Fecundity & Spawning

LO: extrapolate effects of physical conditions on fecundity and spawning of fish

Reproductive Strategies

- combination of evolution, physiology, and behavior

- live bearing (viviparous) elasmobranchs, sebastes; low fecundity; high age at first reproduction; long lived; internal fertilization

- egg broadcast or tending (oviparous) most marine teleosts; high fecundity (related to body length); variable age at first spawning

  - batch (multiples in sequence) or single (all at once) spawners

  - determinate: 'known' number of eggs prior to spawning; indeterminate: insufficient differentiation of oocytes to allocate to specific spawning season

  - spawn once and die (semelparous or monocyclic)

  - spawn multiple times (iteroparous or polycyclic) most species, accommodate environmental variability

Reproductive Plasticity

- in response to chronic or episodic environmental conditions
- Bullhead (*Cottus gobio*) in acid northern waters females long-lived, 9 years, mature at age 2, spawn once per year; in southern basic waters < 5% reached age 2, matured at age 1, spawned at least 4 times per year (Fox 1978)
- Among years: shifts in timing of spawning, location of spawning, gonad production, spawning activity (egg reabsorbption)

Three general groups based on gametogenetic development (Billard 1981):

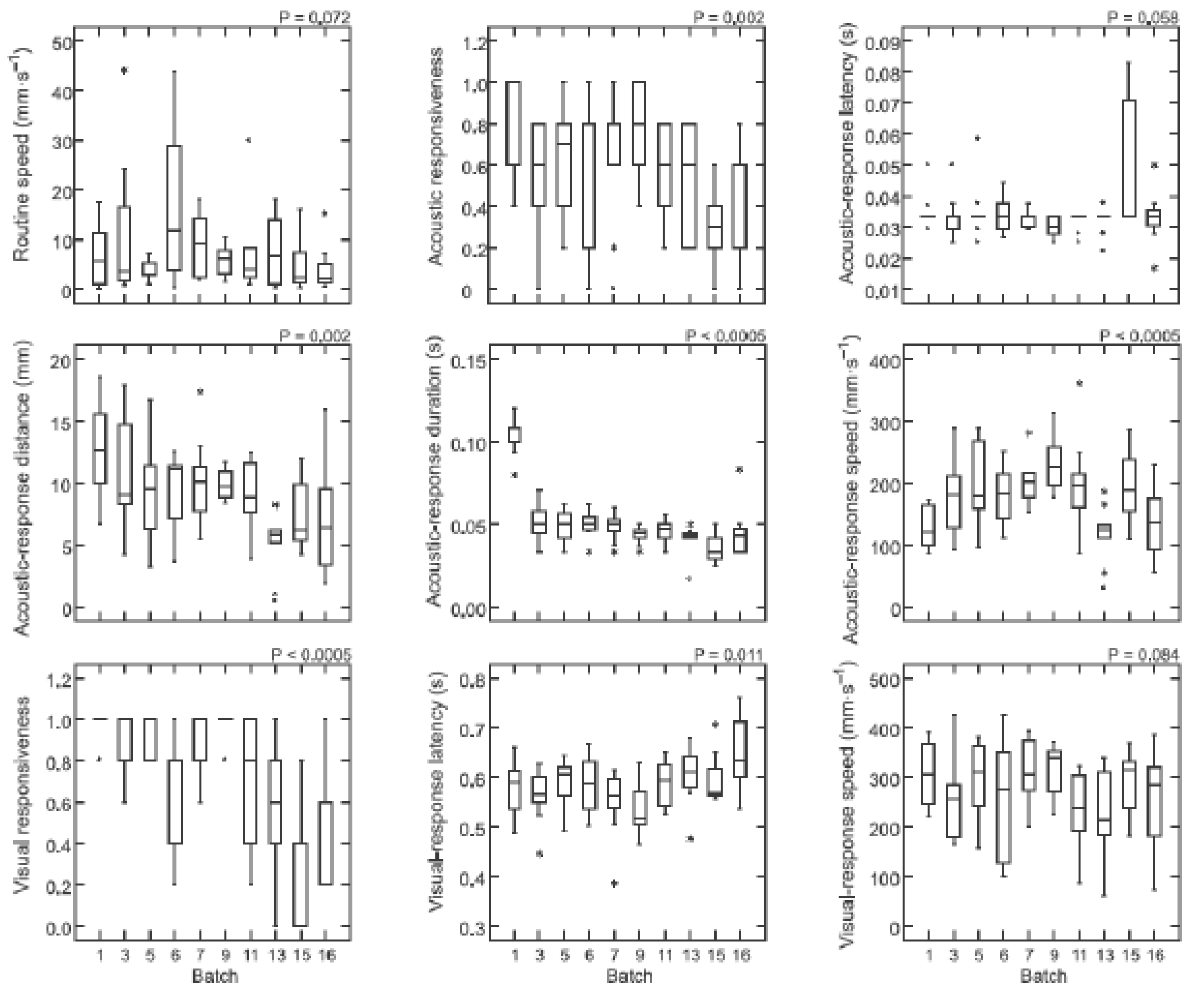
- completed in summer and fall, spawning at onset of cold season (low temp, short photoperiod)
- begins in fall but suspended in winter, maturation and spawning completed in spring or summer
- completed during increasing temperature and photoperiod, spawning in spring/summer

Bet-Hedging in Variable Environment

Red Drum

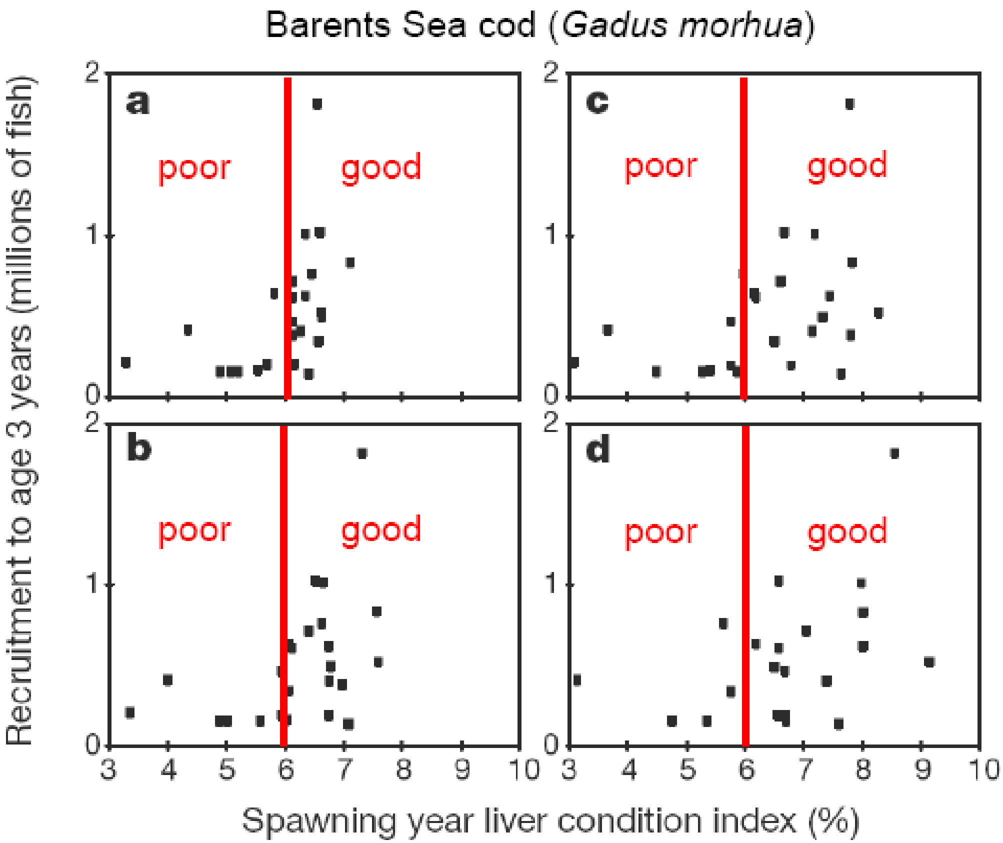
(*Sciaenops ocellatus*)

- serial spawner
- egg batches differ in characters, survival
- may be due to female condition



Fuiman et al. 2005

Female Condition & Fecundity



- lipid stored in liver for egg production
- use lipid as index of egg production
- includes number and quality of eggs
- quality function of female condition
- female condition function of environment (mainly temperature)

Marshal et al. 1999

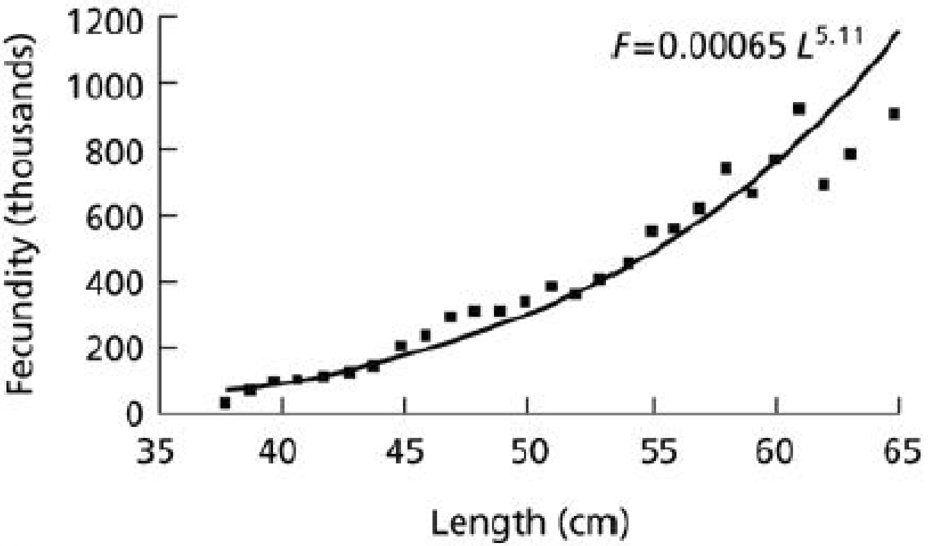
Fecundity Characteristics

- very high 10^4 to 10^6 eggs
- external fertilization (exception *Sebastes* ~2.5×10^3 larvae)
- pelagic, buoyant (exceptions herring, Pacific cod: demersal)
- high energetic cost: 1/6 to 1/5 body weight spawned per year
- fecundity proportional to weight (increasing surplus energy into gonad as fish age)

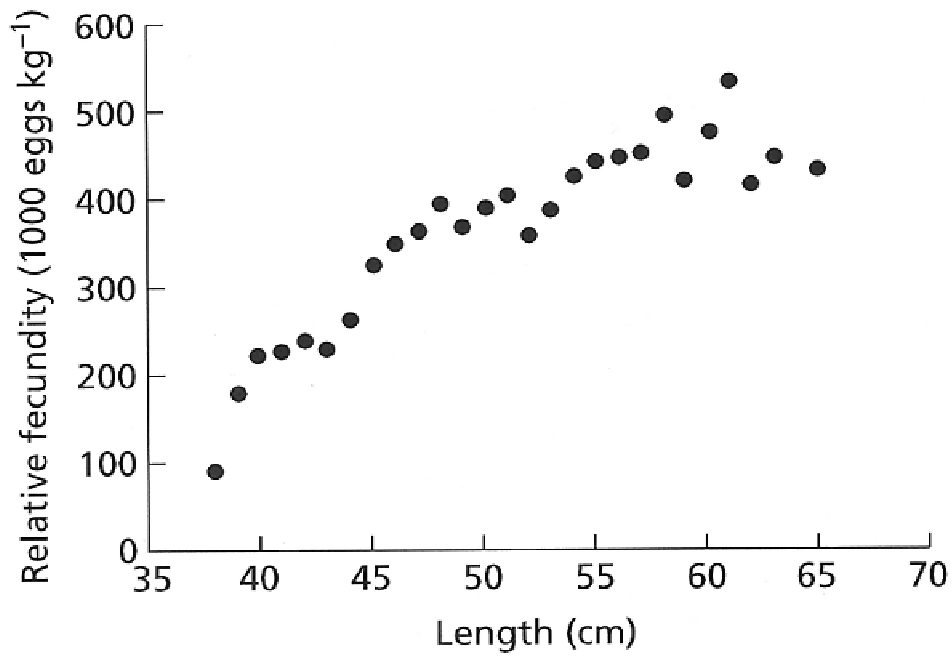
Fish Fecundity

- fecundity (#, mass) increases with length

- trade-off between growth and reproduction



Blue whiting (*Micromesistius australis*)



Jennings et al. (2001) Fig. 3.8, 3.9

Population Regulation via Fecundity

- variability in fecundity
- fecundity and food supply
- density-dependence of fecundity
- fecundity changes with harvest pressure

Timing & Duration of Spawning

Boreal species: once/year over brief period with low variability, spawn often in winter or early spring

e.g. 70 year spawning records of North Sea plaice, Norwegian herring, Fraser River sockeye, arctic cod:

spawning date s.d. <1 week (Cushing 1969)

Temperate species: repeat or batch spawning, protracted period with high variability, spawn late spring or summer

e.g. CA sardine and northern anchovy:

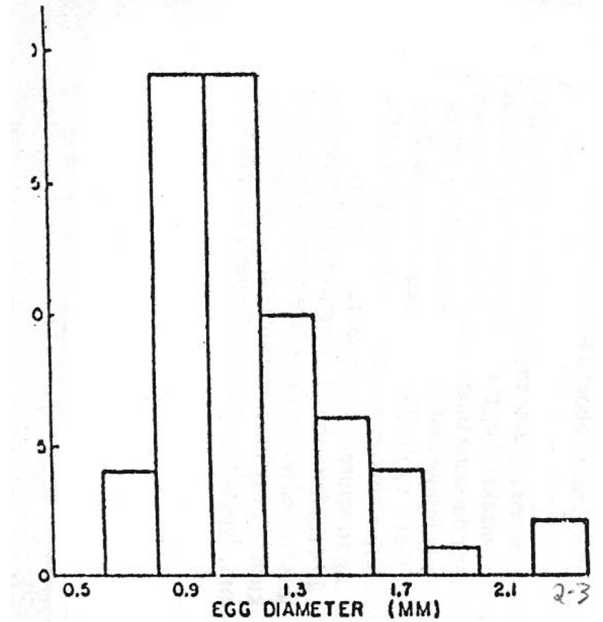
spawning date s.d. ~7 weeks

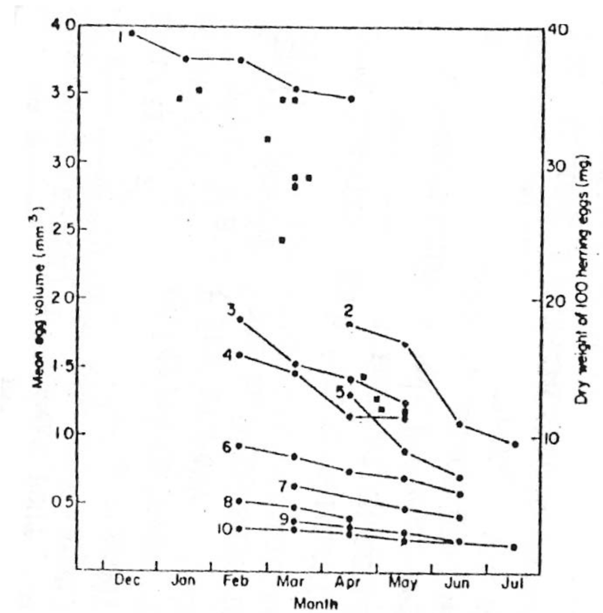
Tropical species: continuous spawning, no seasonality

Why temporal differences?

Egg Size

- number and quality regulated to maximize fitness
- egg size (weight, diameter) correlated with larval size, growth rate, survival time without food, and mouth gape (i.e. prey size) (Blaxter & Hempel 1963)
- egg size proportional to amount of yolk (i.e. egg quality)
- egg size proportional to 1/egg number
- narrow range of egg size within species (factor of 2)
- egg size varies with: spawn time (decreases within season), female size (larger female, larger eggs)





Fish Eggs

Egg Size: weight, diameter $\propto$ incubation period

Advantages of larger eggs:

- behavioral and physiological capability when emerge
- resistant to starvation because weight-specific metabolic rates are lower
- shorter larval periods

Disadvantages:

- r vs k strategy of egg laying (?)

Planktonic vs. Demersal

- demersal eggs have low water content (55-85% of wet wt) to increase specific gravity
- planktonic > 90% wet wt

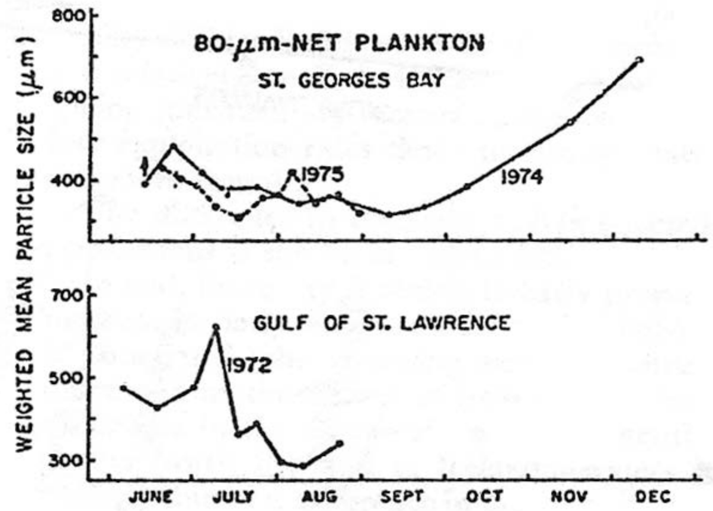
Planktonic vs Demersal

Trait	Planktonic	Demersal
Water content	> 90% wet weight	55-85% wet weight, increases specific gravity
Diameter	0.5 – 5.5 mm, ~ 2.0 mm	≥ 15 mm
Number at Spawning	10^5 – 10^6, depends on species	< 10^5, exception sturgeon 10^6
Spawning Location	in water column, away from benthic predators	close to or on substrate
Spawning Strategy	dispersion	coalesce
Development at Emergence	less	more

Egg Size & Spawning Season

- winter/early spring environment more variable, larger egg (more yolk)
- egg size related to plankton size (mean plankton size decreases from spring to summer but evidence not definitive Ware 1977)
- egg size based on relationship between size, growth rate, and mortality rate (with aim to maximize fitness)
    - egg mortality, growth ∝ 1/size
    - incubation time ∝ 1/temperature
    - # eggs ∝ 1/egg weight
    - egg diameter declines with temperature

So, incubation time correlated with egg diameter



(Ware 1977)

Egg Size & Spawning Season

$$N_t = \frac{N_0 W_0 Q}{\left(abt + W_0^{\,b}\right)^{Q/b}}$$

Ware 1975

where:

N_t number at time t; W weight; Q growth constant; a,b, growth weight constants,

Result:

- with long incubation time, maximum survival occurs with large eggs (minimize mortality during yolk-sac period)
- with short incubation time, maximum survival with maximum number of eggs

Fitness: maximize survivors, tradeoff between # eggs (r) and egg weight (k)

Egg Size & Spawning Season

Ware's model consistent with decrease in egg size from spring to summer and increase from fall to winter

Confounding Evidence and Alternate Explanations:

- egg size declines from spring (diatoms, *Calanus*) to summer (dinoflagellates, small copepods) with prey size
- winter: larger energy needed due to low food and more variable conditions
- relationship between egg size and temperature (rationale temp $\propto$ metabolism)?
- Is predation constant through seasons? (assumed in Ware's model)

Probably multiple factors contributing

Fecundity & Population Dynamics

Bagenal (1973): since correlation between # eggs and recruitment, should be a density-dependent function

- variation in fecundity in 5 species 34% to 56% (length adjusted) but 250% in another

Concluded fecundity unlikely to regulate recruitment since:

1. year class variability exceeds annual variability
2. relation between egg number and recruitment poor

Is Fecundity Density-Dependent?

Bagenal (1973)

Empirical evidence from pike in Lake Windermere (4 years data), plaice in N. Atlantic (5 years data), Norway pout (ranged 2 to 2.5 times)

Nikolskii et al. (1973)

Evidence from salmon, Baltic sprat, Black Sea anchovy

But rare correlation between recruitment and number of eggs, therefore density-independent factors (i.e. environment) are also likely important

Compensatory Mechanisms?

As population declines, increased fecundity

Relationship between fecundity and length (Schopka & Hempel 1973):

$$\text{fecundity} \approx aL^4$$

Since fishing reduces mean length, fishing may have greater effect on spawning potential then on biomass.

Since larger fish produce more viable larvae, effect may be magnified

Hjort started it all…

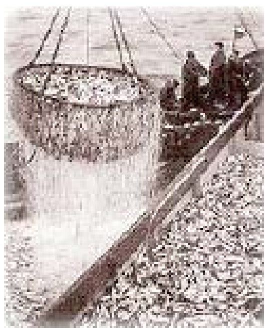
Hjort (1914) stated that the “numerical value of a year class is determined at a very early stage...”.

Also,
“...it was difficult to avoid the conclusion, that the actual quantity of eggs spawned is not a factor in itself sufficient to determine the numerical value of a year-class.”

1926 two hypotheses:

1. Must feed during the critical period
2. Transport away from nursery areas is bad

Herring & Cod NE Atlantic



Herring

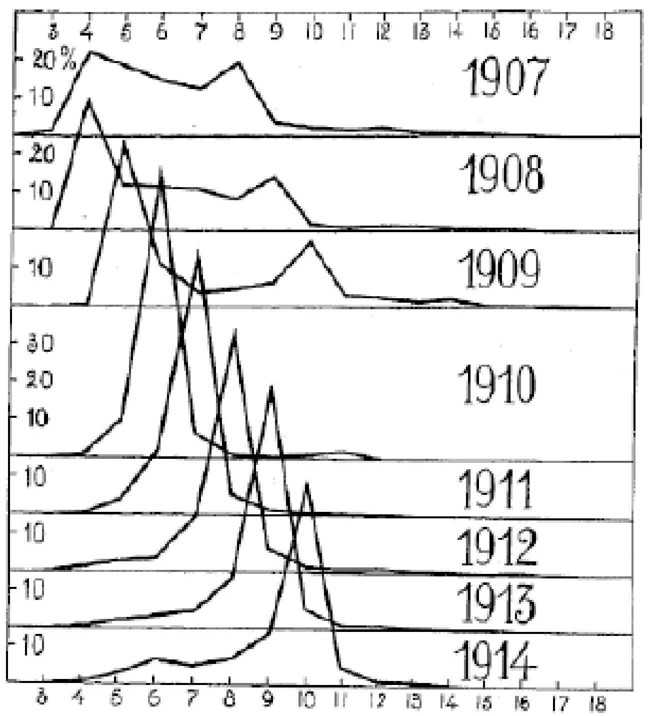
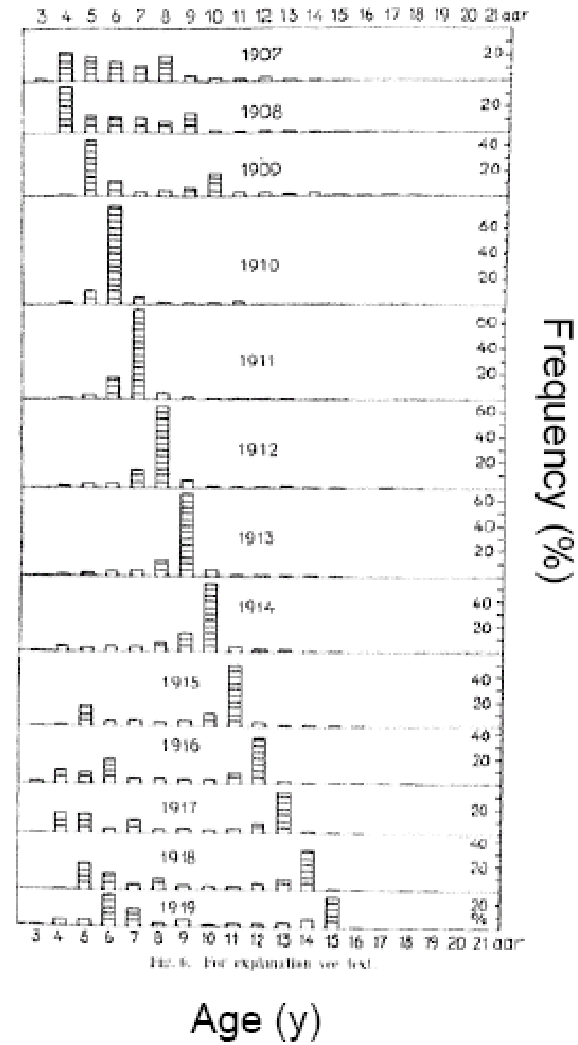


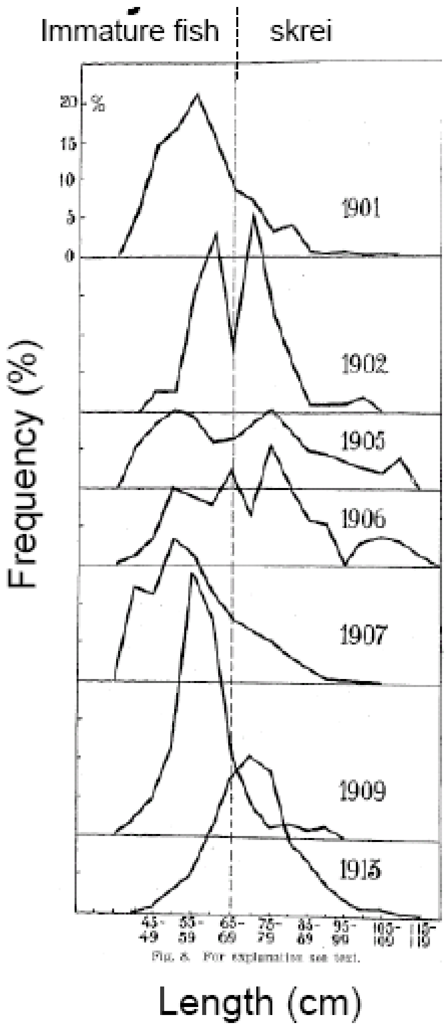
Fig. 5. Composition in point of age of spring herring for the years 1907—1914; average of all samples examined in each year. For 1914 only samples from February included.



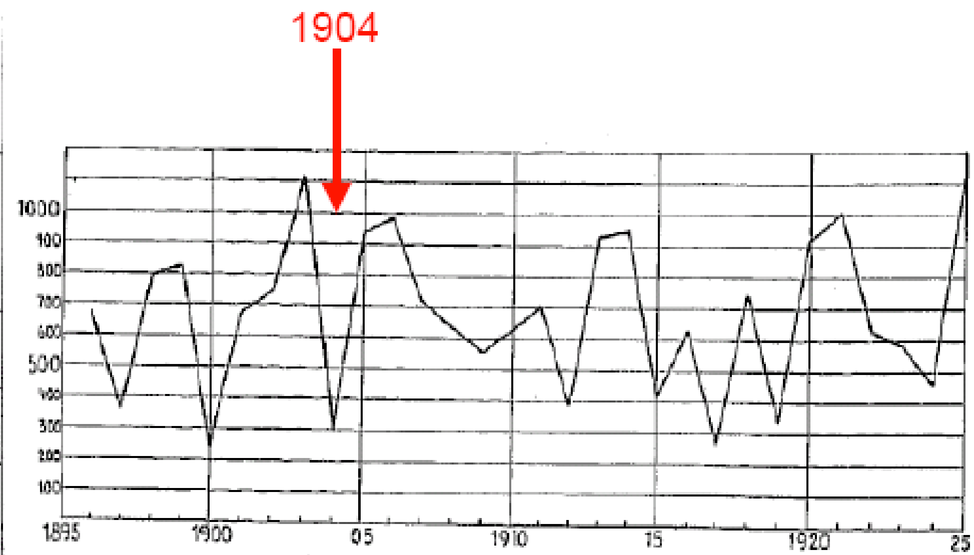
Herring & Cod NE Atlantic

Cod

skrei= spawning



Percipitation (rain & snow)



- found that dry years good for herring and cod but not always
- runoff related: food for larvae and transport