Science, Service, Stewardship

Understanding reproductive dynamics of marine fishes to inform fishery management

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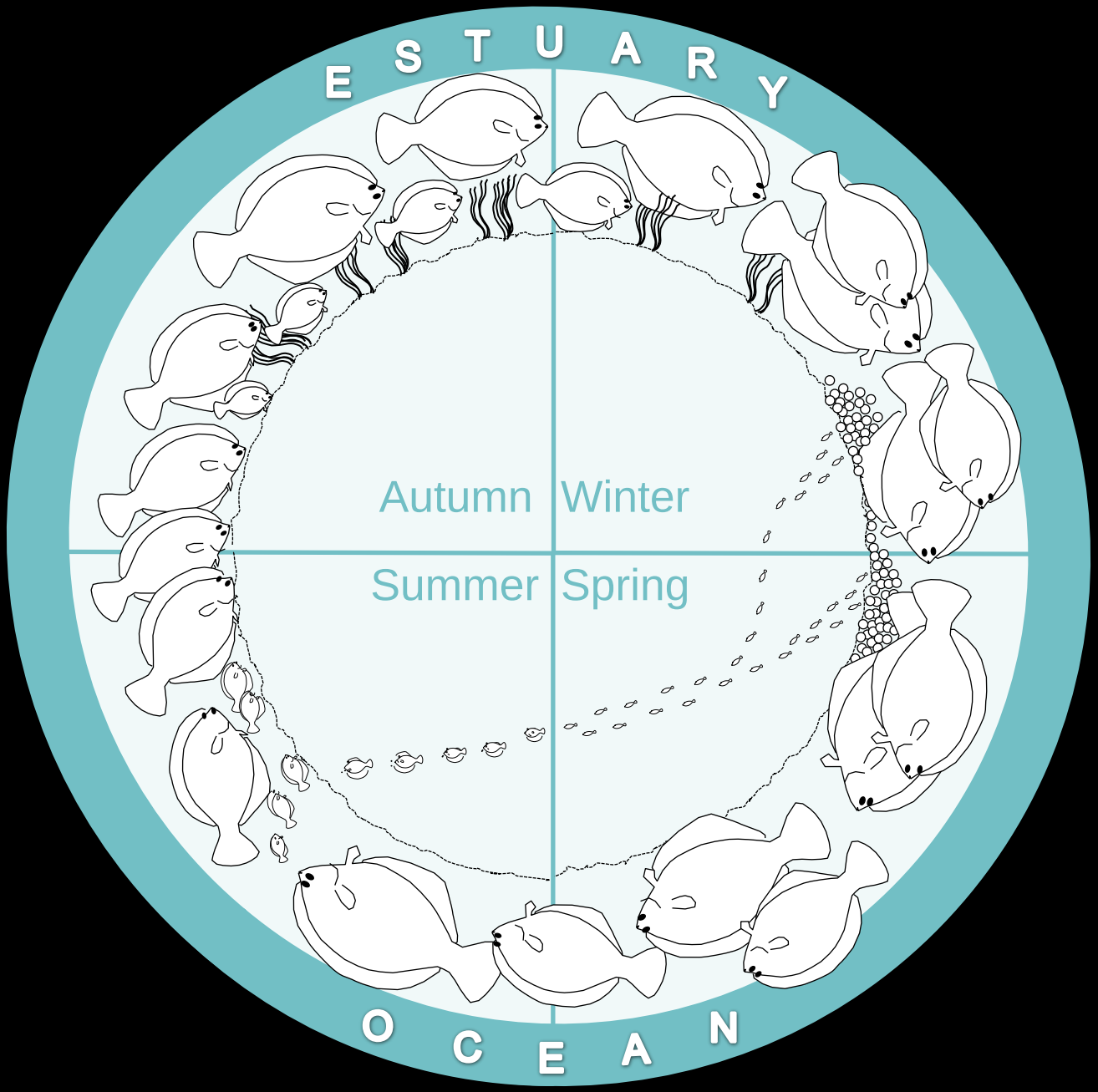
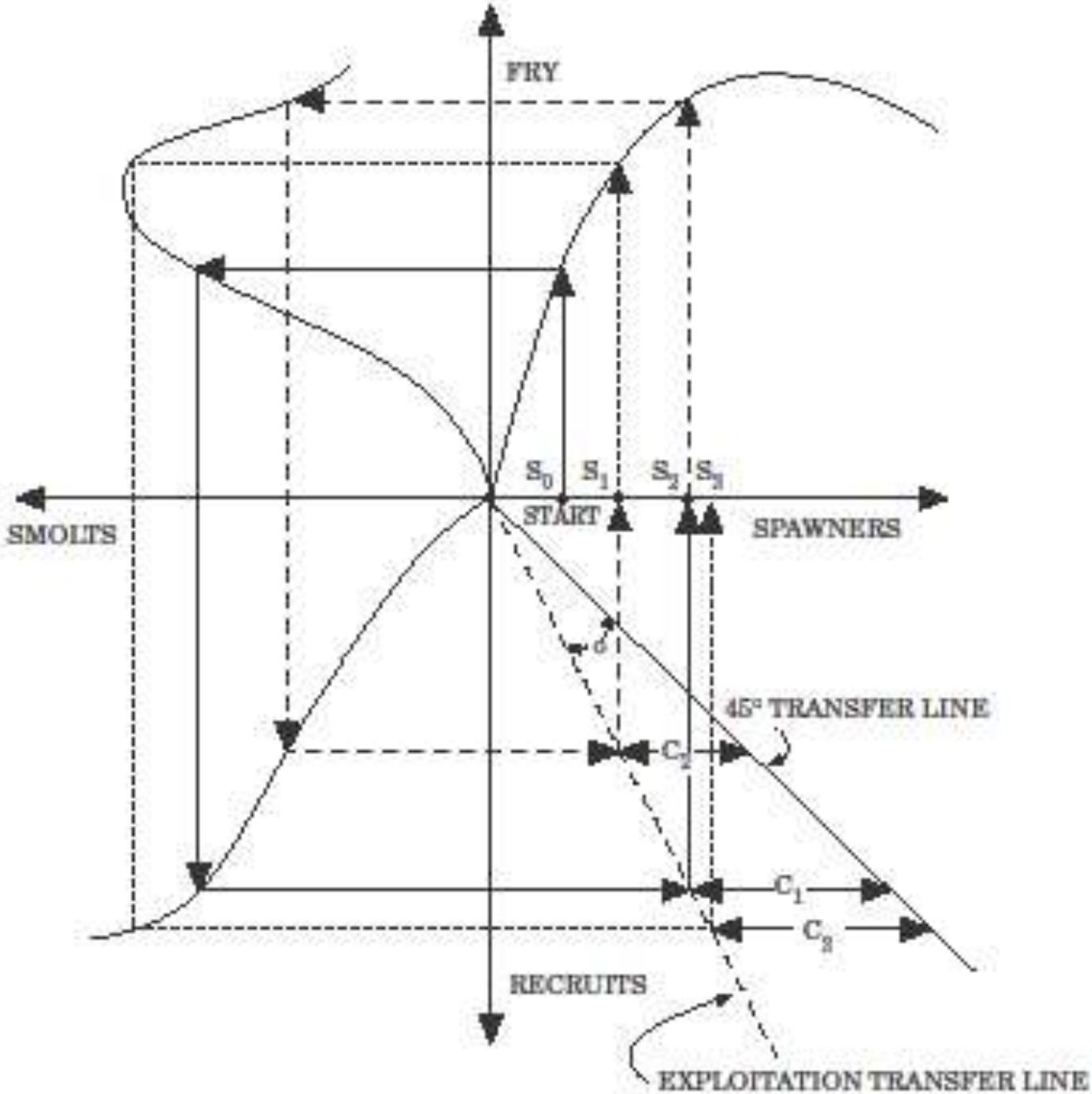
Outline

- Motivation: improve stock assessment
- Getting the data & models right
    - Maturity
    - Spawning frequency
    - Fecundity
- Examples: flounder, dolphinfish, et al.
- Applications, summary & future directions



Feeding, growth, reproduction, and movements by coastal winter flounder

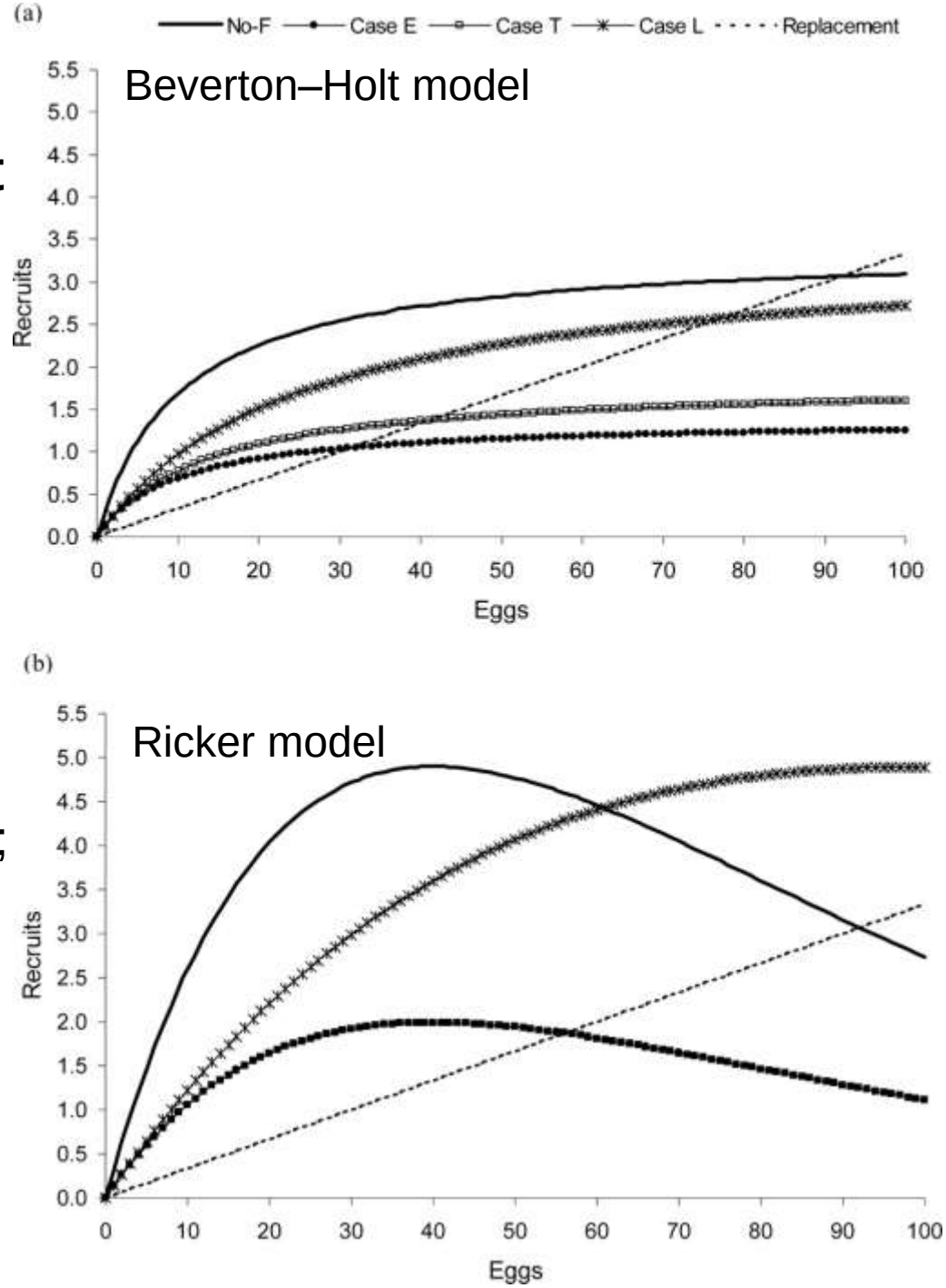
A multi-stage spawner-recruit model (Paulik 1973)



All recruitment models predict reduced recruits at low levels of spawner abundance

Figure (right)
Recruitment functions
using a multistage models

Case F, no pre-recruit F
Case E, early compensation;
Case T, compensation throughout;
Case L, late compensation.



Brooks EN , Powers JE (2007)
ICES J. Mar. Sci. 2007;64:413-424

ICES JOURNAL OF MARINE SCIENCE

SNE/MA Winter Flounder
Trends in Recruitment and Spawning Stock Biomass

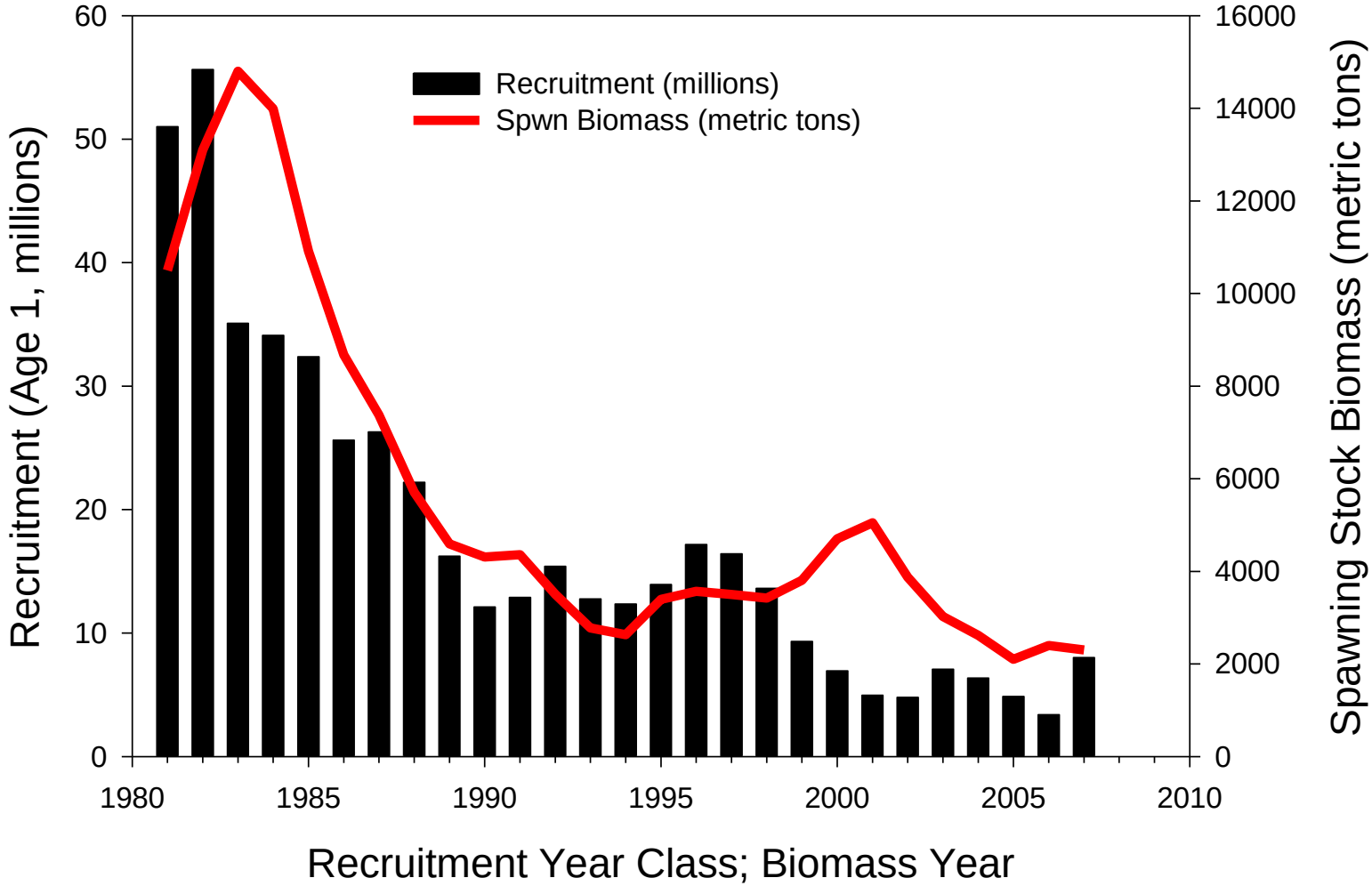
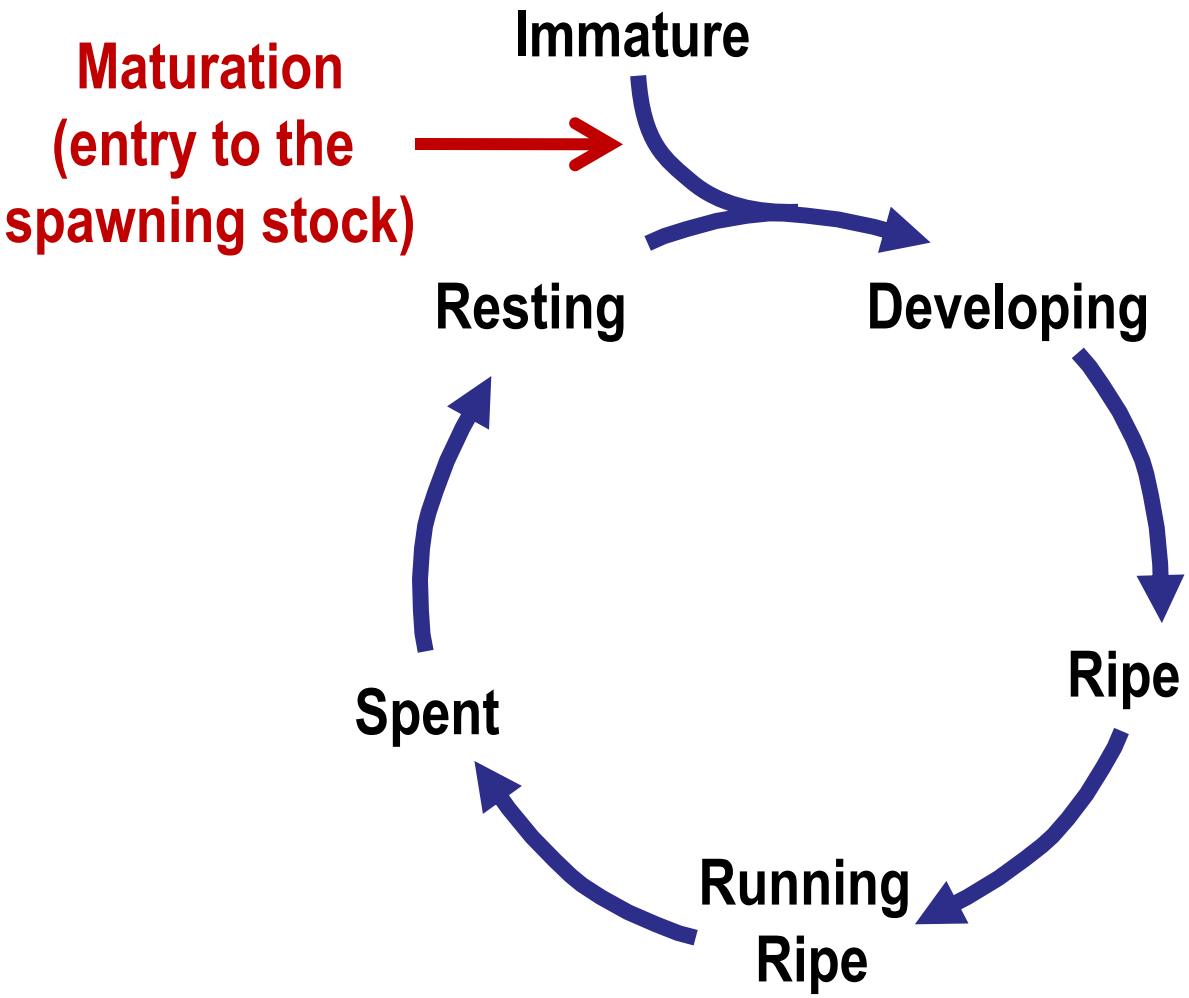


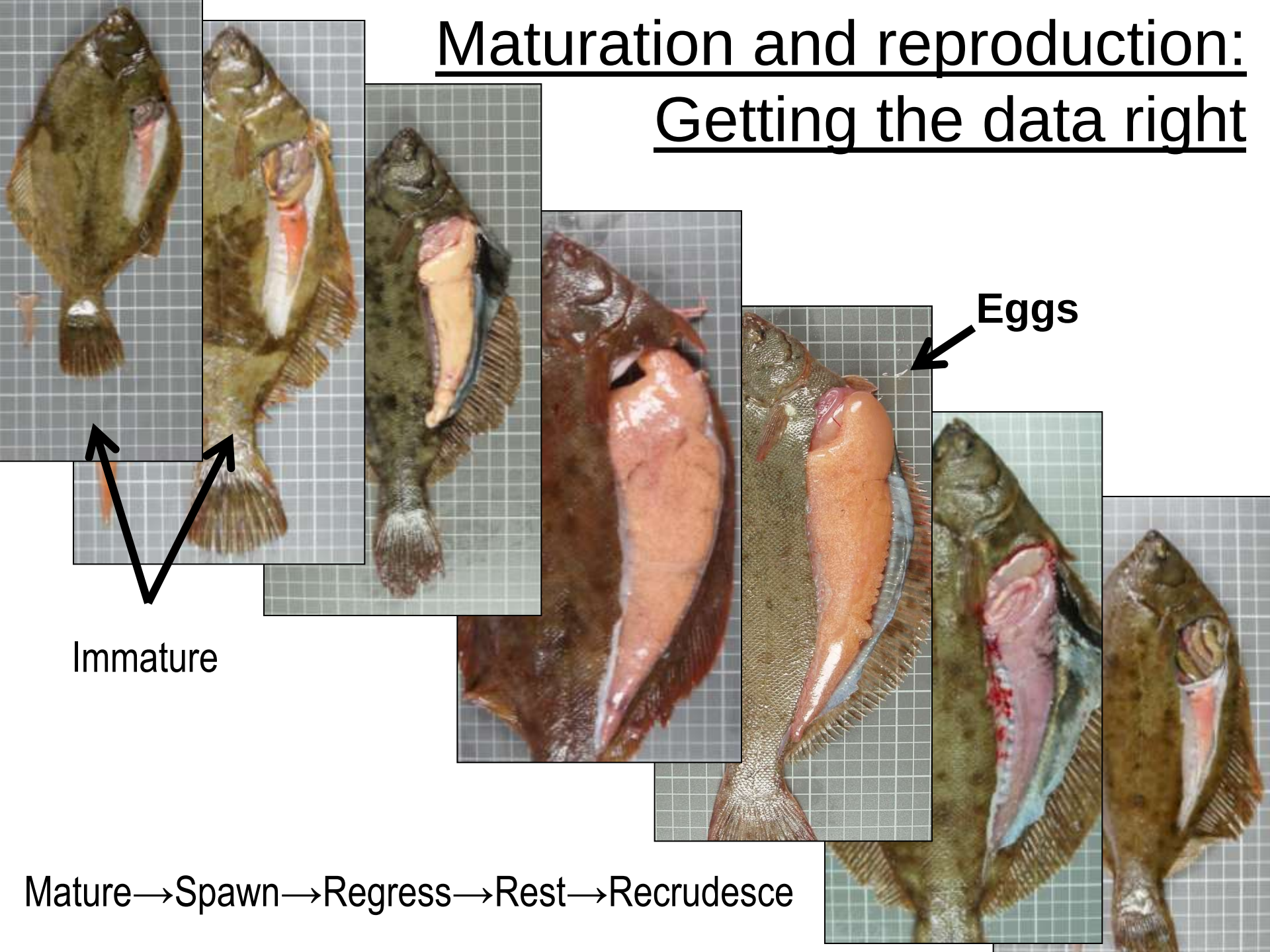
Figure 11.18. Trends in recruitment (age 1) and spawning stock biomass for SNE/MA winter flounder.

NMFS-NEFSC's Maturity Classification Sheme



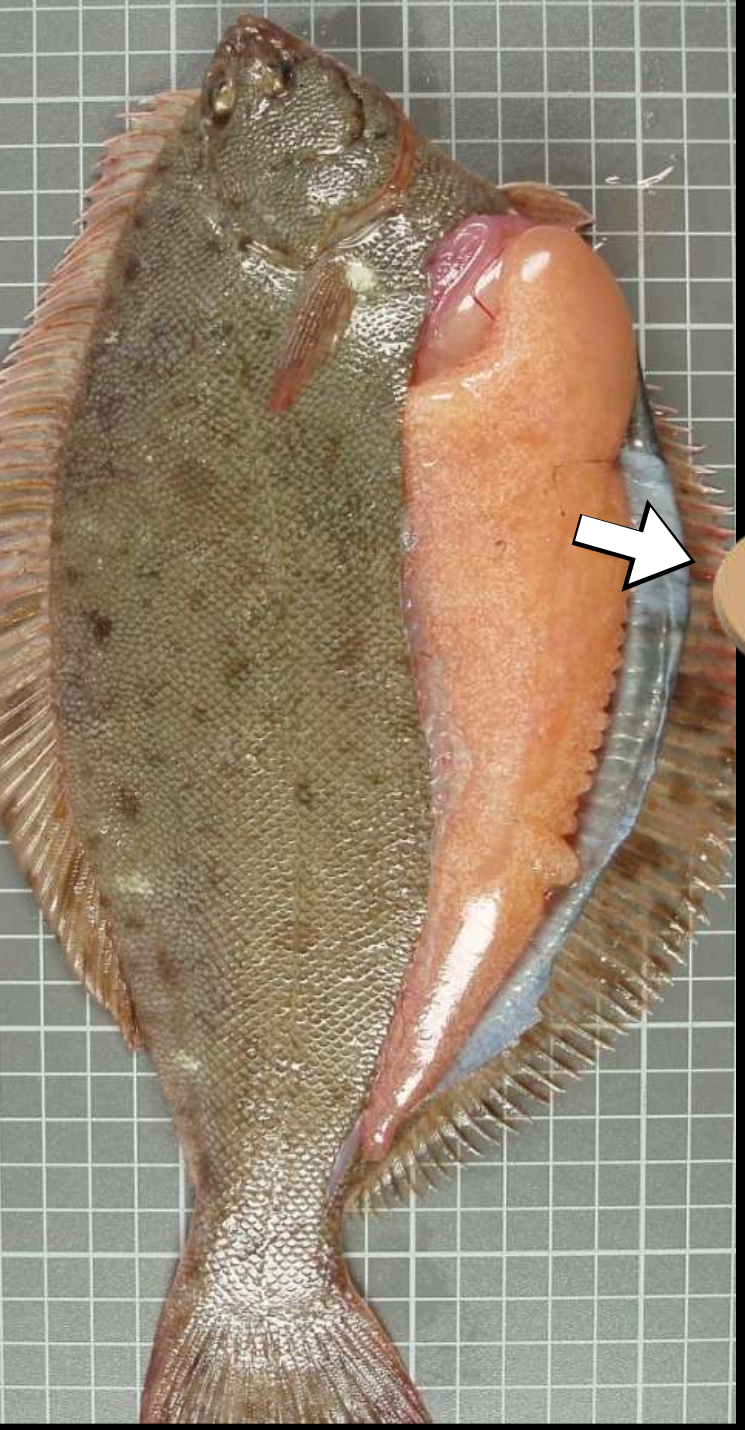
Burnett et al. (1989) http://www.nefsc.noaa.gov/publications/tm/pdfs/tmfnec76.pdf

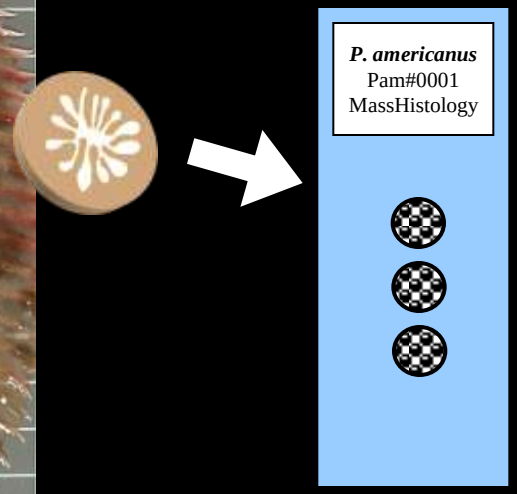
Maturation and reproduction: Getting the data right



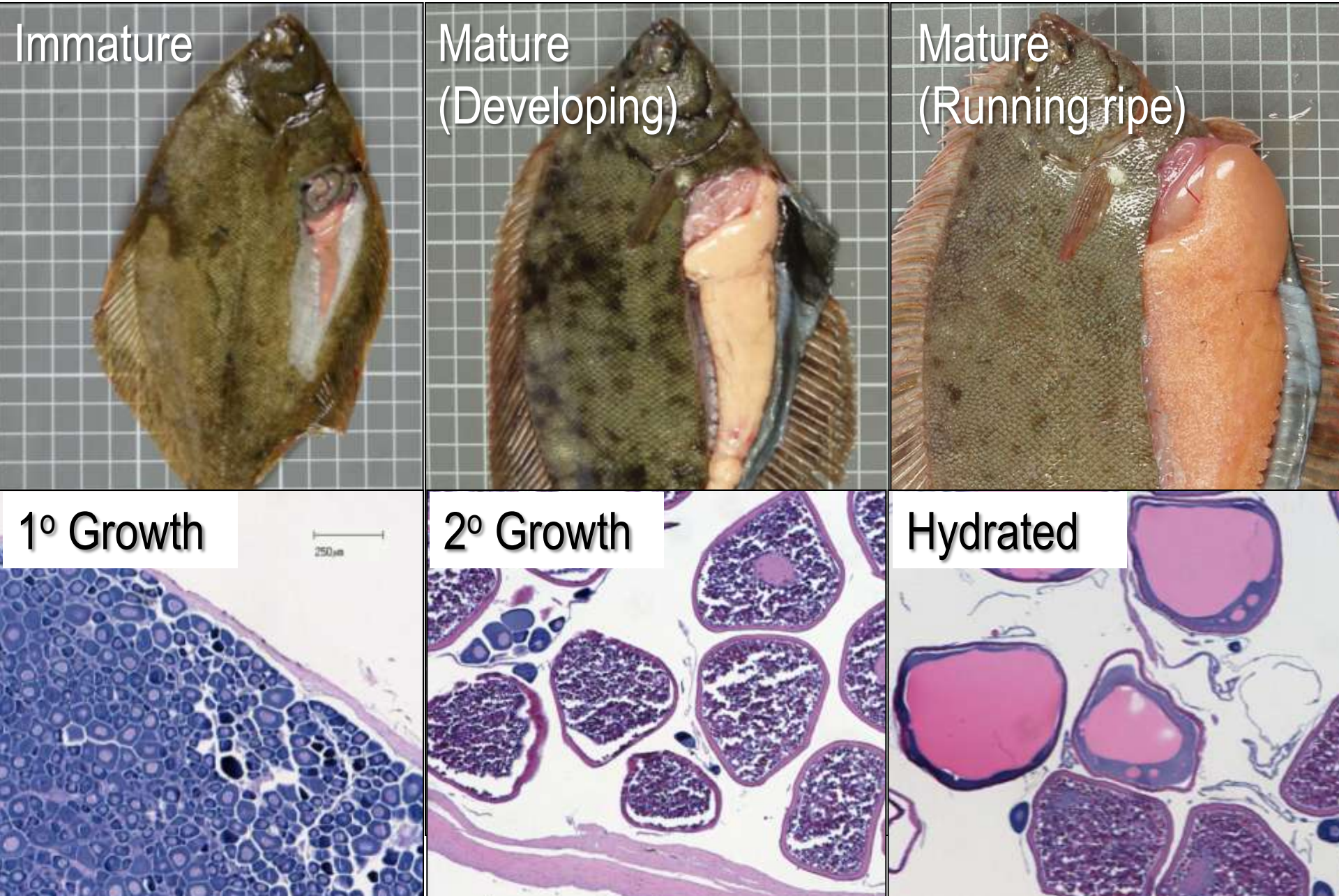
Mature→Spawn→Regress→Rest→Recrudesce

Getting the data right: gonad histology

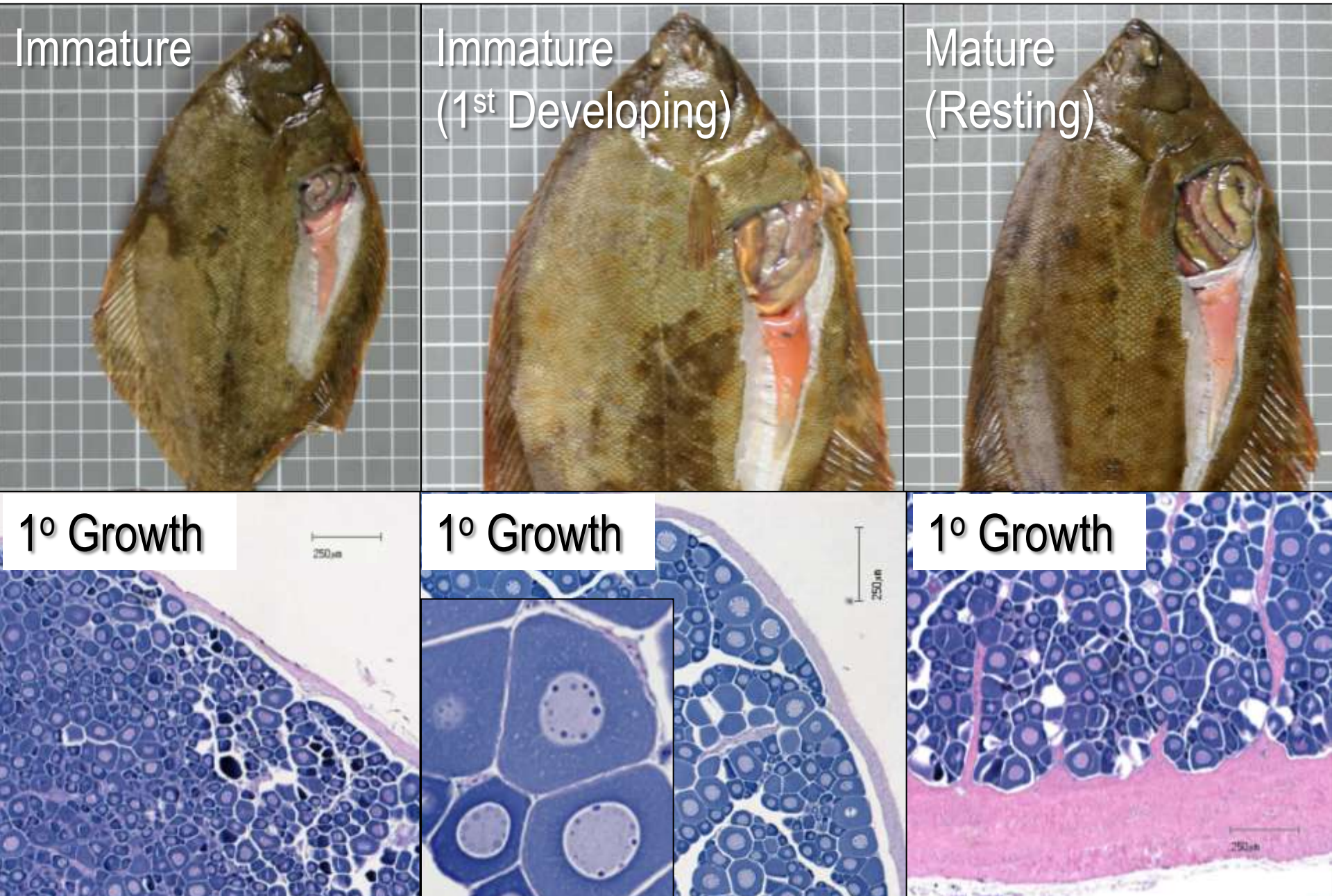




Getting the data right: gonad histology



Getting the data right: gonad histology



Maturity ogive: Getting the models right

- Logistic model (logit link function)

  $f(x) = 1 / 1 + e^{-(\alpha + \beta x)}$

- Cumulative normal model (probit link function)

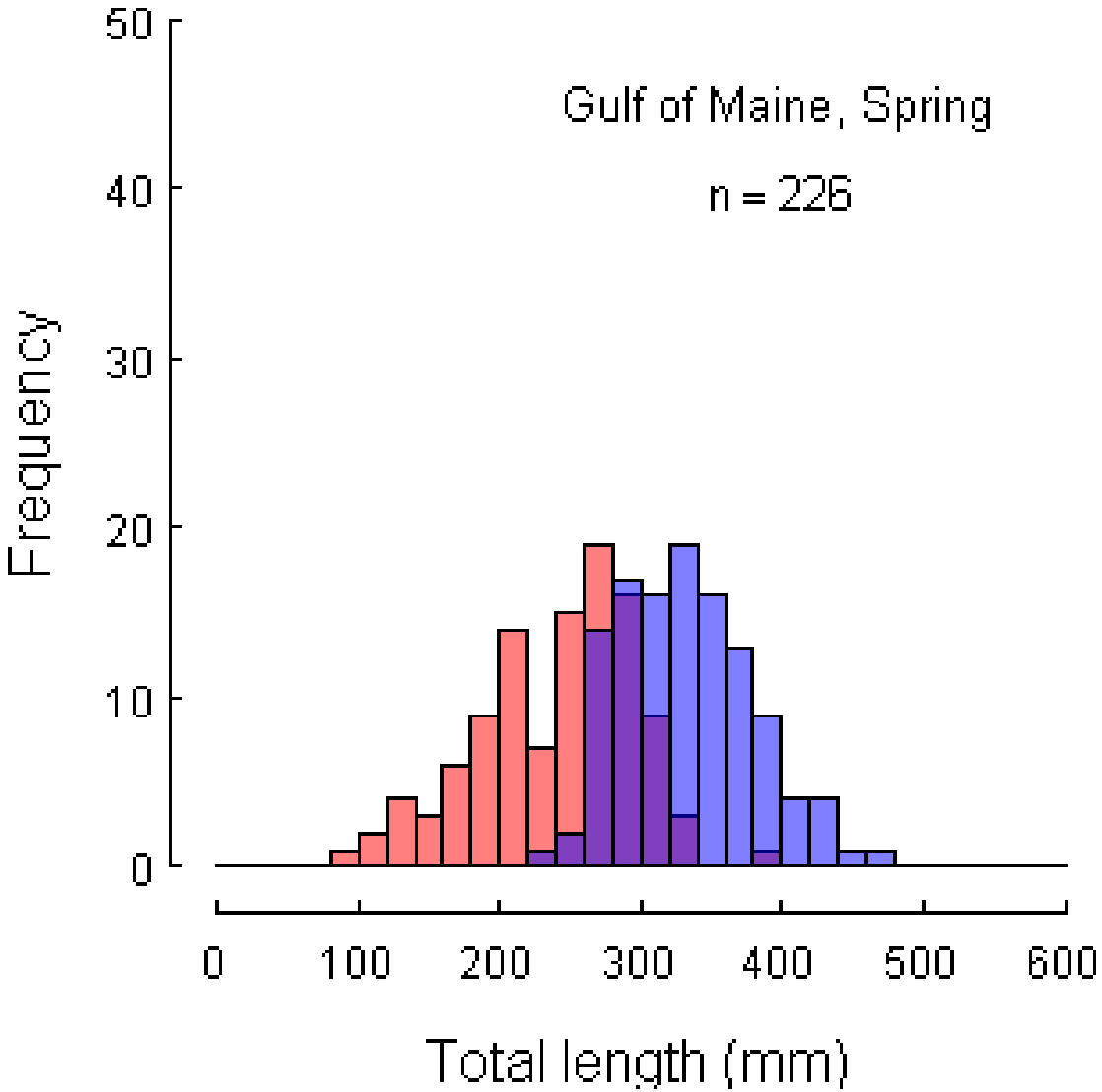
  $f(x) = \varphi(\alpha + \beta x)$

- Hazard model (complementary log-log link)

  $f(x) = 1 - \exp\{-e^{(\alpha + \beta x)}\}$

All models are sigmoidal, with binomial response variables (0,1), and 2 parameters (α, β).

Model selection-function type

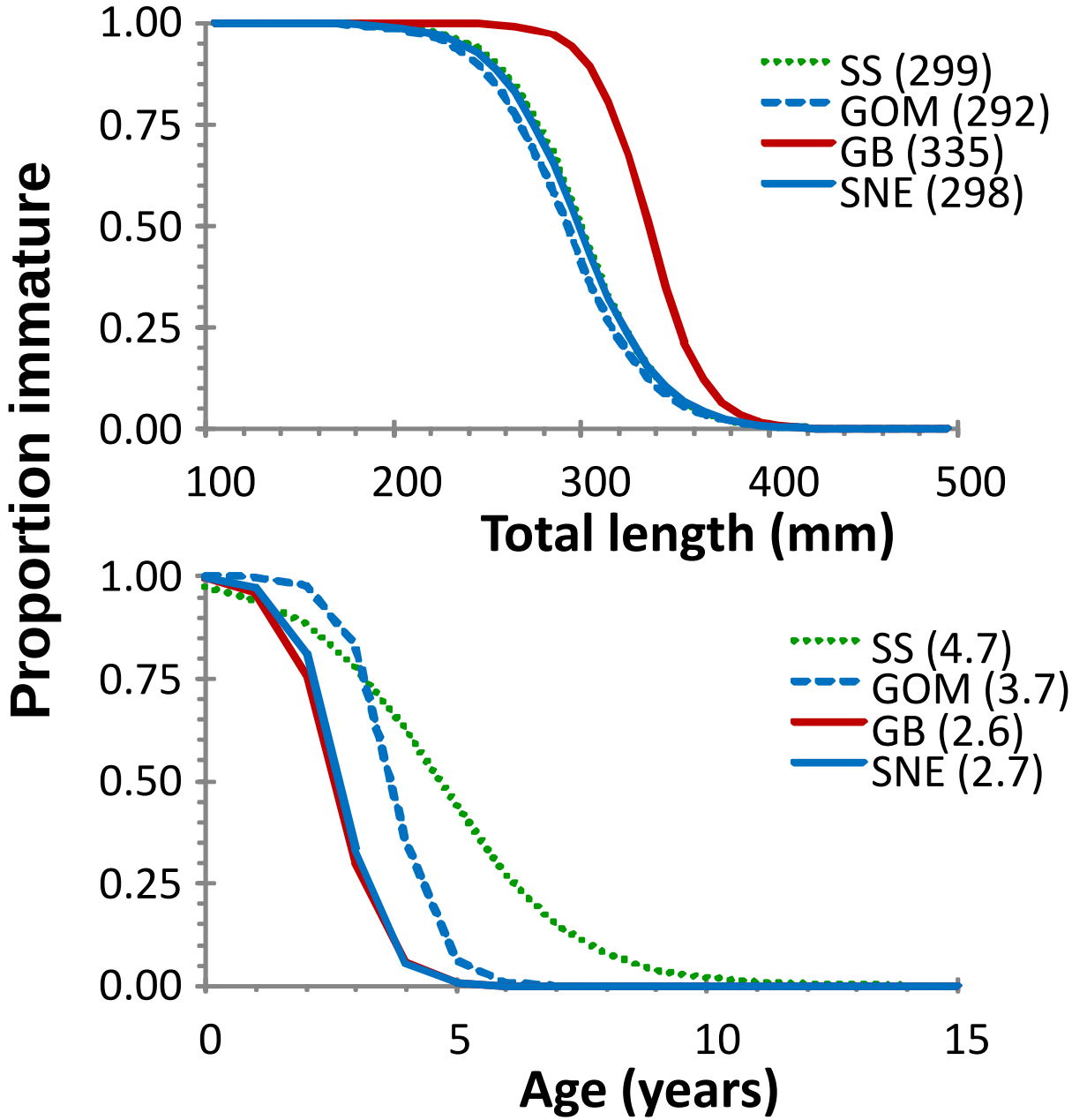


Red (immature)
Blue (mature)
Purple (both)

Gulf of Maine, Spring

Model (K=2)	AIC	L_{50}
Logit	173.3	288 mm
Probit	173.1	288 mm
Clog-log	179.9	307 mm

Model selection -- length & age

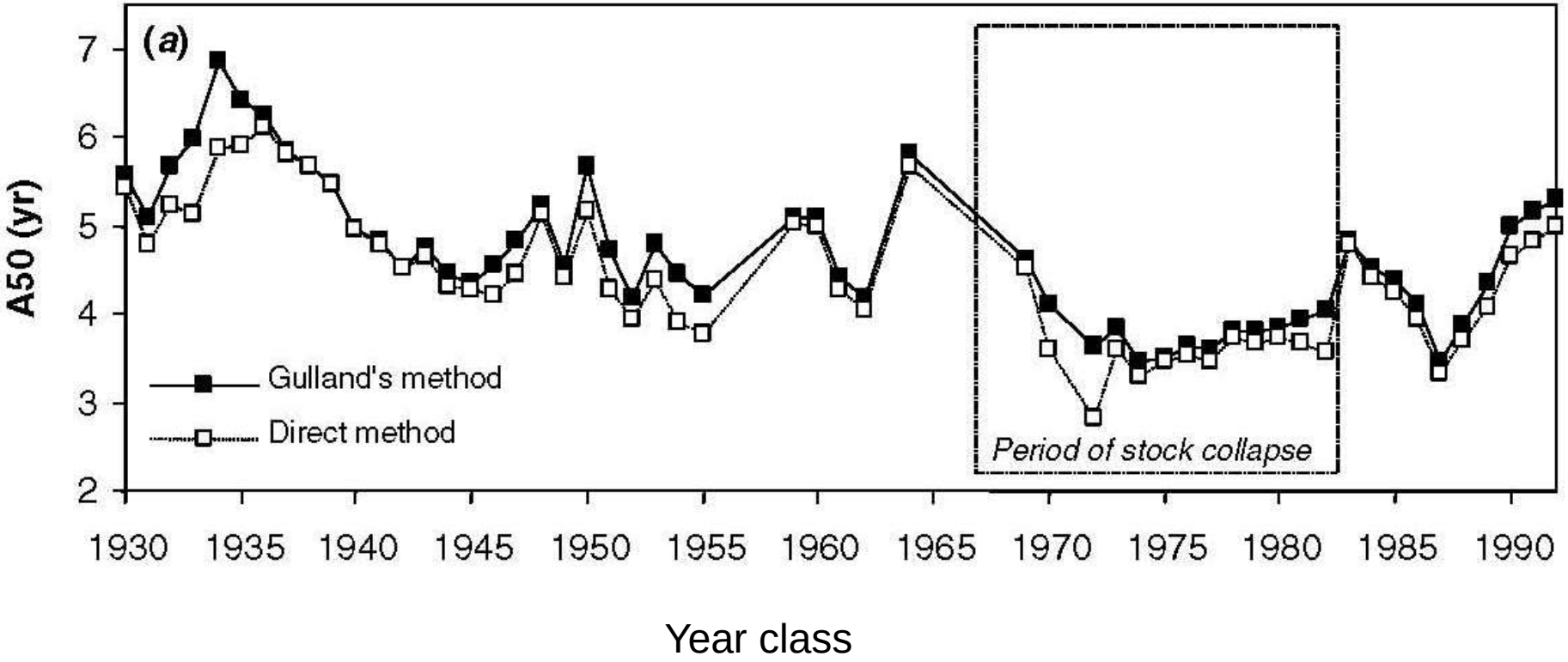


Logit model (example)

Model	K	AIC
~stock	6	873.5
~TL	2	394.7
~TL + stock	7	387.3
~TL * stock	12	389.8

Atlantic herring (*Clupea harengus*)

Temporal variation in maturity (within a stock)

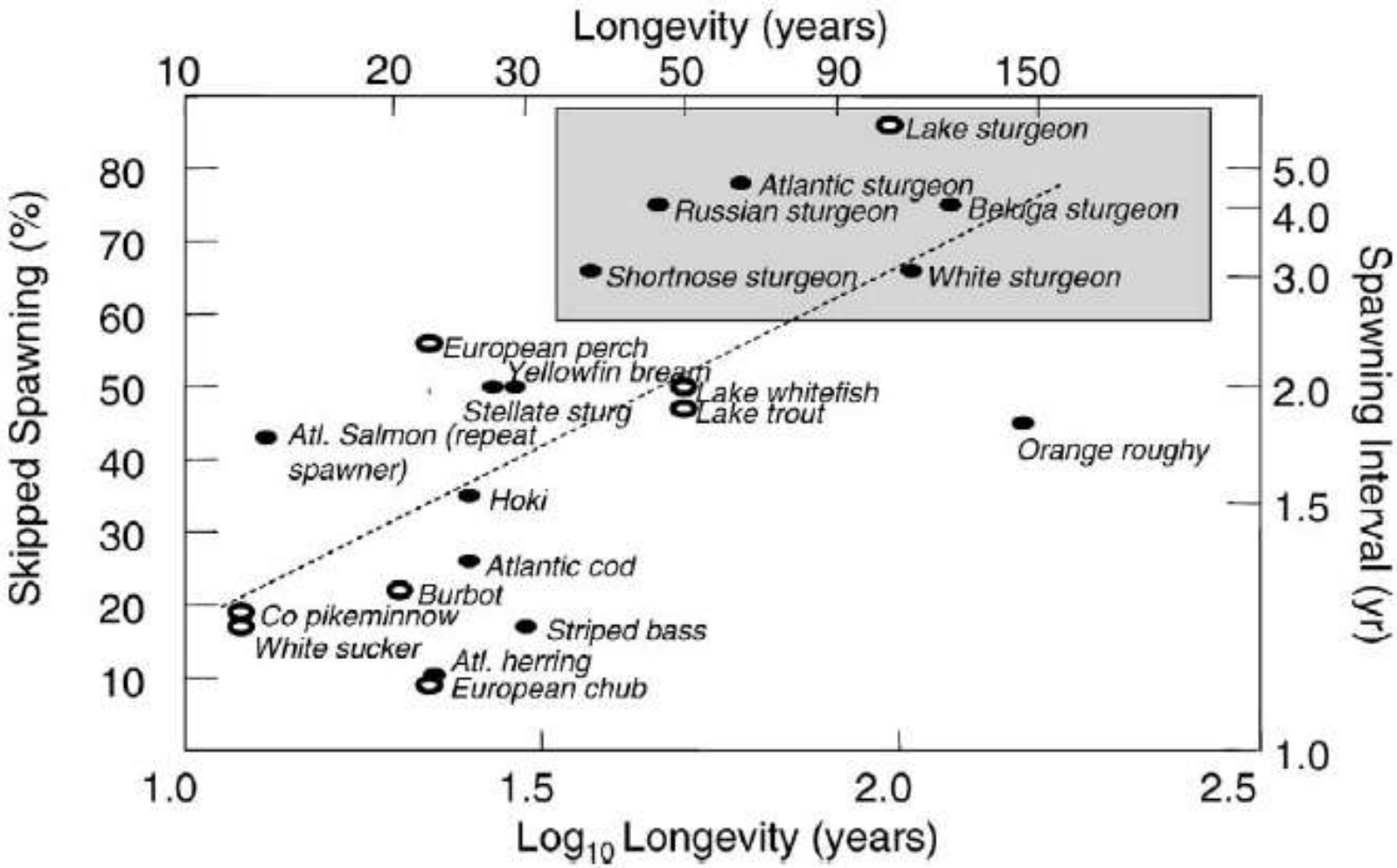


Source: Engelhard and Heino (2003)

“For many marine species,
the location and timing of spawning with respect to environmental factors acting during incubation and early larval development are far more important than the number of eggs spawned.”
Paulik (1973)

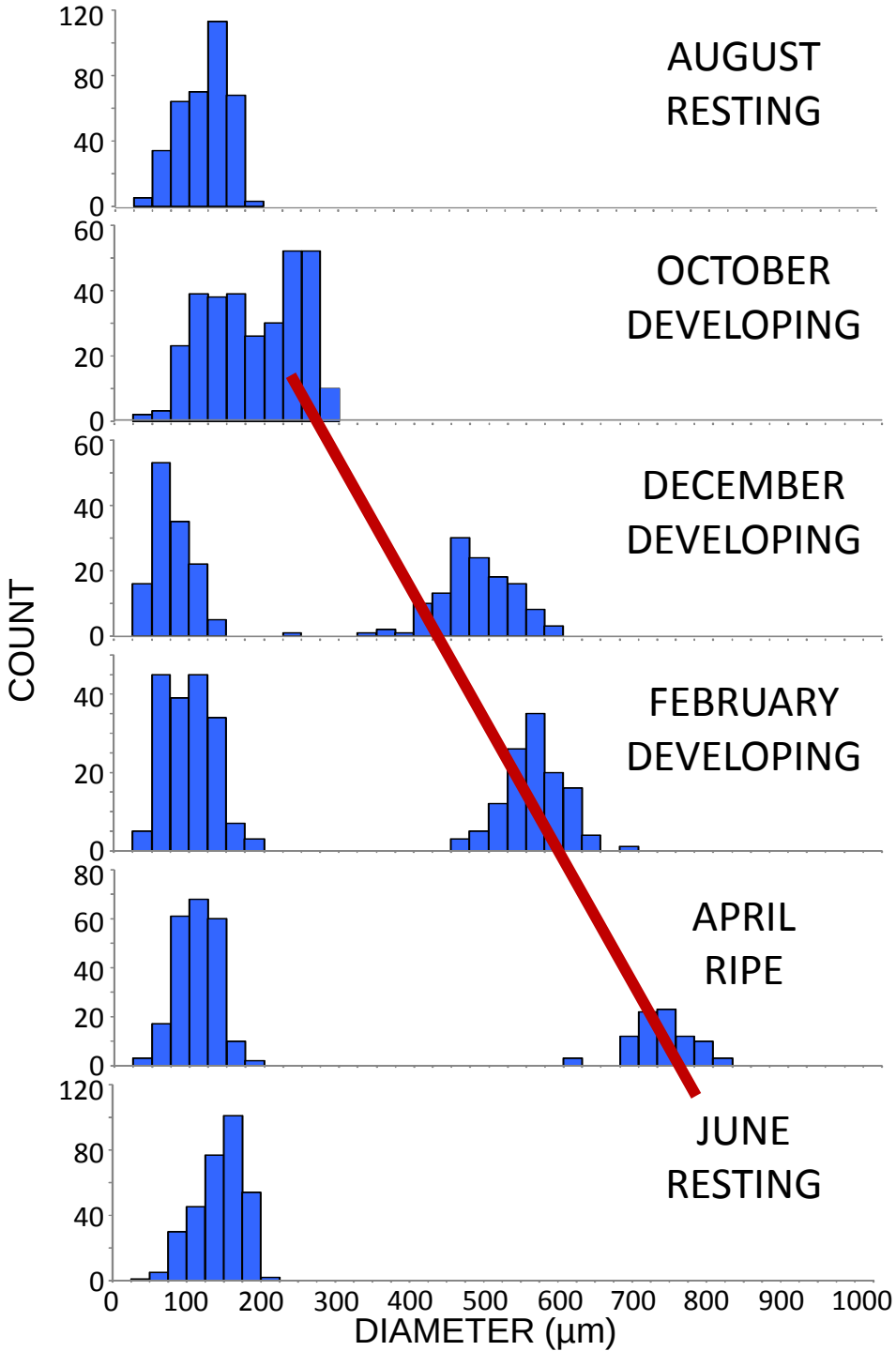
What if the number of eggs is zero?

Spawning frequency: getting the data right



- Non-annual (grey box) and skipped spawning are not unusual
- The frequency of skip spawning is associated with longevity

Secor (2008)



Winter flounder have group-synchronous oocyte development.

If they skip spawn, it is the 'resting' type, and the larger oocyte cohort does not even develop.

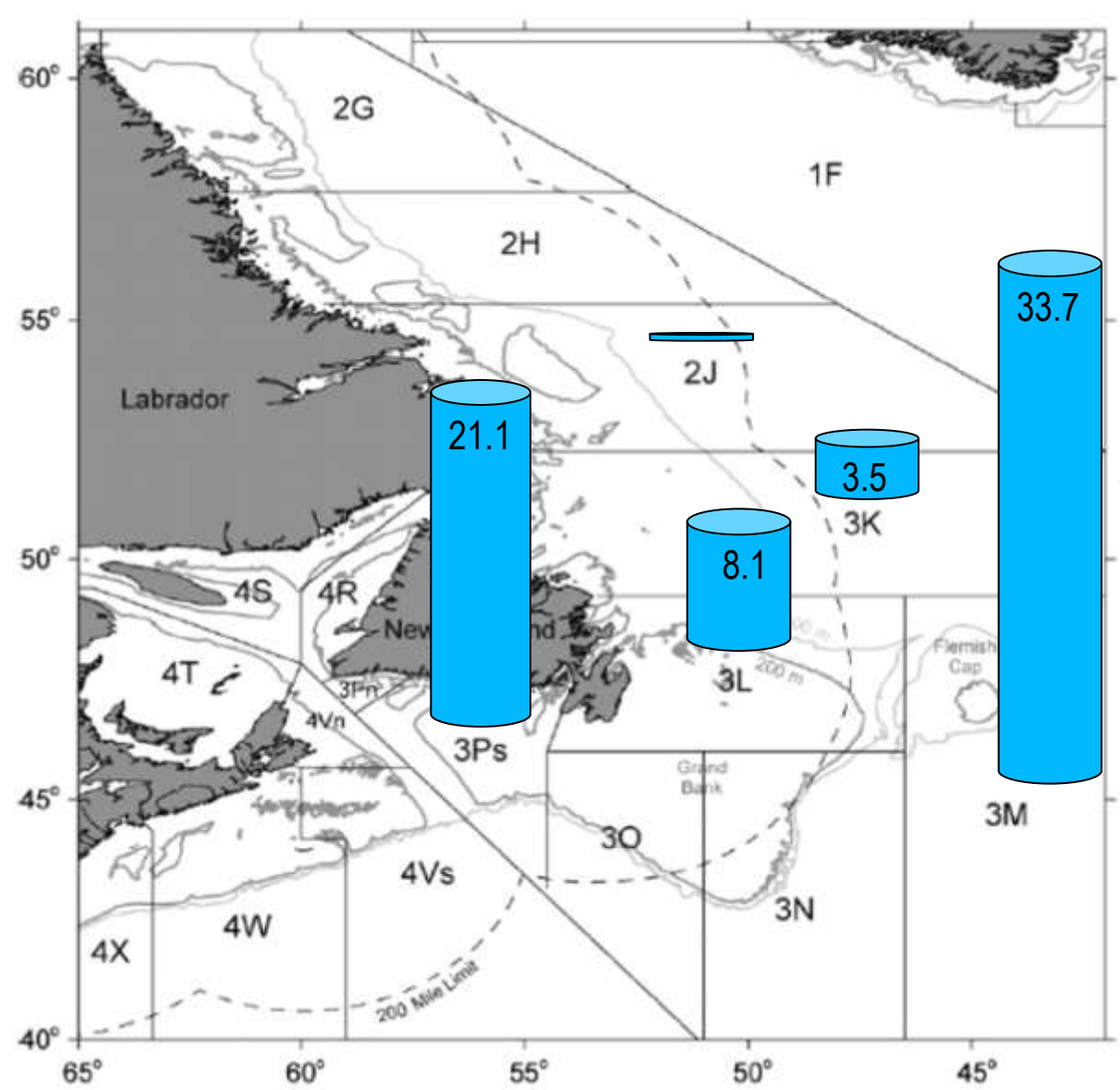
Skipped Spawning Rates (2010)

- In 2010: low & restricted to GOM (1.3%)

Stock	Mature Females	Skipped Spawners	% Skipped
GOM	151	2	1.32
GB	35	0	0.00
SNE	146	0	0.00

- Higher rates in earlier studies:
  - 19% (n = 47, Burton & Idler 1984)
  - 5% (n = 63, Wuenschel et al. 2009)

- Interannual variation not known

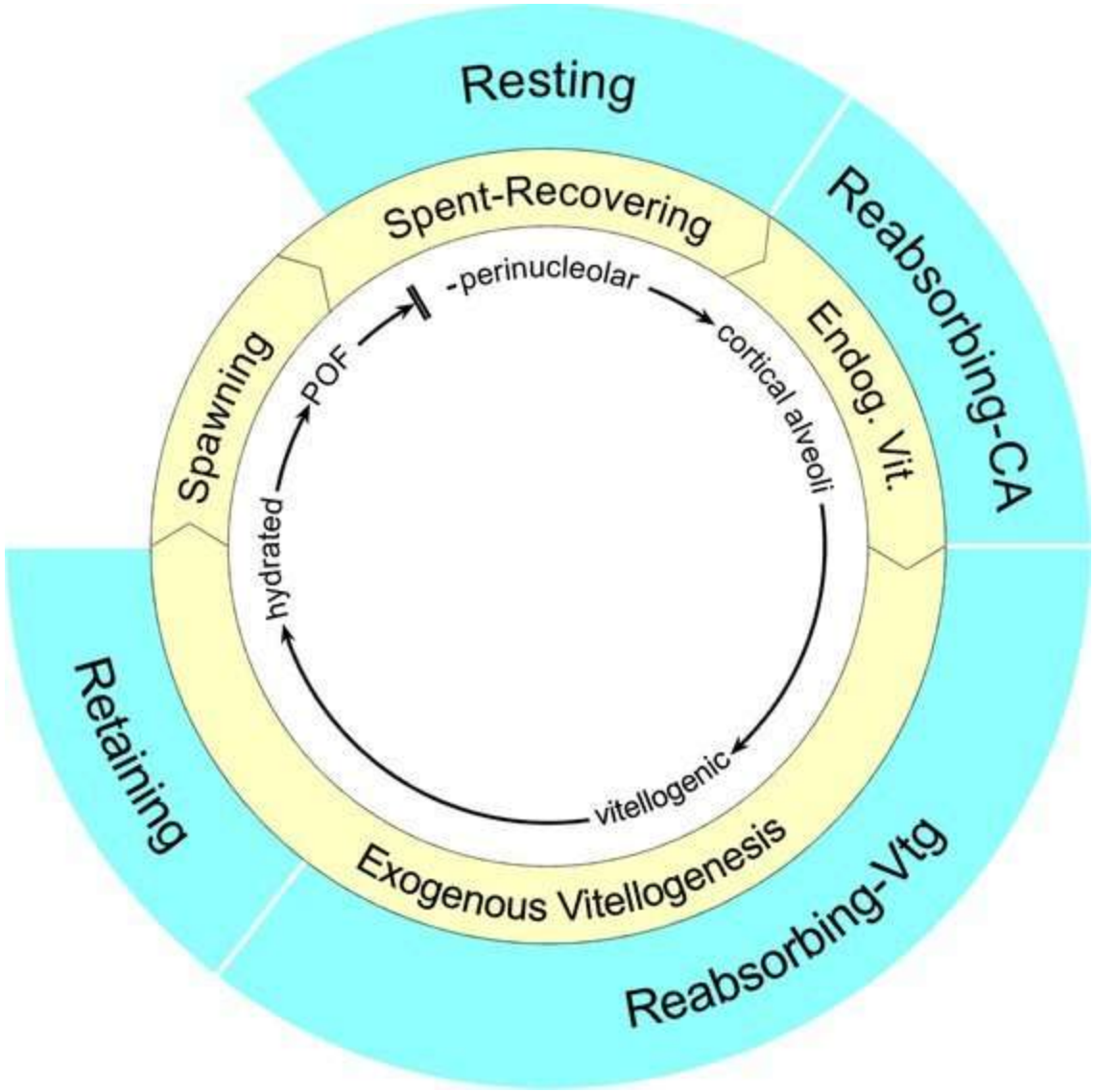


Atlantic cod
% skipped spawned females
per annum (mean, 1978-2004)

"Skipped spawning was most common in fish of medium size (60-79 cm).
Non-reproductive cod were characterized by lower liver condition than reproductive cod"

Rideout et al. ICES J. Mar. Sci. 2006;63:1101-1110

Processes for skipped spawning: Resting, reabsorbing, retaining (outside ring)



Rideout and Tomkiewicz (2011)

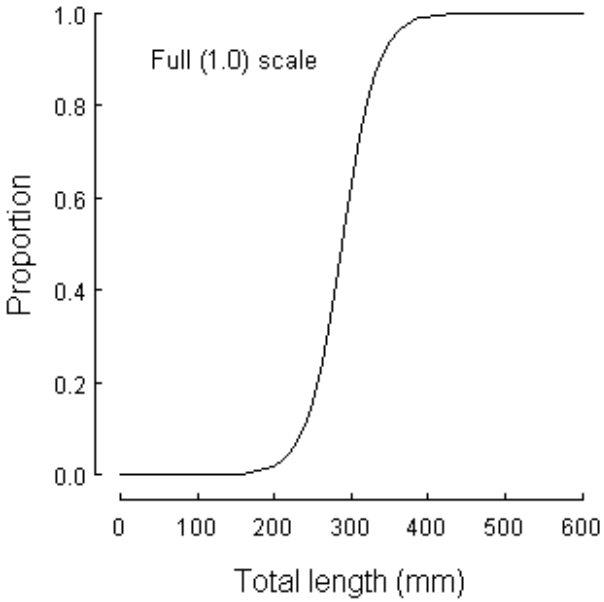
Including skipping in the maturity schedule

- 2-parameter

$$f(x) = 1 / 1 + e^{-(\alpha + \beta x)}$$

$\alpha = -12.82$

$\beta = 0.0446$



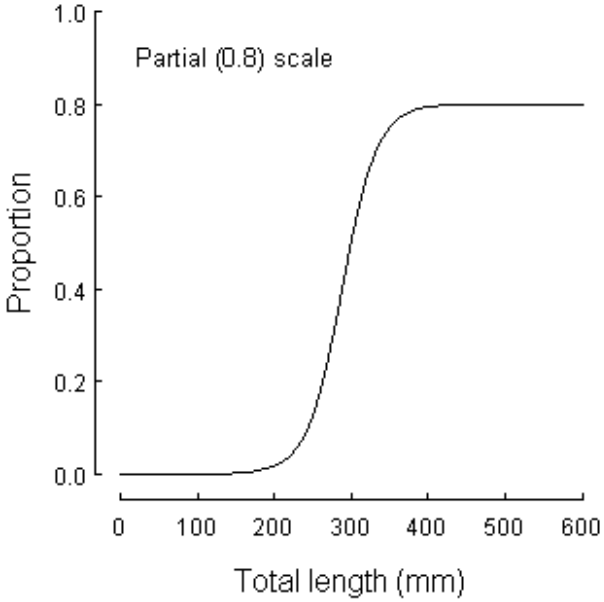
- 3-parameter

$$f(x) = \gamma / 1 + e^{-(\alpha + \beta x)}$$

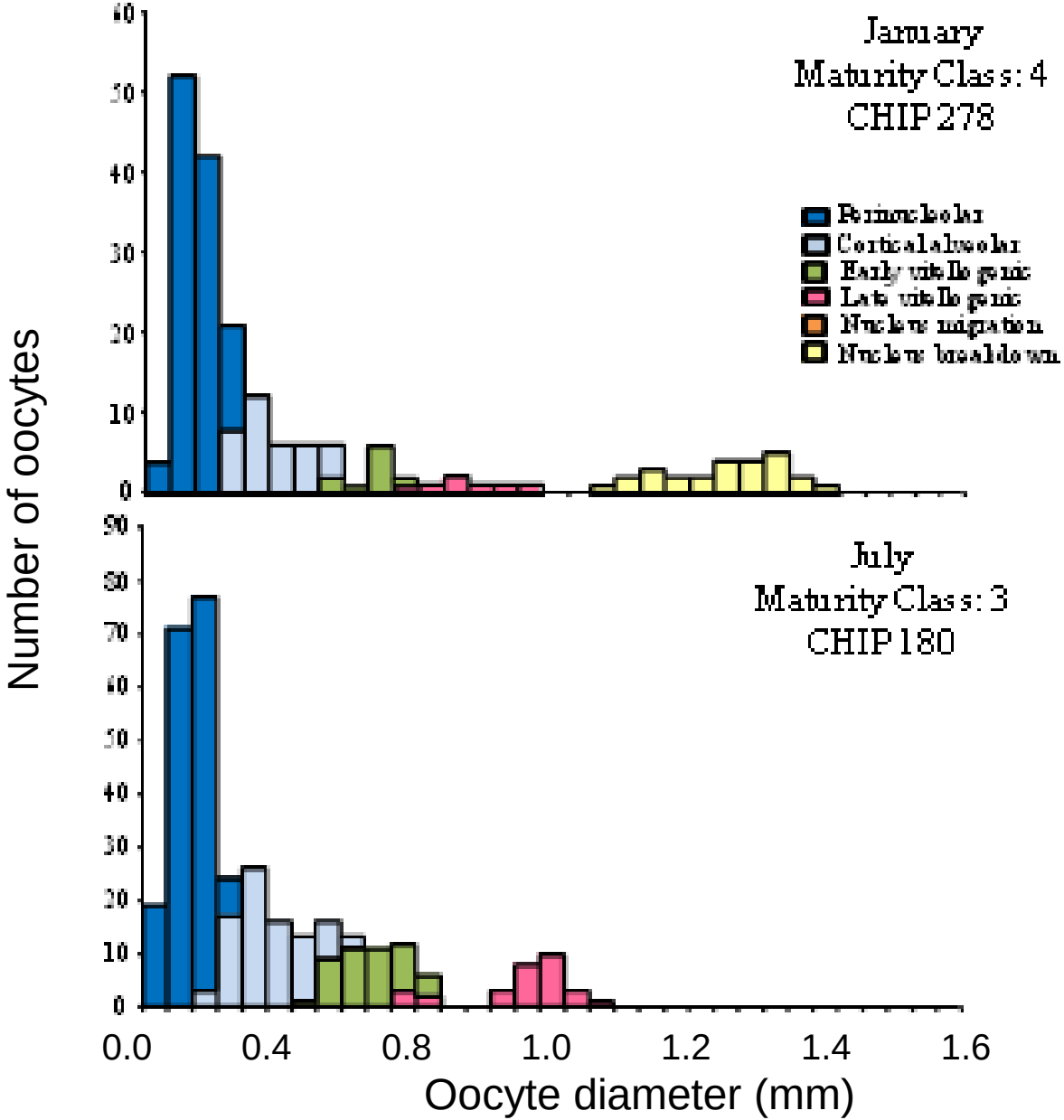
$\alpha = -12.82$

$\beta = 0.0446$

$\gamma = 0.8$



Dolphinfish are different. They have asynchronous oocyte development



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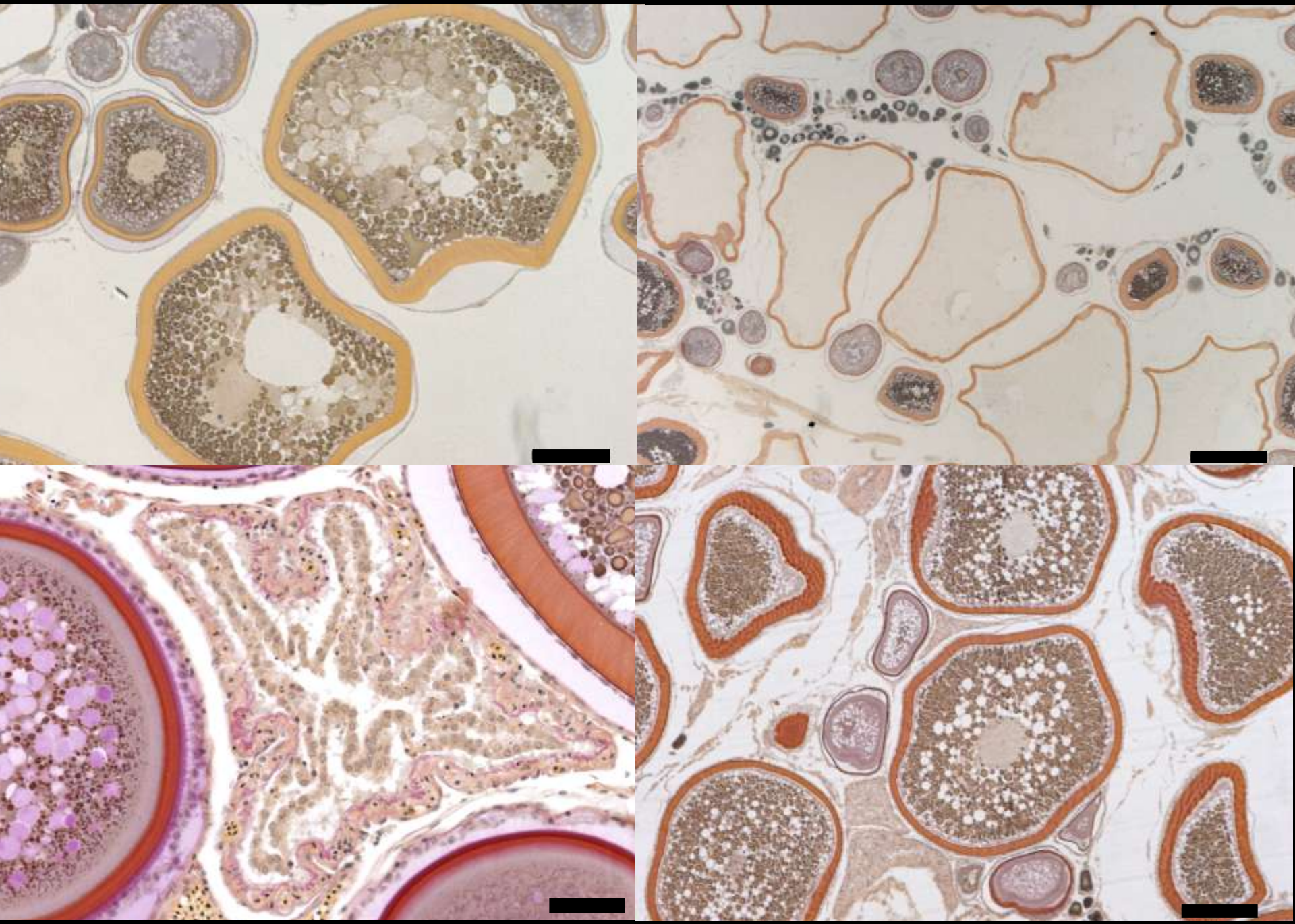
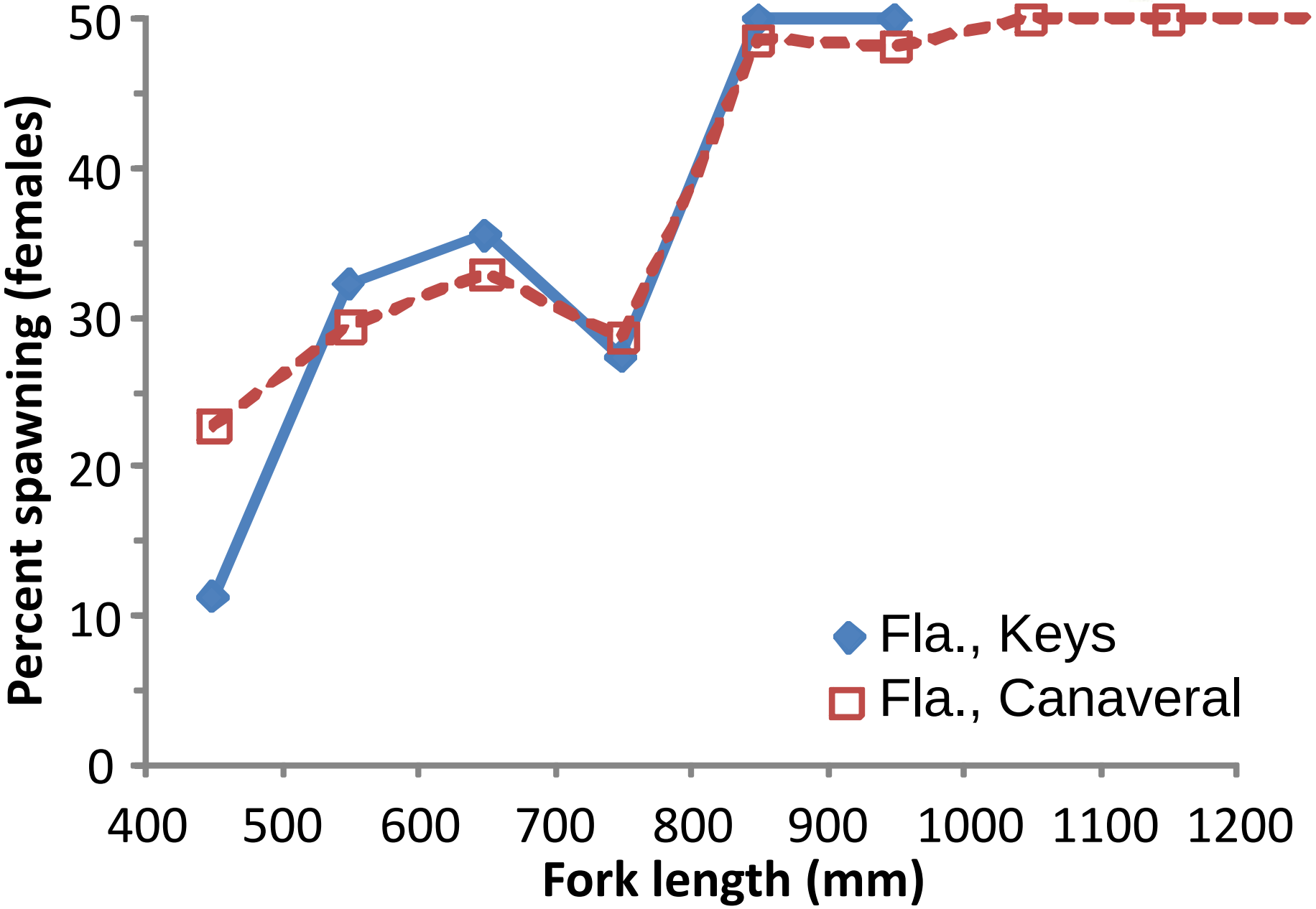
Dolphinfish – batch spawners?

"Female dolphin … spawn twice (perhaps as many as three times) per year."

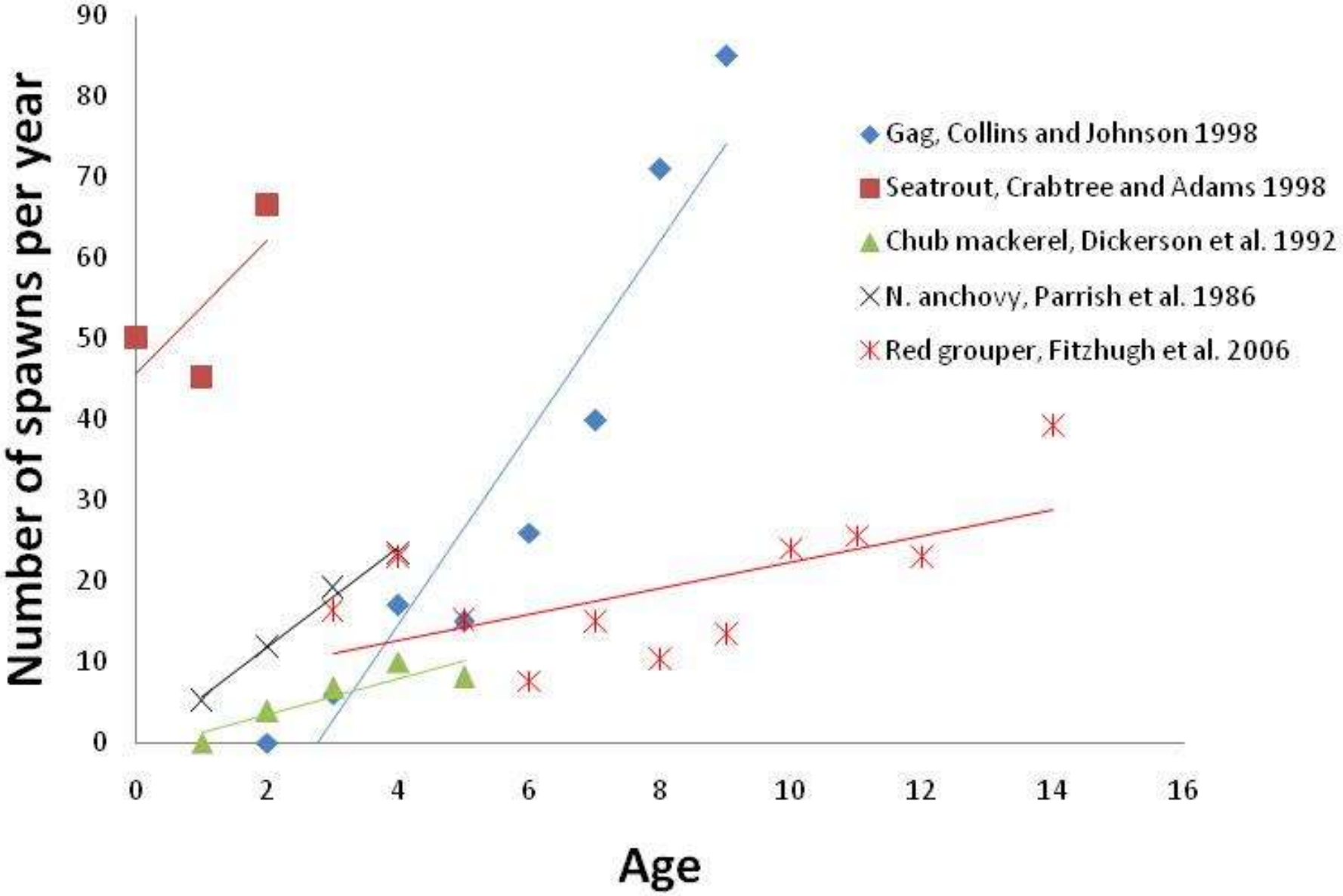
Beardsley GL, Jr. 1967. Age, growth, and reproduction of the dolphin, *Coryphaena hippurus*, in the straits of Florida. Copeia 1967 (2):441-451.



Spawning females, percent



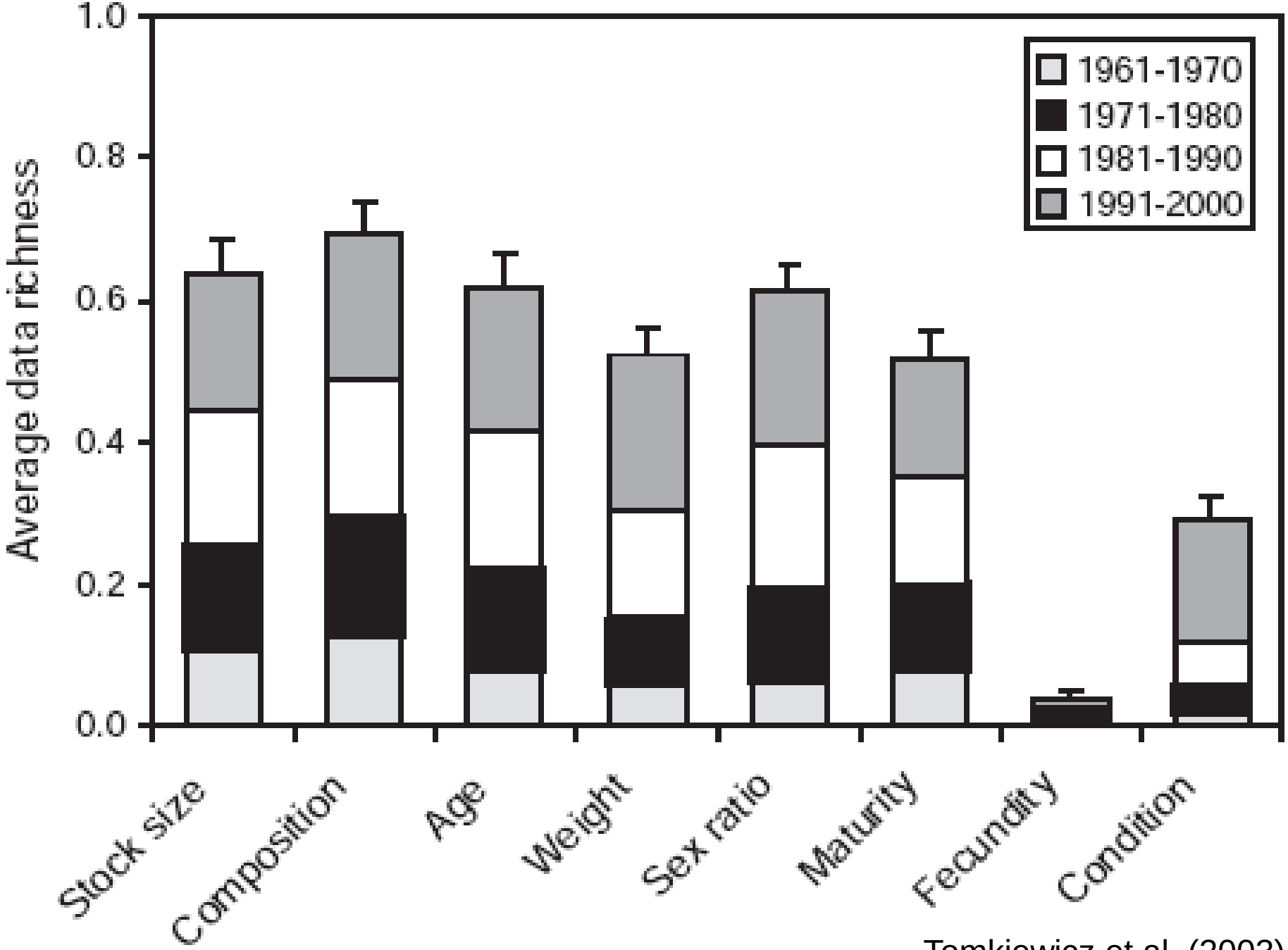
Spawning frequency by age



Return to published wisdom….

“For many marine species,
the location and timing of spawning with respect to environmental factors acting during incubation and early larval development are far more important than the number of eggs spawned.”
Paulik (1973)

Production vs. mortality?



Tomkiewicz et al. (2003)

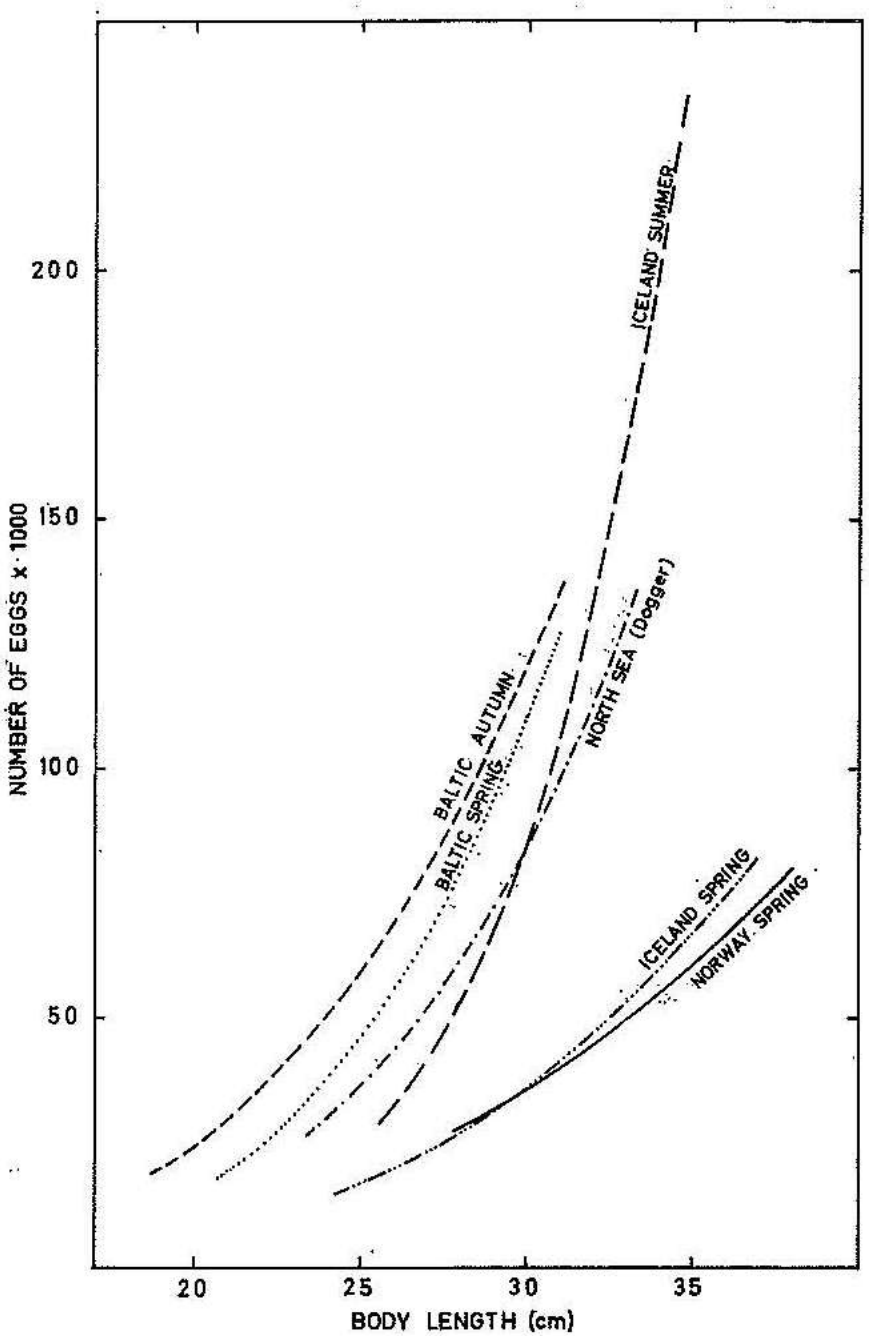


Figure 124. Fecundity and body length in various populations of herring.

$$f = a \times L^b$$

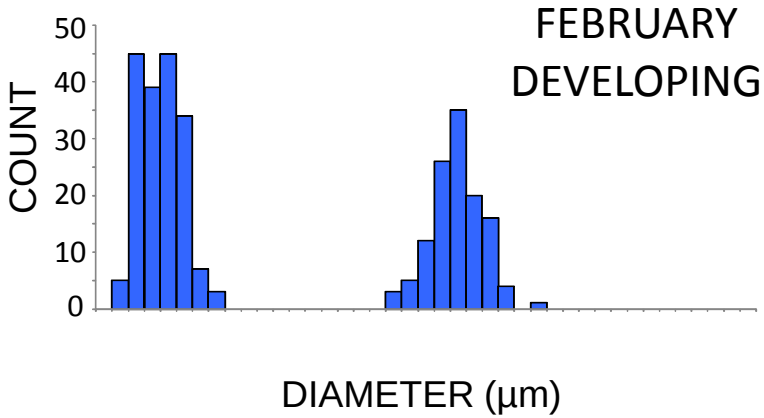
b: 3.4—6.8

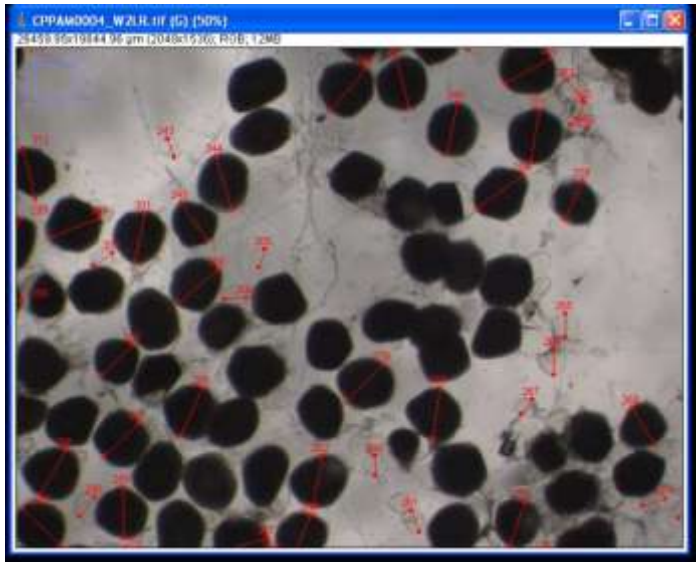
$$f = a \times W^b$$

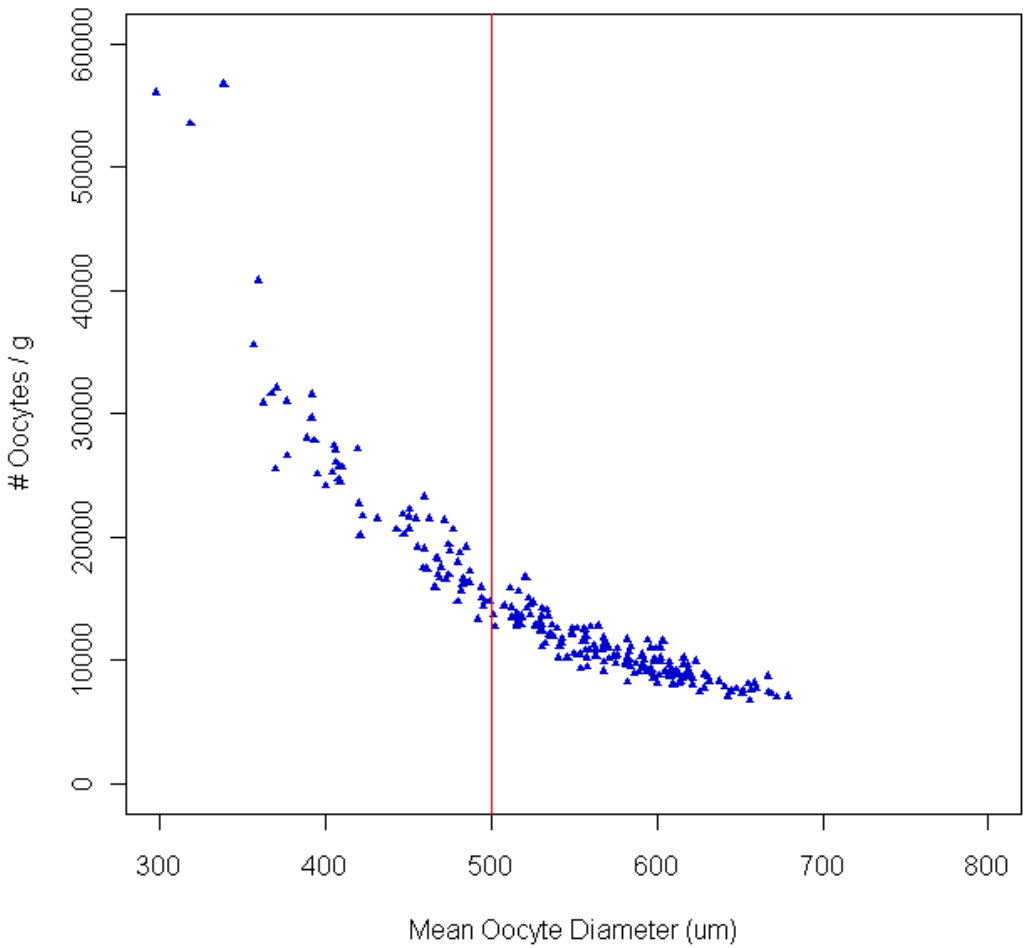
b: 1.1—2.1

Schopka and Hempel (1973)

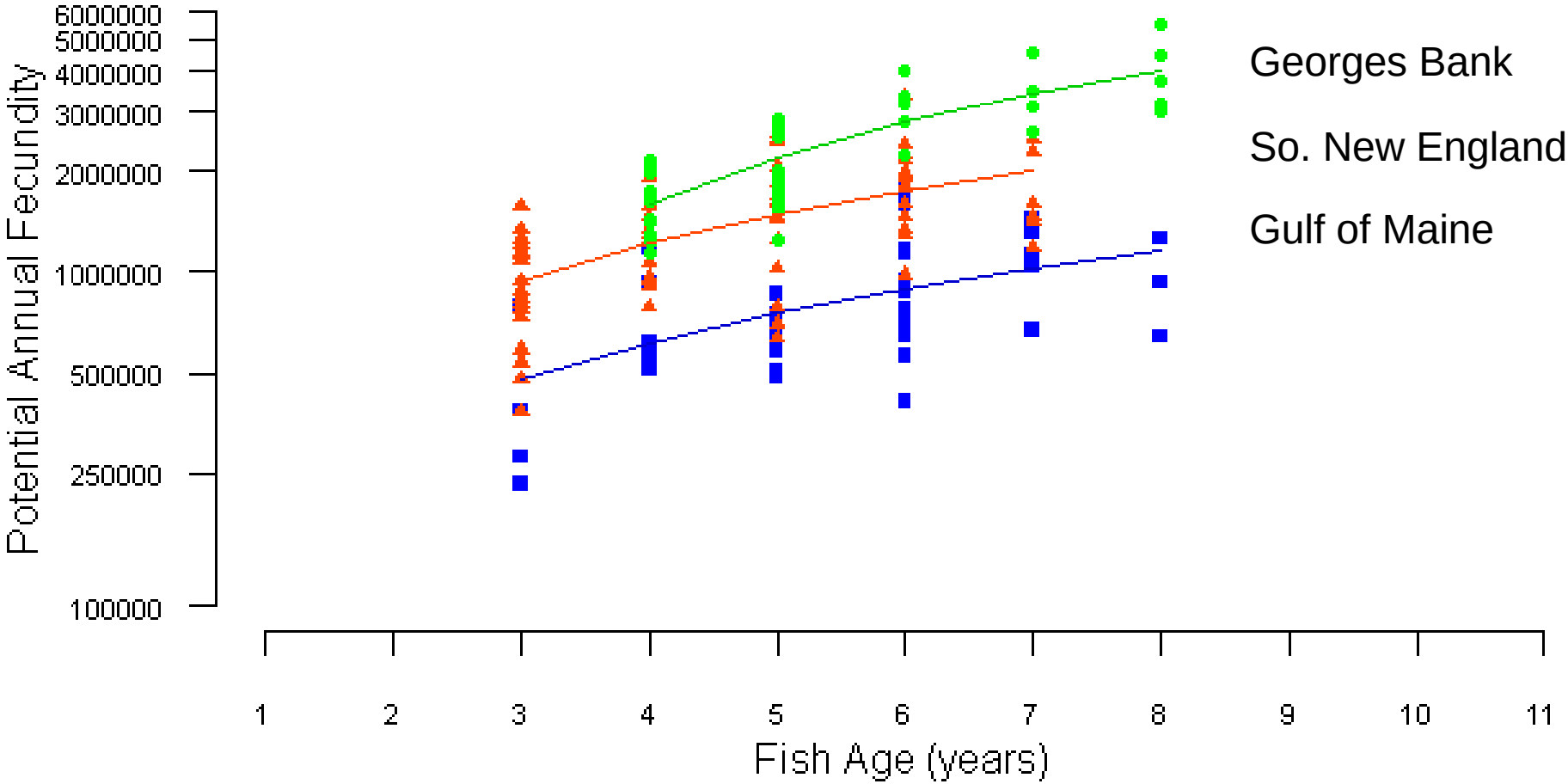
Autodiametric curve analysis
A rapid method
to estimate fecundity





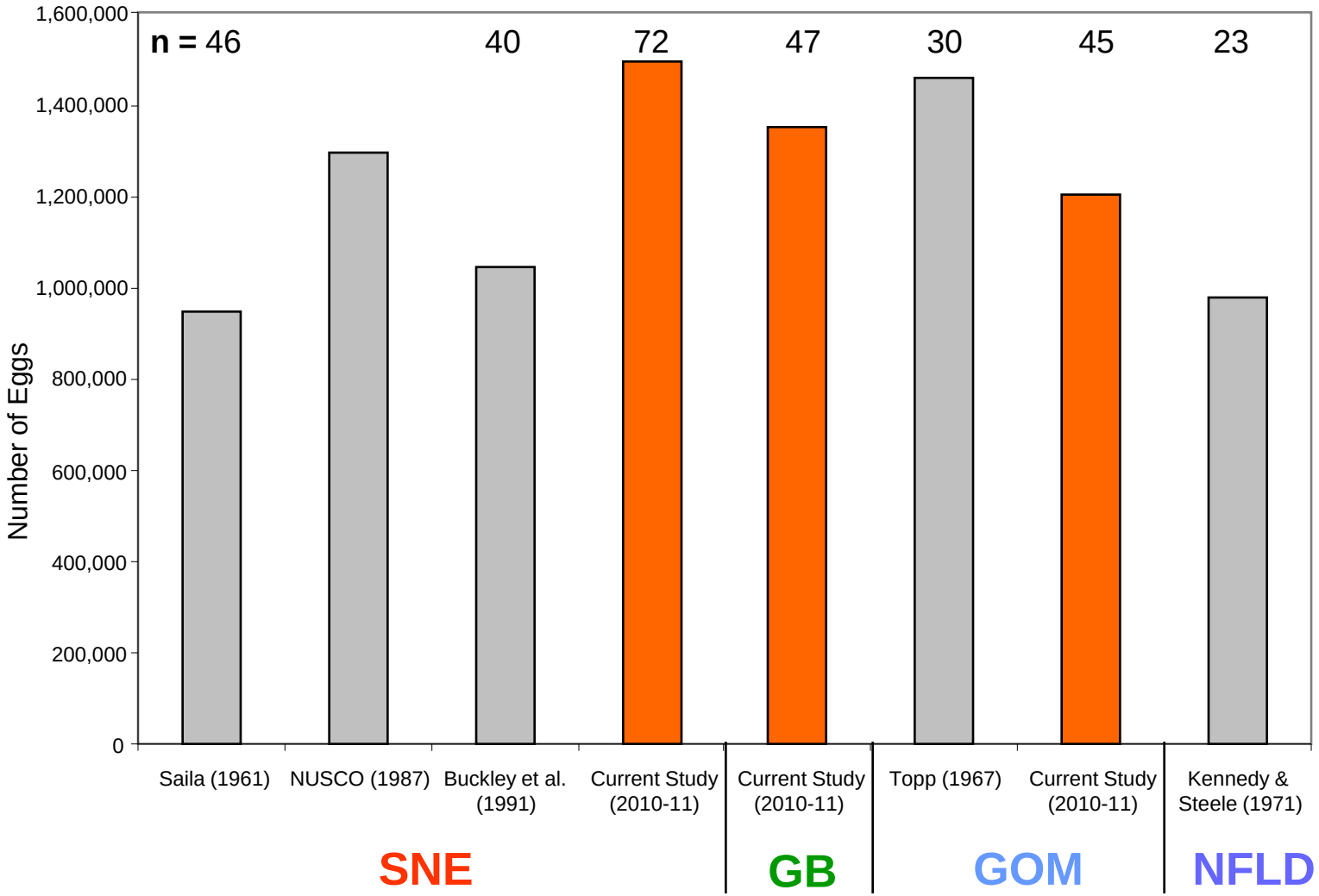


Model	K	AIC	ΔAIC	Wt.
Base	3	266	163	
Stock	5	102		0.78
Interaction	7	105	3	0.22



Comparison to Earlier Fecundity Studies

- Calculated fecundity based on reported relationships
- Estimates for an 800g fish



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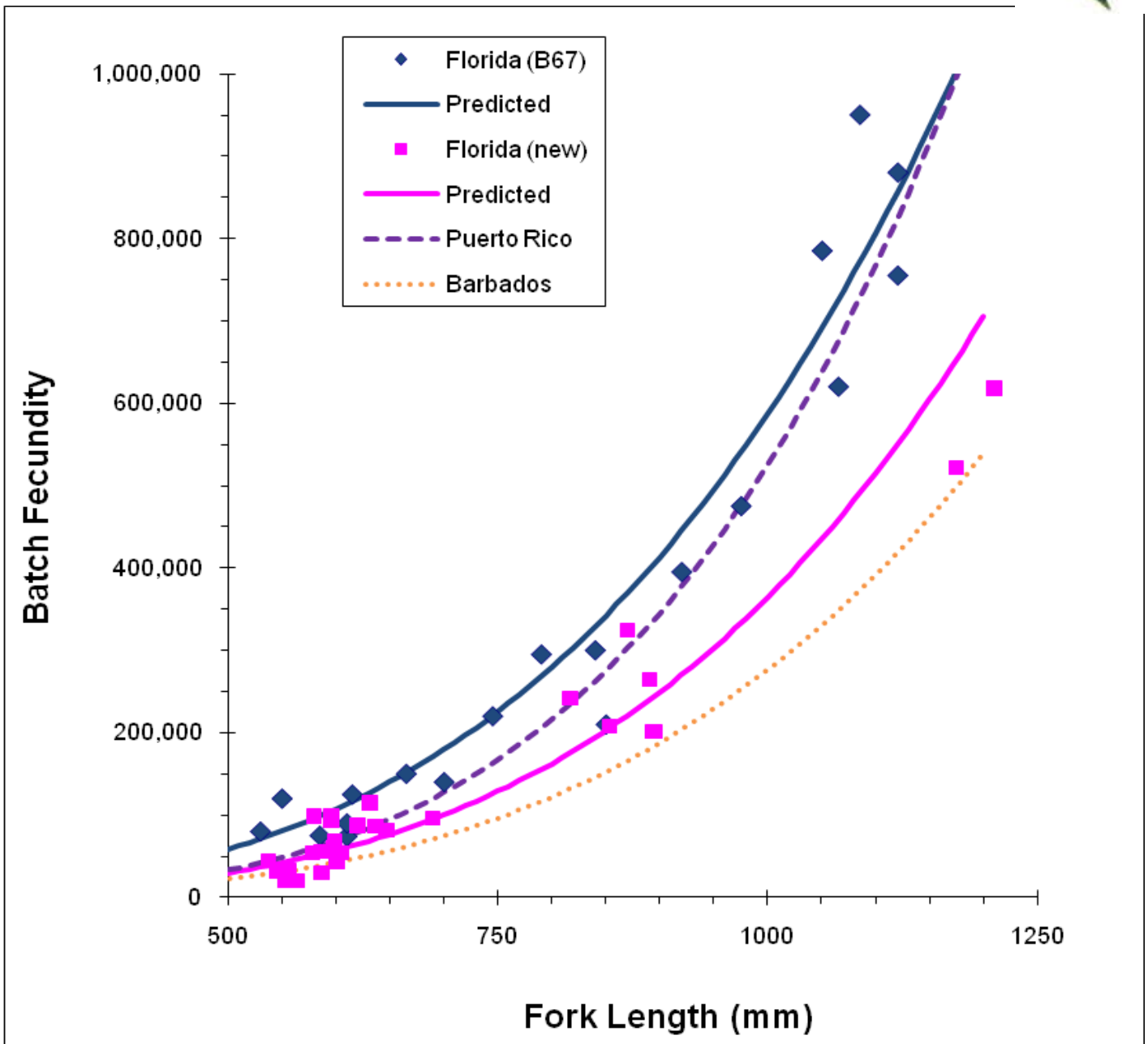
Dolphinfish – how fecund?

"Female dolphin produce
80,000-1,000,000
eggs at each spawning"

Beardsley GL, Jr. 1967. Age, growth, and reproduction of the dolphin, *Coryphaena hippurus*, in the straits of Florida. Copeia 1967 (2):441-451.

Batch fecundity by size



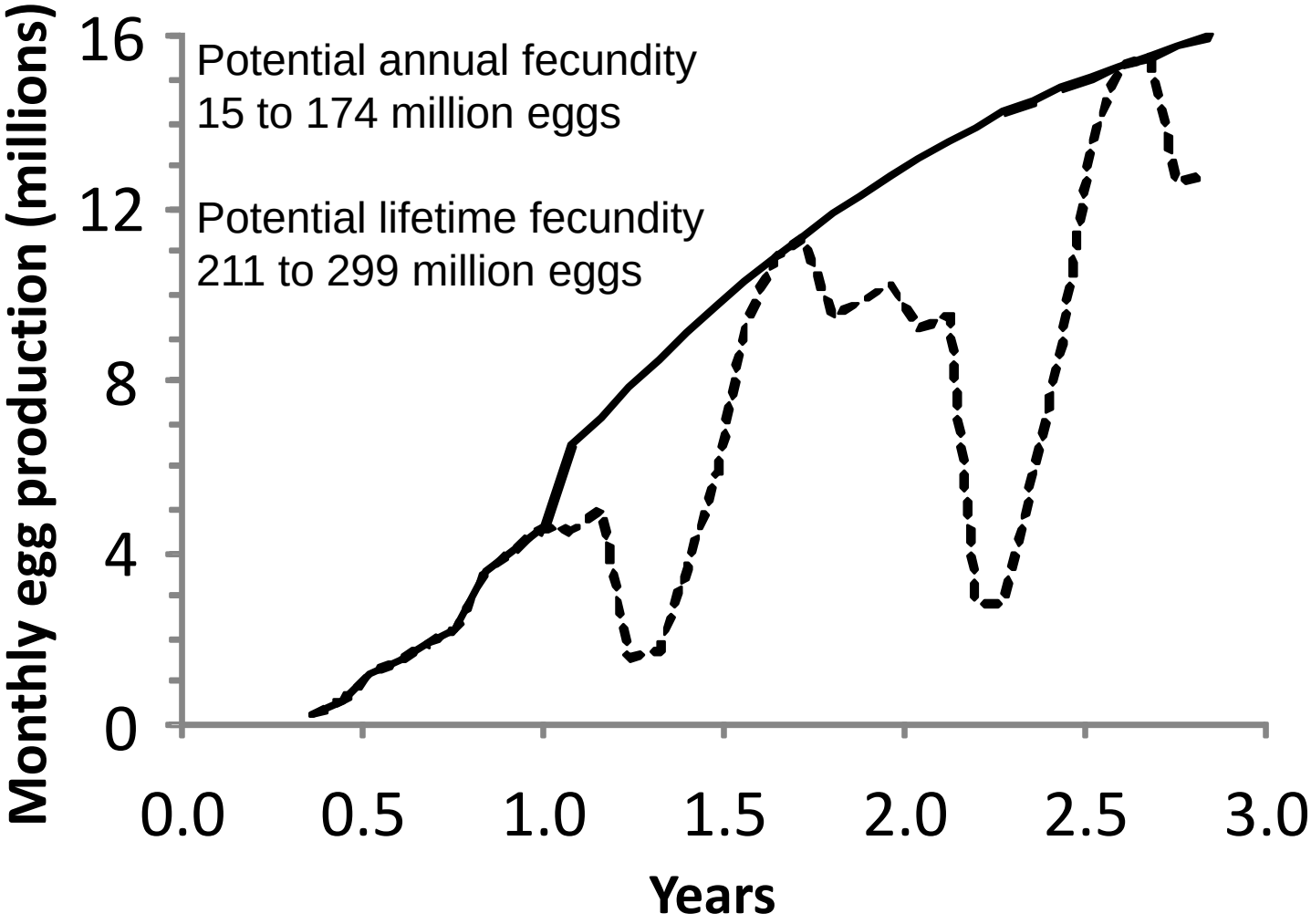
Egg production: the model

$$EGGS = \sum_{a=0}^{n} N_a \, PM_a \, BF_a \, SF_a$$

EGGS is expected lifetime number of eggs produced per recruit,

N_t is the number of females per age class *a*
PM_t is the probability of being mature at each age class
BF_t is the average number of eggs per batch at each age class
SF_t is the number of batches produced by a fish at each age class

Egg production by age (predicted)



Reproductive parameters (McBride et al., unpublished ms.)
Von Bertalanffy growth parameters (Schwenke and Buckel, 2008)
No mortality included

Black Rockfish (*Sebastes melanops*)

Table 5

Age group-specific relative larval production for 1996–98 for female black rockfish off Oregon.

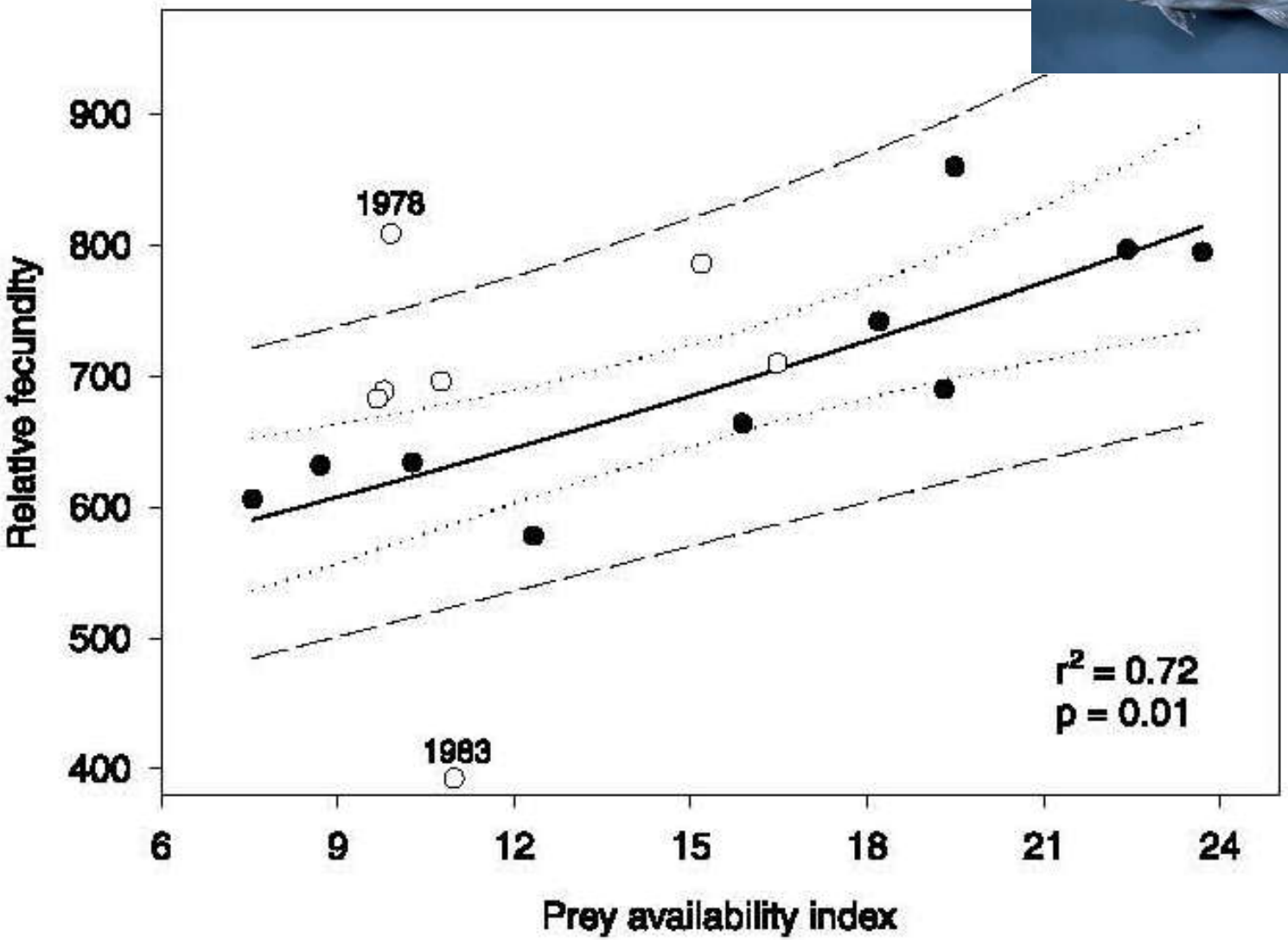
	Percentage of relative larval production		
Age group	1996	1997	1998
6–8	26.4%	43.1%	65.3%
9–11	60.1%	49.6%	32.9%
12–14	11.3%	5.8%	1.8%
15 and older	2.2%	1.5%	0.0%

Main conclusions: Age truncation eliminates females with….

- higher fecundity per individual,
- greater success in carrying eggs through to the larval stage,
- longest overall parturition season.

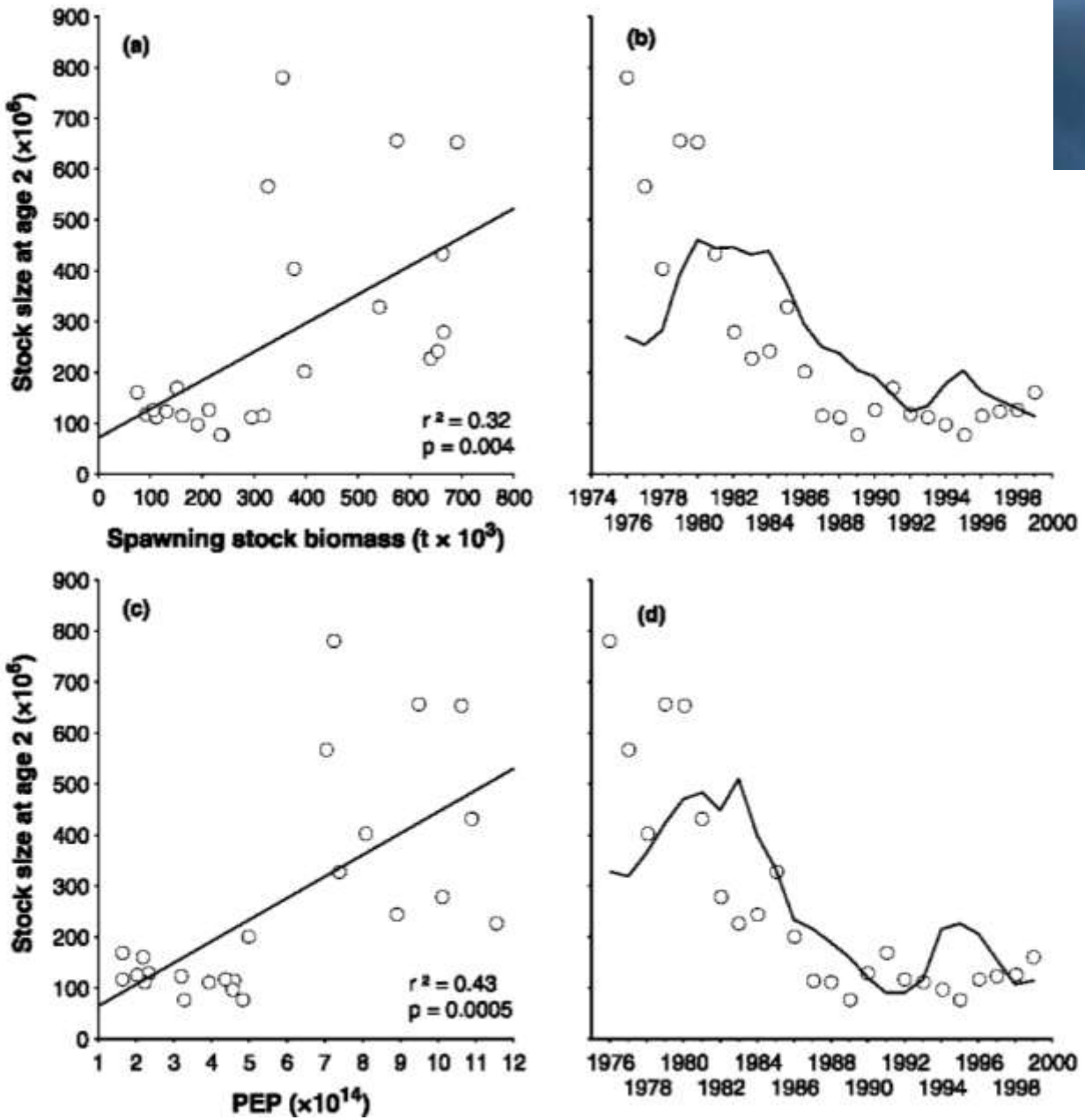
Bobko and Berkeley (2004)

Baltic cod (*Gadus morhua*) fecundity
In relation to prey (sprat and herring) forage



Fecundity often varies with time, in this case:
Fecundity varies with food consumption

Kraus et al. (2002)



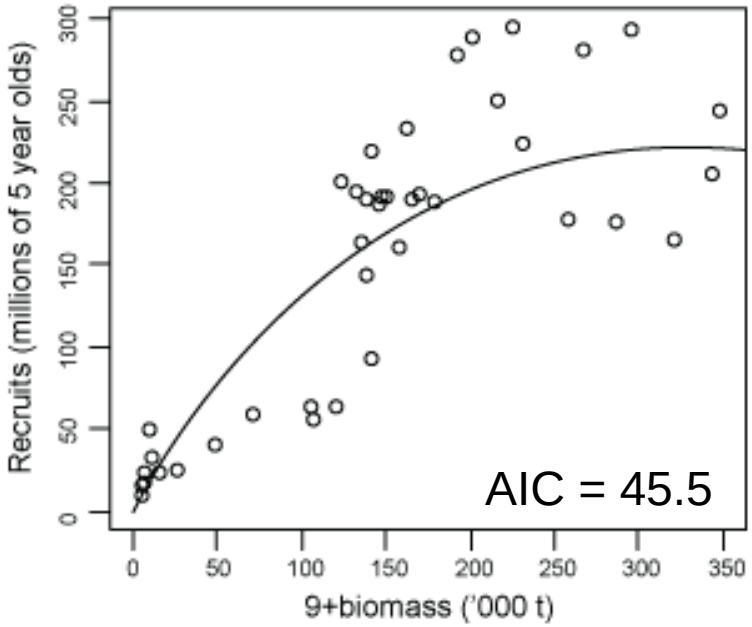
Baltic cod (*Gadus morhua*)

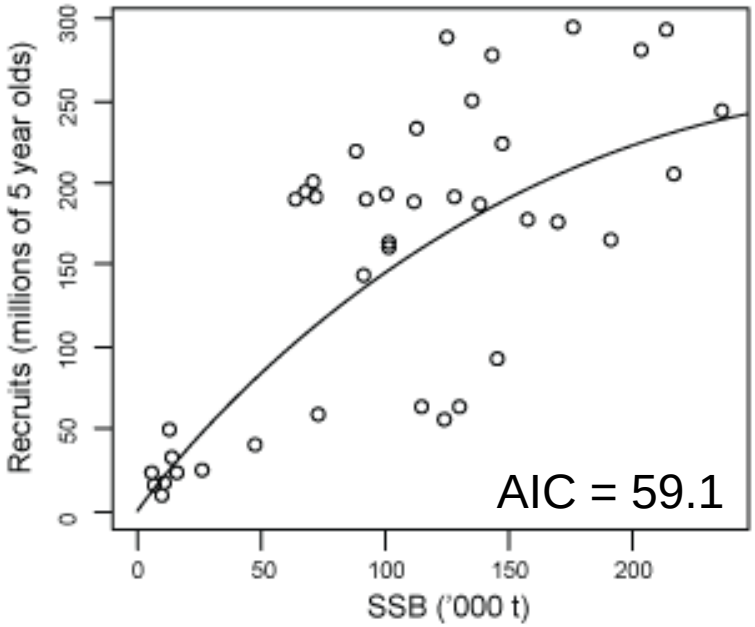
Alternative indices
of reproductive potential

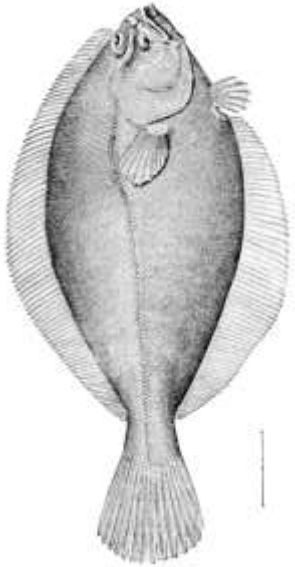
SSB
(Spawning Stock Biomass)
Traditional index

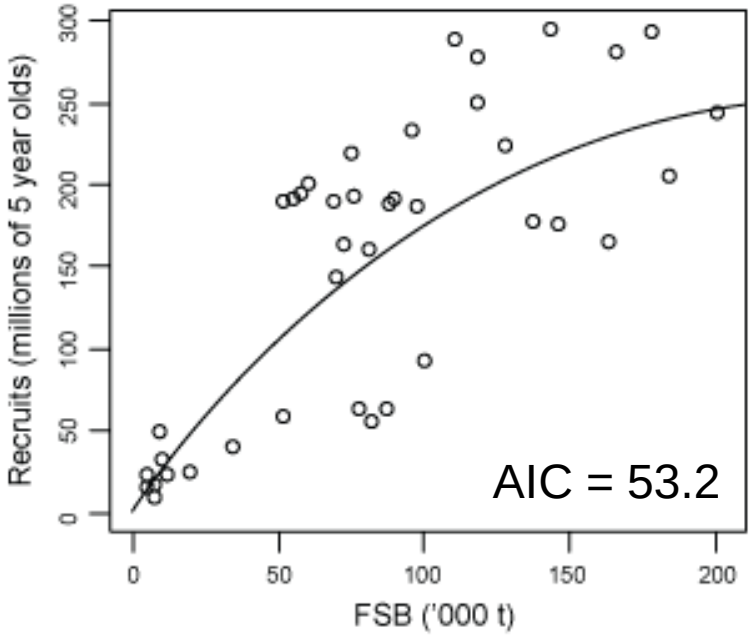
PEP
(Potential egg production)
Improves predictive value

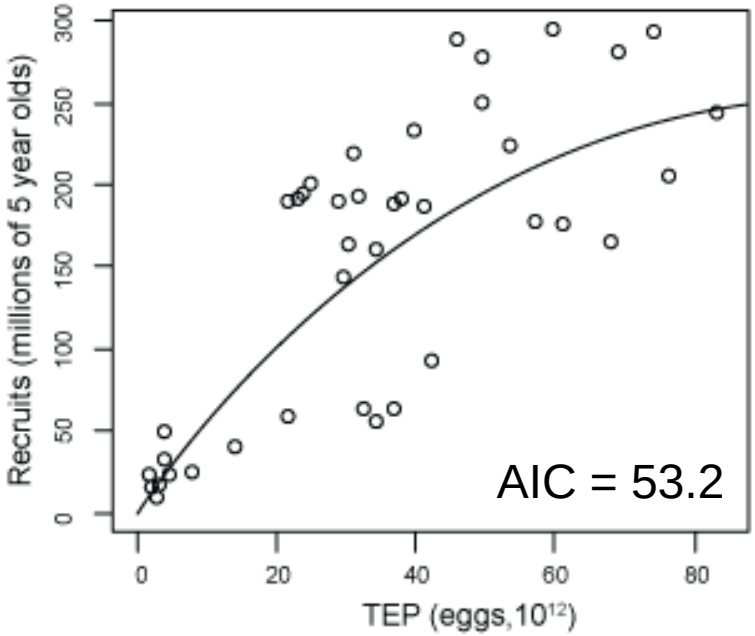
Kraus et al. (2002)











American plaice (*Hippoglossoides platessoides)* Morgan (2008)

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Maturity, spawning frequency, fecundity

Rapid progress continues in this field:

- Gonad histology to validate maturity classification
- Awareness of skipped spawning
- Improved methods for fecundity estimation

Each of these traits is dynamic:

- What is the range of values?
- Why is there such a range of values?
- How can we best measure theses values?
- Which new data streams should be developed?
- Who will apply them to stock assessment?

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Where do you fit in?

- Research, uncover mechanisms
- Monitoring trends, indicators of change
- Assessment, status and trends, dynamics, and prediction
- Advisory services, options for mitigation, adaptation, and stabilization
- Policy implementation, best response based on multidisciplinary considerations

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Collaborators

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