Fisheries Oceanography

OCN 621

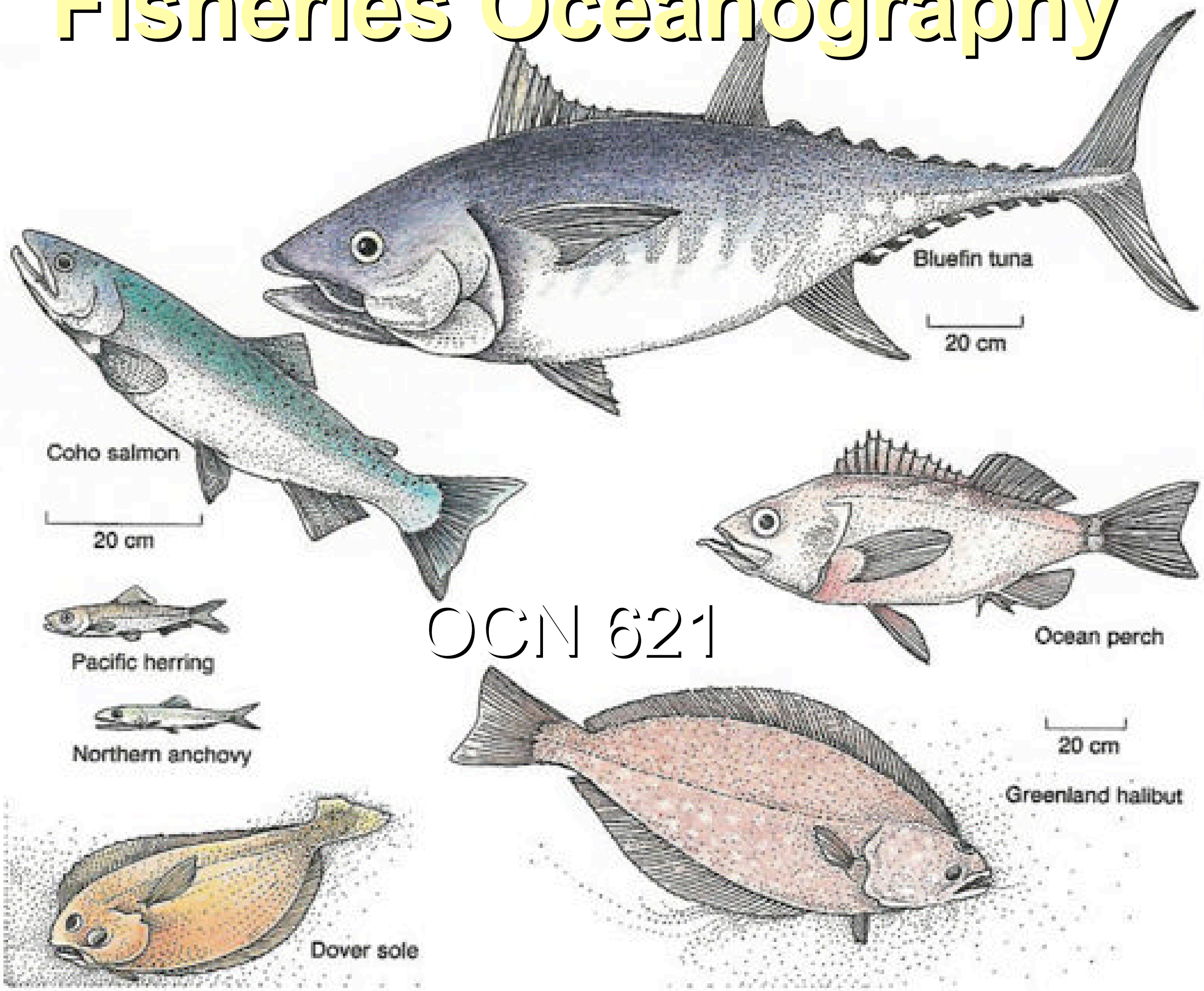

Figure 16.12
Commercially harvested members of the bony fish.

Food from the Sea

- "Fisheries" definition -- includes all "fished" species
  - Seaweed, including kelp
  - Invertebrates (lobster, crab, krill, oysters, shrimp, etc.)
  - Fish: bottom dwellers, e.g., hake, haddock, cod, and pelagic fish, e.g., sardine, anchovy, herring (small) and mackerel, tuna, etc. (large)
  - Whales

Why are we talking about fisheries?

- Important as food for us!
  - ~18% of world's total protein intake, ~$86 billion industry, ~43.5 million people employed

- Important "top" predators in marine food webs
  - Keystone Species Concept: Paine (1969): A species whose impacts on its community or ecosystem is disproportionately large relative to its abundance or total biomass (e.g., kelp forest otters)
  - Some fish may be keystone species, others just the "top" predator in an ecosystem
  - "Ecosystem engineers": create, modify & maintain habitats

Over-fishing removes the top predators, which affects the entire food web

"Fishing down the marine food web" (Pauly et al. 1998)

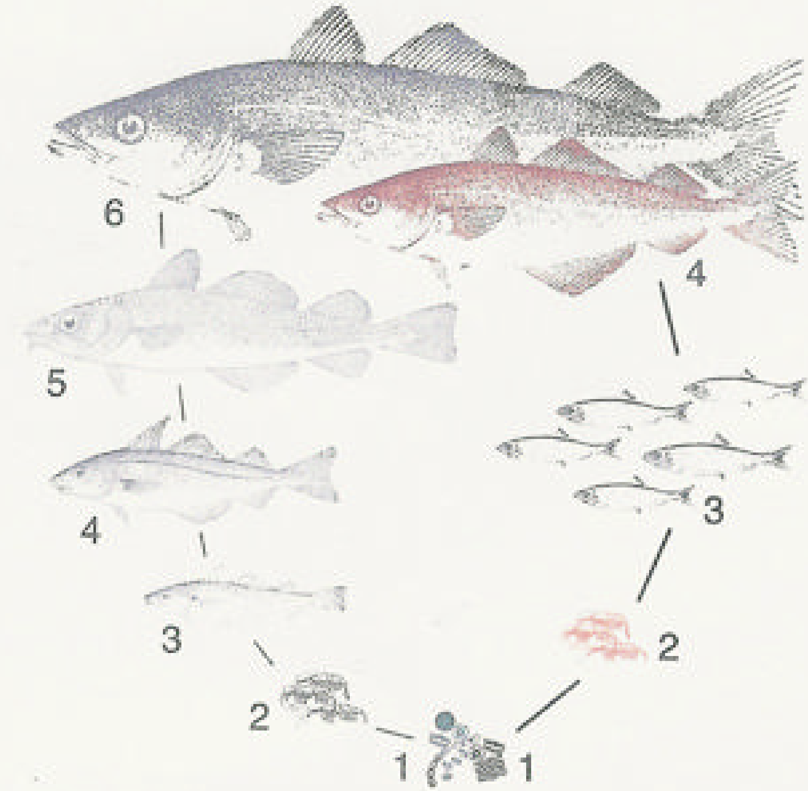

FIGURE 19. WHAT FISHING DOWN THE FOOD WEB MEANS FOR A TYPICAL PREDATOR.

As once-abundant large prey become scarcer, smaller prey must be consumed. This then affects the whole food web, resulting in fewer steps between the extremes of the predators and the plankton.

Pauly & Maclean 2003

More “why’s” directly relevant to planktonic ecosystems

- **Role of fish eggs, larvae and juveniles in open ocean food webs: prey and predator, depending upon life cycle stage**

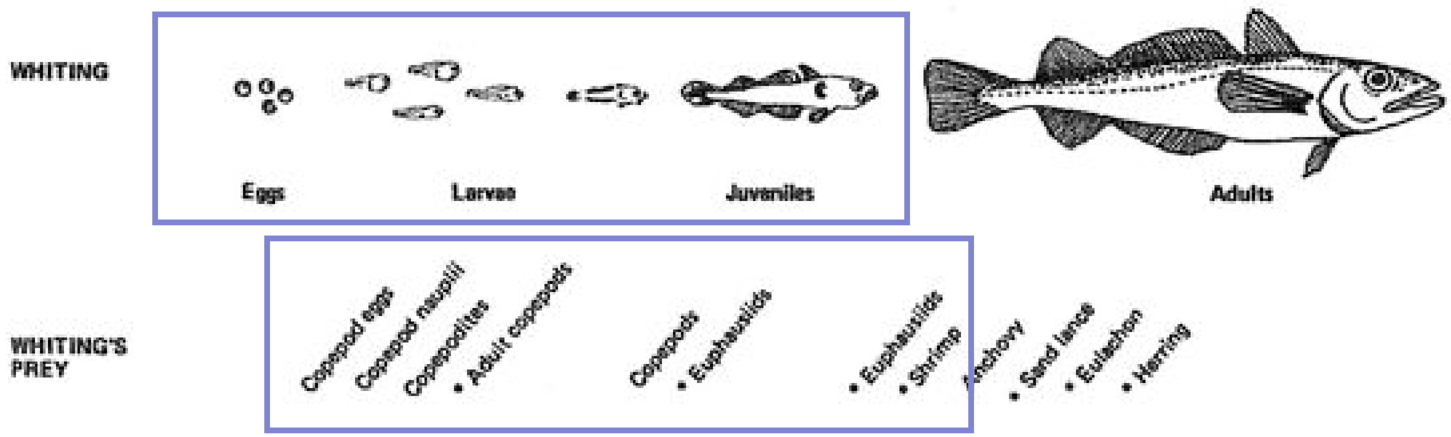

Figure 6.11. Pacific whiting prey fish eaten at various life history stages. (Asterisk indicates major prey species.) Modified from Livingston and Bailey (1985). Mar. Fish. Rev. 42(2):16–22.

Developmental Stages

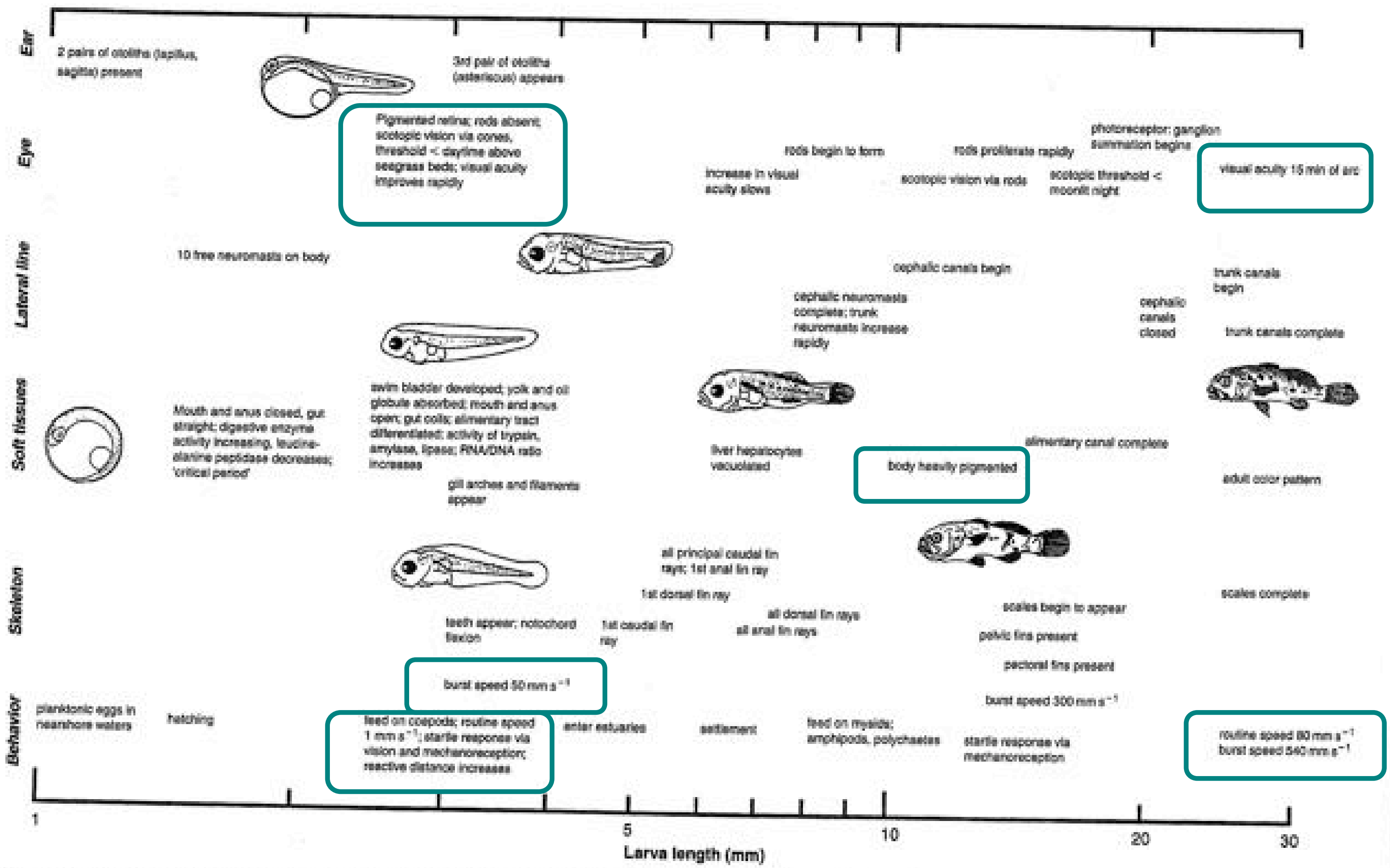

Figure 1.13 Composite of developmental changes in body form, function, and ecology in red drum (*Sciaenops ocellatus*). Data from numerous sources. Drawings from Holt *et al.* (1981) and Pearson (1929).

K.E. Selph, OCN 621, Spring 2010

Fuiman & Werner 2002

Fish Larvae

Fresh vs. Marine Larvae

- Fresh water eggs tend to be bigger, as do their larvae (more advanced)

- Marine larvae take longer to develop: avg. time 36 days, relative to freshwater larvae developing in 21 days.

- More likely to broadcast eggs in marine environment, with more eggs per spawning event

Why? Patchy food supply vs.
Competition for food

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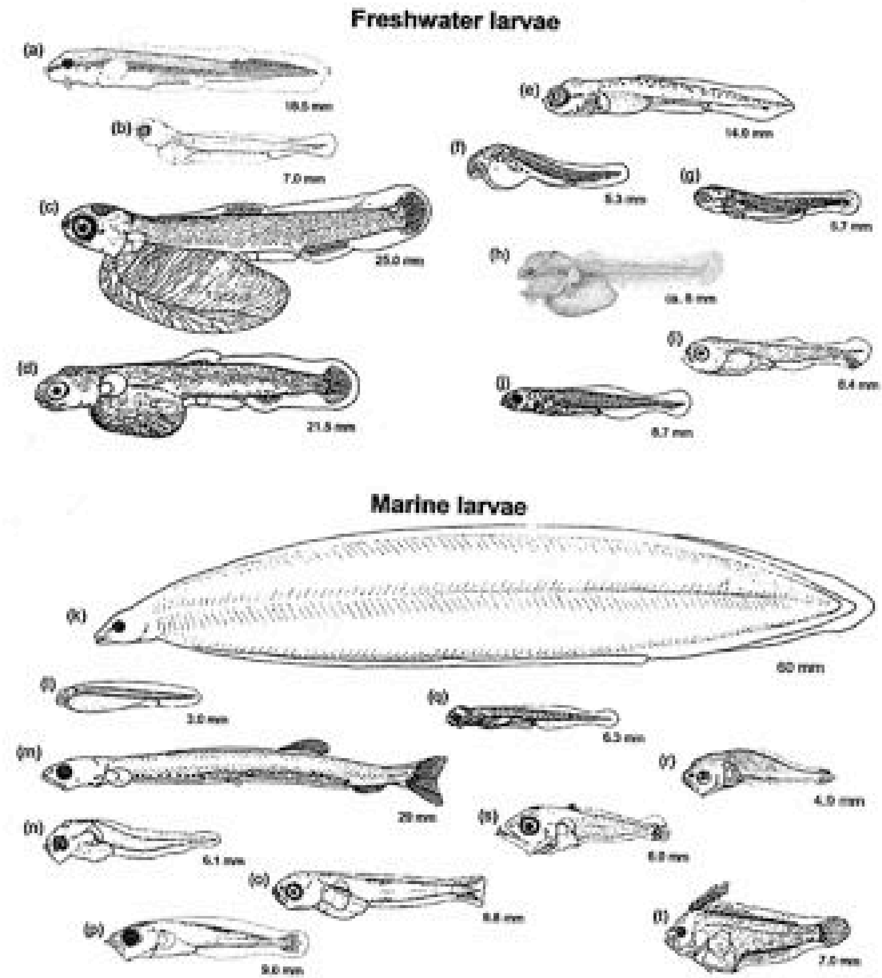

Figure 1.3 Representative stages of larvae for selected species of freshwater and marine fishes. Sources are given in parentheses: (a) lake sturgeon, *Acipenser fulvescens* (Jude 1982); (b) bloater, *Coregonus hoyi* (Auer 1982); (c) chinook salmon, *Oncorhynchus tshawytscha* (Kendall & Behnke 1984); (d) lake trout, *Salvelinus namaycush* (Fish 1932); (e) northern pike, *Esox lucius* (Gihr 1957); (f, g) common carp, *Cyprinus carpio* (Nakamura 1969); (h) brown bullhead, *Ameiurus nebulosus* (Armstrong & Child 1962); (i) largemouth bass, *Micropterus salmoides* (Conner 1979); (j) yellow perch, *Perca flavescens* (Mansueti 1964); (k) American eel, *Anguilla rostrata* (Schmidt 1916); (l) Japanese anchovy, *Engraulis japonicus* (Mito 1961); (m) Atlantic herring, *Clupea harengus* (Ehrenbaum 1909); (n) haddock, *Melanogrammus aeglefinus* (Dunn & Matarese 1984); (o) walleye pollock, *Theragra chalcogramma* (Matarese *et al.* 1981); (p) Atlantic cod, *Gadus morhua* (Schmidt 1905); (q) striped bass, *Morone saxatilis* (Mansueti 1958); (r) Atlantic croaker, *Micropogonias undulatus* (Hildebrand & Cable 1930); (s) bluefin tuna, *Thunnus thynnus* (Collette *et al.* 1984); (t) California halibut, *Paralichthys californicus* (Ahlstrom *et al.* 1984). Drawings reproduced with permission of Great Lakes Fishery Commission (a, b), American Society of Ichthyologists and Herpetologists (c, n, s, t), Muséum d'Histoire Naturelle Genève (e), National Science Museum Tokyo (f, g), Syracuse University Press (h), Kyushu University (l), Estuarine Research Federation (n)

Larvae vs. Juveniles: Metamorphosis

- Definition: A complete alteration of form and habit
- In fish not as extreme as in insects and in some forms (direct development) the larval stage is absent
- Change in habit: planktonic to benthic/substrate
- Change in form: eye migration (flat fishes), filter feeders to parasites (lampreys), reduction in size (eels), specialized structures occurring only in larvae (adhesive organs, elongated fins and spines, etc.)

Metabolic rate & Stored Energy

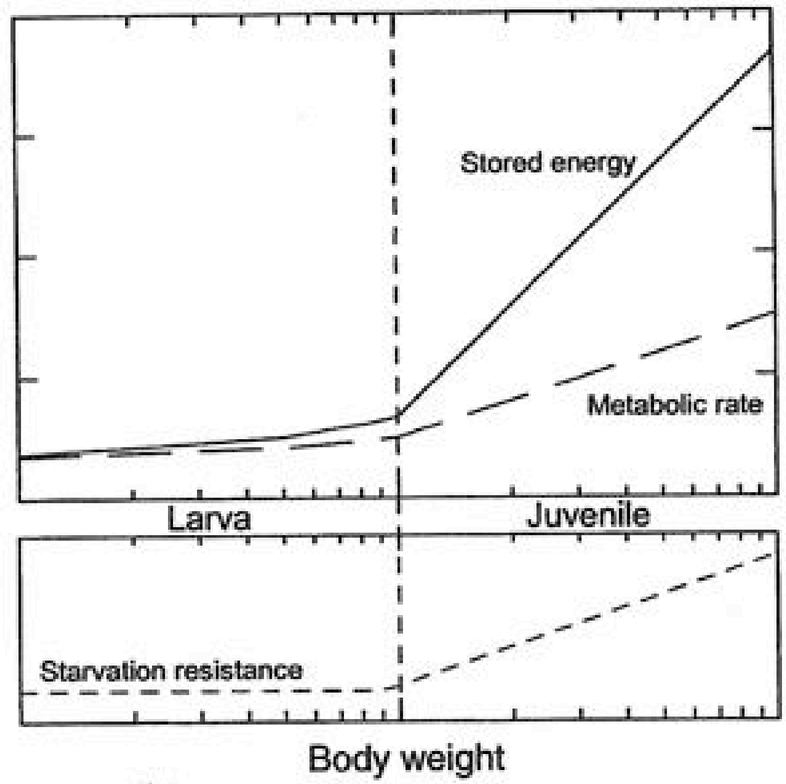

Figure 1.11 Changes in stored energy and metabolic rate with growth during the larval and juvenile periods. Stored energy is directly proportional to body weight through both periods (although the logarithmic abscissa distorts this trend). Metabolic rate is proportional to body weight for larvae (that is, weight-specific metabolic rate is constant), whereas weight-specific metabolic rate decreases in the juvenile period. The diverging trends result in increasing starvation resistance, the ratio of stored energy to metabolic rate in units of time.

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“Recruitment”

- Definition: fish surviving to the point of becoming exploitable, as defined by gear, fishing area or rules (i.e., size, sex, other factors)
- Low Recruitment
  - Over-fishing of adults → low reproduction → low recruitment
  - Environmental Factors? Even without fishing pressure, there is high recruitment variability year-to-year

March 13. 2008 Article in NY Times

Collapse of Salmon Stocks Endangers Pacific Fishery

By FELICITY BARRINGER

Federal officials have indicated that they are likely to close the Pacific salmon fishery from northern Oregon to the Mexican border because of the collapse of crucial stocks in California's major watershed.

That would be the most extensive closing on the West Coast since the federal government started regulating fisheries.

"By far the biggest," said Dave Bitts, a commercial fisherman from Eureka, Calif., who is at a weeklong meeting of the Pacific Coast Fisheries Management Council in Sacramento.

"The Central Valley fall Chinook salmon are in the worst condition since records began to be kept," Robert Lohn, regional administrator for the National Marine Fisheries Service in Portland, Ore., said Wednesday in an interview. "This is the largest collapse of salmon stocks in 40 years."

Although the Washington and Alaska fisheries are not affected, the California and Oregon ones produce "some of the most valuable fish, ones that are prized from West Coast seaports all the way to East Coast restaurants," Mr. Lohn said.

The effect on salmon prices is not clear. Mr. Bitts said the effects on commercial and sport fishermen and their communities could run to millions of dollars.

On Wednesday the council closed several minor short-term fishing seasons off California and Oregon in connection with the salmon shortfall.

Counts of young salmon, whose numbers have dwindled sharply for two years, were the first major indication of the problem. The number of fish that survive more than a year in the ocean, or jacks, is a marker for the abundance of full-grown salmon the next year. The 2007 count of the fall Chinook jacks from the Sacramento River was less than 6 percent of the long-term average, Mr. Lohn said.

U.S. officials indicate they are likely to close a huge coastal area.

The Central Valley salmon runs are concentrated in the Sacramento River, the focus of a water struggle between farmers and irrigation districts on one hand and environmental groups and fishermen on the other.

Three years ago, some conservation groups challenged in federal court an advisory opinion by federal fisheries managers that let federal and state officials increase the water drawn from the Sacramento River Delta for farmers in the San Joaquin Valley and cities in Southern California.

The opinion by the National Marine Fisheries Service said the increase would not harm the three salmon species protected under the Endangered Species Act. The fall Chinook salmon were not under the act.

John McManus, a spokesman for Earthjustice, the group handling the suit, said lawyers in the case had been told that the judge would rule by the end of March.

Federal scientists reported this month that abnormal ocean conditions might be affecting the food chain of young salmon.

13 MARCH, 2008

Science **3 March 1995:Vol. 267. no. 5202, pp. 1324**

Climatic Warming and the Decline of Zooplankton in the California Current

Dean Roemmich and John McGowan

Scripps Institution of Oceanography

Since 1951, the biomass of macrozooplankton in waters off southern California has decreased by *80 percent*. During the same period, the surface layer warmed—by more than 1.5°C in some places—and the temperature difference across the thermocline increased. Increased stratification resulted in less lifting of the thermocline by wind-driven upwelling. A shallower source of upwelled waters provided *less inorganic nutrient* for new biological production and hence supported a smaller zooplankton population. Continued warming could lead to further decline of zooplankton.

H_o: Critical Period

- Hjort (1914)
  - After yolk-sac absorption, larvae must feed within a limited period of time or pass “the point of no return”, after which they will die of starvation regardless of food availability.
    - An extreme interpretation of this hypothesis would be that events during only a very short period of larval history determine relative year class strength.

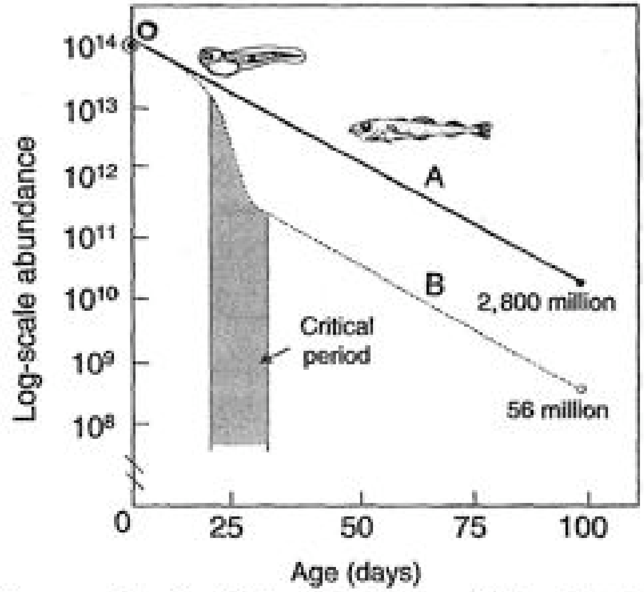


Figure 3.4 Survivorship curves showing effect of a “critical period” on abundance of survivors at 100 days post-hatching. Both populations have an initial mortality rate of $M = 0.10\ \text{day}^{-1}$. The population that experiences high losses in the “critical period,” although recovering to experience the initial $M = 0.10\ \text{day}^{-1}$ rate after the “critical period,” is 50 times less abundant at 100 days post-hatching.

H_o: Match-Mismatch

- Cushing, 1975, North Sea herring
  - Fish spawn on a fixed schedule, but plankton blooms are variable from year to year. Therefore, good recruitment years are those where there is a good match between the timing of the bloom and drift of larvae through nursery area.
  - The attractiveness of this hypothesis is in linking year class success to the main feature in the coastal production cycle (spring bloom) and its mechanistic explanation (critical depth concept)

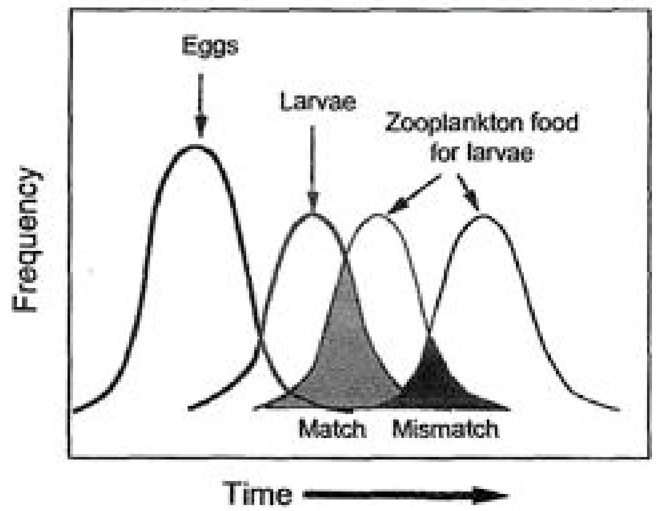
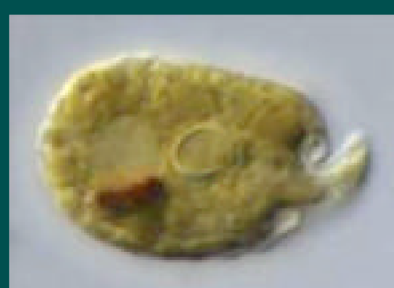


Figure 4.3 Schematic representation of Cushing's Match/Mismatch Hypothesis illustrating variability in the degree of overlap between the timing of a seasonal peak in the production of planktonic food for larvae and the co-occurrence of fish eggs and larvae. The stippled area is a match representing high overlap and the darkened area is a mismatch representing low overlap (redrawn from Leggett & Deblois 1994).

Cowen & Shaw 2002

H_o: Stable Ocean

- Lasker, 1975 & 1978, Northern anchovy
  - First feeding of larvae is dependent upon availability of high densities of appropriate food
  - Requires strong stratification for aggregations of food
    - e.g., anchovy larvae need dense blooms of naked dinoflagellate prey, which develop during periods of low mixing -- shallow (20-30 m chlorophyll max).



Amphidinium sp.

Ceratium sp.

H_o: Predation

Because average fish larvae dies soon after hatching, predation is now believed to be the major source of fish mortality.

If high concentrations of predators (e.g.,piscivorous fish or jellyfish), then higher mortality of larval fish.

Likely that survivors are derived from faster growing cohorts of larvae because they spend less time in the stage vulnerable to predators

i.e., as fish get bigger, they swim fasters and can see predators better: more likely to escape predation

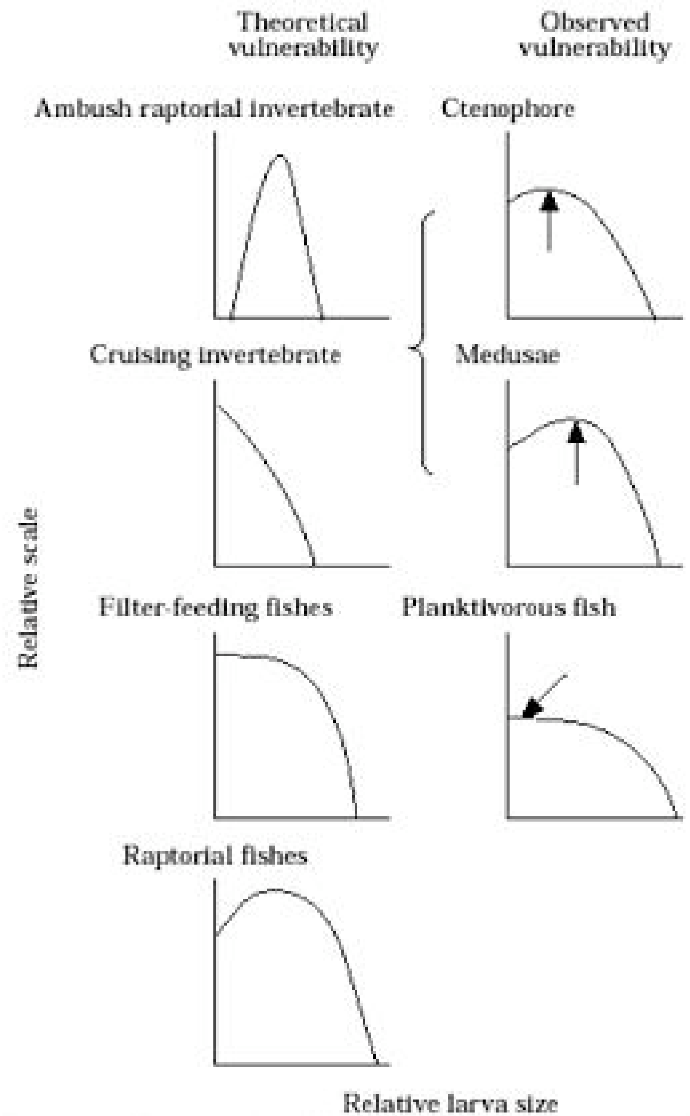


Figure 1. Vulnerability of fish larvae to different types of predators. Theoretical relationships are redrawn from Bailey and Houde (1989). Observed relationships are redrawn from Cowan and Houde (1992). Arrows indicate the relative size of maximum larval vulnerability to the predators.

Cowan et al. 1996

Larval Predation

Larval predation also variably successful

As fish gets bigger, searches larger volume of water, faster, and can "see" farther

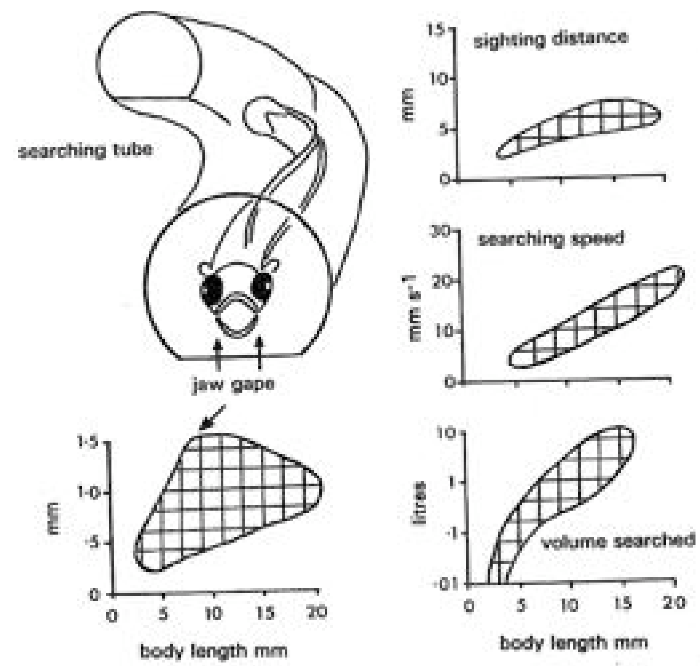


Figure 7.2 Top left: the feeding 'tube' searched by a fish larva. Bottom left: graph showing how the gape of the jaw changes as larvae grow. The shaded area in this and the other graphs is an envelope containing a number of regression lines showing the relationship between jaw gape and body length in several species. Right: three graphs, the relationship between prey sighting distance, searching speed and volume of water searched as the larvae of several species grow. Redrawn from data in Rosenthal and Hempel (1970), Hunter (1981), and Blaxter (1985).

Bone et al. 1995

Feeding success of larvae

- Anchovy larvae fed rotifers (crustaceans)
- Younger larvae have lower success than older larvae.
- Younger larvae can't "see" as far, and can't swim as fast, so don't search as much area

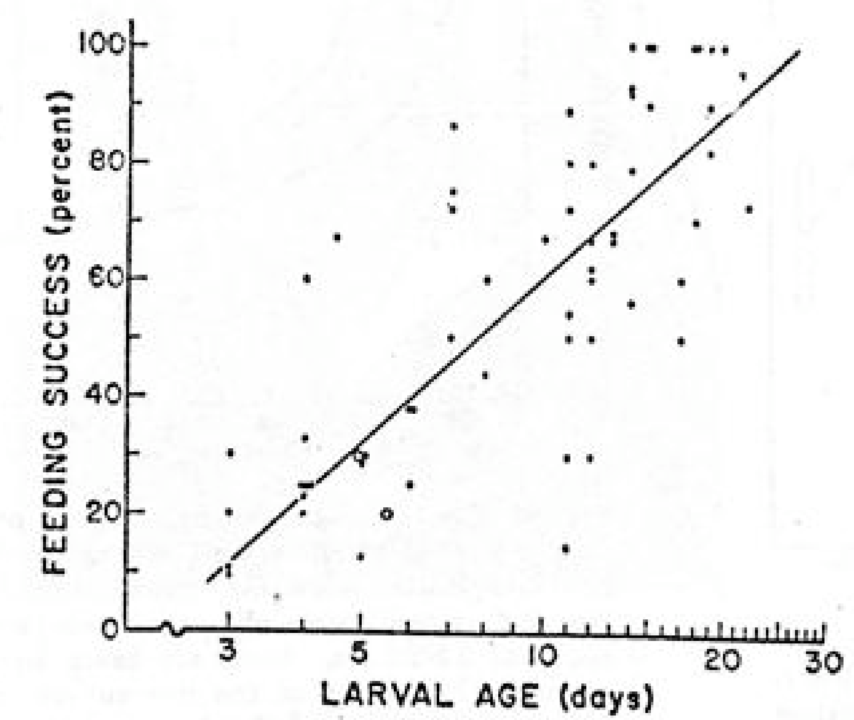


FIGURE 9.—Feeding success (percent of prey captured) of anchovy larvae of various ages fed *Brachionus*. Larval age is plotted on log scale, equation for line is percent success = 93.2 (log age) − 33.30. Two open circles, larvae fed *Gymnodinium*.

Hunter 1972

Why larger larvae feed successfully

- swimming speed
- activity level
- visual development
- response time to prey
- reduced error -- learning
- persistence following miss

Agents of Mortality for Young Fish

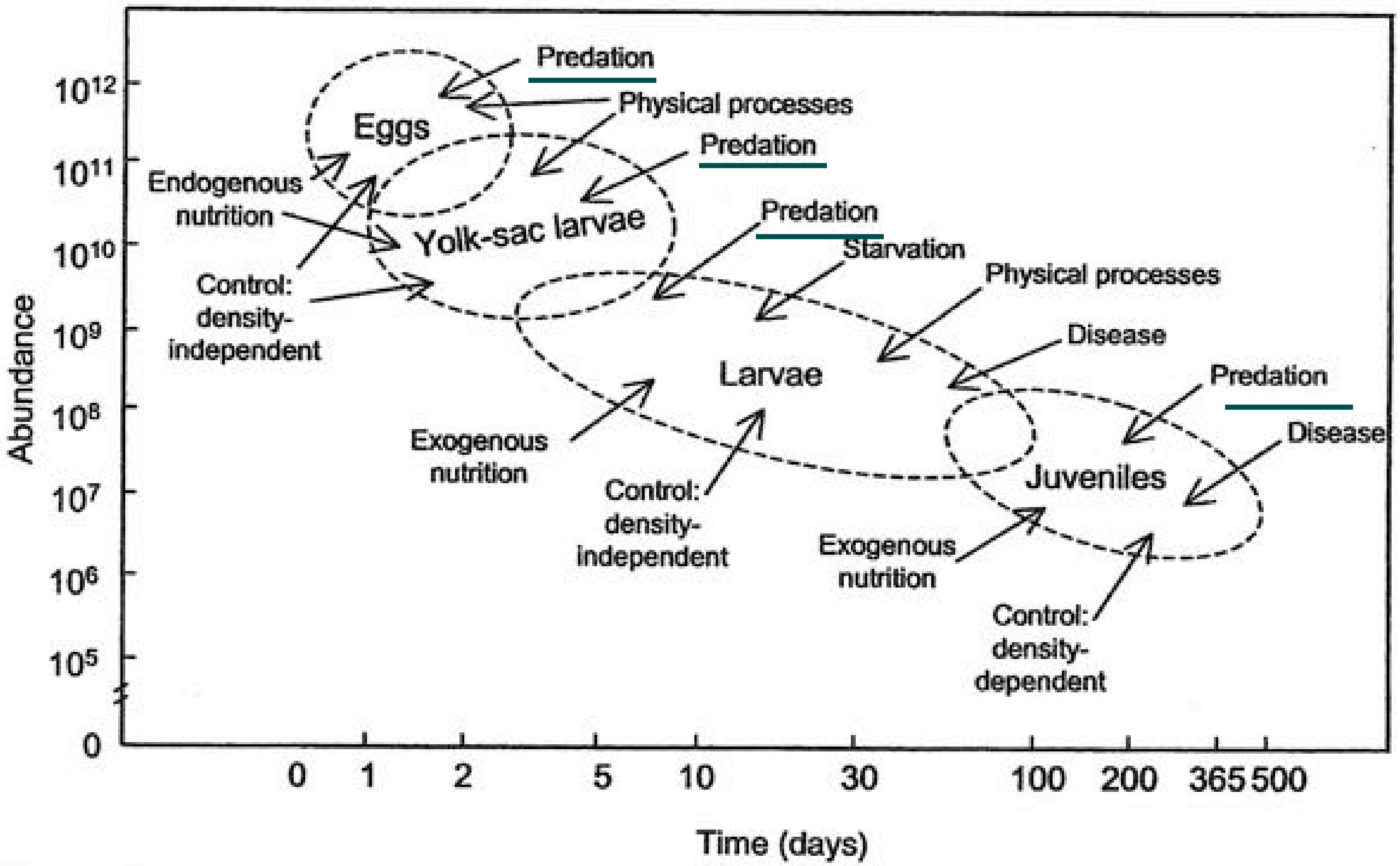


Figure 3.5 Survivorship curve conceptualizing the recruitment process in fishes, including factors that affect mortality and growth. Hypothesized mechanisms of control are indicated (reproduced from Houde 1987 with permission of the American Fisheries Society).

Fuiman & Werner 2002

Aside: Fish Behavioral Changes in Response to Predation

- Avoidance Behavior
  - ***Distribution, e.g., Werner et al. 1983 studying juvenile bluegill sunfish in ponds***
  - ***Schooling: Protection in numbers***
  - ***Escape Activities: sit and wait, run away, or hide?***
- Reproduction
  - Spawning stupor
  - Parental care

Bluegill Sunfish Experiments

- Juveniles (3 size classes) placed in ponds that with or without a predator (largemouth bass)
- Without predator: all 3 size classes found in open water (better food)
- With predator: smallest prey fish stayed in vegetated regions of the pond (suboptimal food for them): resulted in a 27% decrease in growth rates

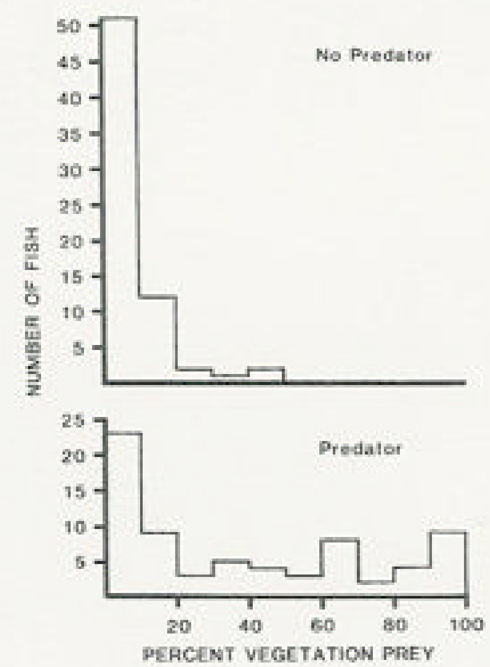
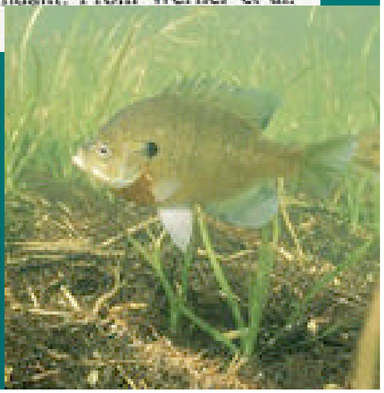
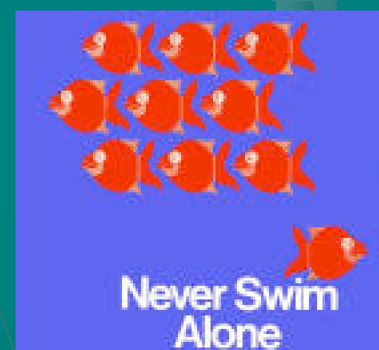


Fig. 1. Prey fish can shift their distribution and foraging patterns in response to changing predation. The number of small, vulnerable bluegill sunfish that foraged in the less profitable, vegetated region of a pond increased when predatory largemouth bass were present, as indicated by the percent of plant-associated prey in their stomachs. Vegetation generally provides a refuge from predators. In the absence of the predator, small bluegill foraged more in open water, where more profitable prey were abundant. From Werner et al. (1983).



Schooling Behavior

- "Schooling" *A group of fish swimming at about the same speed in roughly parallel orientation and maintaining a constant nearest-neighbor distance*
- "Shoal" *all social groups of fish (includes schooling)*
- Schools break ranks during feeding and usually lose their integrity at night
- Shoaling functions: protective role, early predator detection, passive defense, & enhanced food detection
- Usually shoals of clupeoid fish break to feed on particles, but not when filter-feeding. May be more competition involved when particle feeding.



Anchovies Schooling

http://www.junglewalk.com

Escape Activities

- Immobility
  - predators tend to be visual: by not moving, the prey can "hide in plain sight"; also many fish have cryptic coloring so blend in better when still
- Active flight/Refuge Seeking
- Twilight change-over
  - most fish are active either during day or night-time, and their eyes are adapted to function best during their active period. At twilight, the eyes function the worst as the light levels are changing rapidly -- time of increased vulnerability to predation from predators with "intermediate" eyes
    - prey response: cease activity early and start late or form groups (schools)

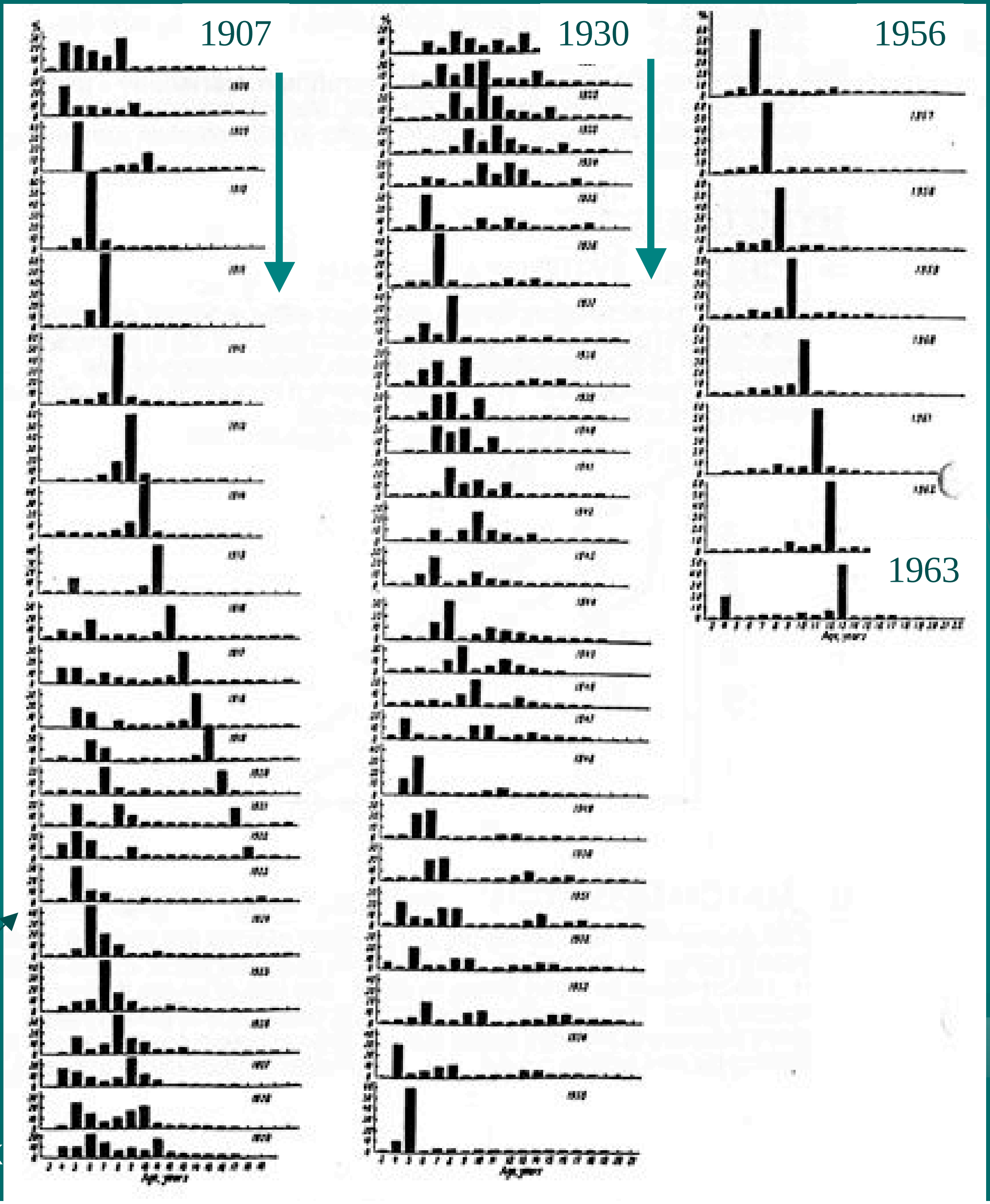
Fish Behavioral Changes in Response to Predation

- ***Reproduction: must spawn successfully, without being eaten and deter potential predators from their vulnerable young***
  - Spawning stupor: a behavior that results in increased mortality from predation.
    - spawning fish are focused on spawning so are especially vulnerable, e.g., they do not take evasive actions when predators approach (widespread behavior in fish)
    - Spawning fish tend to go to predictable places at predictable times: predators have adapted to this behavior
    - Why? Cost vs. benefit
  - Parental care: young fish of species that have parental guards have a higher survivorship

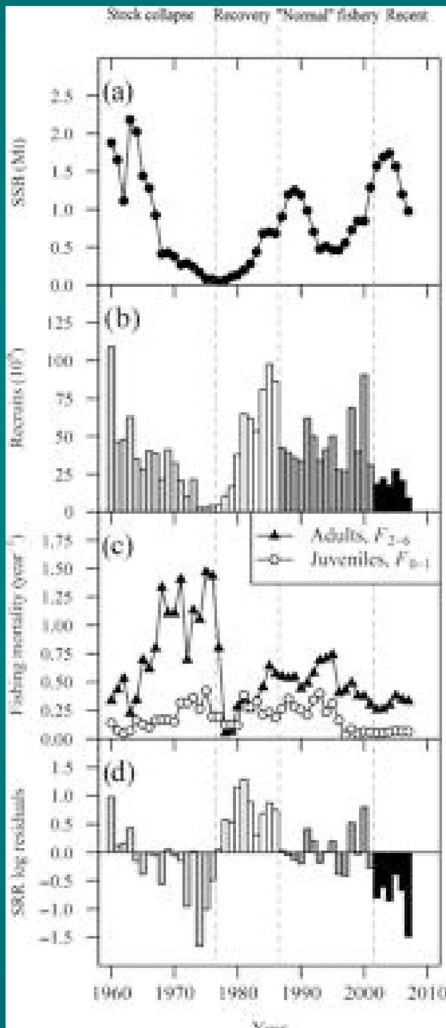
Atlanto-Scandian Herring

Marti 1961:

- -- North Sea herring feeding on *Calanus*
- -- Can see year class as it gets older.
- -- Also can see that only a few years are good, most have poor recruitment.



North Sea herring stock history from the stock assessment: (a) annual changes in SSB; (b) time-series of recruitment at 6 months old; (c) mean annual fishing mortality (F) on the stock for ages 2-6-winter rings (wr; closed triangles) and ages 0-1 wr (open circles) from the stock assessment; and (d) the stock residuals [ln(observed/fitted)] from the segmented-regression (hockey-stick) model



SSB, Spawning Stock Biomass: total weight of fish in stock that are old enough to spawn)

Recruits: 6 month old fish

SRR, Stock Recruitment Relationship: residuals measure productivity of a fish stock relative to expected recruitment of the stock

1965-77: high fishing mortality, collapse of fishery
1977-80: total closure of fishery
1981-88: recovery phase
1989-2000: "normal fishery"

**Payne, M. R. et al. ICES J. Mar. Sci. 2009 0:fsn211v1-6;
doi:10.1093/icesjms/fsn211**

ICES JOURNAL OF MARINE SCIENCE

Why is there a natural variation in recruitment?

- Various explanations focus on the effects of:

1) Food

critical period

match-mismatch

suitability

2) predators

*m = F*D*

adaptive strategies to survive

density dependent population regulation

3) drift/retention area during early life history

closed life cycle: hydrographic containment

Recruitment Variability, cont'd: H_o: Delayed Development

Houde (1987) Fish early life dynamics and recruitment variability: 10-fold or greater fluctuations in fish recruitment can be due to small variations in mortality rates or stage durations in the early life of fish

TABLE 1.—Hypothetical recruitment of young fish under one "good" and three possible "bad" conditions, the latter represented by 25% changes in mortality or growth rates. Recruitment is defined here as the number of survivors at the end of the larval stage.

Condition	Initial number in cohort	Instantaneous mortality coefficient (d^{-1})	Age at metamorphosis (d)	Number of recruits
Good	1×10^6	0.100	45.0	11,109
Bad-1	1×10^6	0.125	45.0	3,607
Bad-2	1×10^6	0.100	56.2	3,625
Bad-3	1×10^6	0.125	56.2	889

note:
$F_t = F_0 e^{-m(t)}$

Agents of Mortality for Young Fish

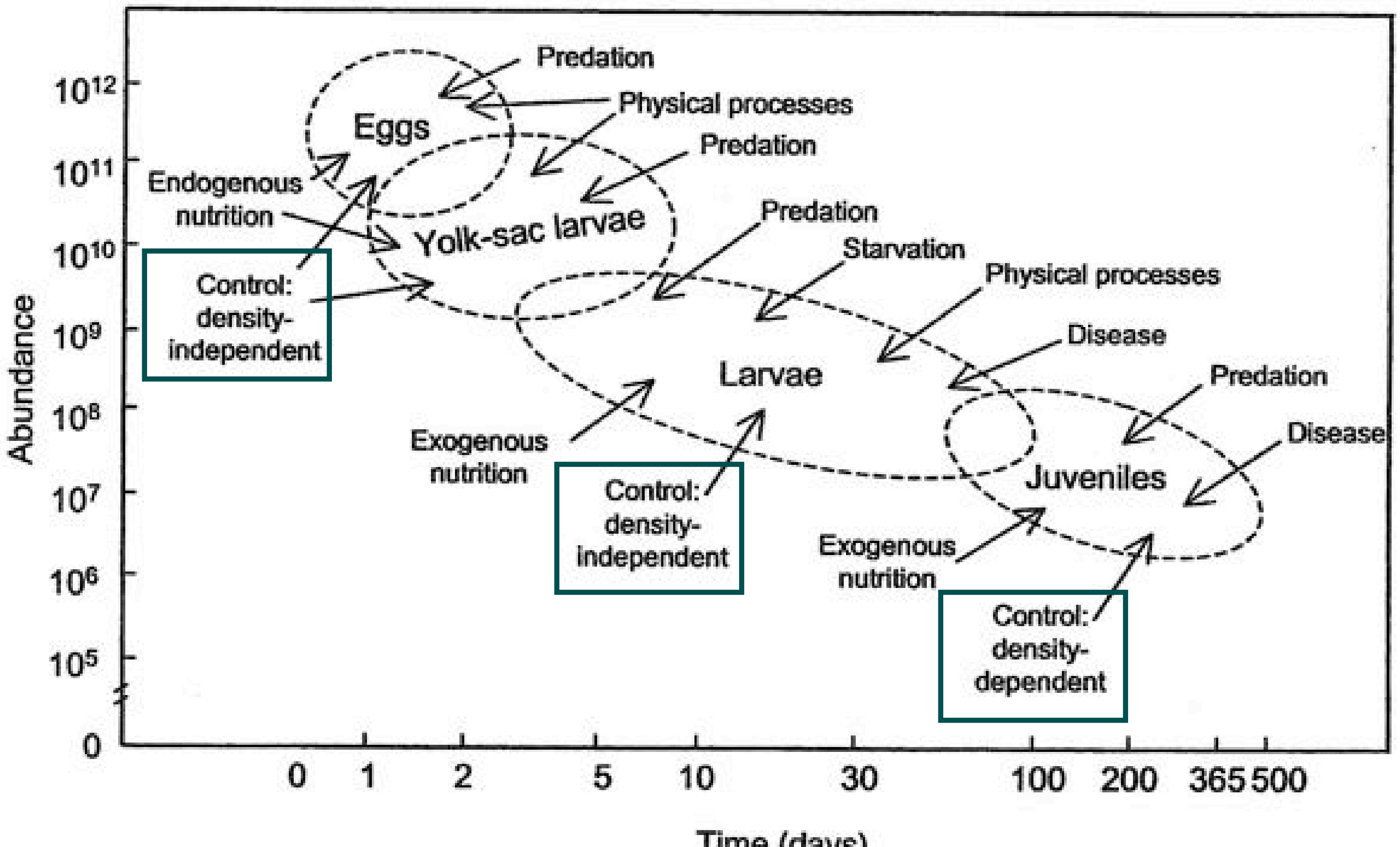


Figure 3.5 Survivorship curve conceptualizing the recruitment process in fishes, including factors that affect mortality and growth. Hypothesized mechanisms of control are indicated (reproduced from Houde 1987 with permission of the American Fisheries Society).

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Density-dependent Population Regulation

- *Potential contributing mechanisms*:
  - Reduced fecundity of adults due to food limitation
  - Predation of adults on larvae or juveniles
  - Direct competition for food between juveniles and adults
  - Indirect effects of adults on food supply for larvae, e.g., adults reduce stocks of adult copepods to low levels, resulting in low abundance of nauplii

H_o: Retention Area

- Survival depends upon being retained in areas ("nursery grounds") with specific hydrographic characteristics vs. loss to offshore advection

  e.g., Migration Triangle Hypothesis

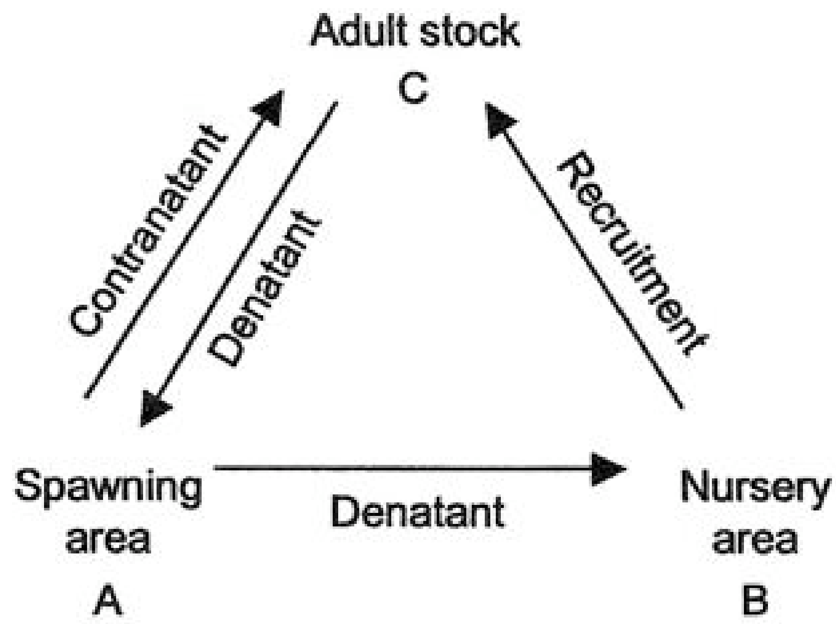

Figure 8.3 The Migration Triangle Hypothesis. In Harden Jones' (1968) original formulation, the three components of the population were spatially distinct. Completion of the life cycle required either active migration (adults) or hydrographically assisted movements (eggs and larvae).

Coastal Conveyor Belt

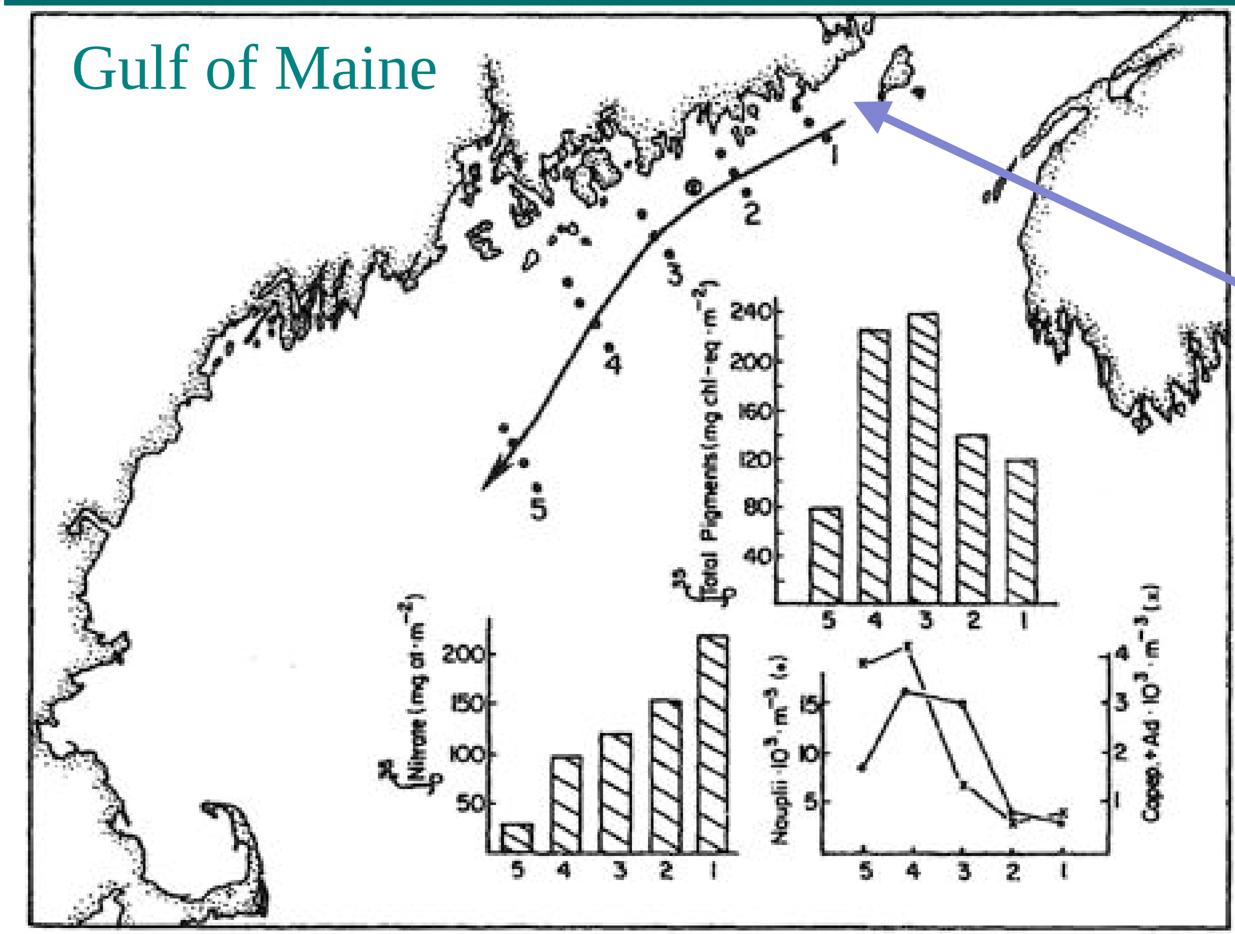

Figure 4.6 Summary plot of the changes in nitrate, chlorophyll, and naupliar and copepodid stages of copepods along the eastern Maine coastal current/plume system for July 1985, used here to illustrate the coastal conveyor belt. The nitrate and chlorophyll histograms are the averages of the vertically integrated (to 35 m depth) values at the stations shown for each of the five transects. The arrow is a streamline of the geostrophic current (reproduced from Townsend 1992 with permission of Oxford University Press).

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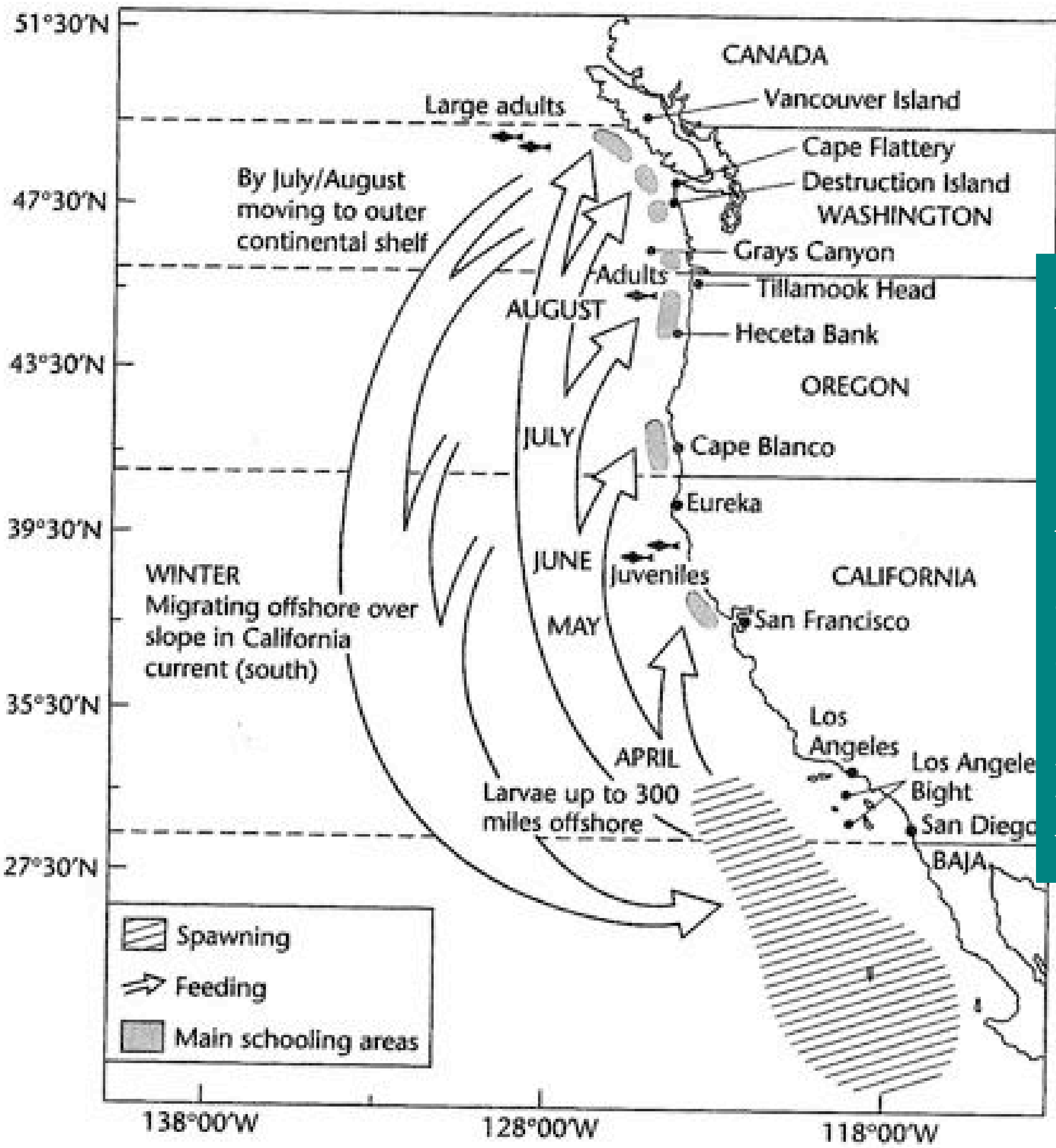
- Herring spawn in late summer through autumn.
- Extended larval stage, then complete transition from larvae to juvenile when 5-8 months old.
- Later, current turns offshore: into a cyclonic gyre, retaining larvae in area.

Pacific Hake



Adults migrate south over shelf in winter

Spawn off So. Cal (deeper than mixed layer and as far as 300 km offshore): larvae drift inshore

High recruitment:weak upwelling

Fig. 15.3 General routes and timing of the spawning and feeding migrations of Pacific hake. (After Bailey *et al*. 1982.)

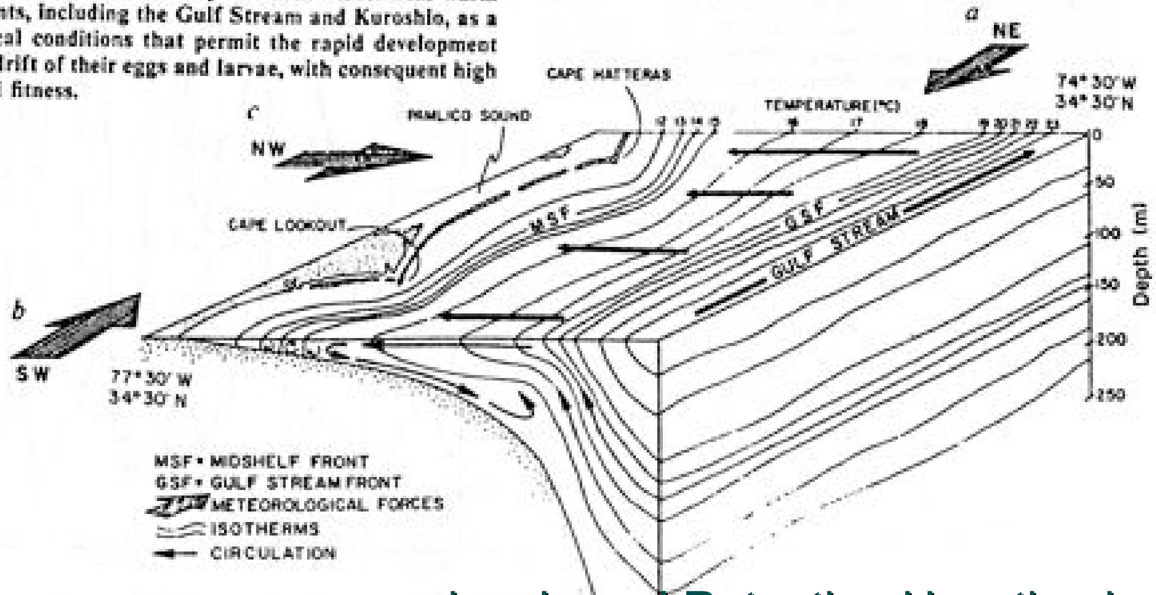
Member/Vagrant Hypothesis

Recruitment for many marine organisms depends on survival and transport of eggs and larvae from spawning grounds to nursery areas[1]. We investigated the effects of winter storms and the Gulf Stream on the spawning, development and drift of the Atlantic menhaden, *Brevoortia tyrannus*, which spawns offshore[2] and metamorphoses in estuaries[3]. Spawning was maximal during storms in water upwelled near the western edge of the Gulf Stream. Eggs and larvae drifted shoreward with abundant food in the warm surface stratum of a density-driven circulation maintained by the large sea–air heat flux. We suggest that the Atlantic menhaden and other species have evolved to reproduce in winter near warm boundary currents, including the Gulf Stream and Kuroshio, as a result of physical conditions that permit the rapid development and shoreward drift of their eggs and larvae, with consequent high recruitment and fitness.

Winter storm effects on the spawning and larval drift of a pelagic fish

David M. Checkley Jr, Sethu Raman, Gary L. Maillet & Katherine M. Mason

NATURE VOL 335



a.k.a. Larval Retention Hypothesis

Menhaden off N. Carolina in winter: spawn

Eggs float, larvae feed on µzp, enter estuaries and become juveniles in 30-90 days

Same strategy: flounder, striped mullet and Japanese sardine

- Members able to remain in favorable geographic setting (i.e., allows them to complete their life cycle)
- Vagrants fail to reach appropriate habitat, generally don't reproduce
- Key element: larvae must reach & remain within the nursery sites after spawning

Summary: Why does fisheries recruitment vary so much even in the absence of fishing pressure?

Basic species ecology with practical implications

- Vulnerability during early life history
  - Starvation -- first feeding
  - Predation -- poor escape abilities

  (side topic: adaptive behavioral responses to predation)
  - Delayed development
- Oceanographic context - random component
  - timing and magnitude of food availability
    - productive periods -- blooms & lags
    - stable periods -- prey aggregation
  - timing and magnitude of predator outbreaks
  - Vagaries of ocean currents -- drift/retention