Concepts of marine ecosystem carrying capacity, and their application to NE Pacific herring populations

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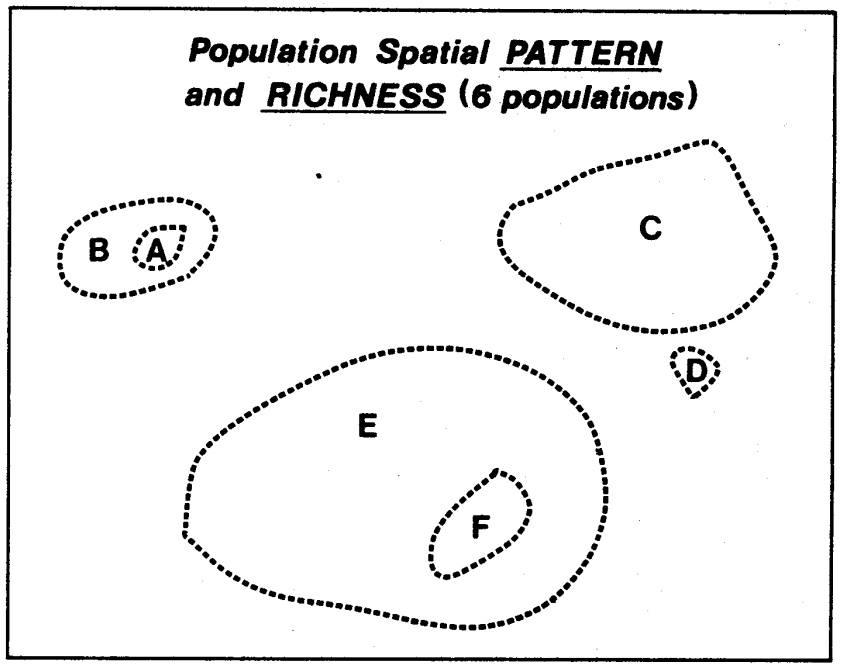
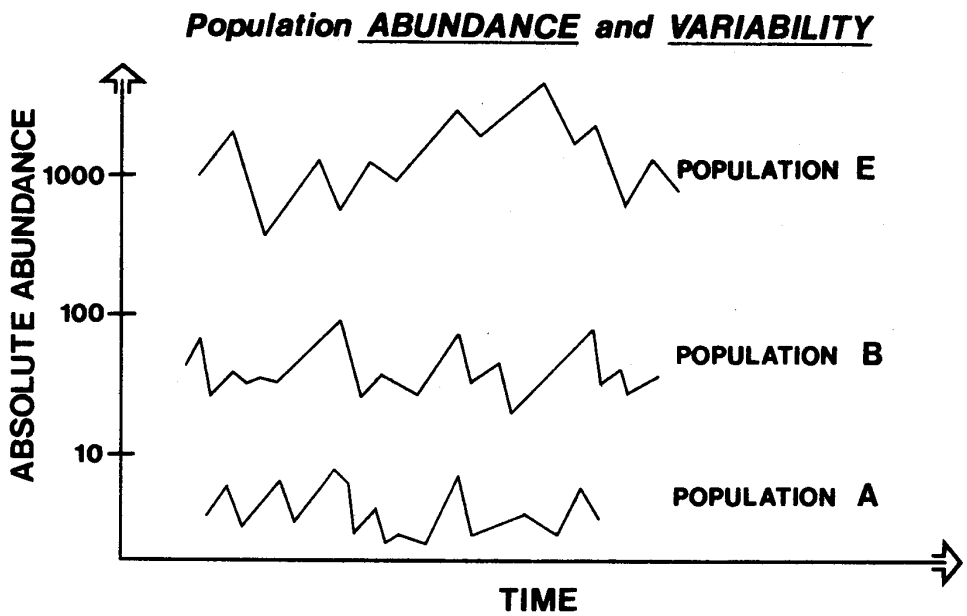
M. Sinclair. 1988. Marine Populations (University of Washington Press. Seattle)

4 components of population regulation:

- what determines the number of different populations of a species (i.e. population richness)?
- What determines the geographical patterns of the populations of a species?
- What controls the absolute (mean) abundance of populations?
- What controls the temporal fluctuations in abundances of populations?





M. Sinclair
(1988. Marine Populations. University of Washington Press. Seattle)

Absolute abundance level

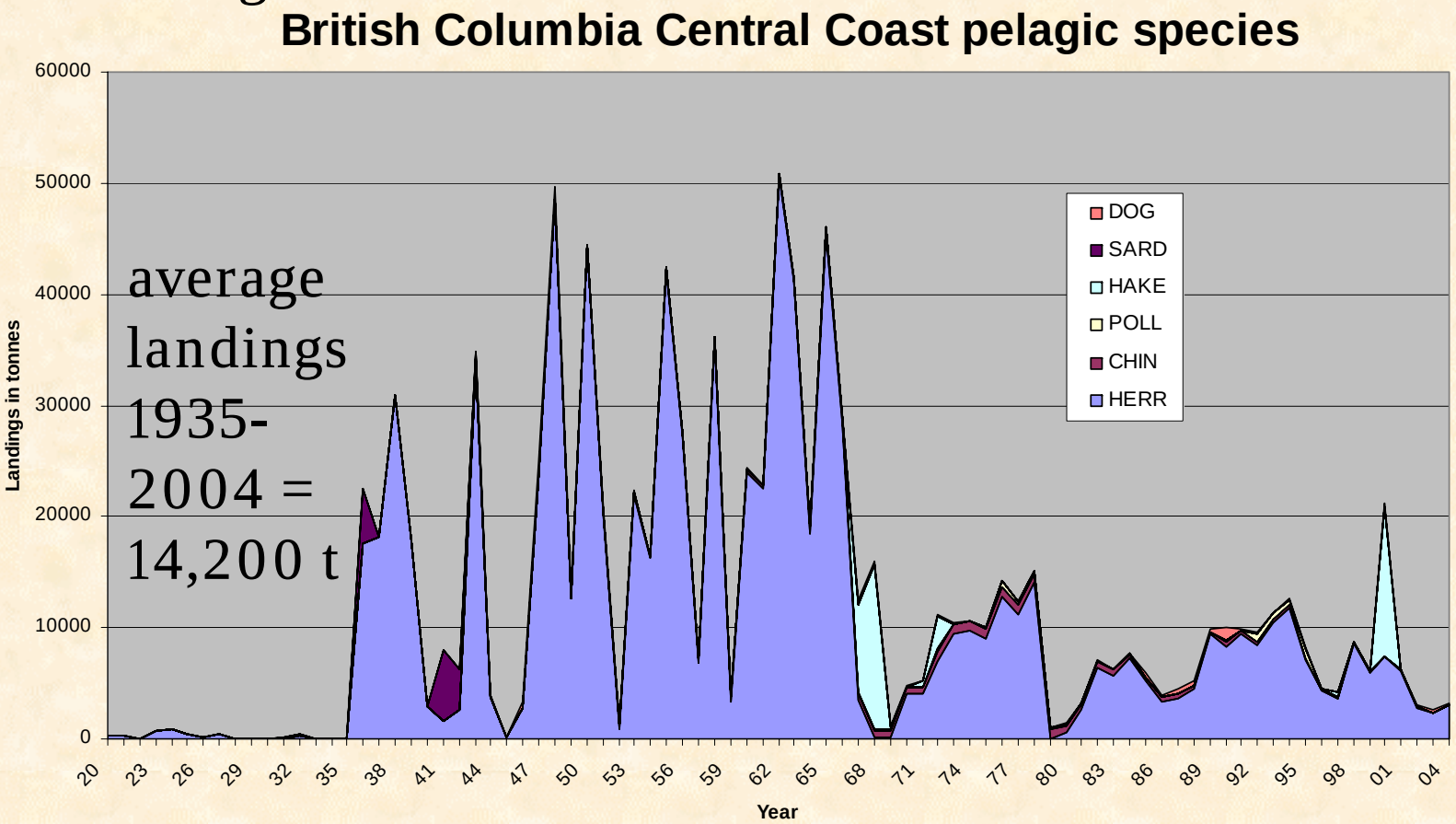
- a central concept for:
  - understanding how marine ecosystems function and respond to perturbations, and
  - how to develop ecosystem-based management

- is related to concepts of "carrying capacity"
  - not received as much attention as what controls temporal fluctuations ("recruitment")
  - central to PICES' CCCC Program ("Climate Change and Carrying Capacity")
  - beginning to be considered (e.g. within CFAME Task Team)

“Carrying Capacity” in marine systems

Often considered in terms of “Sustainable catch”

- complicated by management actions/regulations
- dangerous !



1920 2004

“Carrying Capacity” in marine systems

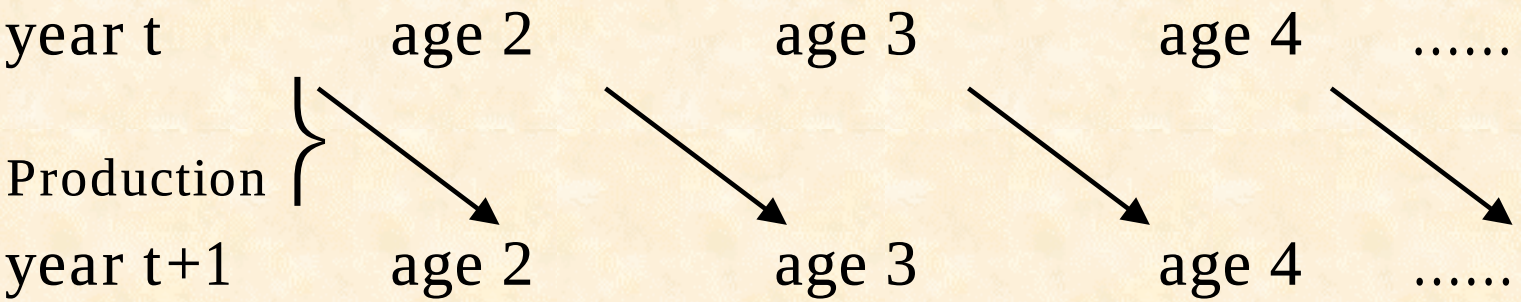
Define “carrying capacity” using biomass rather than numbers, i.e. the ability of an ecosystem to produce new biomass

=> Production

$Biomass_t = Biomass_0 + growth + recruits – catch – deaths$

"Carrying Capacity" in marine systems

Calculate on an age-structured (biomass) basis:



$$\text{Production}_{t \Rightarrow t+1} = (\text{Biomass}_{t+1} + \text{Catch}_t) - \text{Biomass}_t$$

"Carrying Capacity" in marine systems

Since $\text{Production}_{t \Rightarrow t+1} = (\text{Biomass}_{t+1} + \text{Catch}_t) - \text{Biomass}_t$

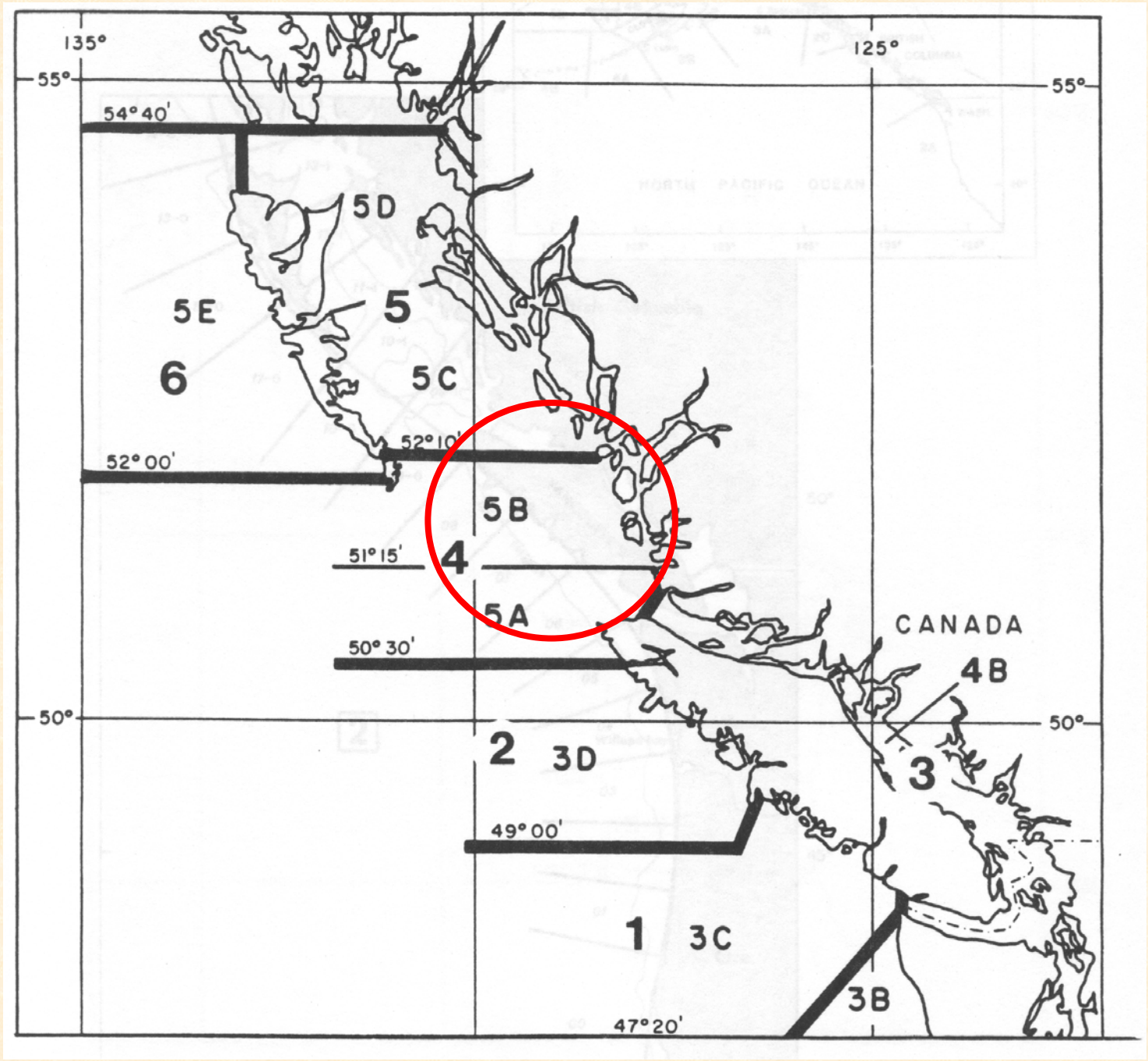
- calculate using instantaneous rates:

$$\frac{(B_{t+1} + \text{Catch}_t)}{B_t} = e^{(G-M)}$$

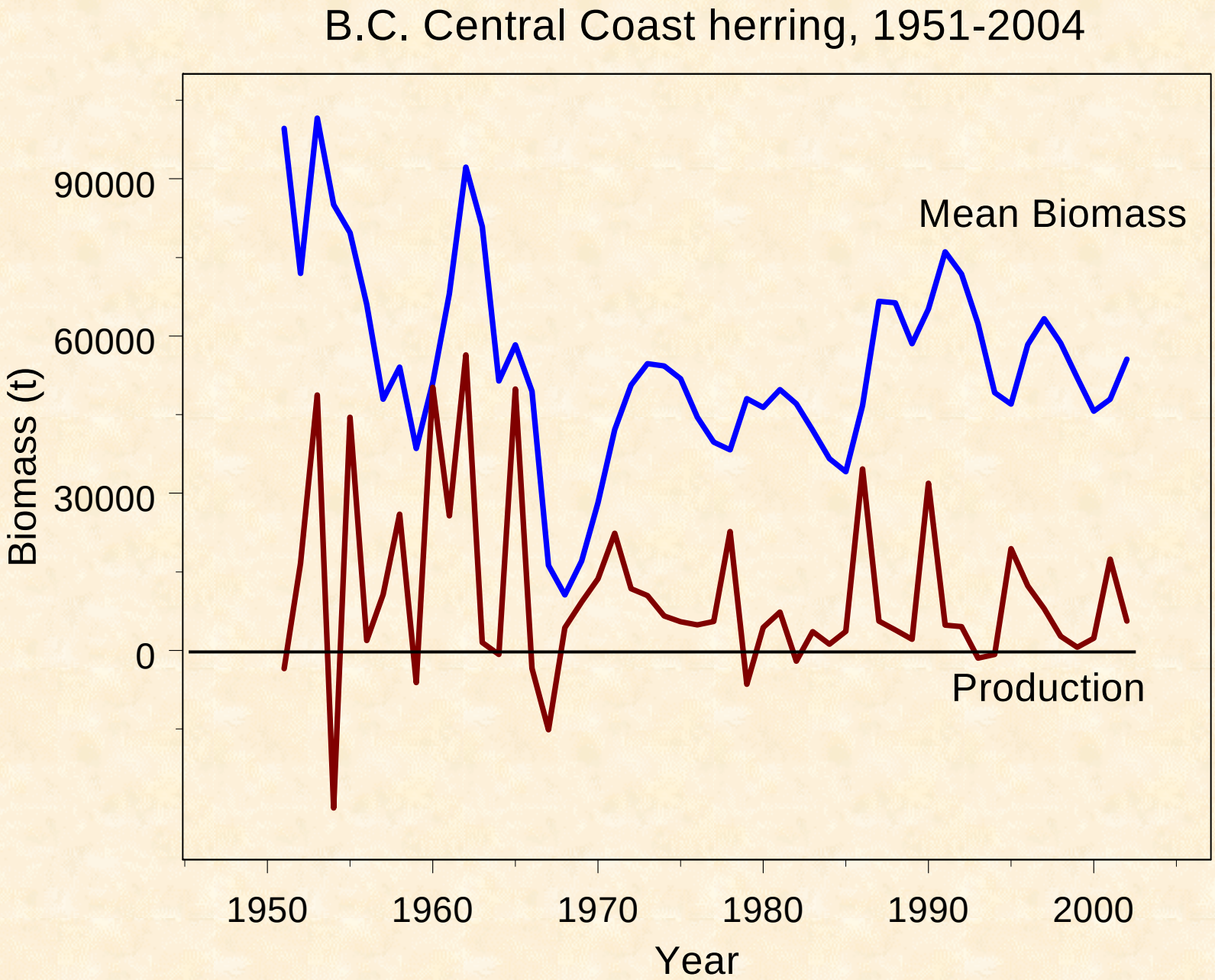
with G instantaneous growth rate
M instantaneous nat. mortality

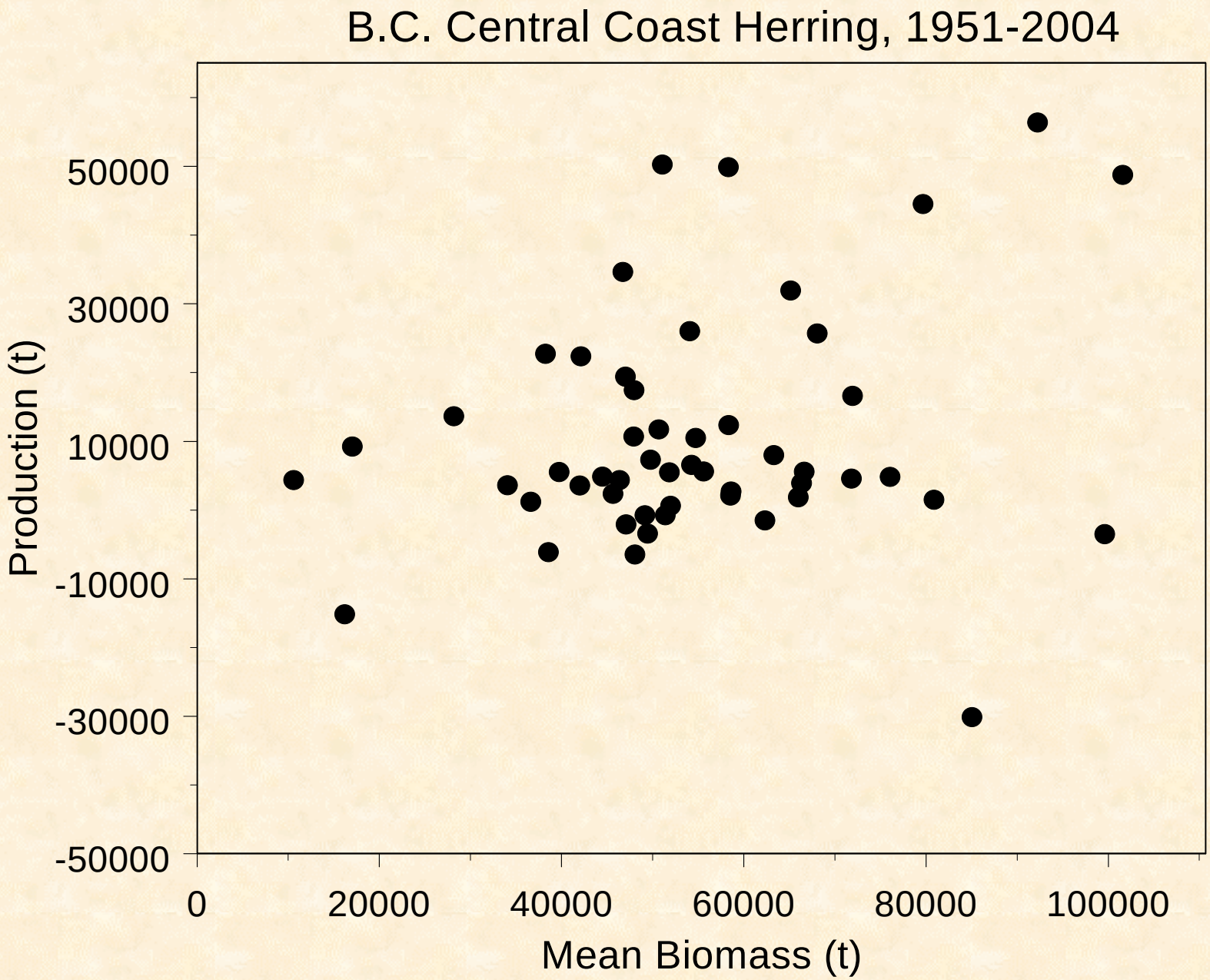
$$\log_e [\, (B_{t+1} + \text{Catch}_t) / B_t \,] = (G - M)$$

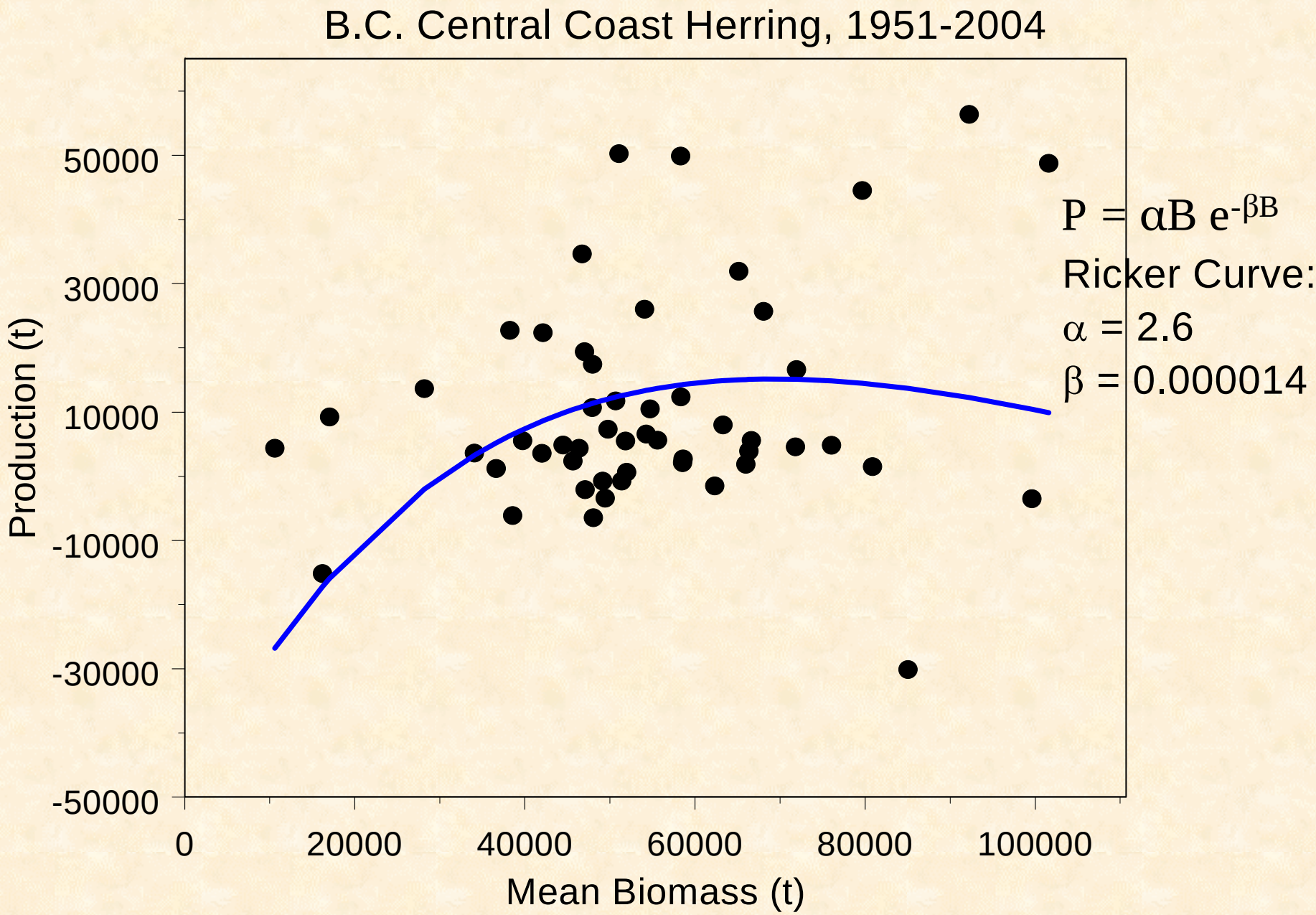
$(G - M)\, \overline{B}_{t \Rightarrow t+1}$ is the **production over time t ⇒ t+1**
with $\overline{B}_{t \Rightarrow t+1}$ the geometric mean biomass during year t

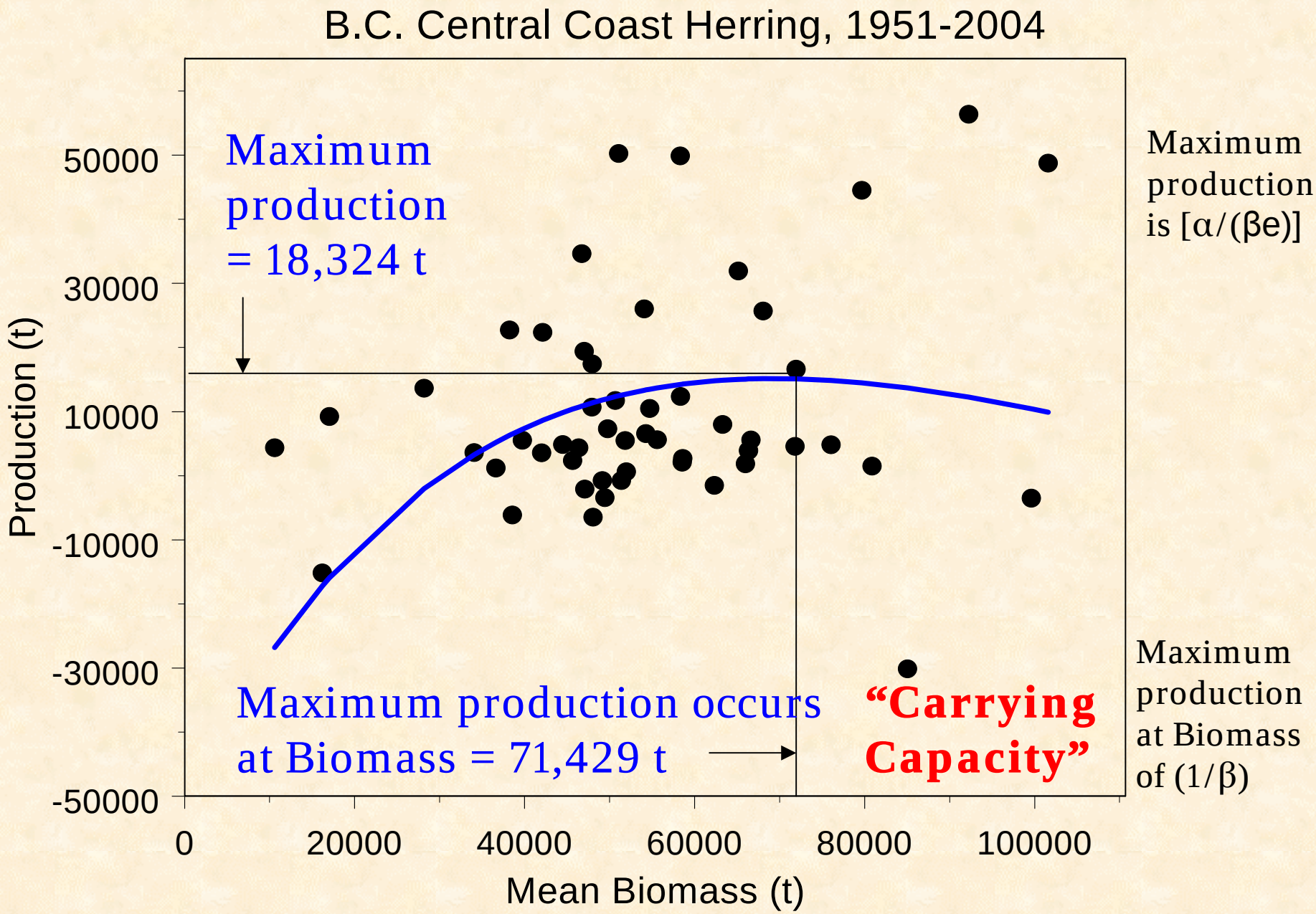


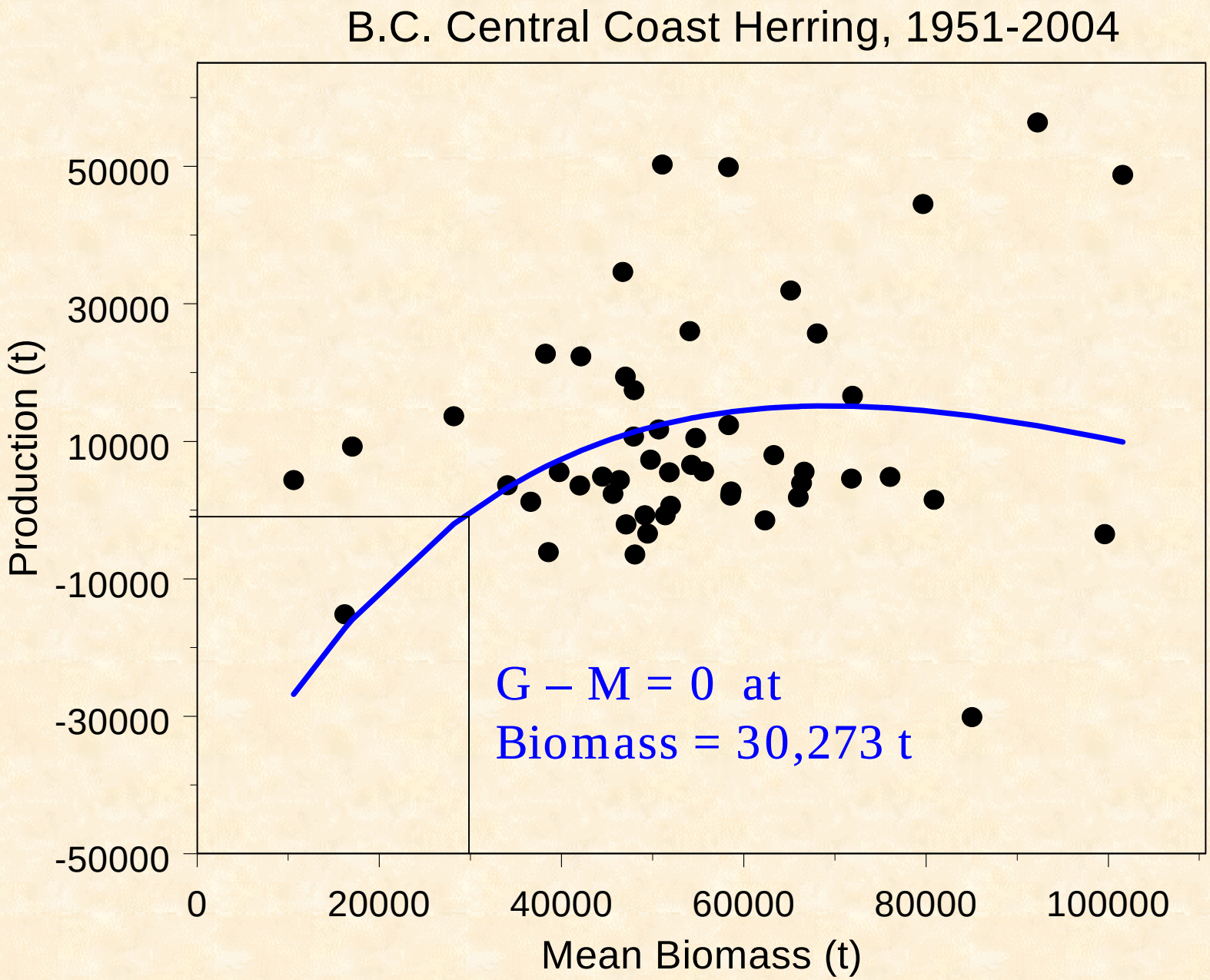
Application to the herring population in the central coast, British Columbia

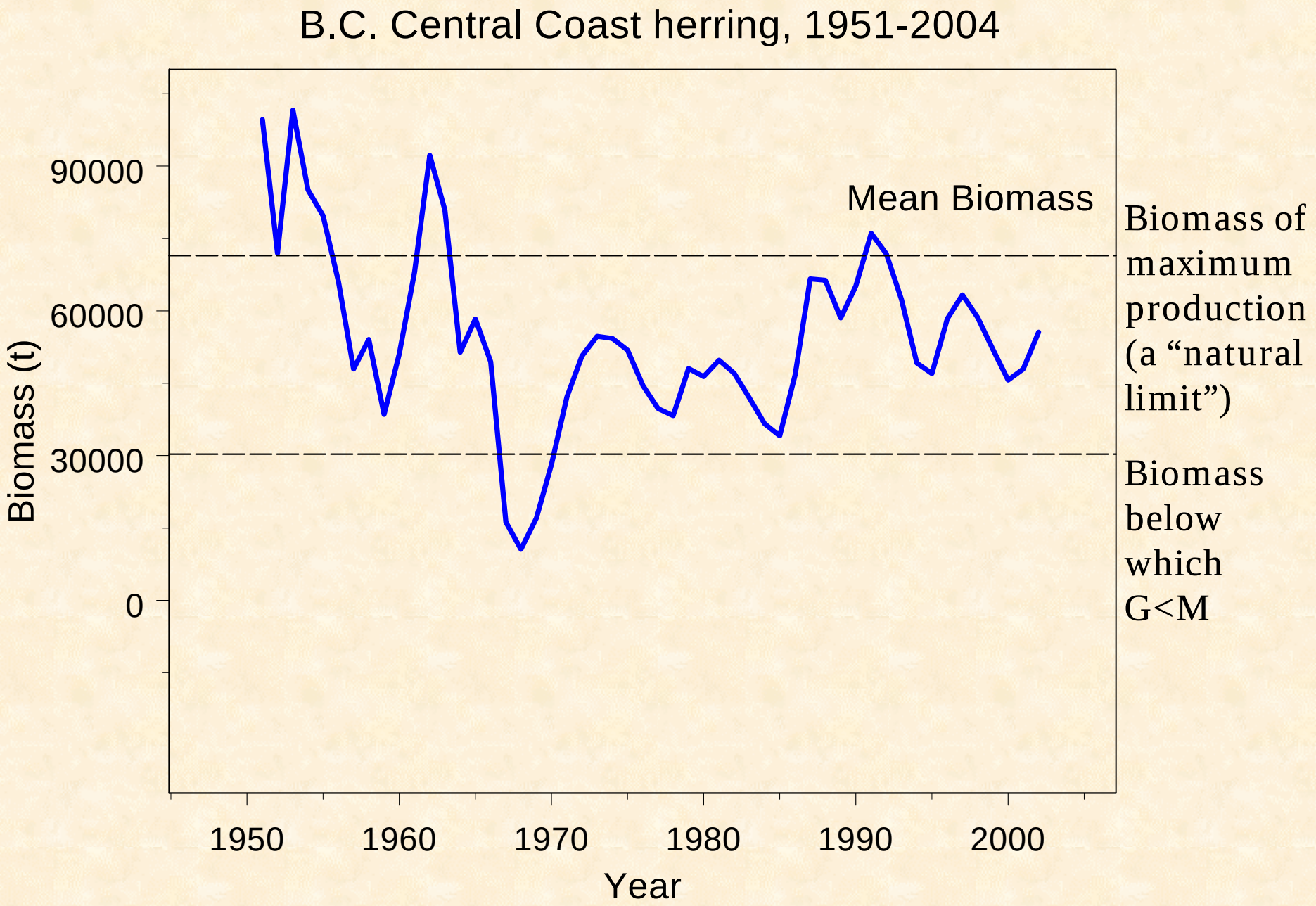

B.C. Central Coast herring, 1951-2004
Biomass (t)
90000
60000
30000
0
Mean Biomass
Production
1950
1960
1970
1980
1990
2000
Year

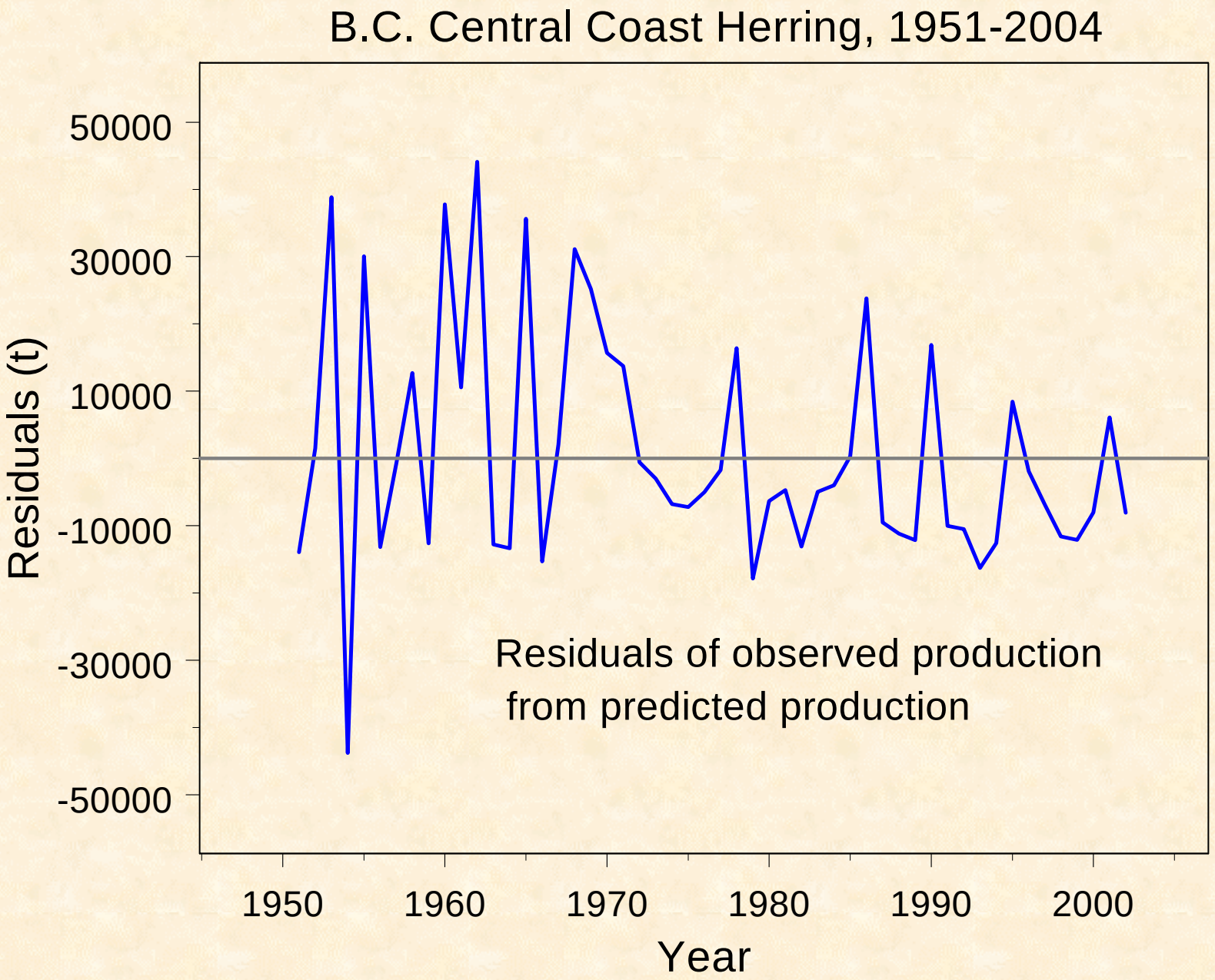

B.C. Central Coast Herring, 1951-2004
Production (t)
50000
30000
10000
-10000
-30000
-50000
0
20000
40000
60000
80000
100000
Mean Biomass (t)

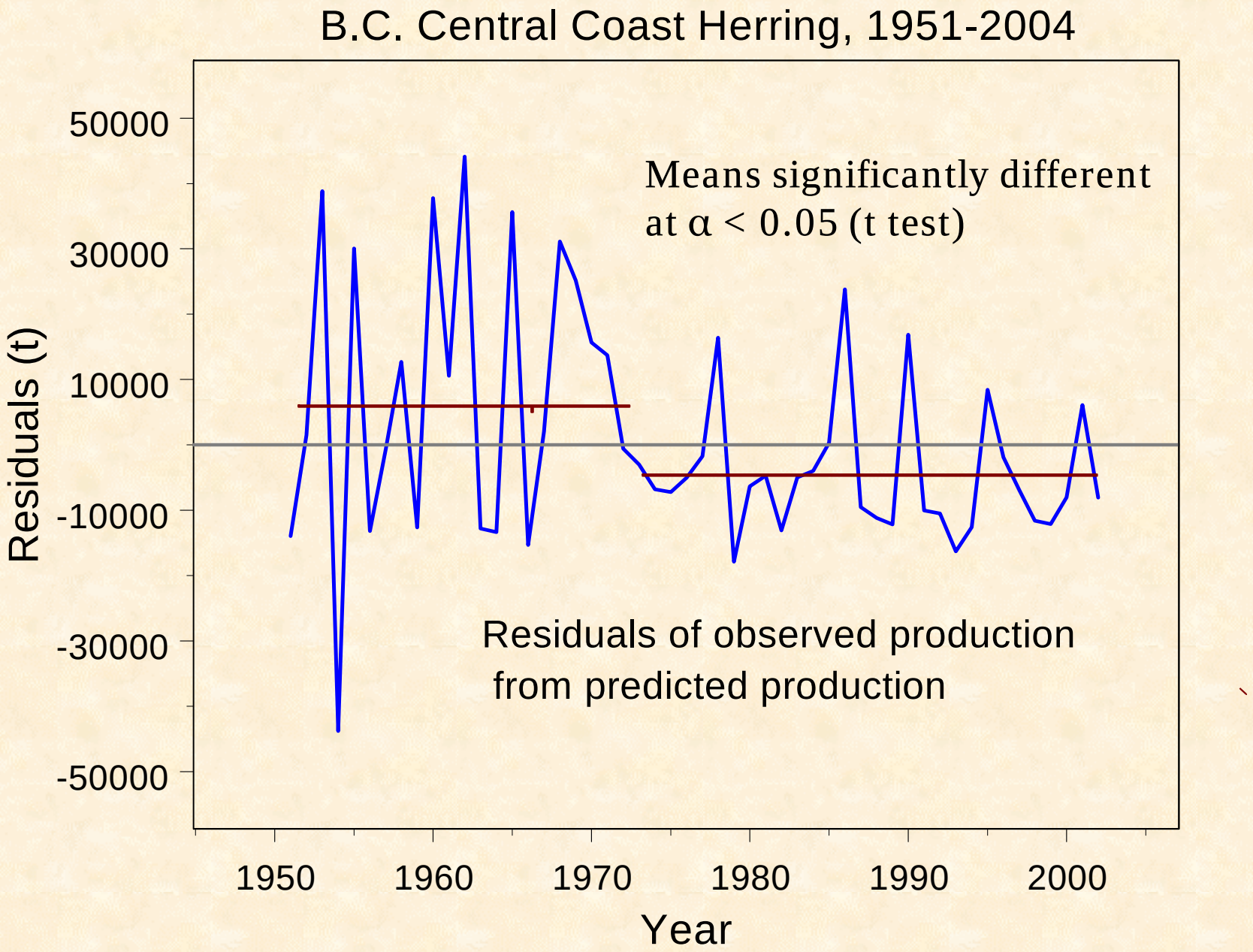

B.C. Central Coast Herring, 1951-2004
Production (t)
50000
30000
10000
-10000
-30000
-50000
0
20000
40000
60000
80000
100000
Mean Biomass (t)
P = αB e^-βB
Ricker Curve:
α = 2.6
β = 0.000014


B.C. Central Coast Herring, 1951-2004
Maximum production = 18,324 t
Maximum production is [α/(βe)]
Maximum production occurs at Biomass = 71,429 t
"Carrying Capacity"
Maximum production at Biomass of (1/β)
Production (t)
Mean Biomass (t)
50000
30000
10000
-10000
-30000
-50000
0
20000
40000
60000
80000
100000


B.C. Central Coast Herring, 1951-2004
Production (t)
50000
30000
10000
-10000
-30000
-50000
0
20000
40000
60000
80000
100000
Mean Biomass (t)
G – M = 0 at
Biomass = 30,273 t


B.C. Central Coast herring, 1951-2004
Biomass (t)
90000
60000
30000
0
1950
1960
1970
1980
1990
2000
Year
Mean Biomass
Biomass of maximum production (a "natural limit")
Biomass below which G<M


B.C. Central Coast Herring, 1951-2004
50000
30000
10000
-10000
-30000
-50000
Residuals (t)
Residuals of observed production
from predicted production
1950
1960
1970
1980
1990
2000
Year


B.C. Central Coast Herring, 1951-2004
Means significantly different
at α < 0.05 (t test)
Residuals of observed production
from predicted production
Residuals (t)
50000
30000
10000
-10000
-30000
-50000
1950
1960
1970
1980
1990
2000
Year

Conclusions

- Carrying Capacity is a statistical concept, which can be calculated using this approach;
  - Carrying Capacity of herring in central coast of B.C. is ≅ 70,000 t (= 2.27 t km^{-2})
  - biomass at which instantaneous growth = instantaneous natural mortality in central coast B.C. herring ≅ 30,000 t (= 0.96 t km^{-2})
  - using a different approach (applied 15 yrs ago), herring biologists set a "Cut-off" biomass (for no fishing) of ≅ 17,600 t (spawning biomass), which was estimated to be ¼ of the virgin biomass
- actual Productive Capacity of an ecosystem for a population is not stable, but varies inter-annually (e.g. residuals plot)

Next Steps

- compare residual production time series with environmental factors to identify key drivers of inter-annual variability in Carrying Capacity for herring;
- analyse other herring populations in B.C. and Alaska to identify and compare Carrying Capacity levels, and their patterns of inter-annual variability;
- expand comparisons across the Pacific;
- analyse a species for which annual recruitment is less significant than it is in herring