Size-Selective Fishing and Its Implications for Salmon

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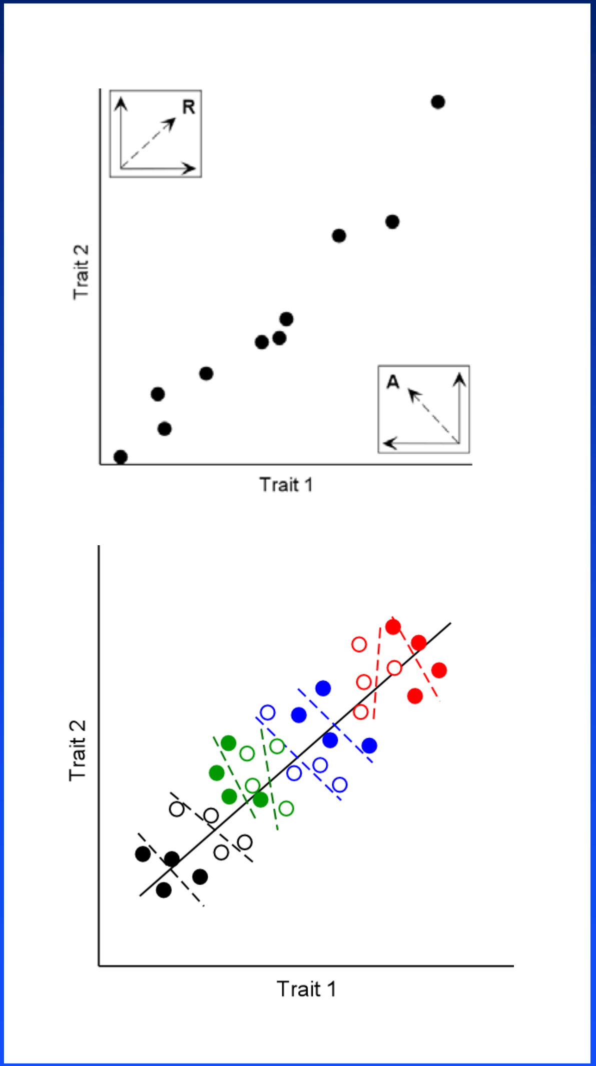
Outline

- Summarize what is known about evolutionary effects of fishing
- Describe some key studies
- Introduce a modeling approach
  - Apply genetic data to selection models
  - Predict effects of fishing on life history and viability



The problem

- Many fishes have declined in size
- Declines are often correlated with harvest pressure
- Most forms of harvest selective
  - fishing often takes the largest, most fecund fish
  - size is linked to age, fecundity, and growth
- Pronounced climate changes since 1900s
- Hatchery salmon production has escalated
- Can we identify causes of declines?

Is fishing an agent of evolution?

"Simply through the action of fishing, fishers generate selection, causing evolution that changes the sustainable yield."

– R. Law (2000) *ICES J Mar Sci* 57:659

"Our results … raise the possibility that fishing-induced phase shifts in fish communities may affect the recovery of fishes, even after the implementation of severe fishing restrictions."

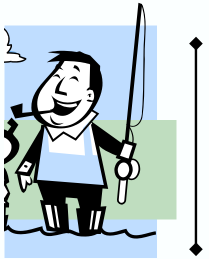
– P. Levin *et al.* (2006) *Conserv Biol* 20:1181

Why is so little attention paid to evolutionary effects of fishing?

- Harvest management focuses on short-term yield
- Evolutionary effects may occur on time scales too long to concern managers
- Evidence for fishing-induced adaptive change relies heavily on correlative studies
  - e.g., Pacific and Atlantic salmon, Arctic cod, North sea plaice, rockfishes, and flatfishes, top marine predators
- Distinguishing fishing and environmental variation as factors is difficult
- Direct empirical approaches are generally not feasible

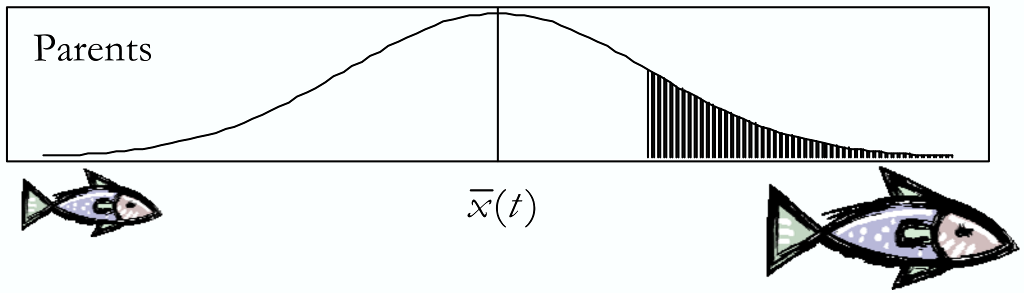
Correlated traits, a little background on Nature vs. Nurture

- Phenotype (*X*)
  - Observed trait value including genetic and environmental contributions
- Breeding value (*A*)
  - Mean trait value an individual parent passes to offspring (genetic component)
- Heritability (h^2)
  - The ratio of variance in breeding values (V_A) to phenotypic variance (V_P)



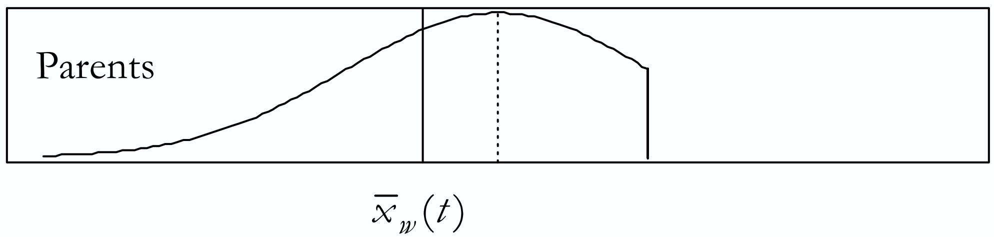
$$h^2 = \frac{V_A}{V_X}$$

- Impose selection on parents

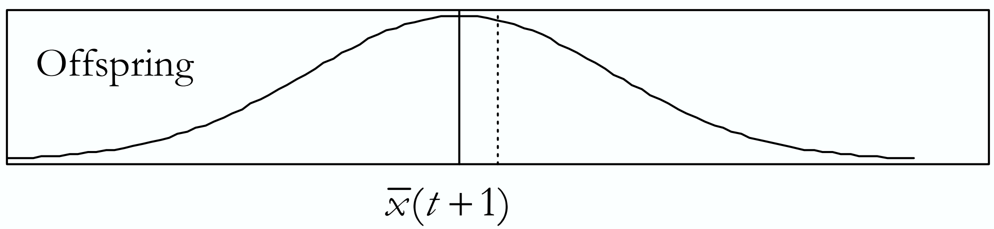


- Selection differential (***S***) is change in mean

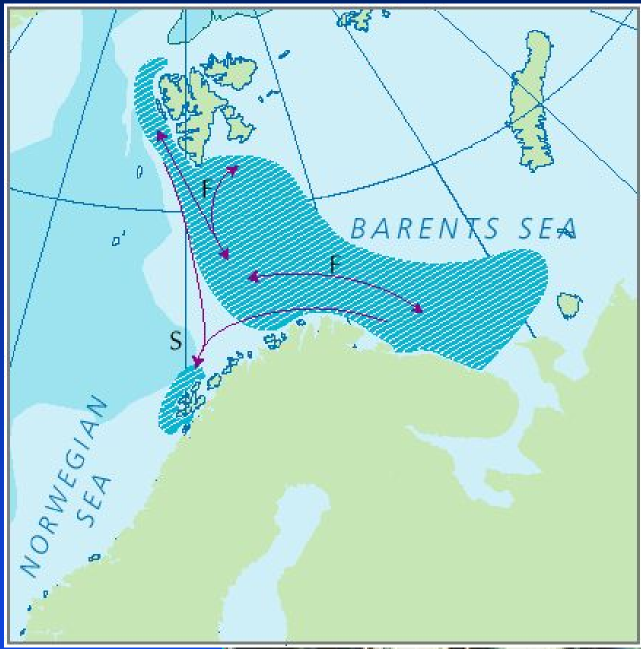
$$S = \overline{x}_w(t) - \overline{x}(t)$$



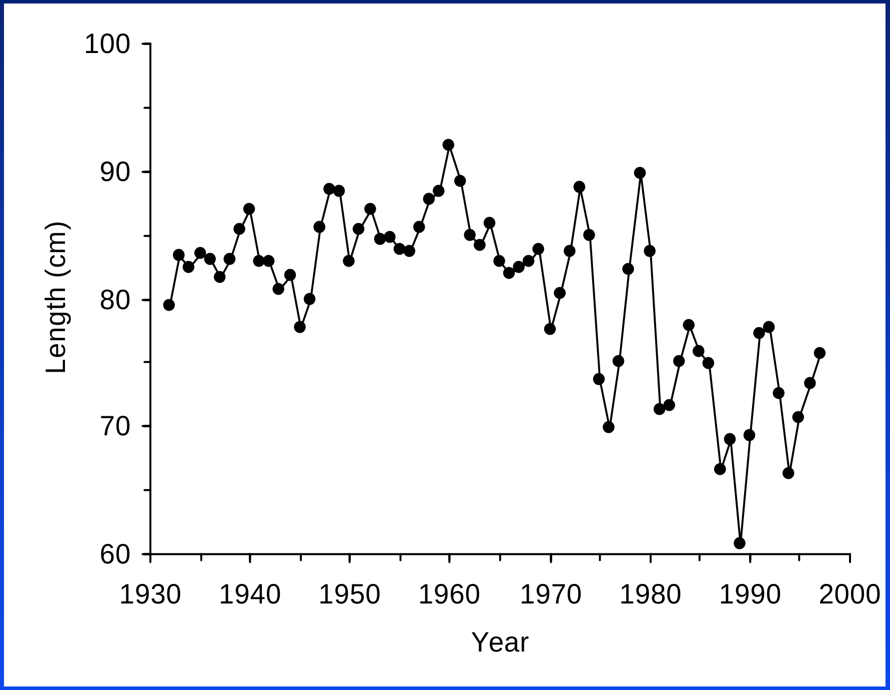
- Response is the change in mean between parents and offspring
  - R=$h^2 S$

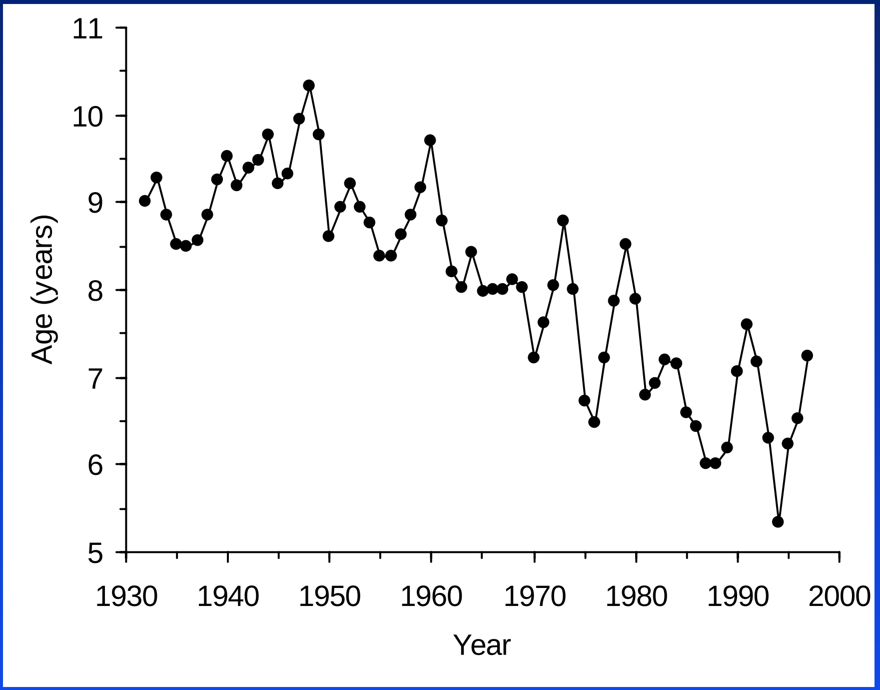


Northeast Arctic cod
(*Gadus morhua*)



Age and size at maturation of Northeast Arctic cod



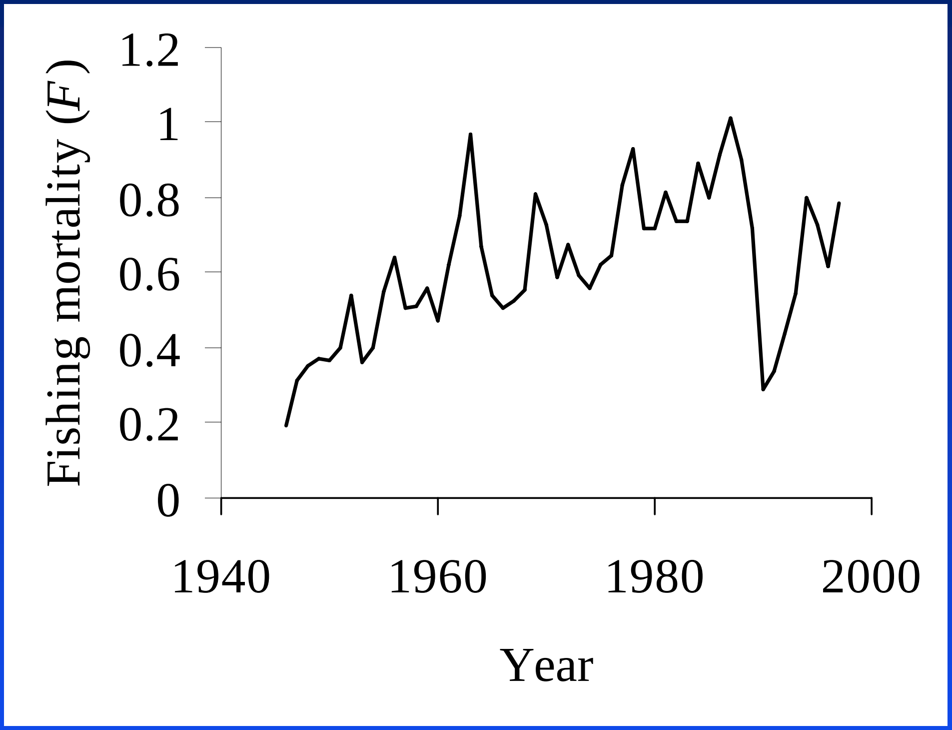


Possible consequences:

- **Sustainable yield ↓**
- **Egg/larval quality ↓**
- **Recruitment variability ↑**

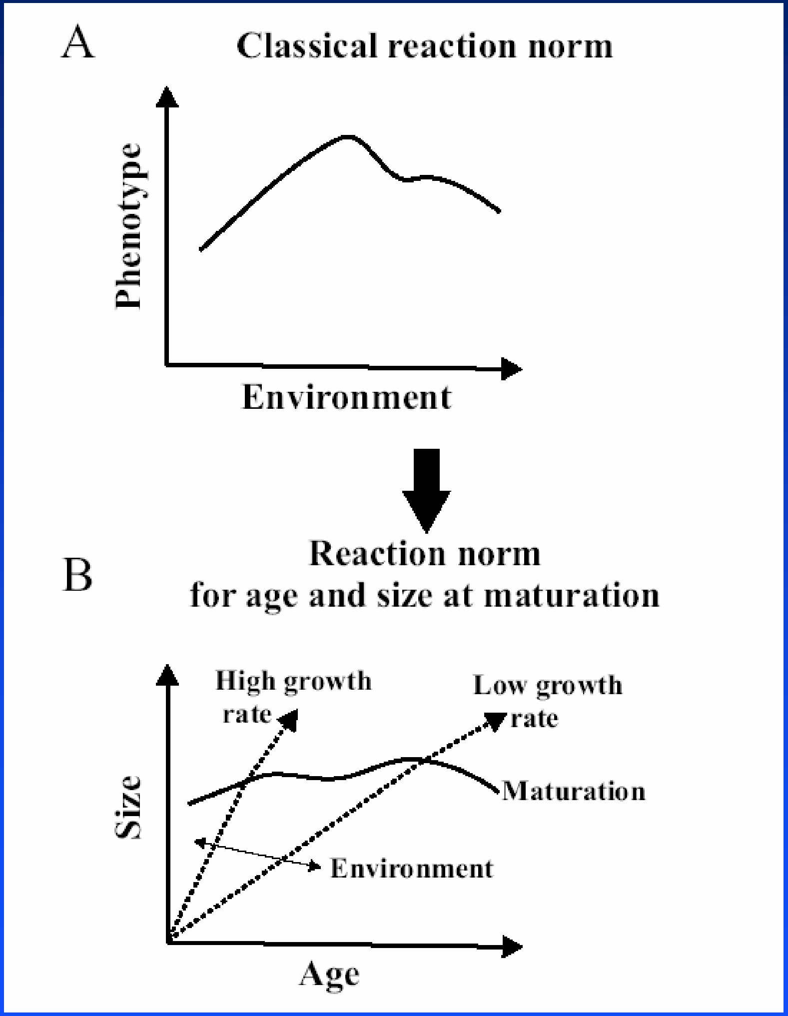
- from Heino *et al.* (2003)

Do declines in cod correspond to increased fishing pressure?



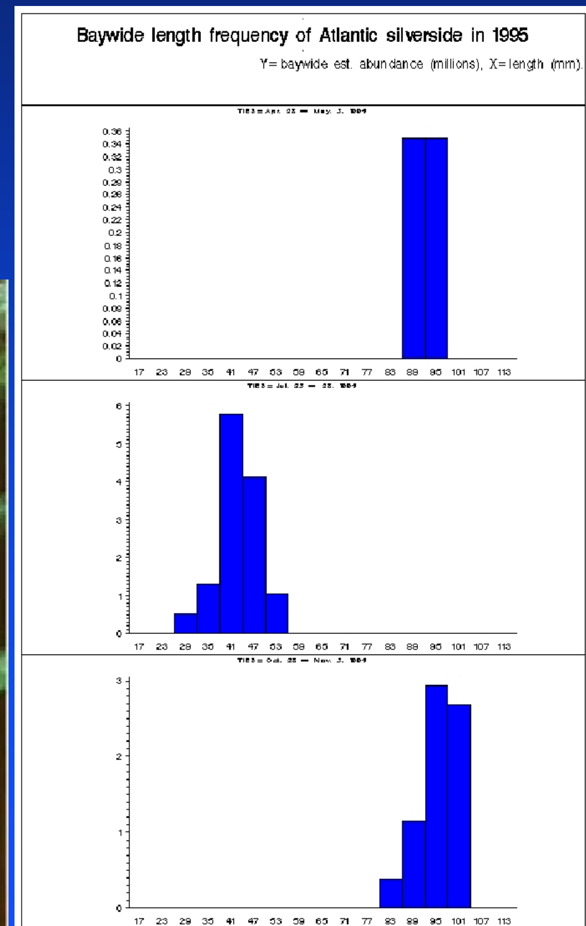
- Total mortality has increased
- Population dominated by younger cod
  $\Longrightarrow$ Younger mean age at maturation

Reaction norm approach

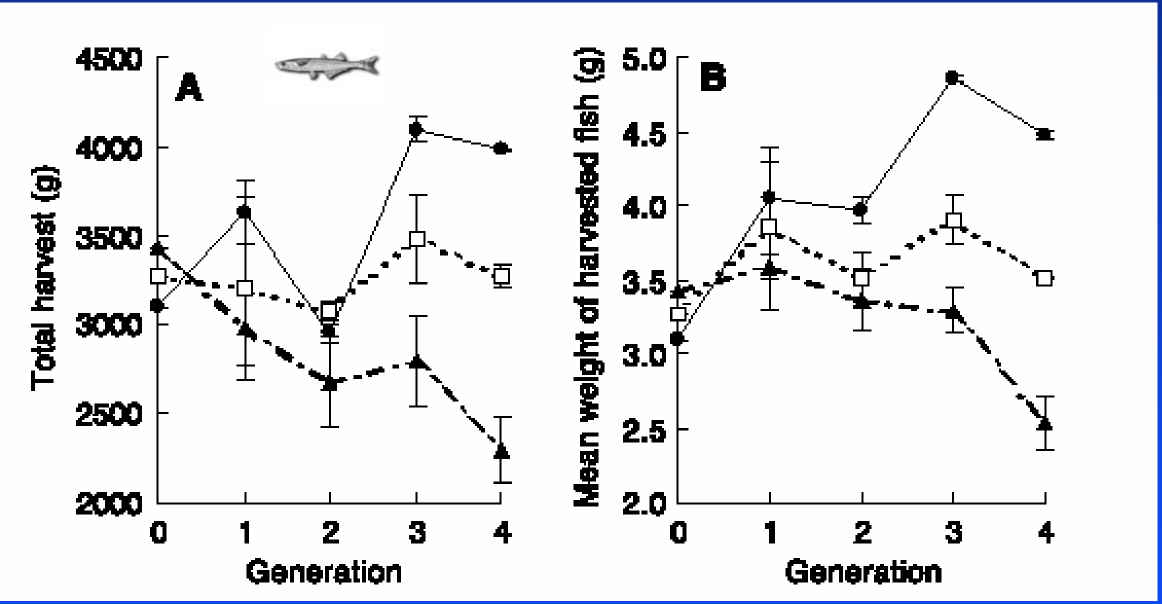


- Reaction norm a measure of a genotype's adaptive flexibility
- Genetic variation underlies sensitivity to environment
- Altered growth affects maturation propensity & distribution of size/age
- Change in age and size at maturation will affect fertility, growth, and survival
- The age-size relationship at maturation itself may respond to selection

Model system: Atlantic silverside (*Menidia menidia*)



Selection on size in Atlantic silverside



-Conover and Munch (2002) *Science* 297:94

- “Small-harvested”: Bottom 90% removed after 190 d
- “Large-harvested”: Top 90% removed after 190 d
- Total biomass, fish size, growth, egg size increased in small- but decreased in large-harvested group
- Short-term gains in yield may come at expense of future yield
- Consider size maxima for harvest size limits?

How selective can fishing be?

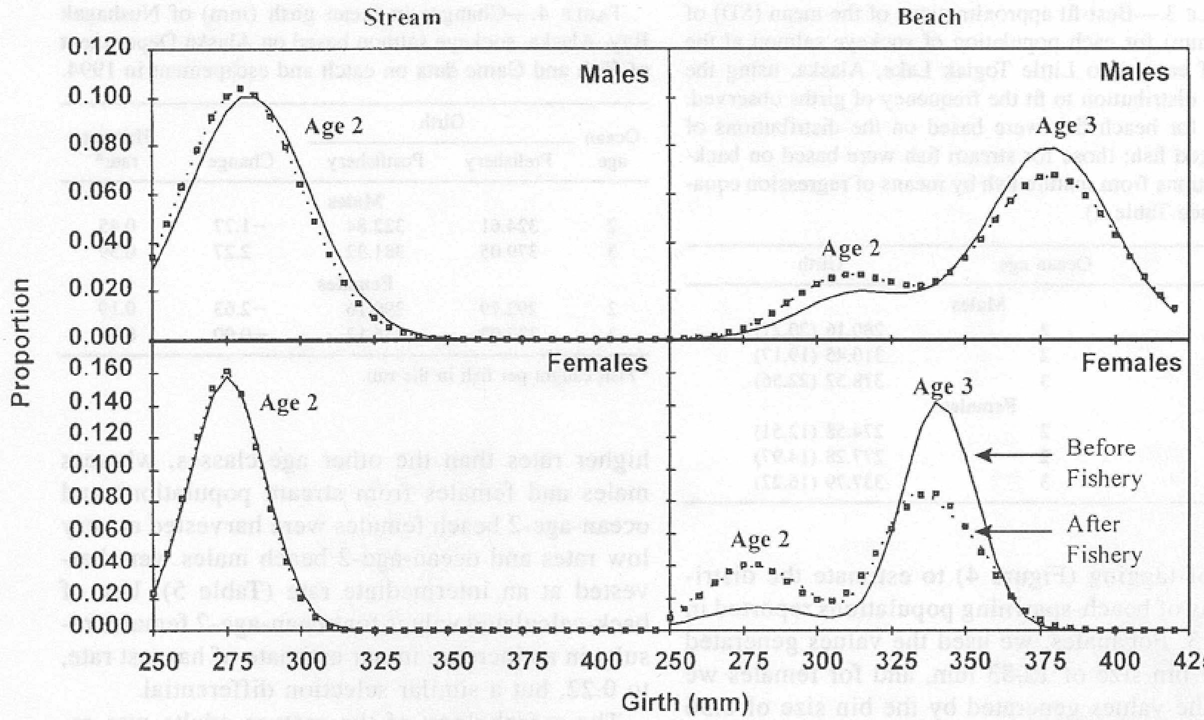
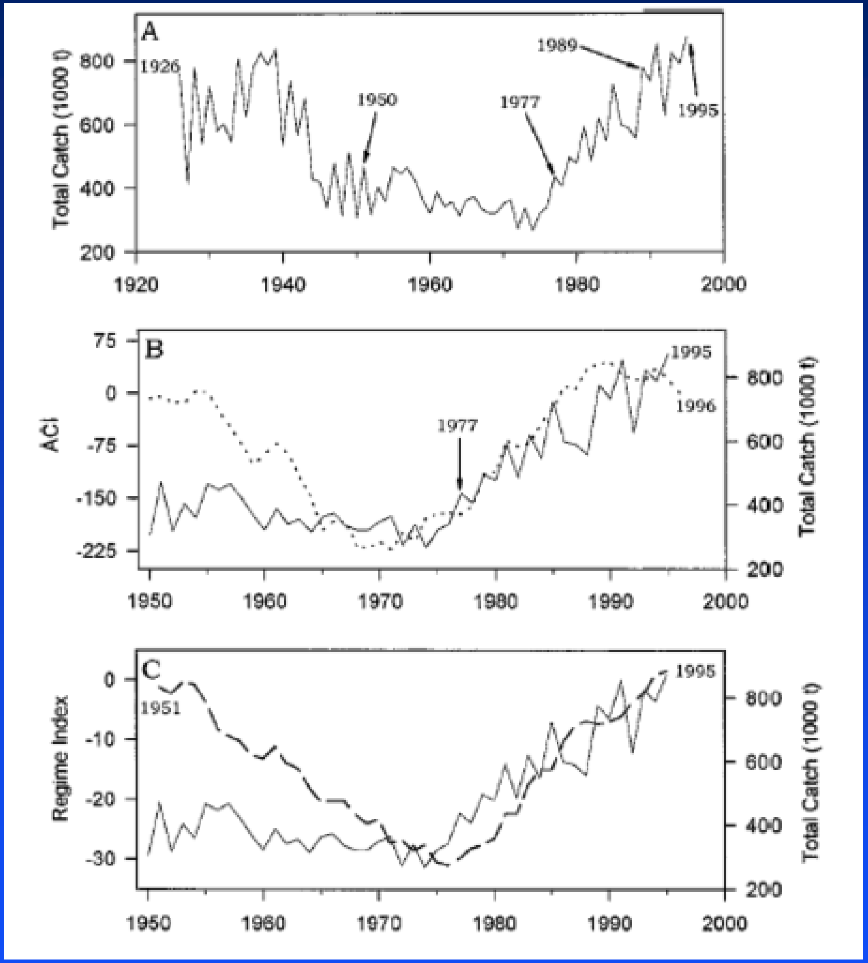


FIGURE 5.—Distribution of girths before and after the fishery for the stream and beach populations in Little Togiak Lake. Squares represent the data on postfishery distributions of girths (see Figure 4). Solid lines represent the prefishery distributions of girths that provide the best postfishery fits (dashed lines) to the data represented by the squares.

- Hamon et al. (2000) *Trans. Am. Fish. Soc.* 129:1300

Salmon catch and climate



-Beamish et al. (1999) *Can. J. Fish. Aquat. Sci.* 56:516

Chinook salmon size trends

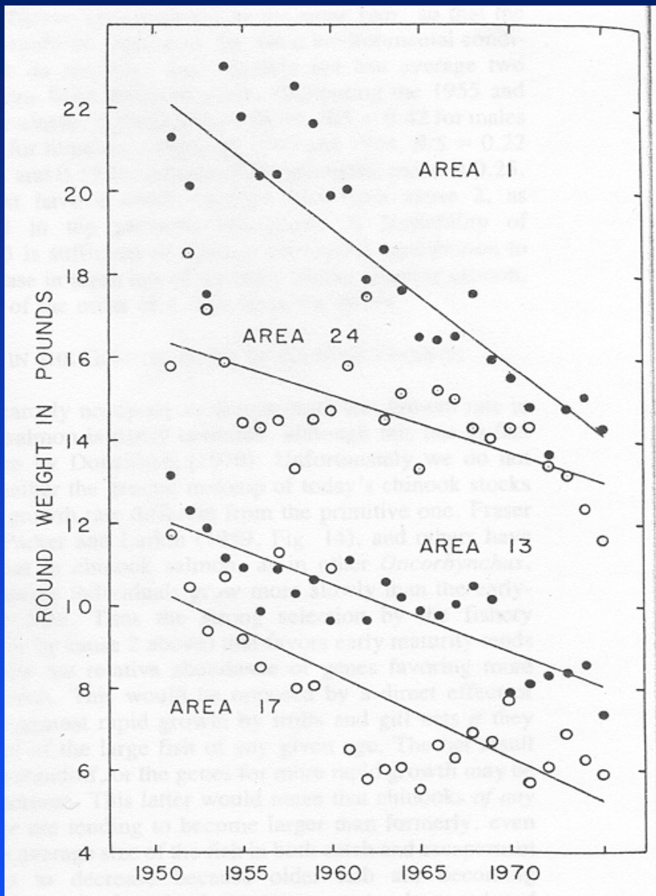
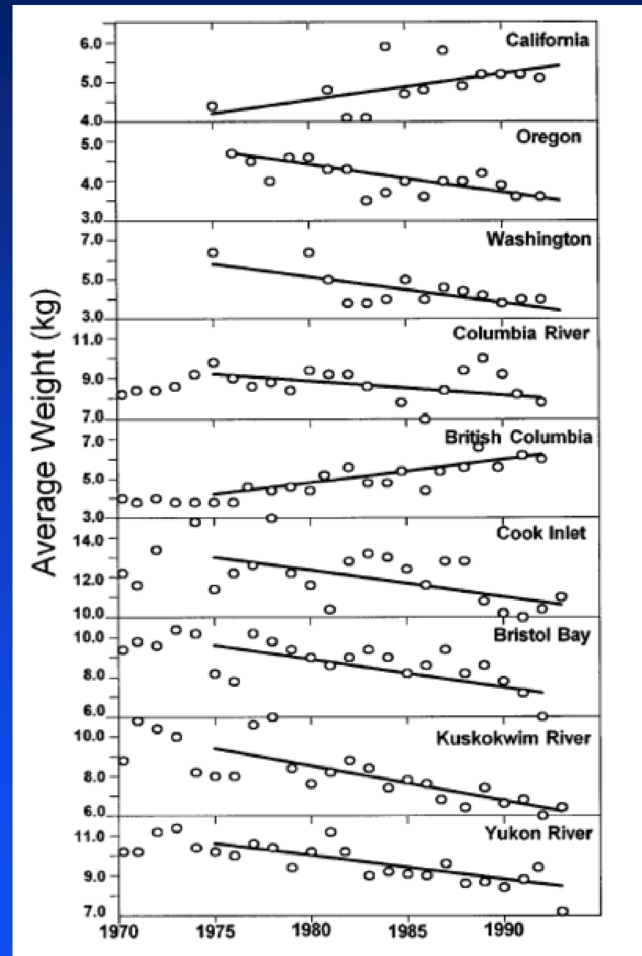


FIG. 12. Mean weights of troll-caught chinook salmon in four statistical areas, with linear trend lines.



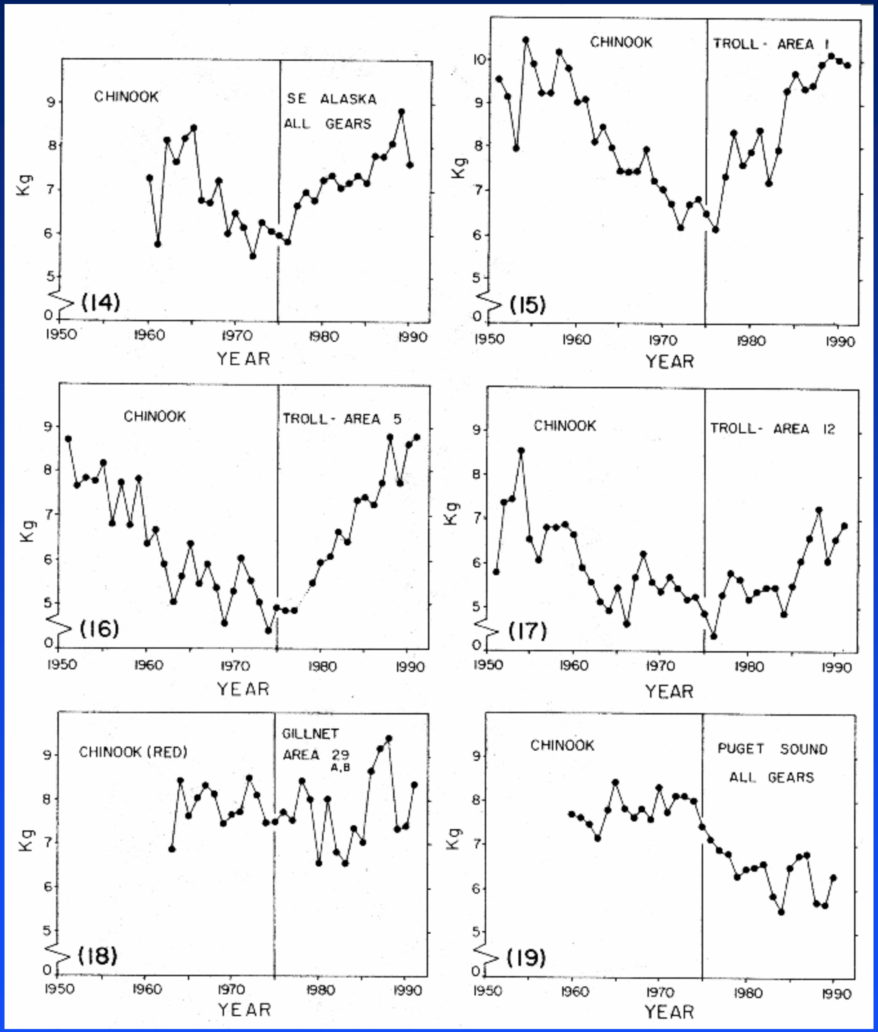
-Ricker (1981) *Can. J. Fish. Aquat. Sci.* 38:1636

-Bigler et al. (1996) *Can. J. Fish. Aquat. Sci.* 53:455

Ricker's conclusions

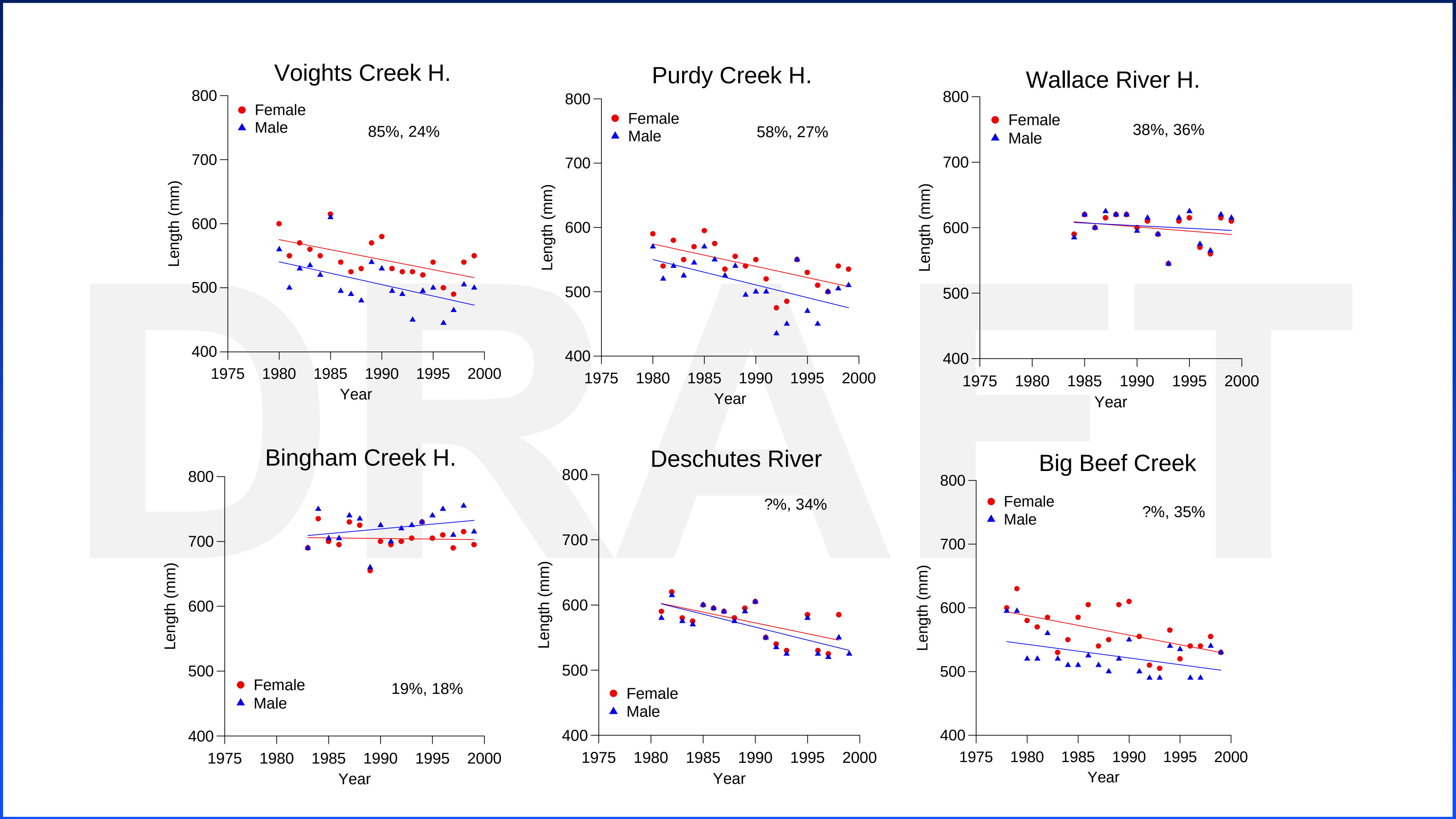
- Possible causes of declines: increased fishing effort, "fishing-up" effect, loss of stocks with larger fish, changing marine environment, selection for younger fish, selection for slower growth, regulatory changes, hatchery production
- Declines in size not consistent with environmental variation
- Increased fishing effort and selective harvest of larger & older fish

Ricker redux



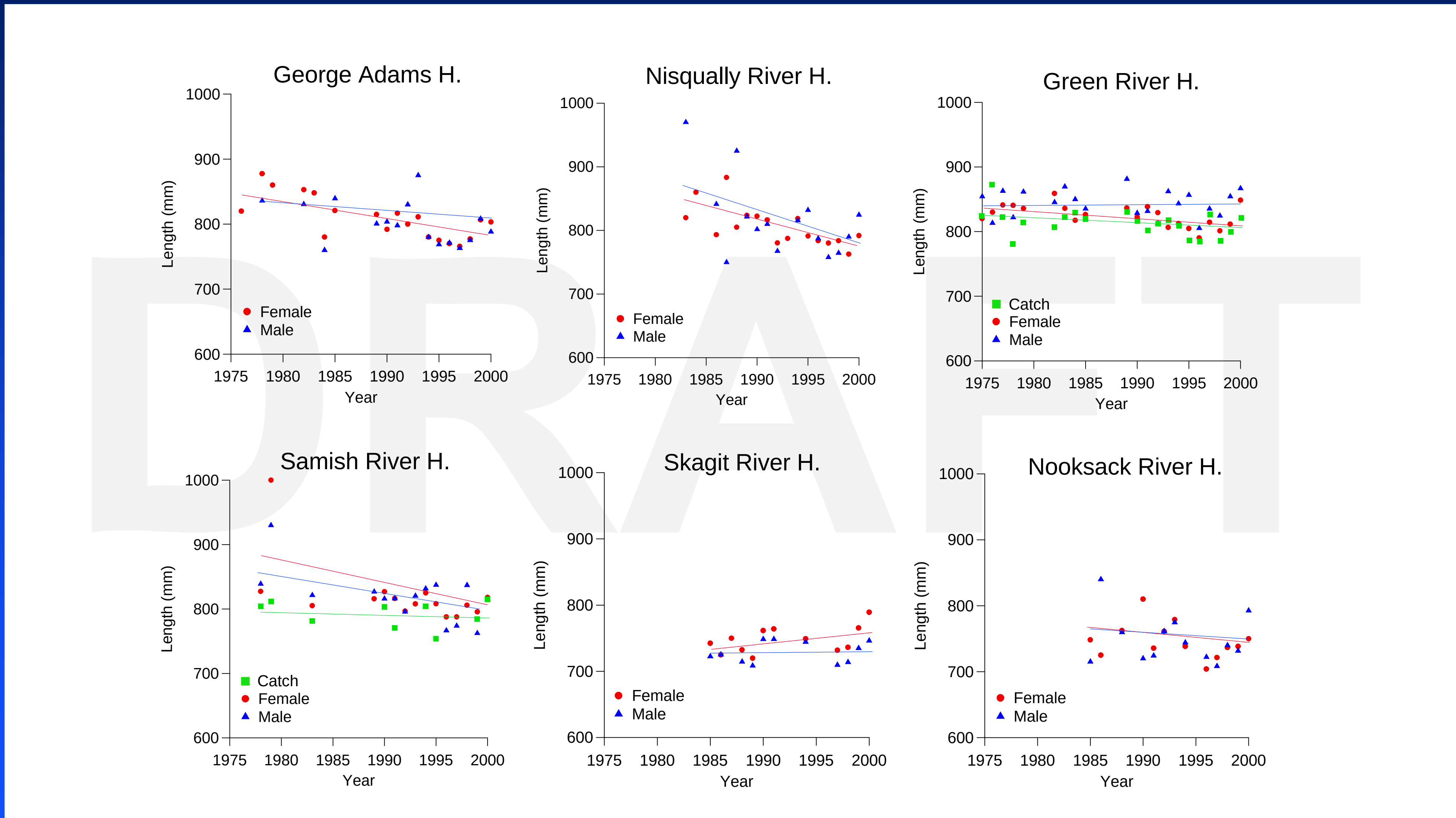
- Ricker (1995) In R. J. Beamish (ed.), *Climate Change and Northern Fish Populations*

Washington coho salmon size trends



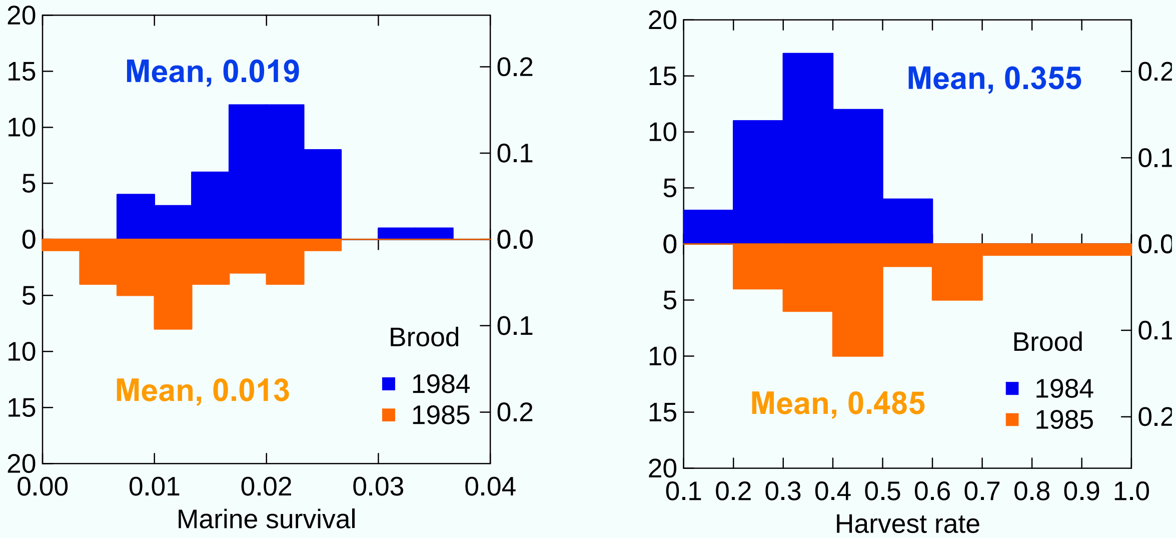
- from C. Knudsen *et al.*, WDFW (unpubl. data)

Washington chinook salmon size trends (age 4 escapement and catch)



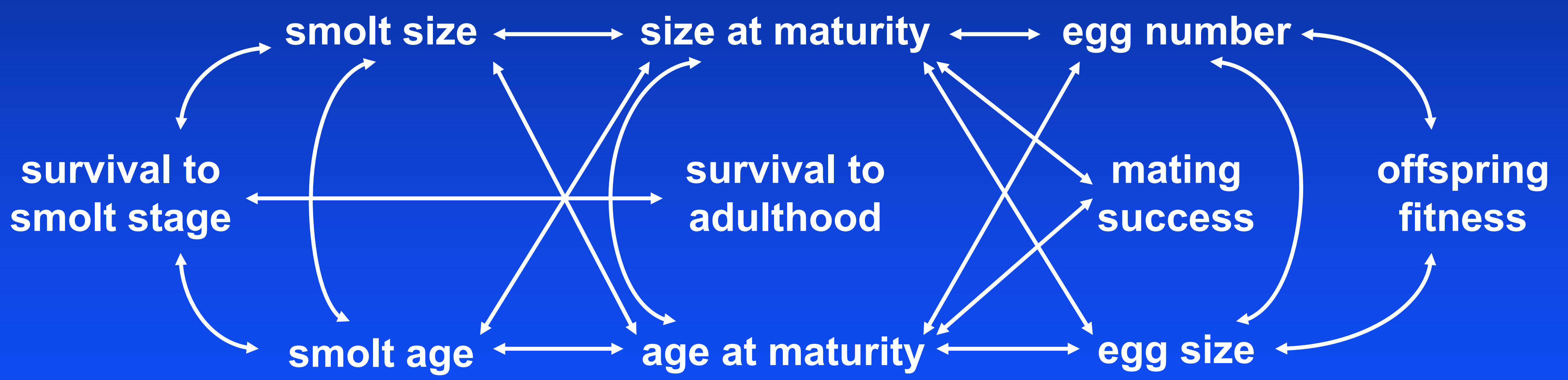
- from J. Hard *et al.*, NMFS & WDFW (unpubl. data)

Family variation in marine survival and harvest rates



- from J. Hard *et al.*, NMFS (unpubl. data)

Prominent features of salmon life history



Covariances of life-history traits in Grovers Cr. (WA) chinook salmon

- Approach: apply empirical estimates of P and G to MV selection models

	Adult age	Fork length	Adult weight	Spawn date	Growth rate
Adult age	719.7 (251.4)	3278.9	375.4	0.069	549.7
Fork length	1705.7	18650.7 (6258.3)	2420.3	0.524	2510.5
Adult weight	143.1	688.0	108267.0 (1082.7)	0.039	353.2
Spawn date	0.046	0.524	0.041	0.008 (0.002)	0.027
Growth rate	575.0	874.8	88.4	0.009	334.1 (102.7)

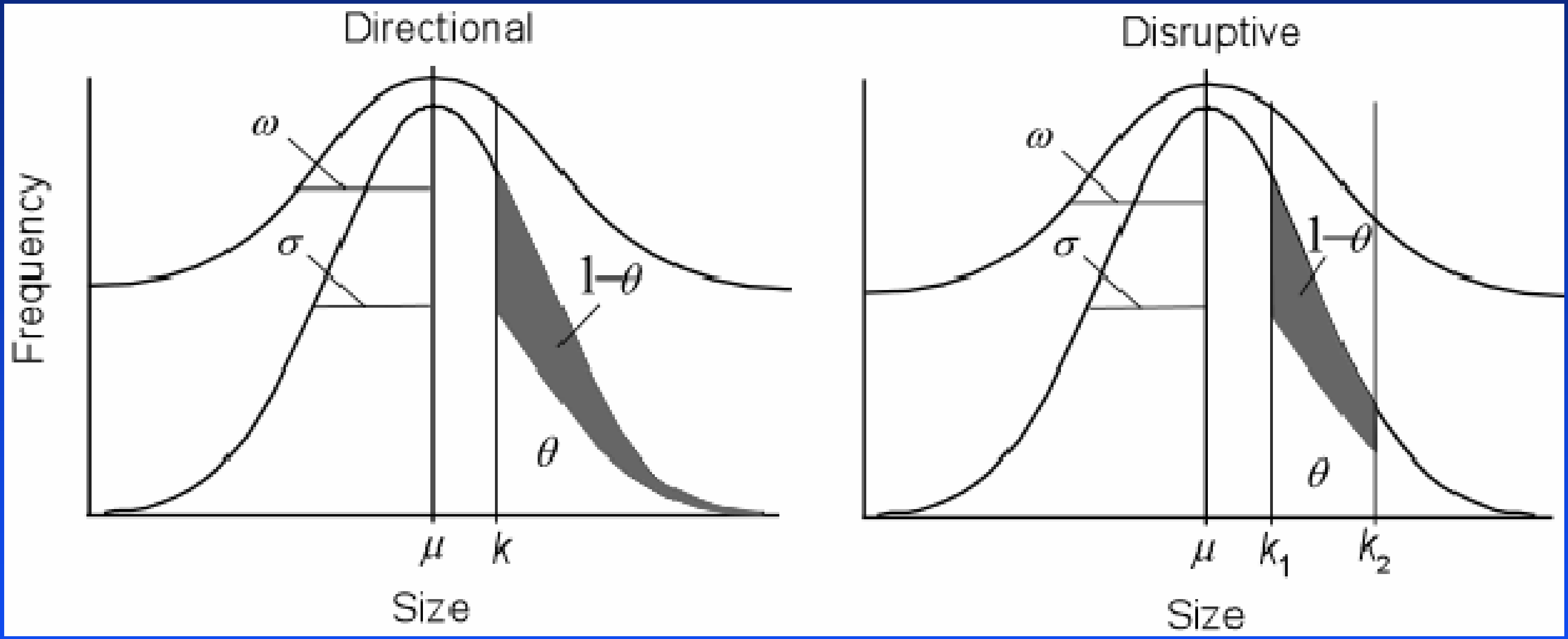
- Data from Hard (2004)

Heritability estimates

Trait	*h^2 (SE)*
Length	0.34 (0.21)
Weight	0.01 (0.09)
Age	0.35 (0.21)
Spawn date	0.23 (0.17)
Growth rate	0.31 (0.20)

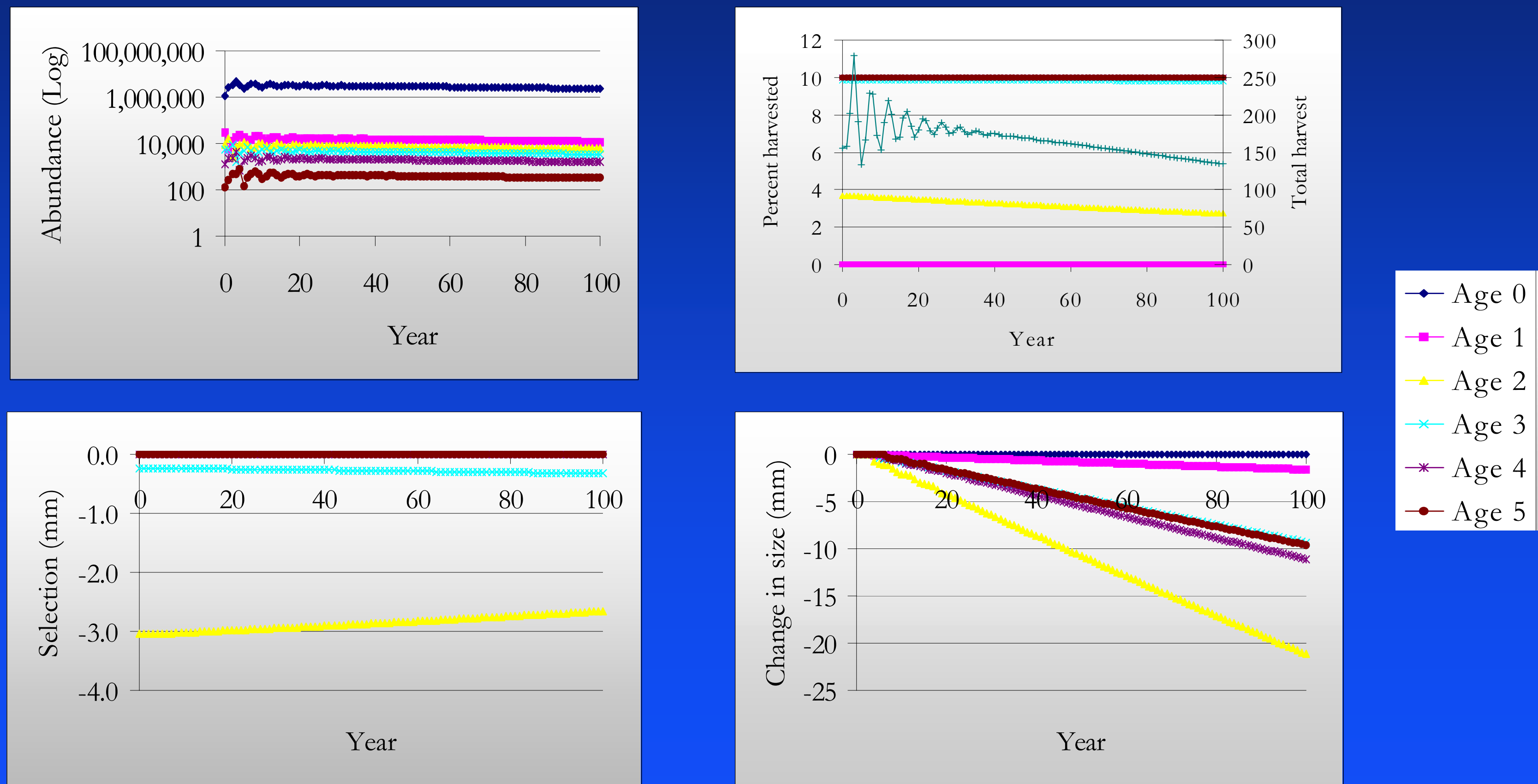
- Data from Hard (2004)

Two forms of harvest selection



Effects of weak directional selection

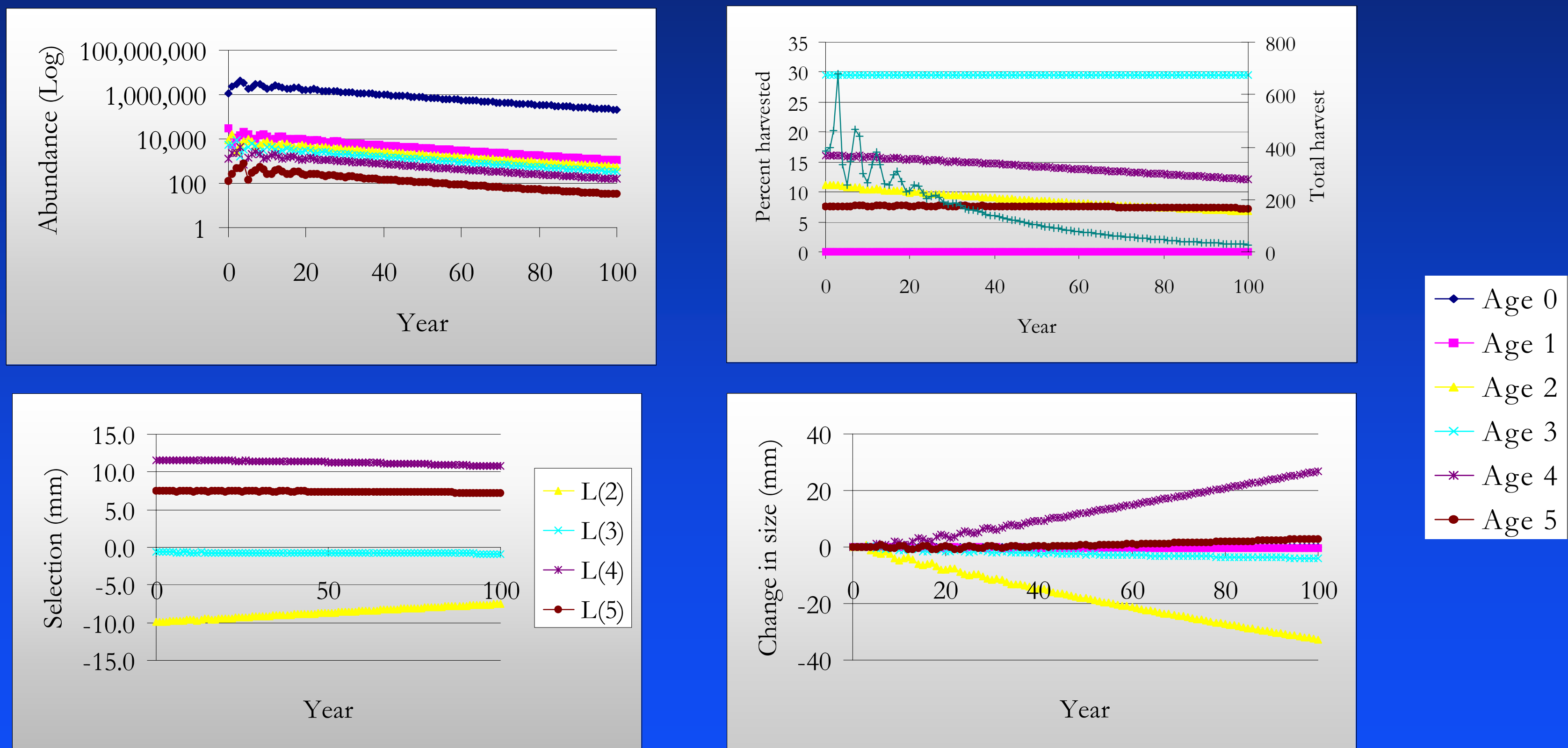
λ = 1.02
Minimum size limit of 500mm
Harvest 10% of age group within size limit



Ages 1, 4 and 5 decrease in size even though selection differential is 0

Effects of weak disruptive selection

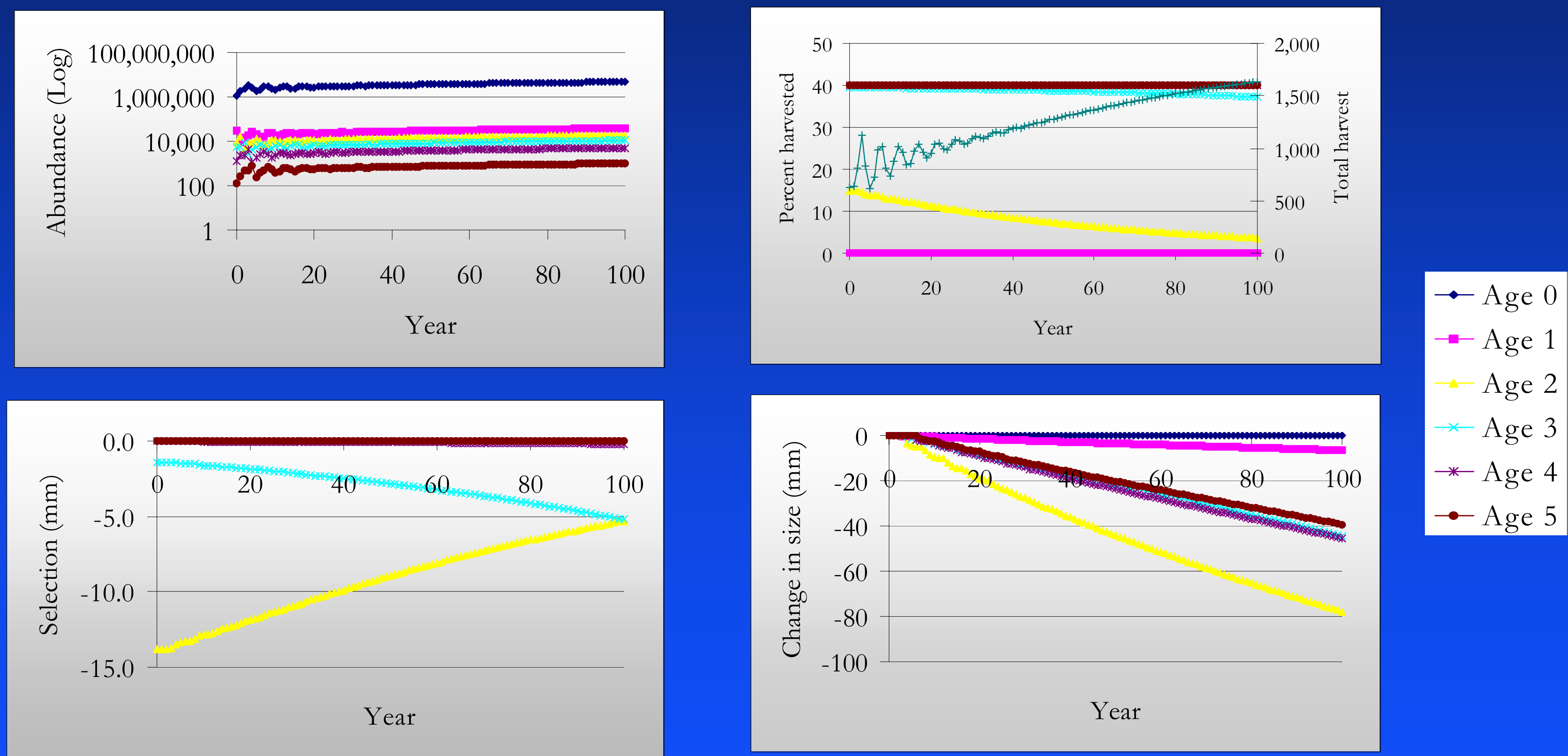
λ = 1.02
Minimum limit 500 and maximum limit 800mm
Harvest 30% of age group within size limit



Bigger age 4 and smaller age 2. No or little response in ages 0, 1, 3 or 5

Effects of strong directional selection

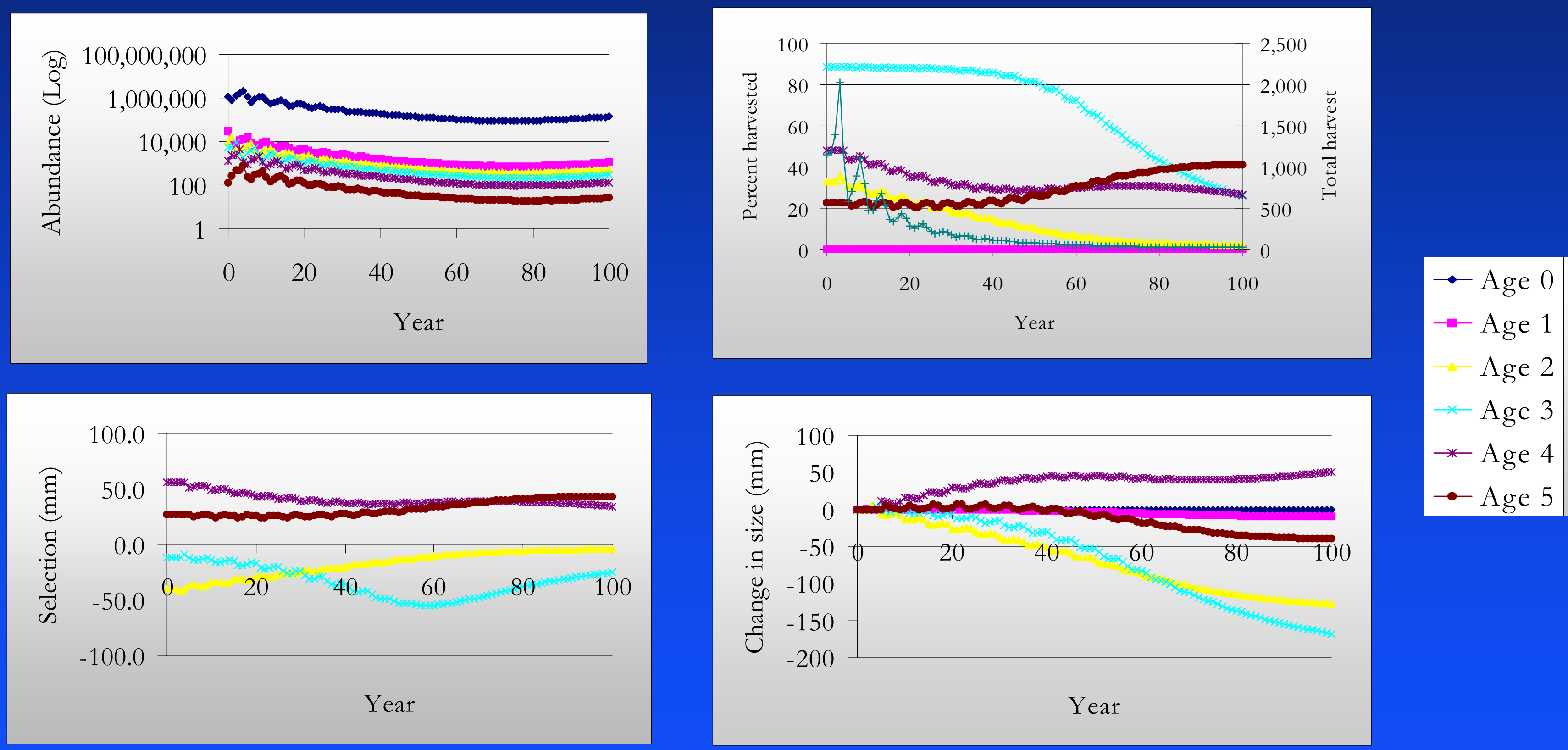
λ = 1.10
Minimum limit 500 mm
Harvest 40% of age group within size limit



Selection on age 3 increases over time, reduction in ages 2, 3, 4 and 5

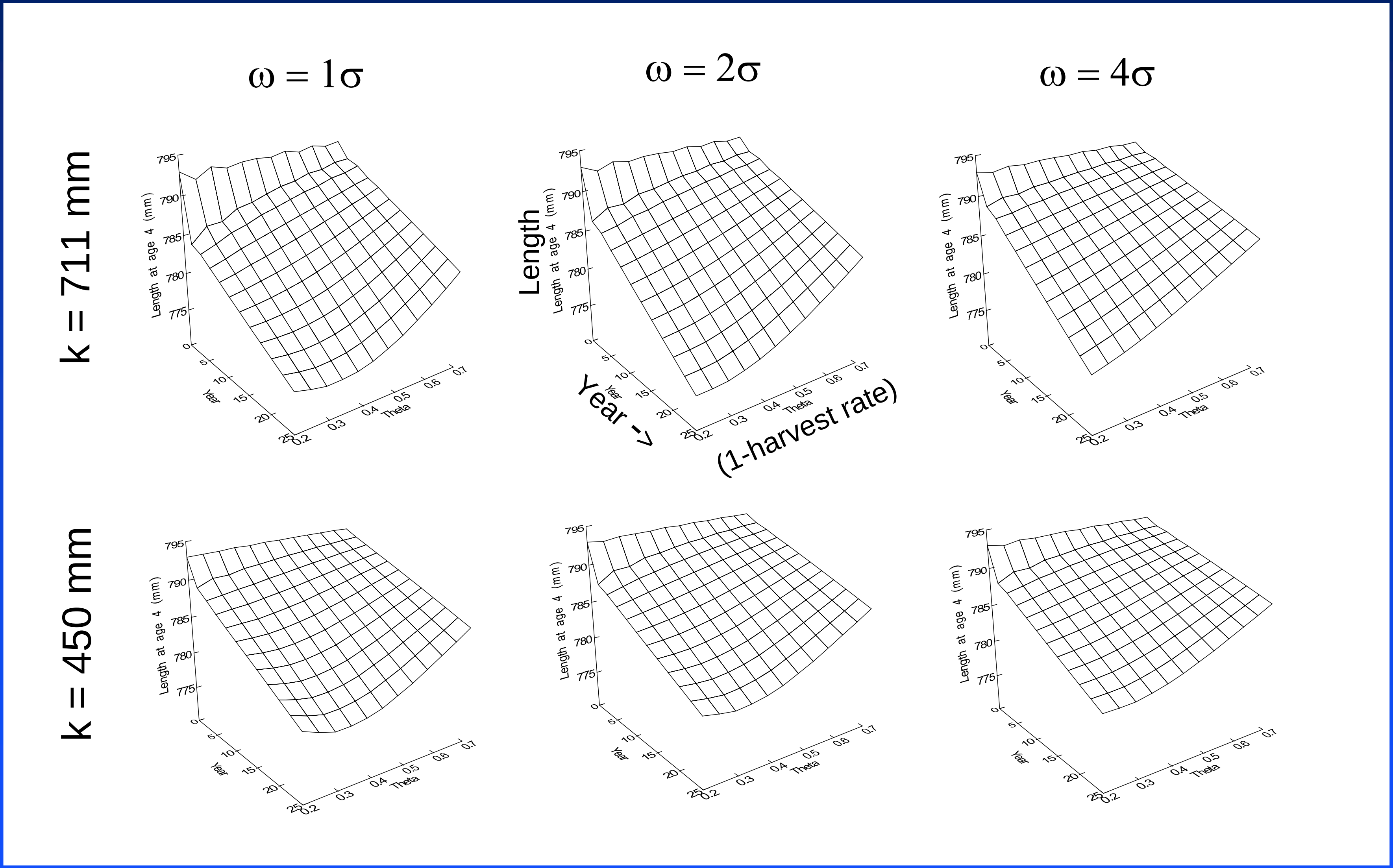
Effects of strong disruptive selection

λ = 1.10
Minimum limit 500 and maximum limit 800mm
Harvest 90% of age group within size limit

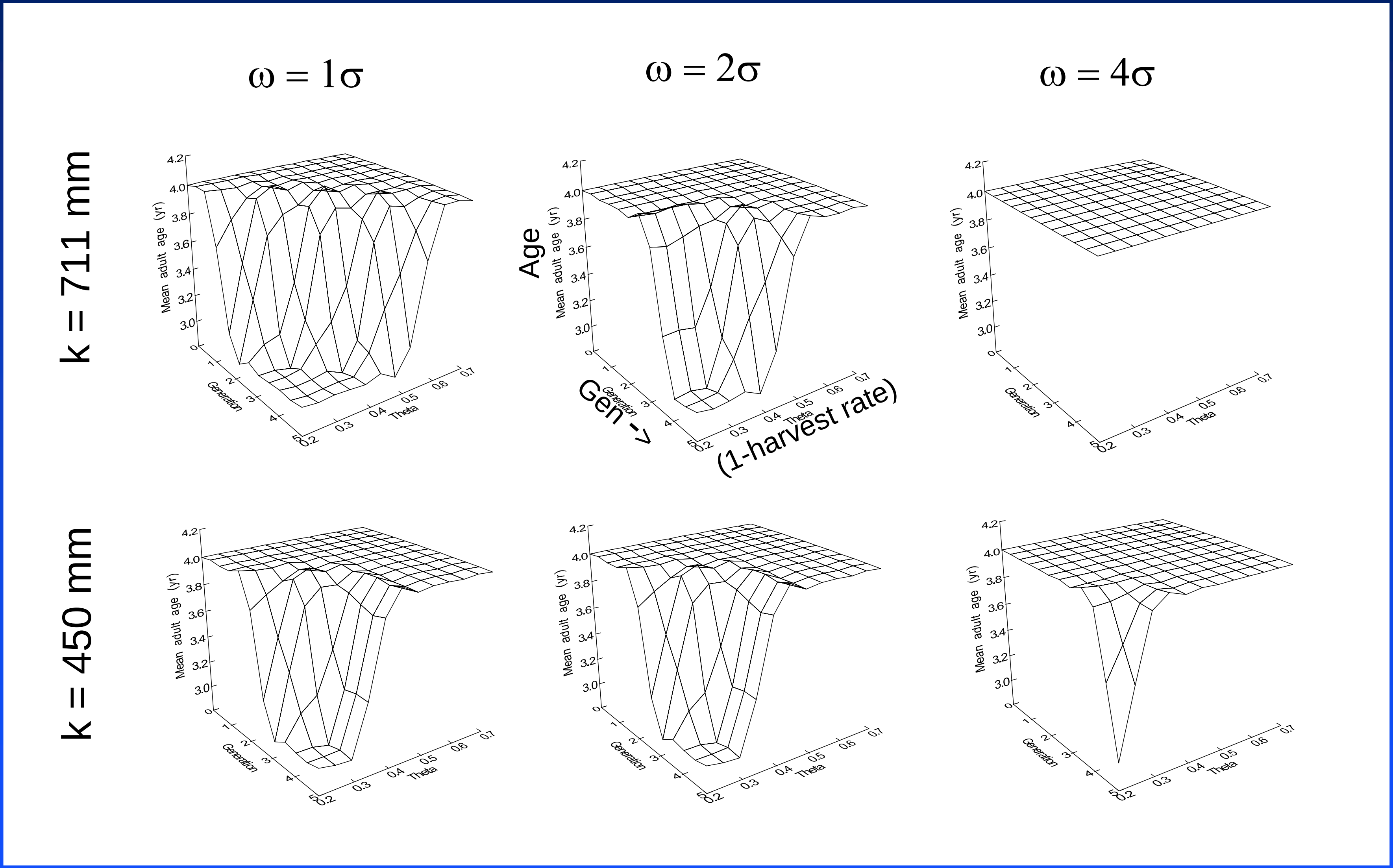


Smaller age 5 despite positive selection

Direct response to directional selection: length at age



Correlated response to directional selection: mean adult age



Modeling summary

- Harvest selection can induce short-term responses in life history
- Critical factors: harvest rate, size threshold, mean and variance of size, strength of natural selection on size, correlations of size with growth and age, population productivity
- Constant harvest rate above a minimum size reduces abundance below levels predicted by a model that does not consider genetic diversity
- All age groups, including those not under selection, respond to selection by becoming smaller and less productive
- Under both directional and disruptive selection, a faster growing population can sustain a higher harvest rate
- Ultimately, adaptation to harvest depends on the genetic and phenotypic relationships between traits

Conclusions

- Size and age at maturity are heritable but strongly influenced by environment
- Age and size covary and are tightly genetically linked
- Other life history traits also respond to fishing
- Vulnerability of chinook salmon life history to fishing is complex
  - Late maturation at large size and low population growth rate ought to increase vulnerability to fishing effects
  - But age structure may provide a buffer
- Selective harvest may reduce size and age on time scales relevant to managers

Implications

For management

- Size-selective harvest likely to affect growth rate and age at maturity as well as size at age
  - Effects of harvest may reduce productivity beyond that explained by demography alone
- Consequences will vary with population productivity and habitat conditions
  - Highly productive populations more likely to cope successfully

For evolution

- The genetic architecture of age and size may augment response to selection for these and other traits
- Harvest selection can affect life history in ways that reduce productivity

- Does size-selective harvest reduce genetic variability?
- Are the evolutionary consequences of fishing reversible?

Recommendations

- Characterize relationship between growth, size, and age structure under selection
- Measure selectivity of harvest and rate of fishing-induced adaptive change
- Identify resilient populations and benign fishing gears and practices
- Reduce harvest selectivity during periods of lower habitat productivity?