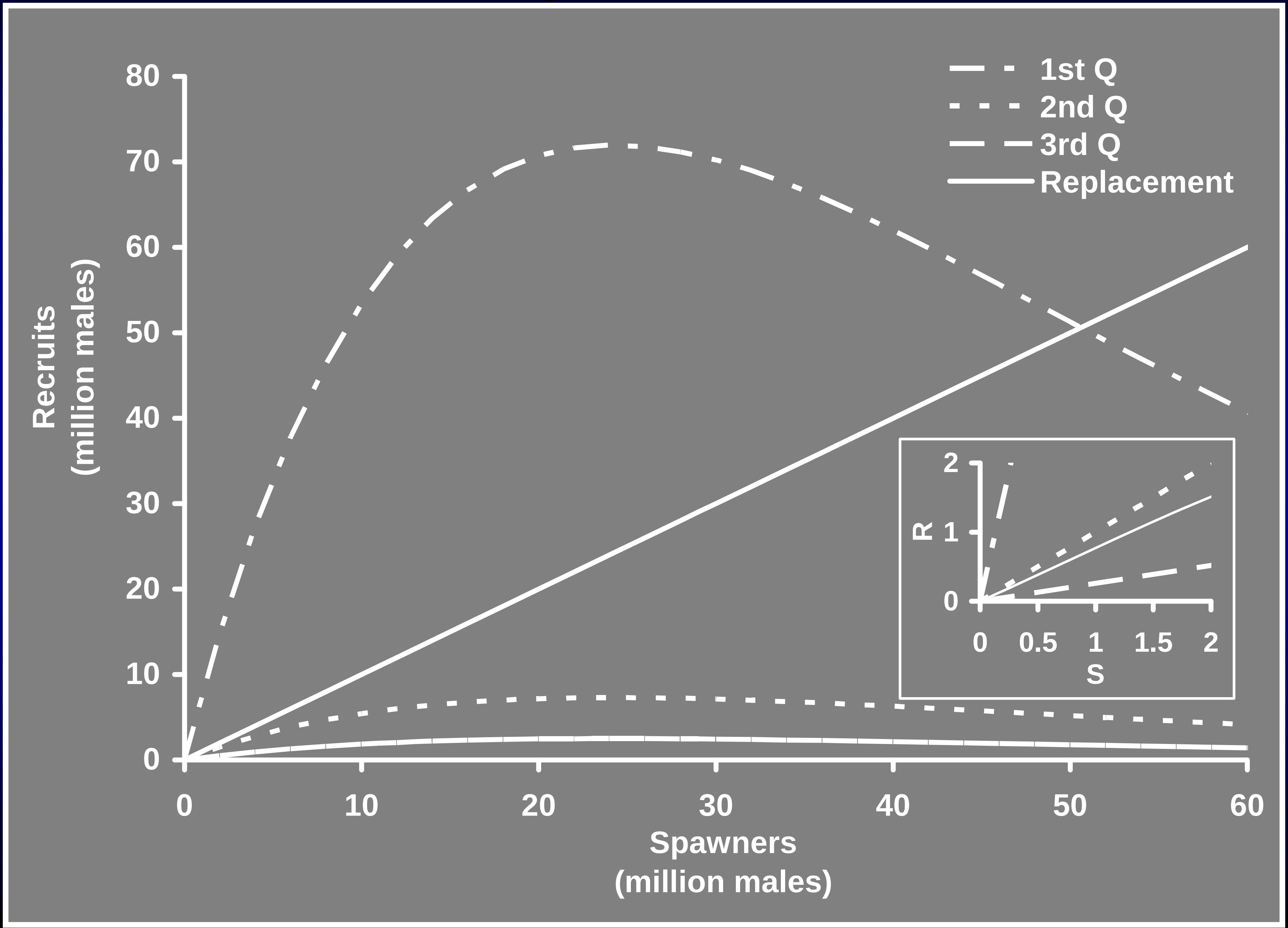
Reduced AIC_c = 98.9



Pacific Cod Spatial Changes



S-R Curves for 3 Quartiles of Cod Biomass



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
- Evidence for three productivity periods (high: 1960-1974, low: 1975-1984, intermediate: 1985-1996)
- 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

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