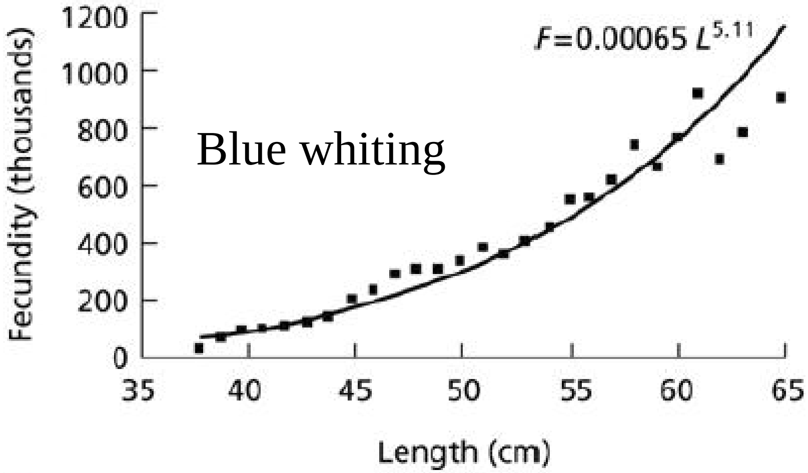
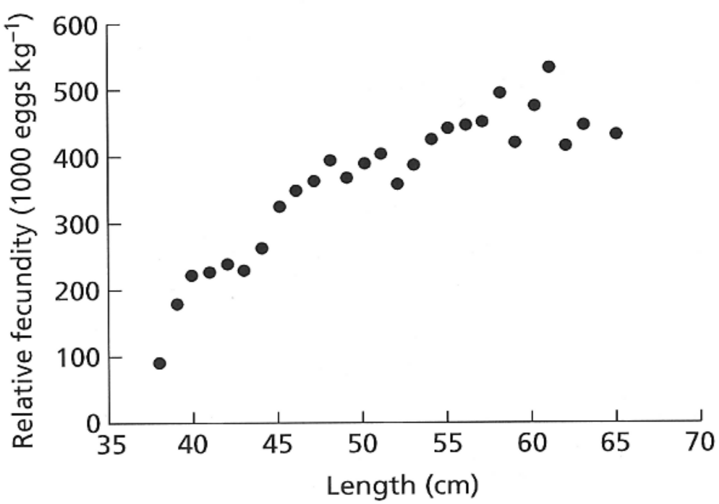
Mortality

LO: extrapolate effects of physical conditions on the mortality of marine fish species

Fecundity & Mortality



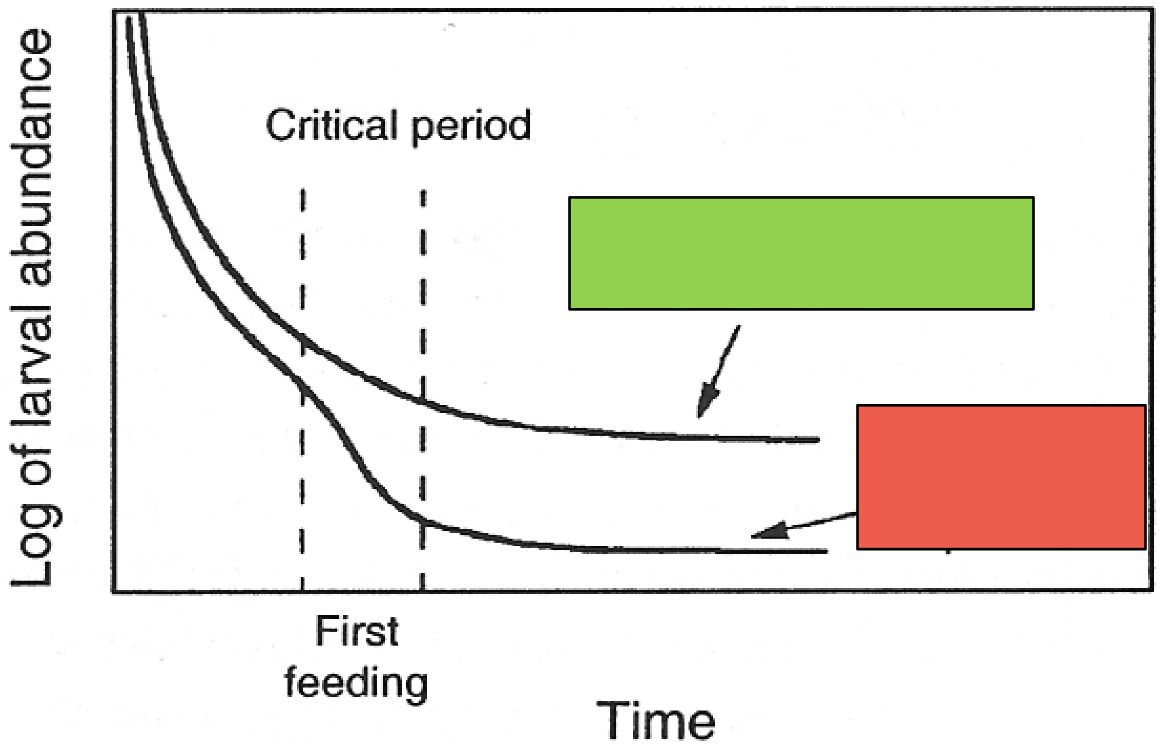


Jennings et al. 2001

- high fecundity: egg production max.10^{12}
- high mortality needed to meet ecosystem carrying capacity
- large range in mortality rates, mortality $\propto$ age (overall mortality)
- short-lived 50-90%/year (anchovy), long-lived 10%/year (sharks, sturgeon)
- natural mortality rates **not** well known, often assumed constant (0.2)
- fishing mortality rates (f) can be 5x natural mortality rates (m) in commercial species

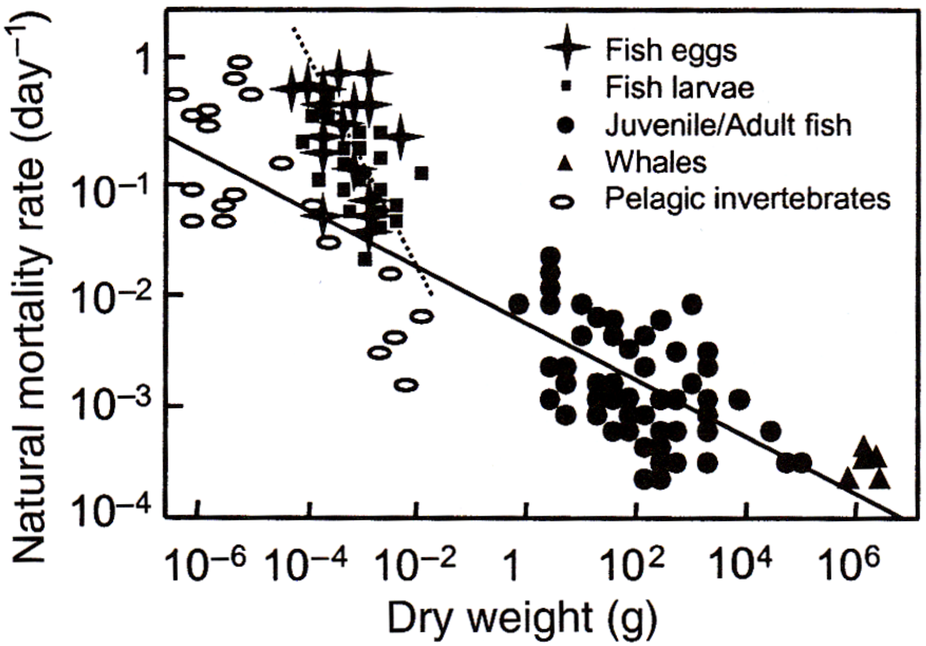
Hjort’s First Hypothesis

- differential mortality between years is a result of food availability at a critical stage during fish development



Leggett & Deblois 1994

Natural Mortality and Weight



- m ∝ weight
- consequence of predation

$M = 0.0053W^{-0.25}$

Overall slope = -.25

Fish eggs & larvae = -.85

McGurk 1986

Table 3.1 The average relationship between *M* and *W* for five species of fishes during the larval stage.

Species	Relationship
American shad	$M = 1.724W^{-0.392}$
Northern anchovy	$M = 1.073W^{-0.353}$
Bay anchovy	$M = 2.284W^{-0.318}$
Walleye pollock	$M = 3.874W^{-0.622}$
Striped bass	$M = 4.875W^{-0.424}$

From Houde (1997).

Mortality & Growth

- mortality decreases with size and age
- marine mean: m = 0.24 (21.3% day^{-1}); freshwater mean: m = 0.16 (14.8% day-1).
- Why marine higher?   smaller average size

Example

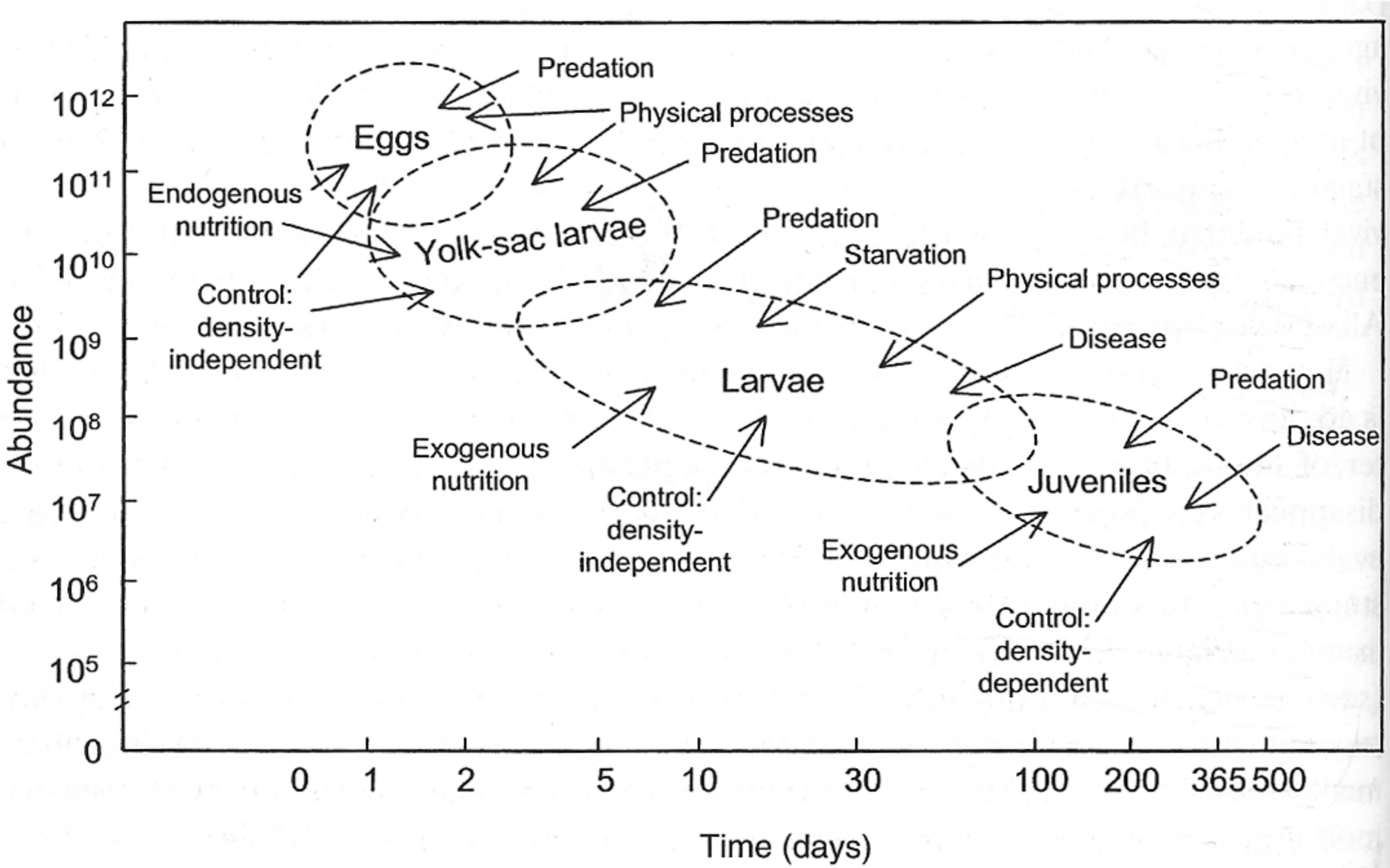
Marine: 1 million larvae, m=0.24, larval duration=36 days

Number of survivors?   180 = >99.9% mortality

Fresh: m=0.16, larval duration=20.7 days, 96.4%

Houde & Zastrow 1993

Sources of Mortality



Which is most important?

Houde 1987, 2002

Starvation (link to Mon lecture)

- Lab studies show massive mortality at end of yolk-sac stage at onset of first feeding.

- extension to natural environments lead to Critical Period Hypothesis (Hjort 1914, 1926)

- low mortality at this time also depends on availability of food: Match/Mismatch Hypothesis (Cushing 1972, 1974, 1990)

- but average conditions won't support larvae: Stable Ocean Hypothesis (Lasker 1978)

- also need high encounter rates to feed: microturbulence (Rothschild and Osborn 1988)

How Important is Starvation?

- point of no return differs among species
- poor condition leads to increased risk of predation
- element of competition but not well documented
- overwinter mortality of smaller individuals

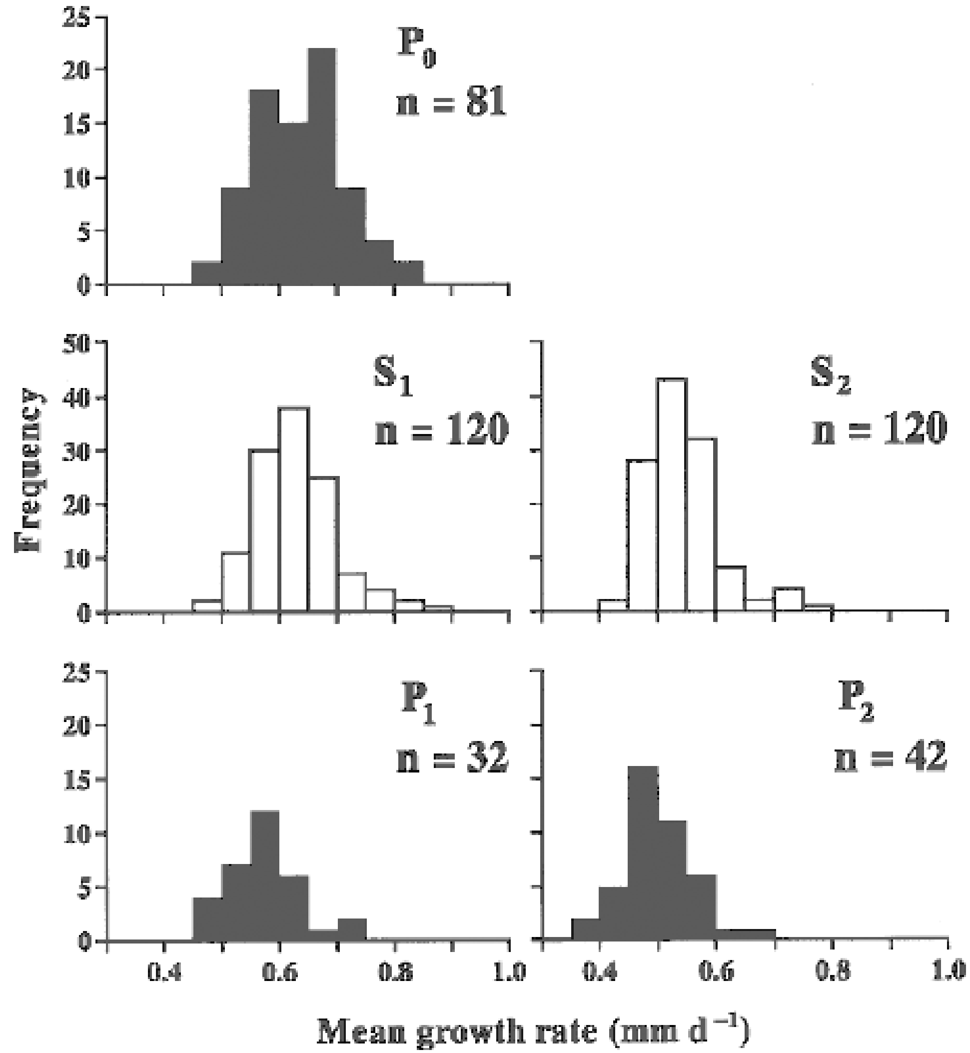
Predation

Slower-growing Japanese sardine larvae were more vulnerable to predators than faster-growing larvae.

Collected live larvae and larvae in guts of predators. Analyzed otoliths to determine growth rate prior to capture or predation.

P = from predator stomach

S = survivor

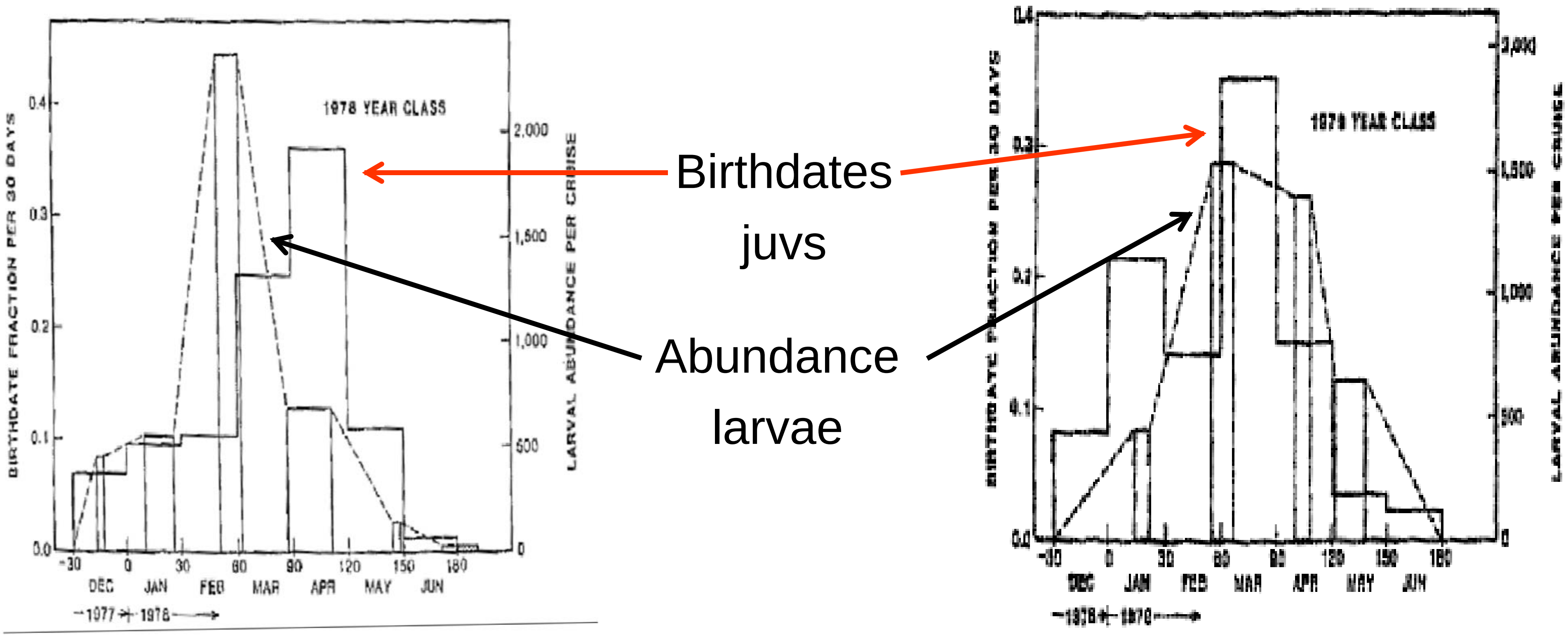


Takasuka et al. 2003

Survival: Egg to Larvae

Hatchdate Frequency Distribution (HFD): compare HFD’s to identify larval survival windows, then infer favorable biotic and abiotic conditions within season

Example: anchovy birth date distributions of juveniles with those inferred from collections of 2.6 - 5.1mm larvae (~hatch to 1st feeding)

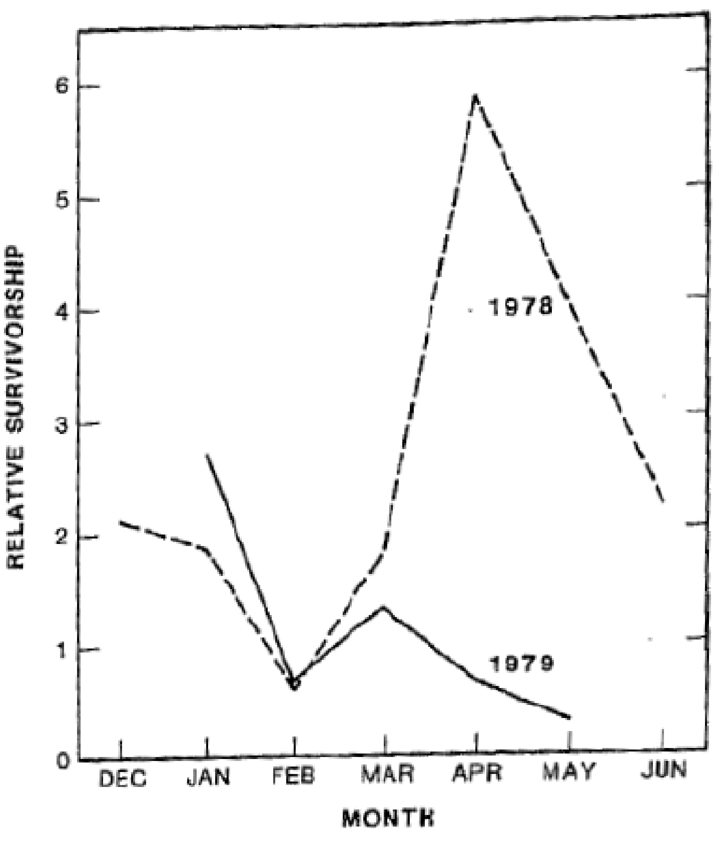


production ~2.1% greater in ‘79 than ‘78

Methot 1983

Survival: Egg to Larvae

Anchovy survival from egg to ~ recruitment greater for eggs spawned in late spring 1978



- water stability and larval transport unimportant
- variation in year class strength was related to survival from early larva to juvenile (6-12 months old)

Methot 1983

Growth & Mortality

Species	Instantaneous growth rate[a] (d^{-1}) G_L	G_U	Larval stage duration[b] (d) t_L	t_U	Instantaneous mortality coefficient (d^{-1})	Number of survivors[c] N_L	N_U	Ratio N_U:N_L
Bay anchovy	0.15	0.35	50	21	0.18	123	22,823	185.6
Atlantic herring	0.03	0.10	173	52	0.04	988	124,930	126.4
Striped bass	0.07	0.20	64	22	0.16	36	29,599	822.2
French grunt	0.24	0.41	20	12	0.16	40,762	146,607	3.6
Atlantic cod	0.05	0.15	112	37	0.08	128	51,819	404.8

[a] G_L = lowest probable rate; G_U = highest probable rate.
[b] T_L = larval stage duration predicted for G_L; T_U = larval stage duration predicted for G_U.
[c] N_L = number of survivors predicted for G_L; N_U = number of survivors predicted for G_U.

N_U = # survivors predicted upper; N_L = # of survivors predicted lower

Take Home Message: modest change in growth or mortality rates can have a large, cumulative effect on survival

Houde 1987

Stage-based Effects of Mortality, Growth, & Duration on Recruitment

		Effect on recruitment (age-1)		
Species	Life stage	M^a	G^b	t^c
All species	Egg	Small	Small	Small
	Yolk-sac larva	Small	Small	Small
Bay anchovy	Larva	Large	Large	Large
	Juvenile	Moderate	Moderate	Moderate
Atlantic herring	Larva	Moderate	Moderate	Moderate
	Juvenile	Moderate	Moderate	Moderate
Striped bass	Larva	Moderate	Large	Moderate
	Juvenile	Moderate	Moderate	Small
French grunt	Larva	Moderate	Moderate	Moderate
	Juvenile	Large	Large	Large
Atlantic cod	Larva	Moderate	Moderate	Moderate
	Juvenile	Moderate	Moderate	Moderate

TABLE 10.—Potential effects on age-1 recruitment of 25% increases or decreases in stage-specific mortality rates, growth rates, or stage durations for five species in the egg, yolk-sac larval, larval, or juvenile stages. The

- sensitivity analysis (± 25%) of assumed mortality, growth, and stage duration on age-1 recruitment
- species differ
- egg and yolk-sac stages less important than larval and juvenile

M – mortality, G – growth, t - duration

Houde 1987

Stage-Based Environmental Effects

Walleye Pollock, Bering Sea: GAM results

Tow-based

	Egg	Yolksac	Preflexion	Late	Juvenile
Year	3.4	5.0	7.4	10.0	9.2
Location	2.5	1.3	1.1	1.4	3.2
Day of year	4.9	5.1	4.8	7.9	0.7
Temperature	0.6	0.9	1.9	1.7	1.1
Wind speed	1.0	1.0	*n. sig.*	0.9	*n. sig.*
Zooplankton	*n/a*	*n/a*	0.8	0.2	0.2
Salinity	1.3	*n. sig.*	*n. sig.*	*n. sig.*	*n. sig.*
r^2	0.543	0.229	0.403	0.551	0.154
% Deviance	51.2	28.8	44.8	59.3	41.3
# Tows	1393	1393	1393	1479	1479

Time-based (annual)

	Egg	Yolksac	Preflexion	Late	Juvenile
SSB	7.1	5.0	0.7	*n. sig.*	*n. sig.*
Temperature	0.9	2.8	8.2	16.0	0.8
Mixing	2.6	0.4	*n. sig.*	5.4	8.8
Zooplankton	*n/a*	*n/a*	4.9	3.3	3.8
r^2	0.226	0.149	0.213	0.272	0.081
% Deviance	16.3	14.5	17.3	29.8	19.0
# Tows	1671	1671	1671	1902	1902
# Years	17	17	17	17	17

Rank	Covariate	Possible models	Included models	Weighted deviance
1	Temperature anomaly	5	5	0.26
2	Zooplankton biomass	3	3	0.20
3	Wind mixing	5	4	0.17
4	Year	5	5	0.16
5	SSB	5	3	0.16
6	DOY	5	5	0.11
7	Location	5	5	0.04
8	Temperature	5	5	0.03
9	Wind speed	5	4	0.02
10	Copepods	3	2	0.01

% total deviance explained

- influence of T increased with stage
- winds influenced early stages

Smart et al. 2012

Calculating Mortality

$$-dN = M \times N_t dt$$

$$-Mdt = \frac{1}{N_t} \times dN$$

$$N_t = N_0 \times e^{-M \times t}$$

N number of animals

M natural mortality rate

t age or time

Partition natural & fishing mortality

$$N_t = N_0 \times e^{-((M \times t) + (F \times t))}$$

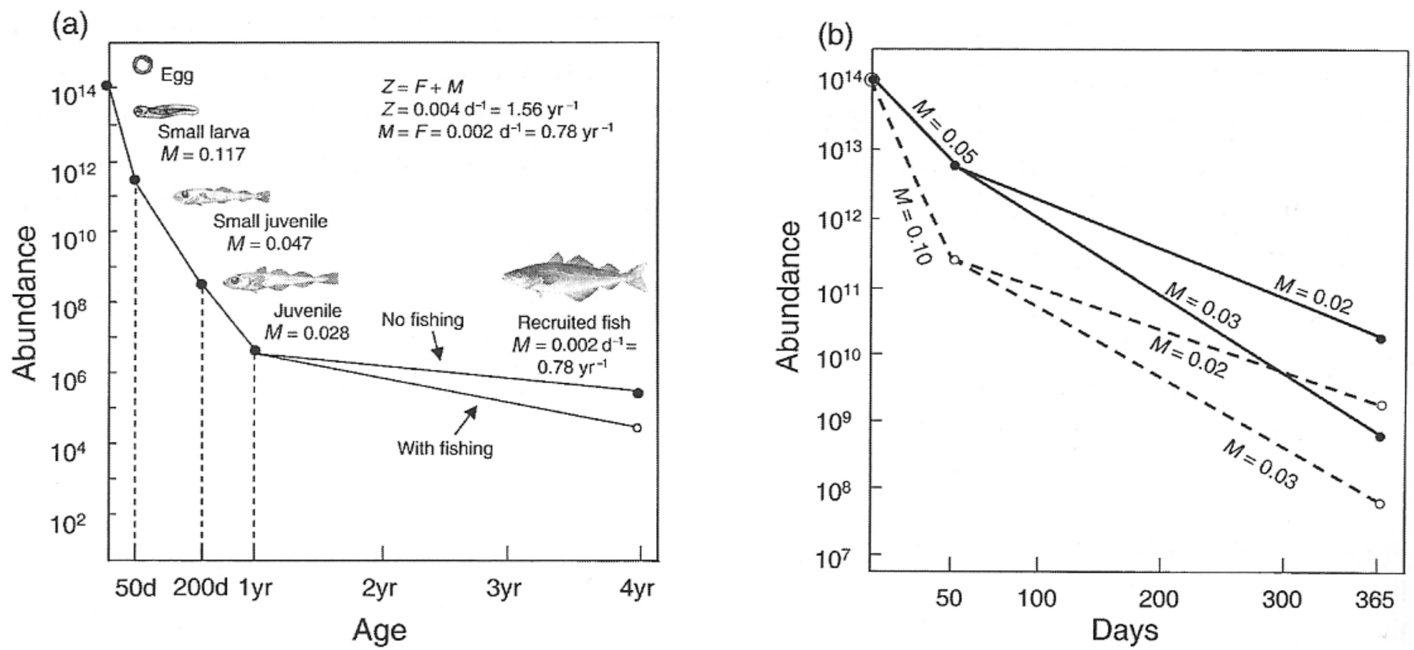
$$N_t = N_0 \times e^{-Zt}$$

Z = M+F

Determining Mortality: 1 Catch Curves

Survivorship

Catch Curves



- instantaneous mortality rate slope of catch curve ($\log_e$ (abund of survivors) vs age)

- critical parameter to Beverton & Holt model and cohort analysis

- poorly known due to gear selectivity, nets don’t catch dead fish, data on escapees limited (juvs and adults only)

- resulting samples: plankton (eggs), juveniles, adults

Catch Curve Assumptions

- age-groups equally available to gear

- recruitment constant (if not use several years of data)

- survival rate uniform over ages (i.e. linear curve)

Ricker (1975) since $M \propto$ age, then linear curve represents balance of increasing M and increasing F in older fish

Supporting Evidence: catch curves for previously unexploited herring convex; similar to survivorship curves for unexploited freshwater populations

Method 2: Tag and Recapture

T fish tagged and returns at R_1 and R_2 (multiple intervals to avoid bias)

Survival rate: $S = R_2/R_1$

Instantaneous Total Mortality: $Z = -\ln(R_2/R_1)$ or $e^{-Z} = R_2/R_1$

Since mortality rate $A = 1-S$ where A is proportion over years time

and exploitation rate $u = R/T$ where $u = FA/Z$

Then $F = uZ/A$, since $Z = F + M$

Potential Sources of Error

- tag loss
- fish deaths due to tagging (initially or continuously)
- incomplete reporting by fishermen or observers
- nonrandom distribution of fish due to behavior: aggregation, emigration, immigration

Method 3: Catch/Effort (CPUE)

- assume N $\propto$ c/f where c = catch, f = effort (i.e. yield/hours fished)

M & q (catchability) constant after recruitment

then knowing age composition: $(c/f)_2/(c/f)_1 = N_2/N_1$

Since $Z = -\ln(N_2/N_1)$ and Z = M + F, F = qf ($F \propto f$)

Then $Z_i = M + qf = -\ln\left((c/f)_{i+1}/(c/f)_i \right)$

So What?

The regression between Z and f has slope q and intercept M