Fisheries Oceanography

OCN 621

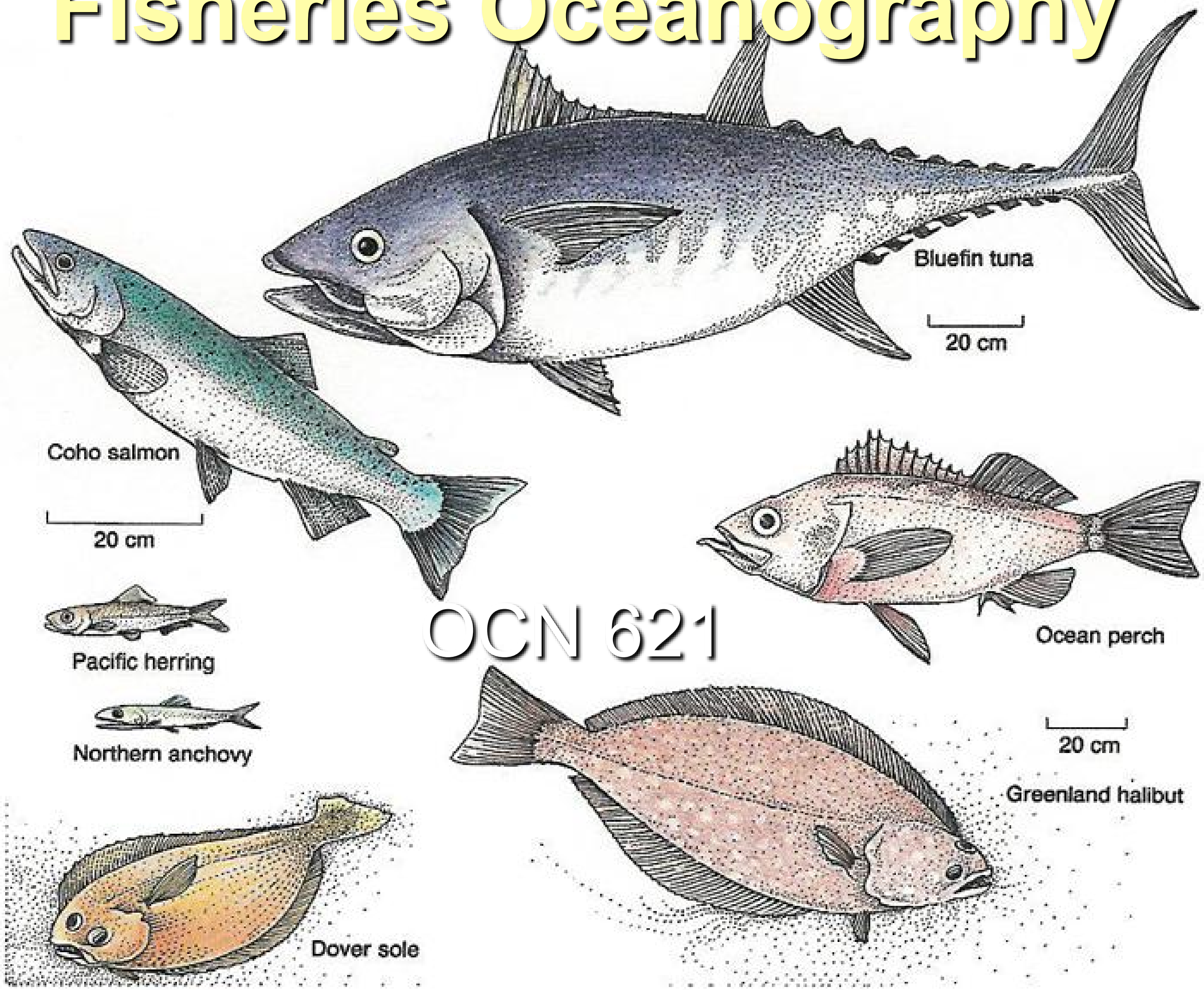


Figure 16.12

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!
  - ~15% of world's total protein intake, ~$102 billion industry, ~45 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

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

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

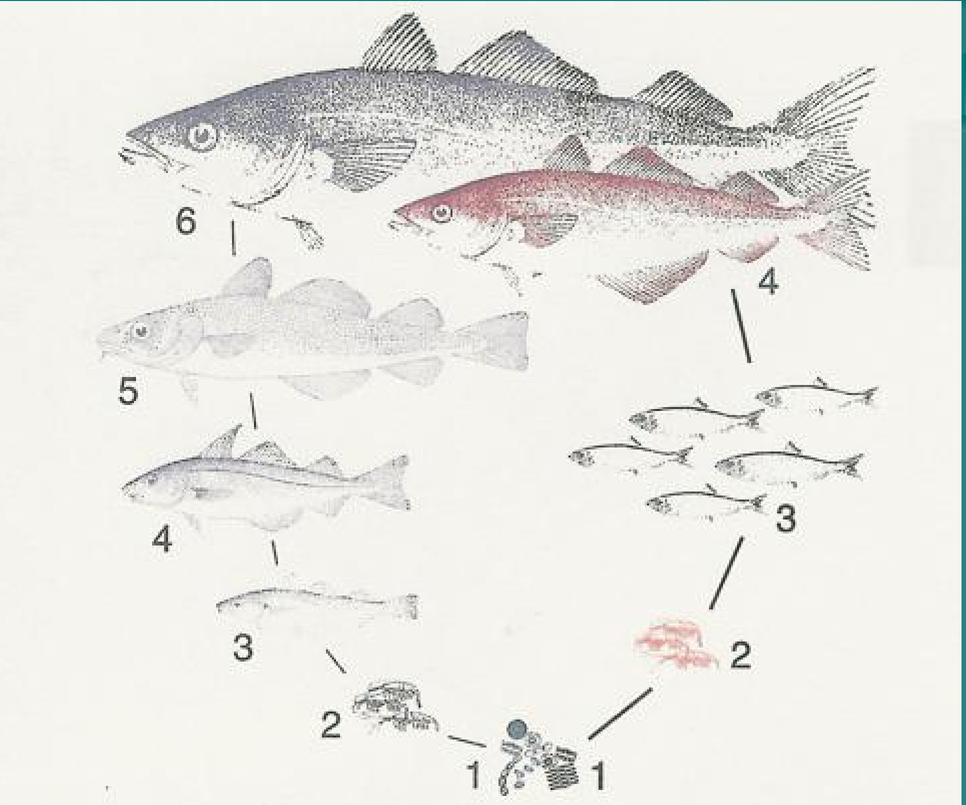


FIGURE 19. WHAT FISHING DOWN THE FOOD WEB MEANS FOR A TYPICAL PREDATOR.

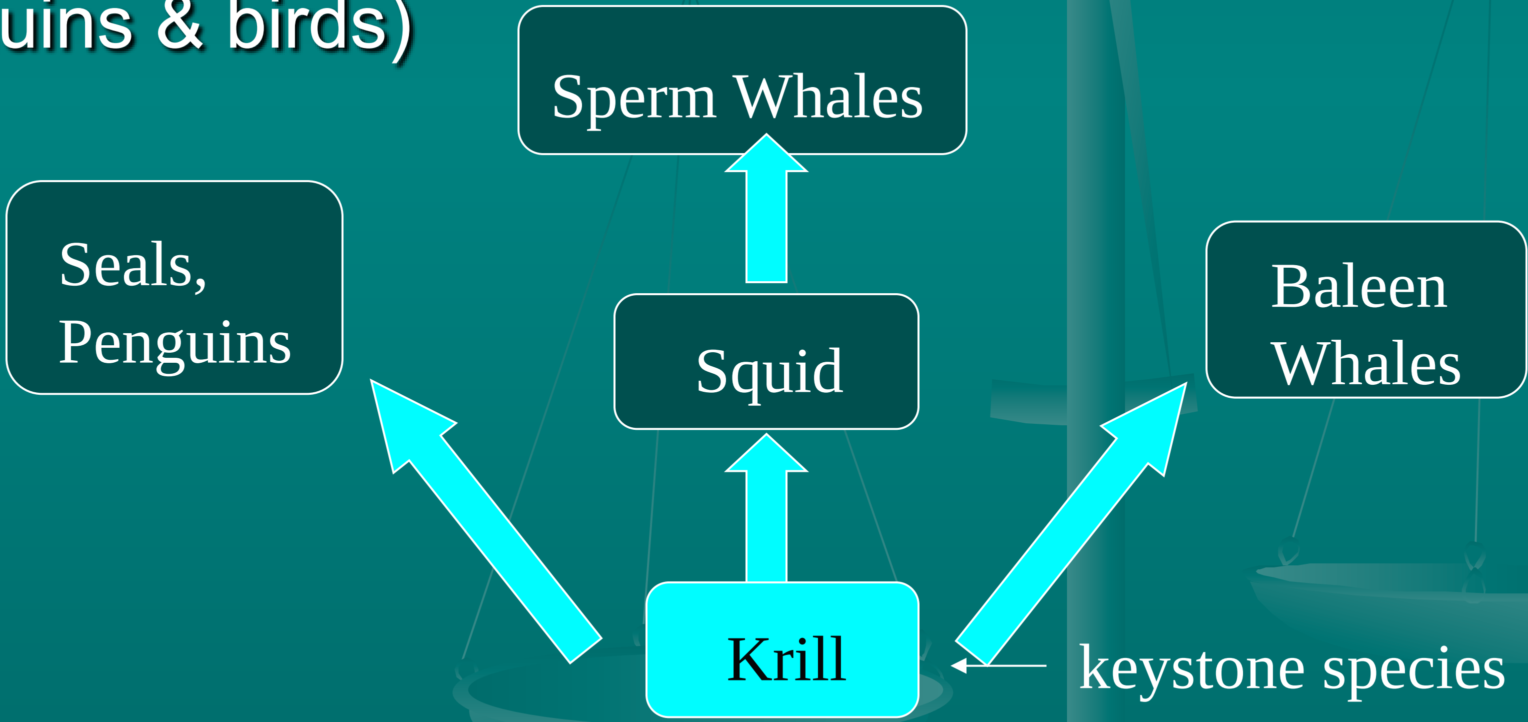
As once-abundant large prey become scarcer, smaller prey must be consumed. This then affects the whole food web, resulting in fewer steps between the extremes of the predators and the plankton.

Pauly & Maclean 2003

Antarctic Ecosystems

- Whales in Antarctica:

  Kill most of the them and change the population balances of the rest of the ecosystem (krill, squids, seals, penguins & birds)



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**

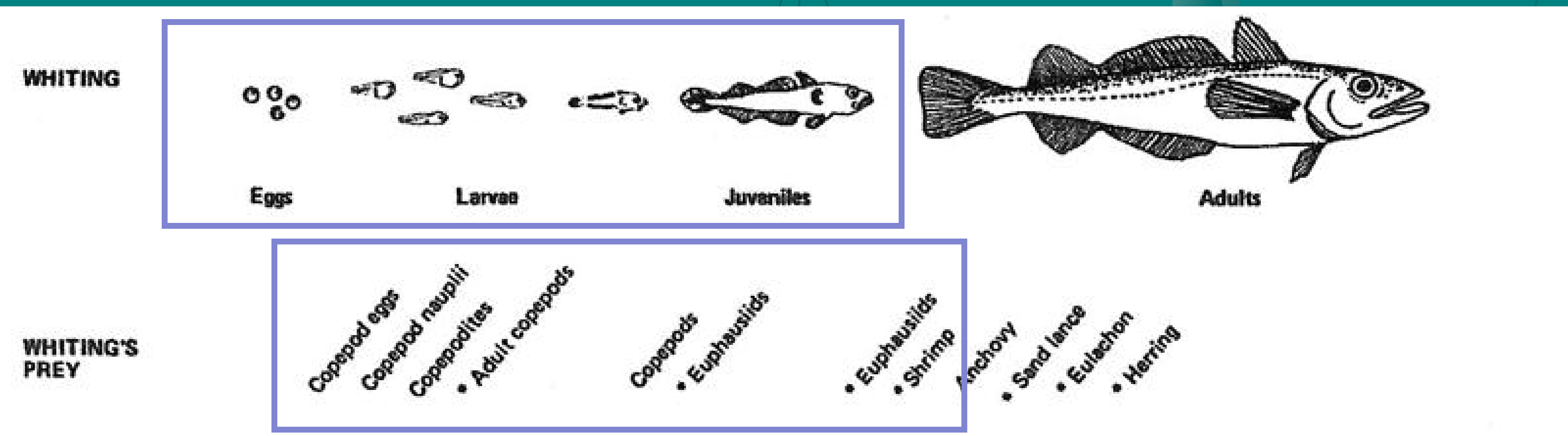


Figure 6.11. Pacific whiting prey fish eaten at various life history stages. (Asterisk indicates major prey species.) Modified from Livingston and Bailey (1985). Mar. Fish. Rev. 42(2):16–22.

Developmental Stages

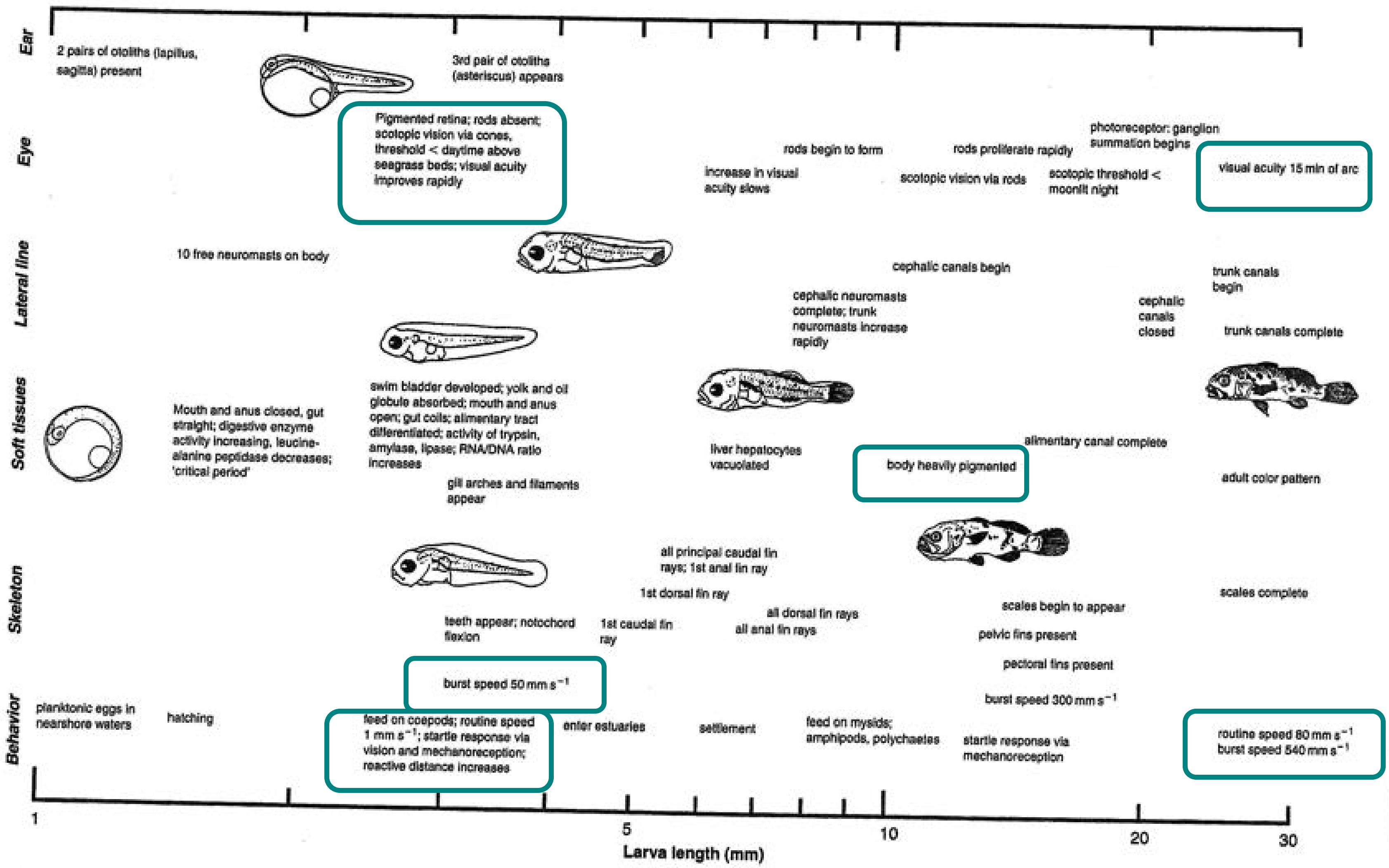


Figure 1.13 Composite of developmental changes in body form, function, and ecology in red drum (*Sciaenops ocellatus*). Data from numerous sources. Drawings from Holt *et al.* (1981) and Pearson (1929).

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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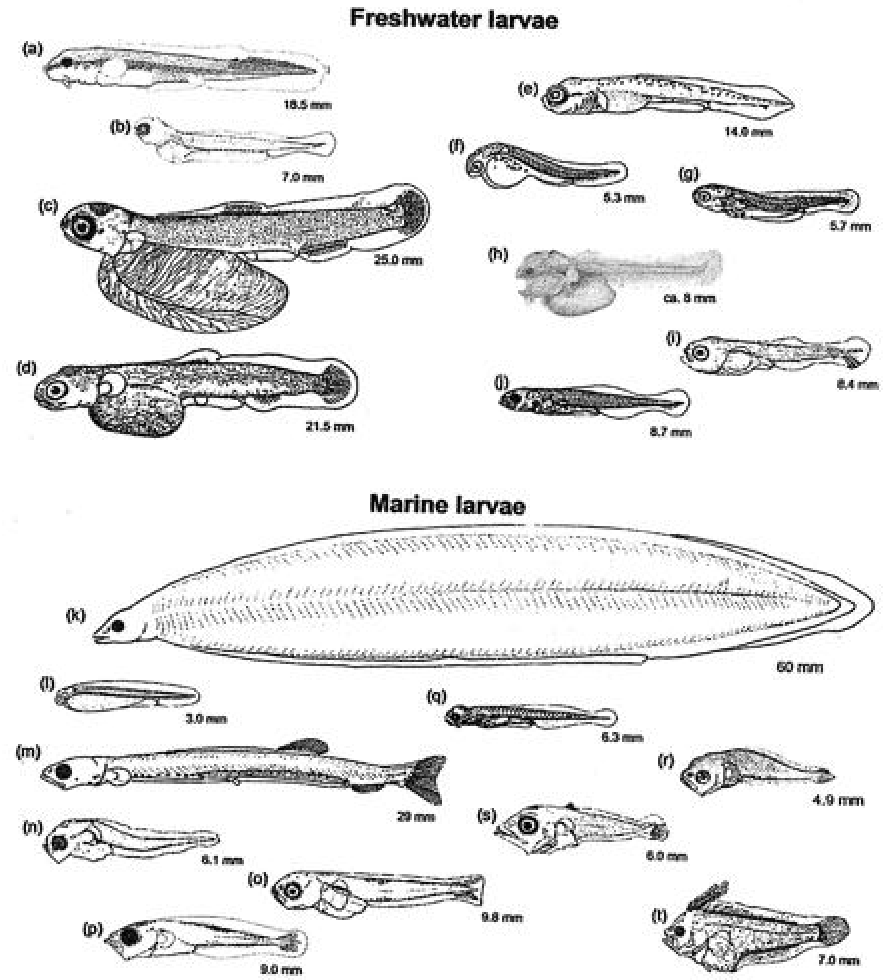


Figure 1.3 Representative stages of larvae for selected species of freshwater and marine fishes. Sources are given in parentheses: (a) lake sturgeon, *Acipenser fulvescens* (Jude 1982); (b) bloater, *Coregonus hoyi* (Auer 1982); (c) chinook salmon, *Oncorhynchus tshawytscha* (Kendall & Behnke 1984); (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 (q).

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.)

"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

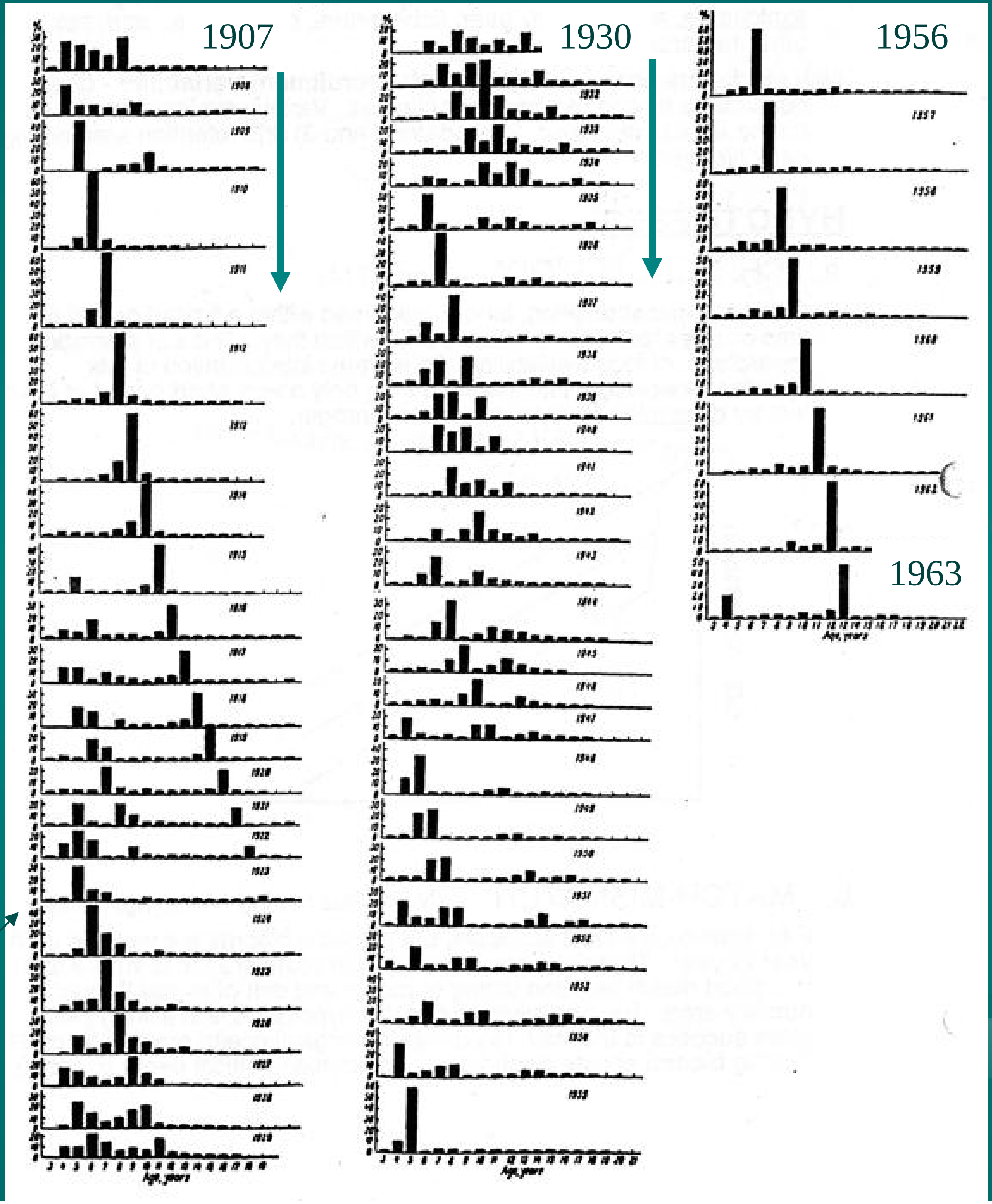
Atlanto-Scandian Herring

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.



What does recruitment variability translate to?

Collapse of Salmon Stocks Endangers Pacific Fishery

- Potential fish stock collapse:
  - Example: Pacific Chinook Salmon Fishery

13 March 2008: "Jack" salmon counted and only at 6% of long term average

1 May 2008: California ocean fishing of Chinook salmon closed

Sept-Nov 2008: $170 million in disaster relief given to fishermen

2009: Fishery still closed

2010: Fishery opened for a limited time

2011: Fish stocks are up – may be a normal fishing year (but still deciding)

Why did the fishery collapse?

- Poor recruitment, due to:
  - 1) overfishing: probably not.
  - 2) poor habitat conditions for spawners/young
    - - Sacramento River – much water diverted for agriculture and dams to prevent flooding, leads to less water/habitat for fish in rivers
  - 3) poor habitat for adults in ocean
    - variable upwelling strength, leading to variable nutrients available for phytoplankton – changing zooplankton stocks (Roemmich & McGowan 1995, Keister et al. 2011, amongst others).

Recruitment Variability: "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:

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

“Critical Period” for Larvae

- 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.

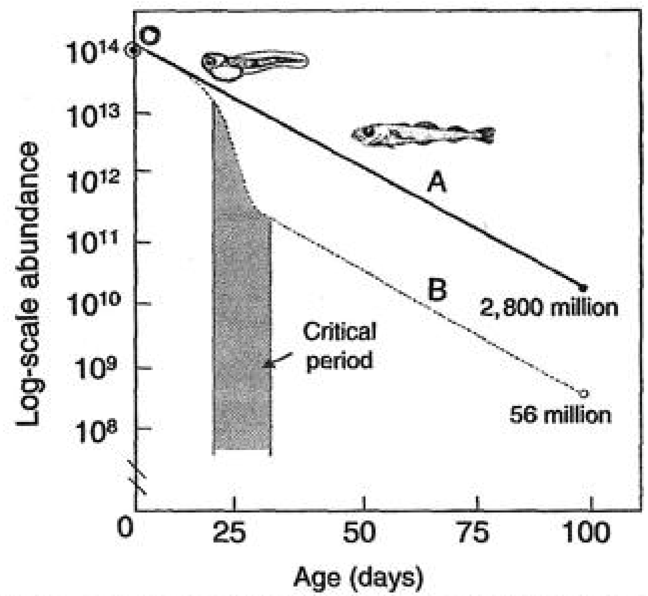


Figure 3.4 Survivorship curves showing effect of a “critical period” on abundance of survivors at 100 days post-hatching. Both populations have an initial mortality rate of $M = 0.10$ day^{-1}. The population that experiences high losses in the “critical period,” although recovering to experience the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

Metabolic rate & Stored Energy

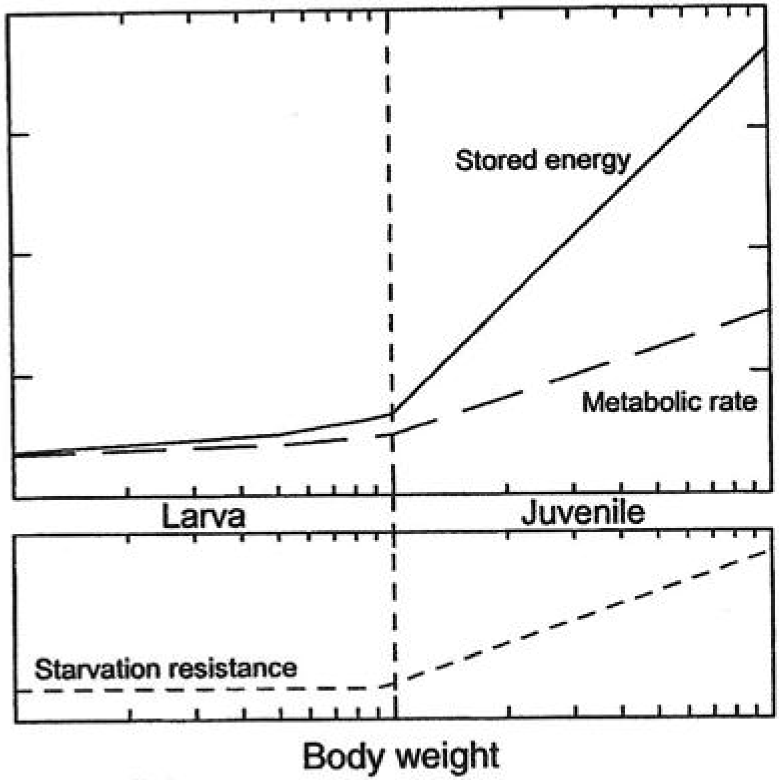


Figure 1.11 Changes in stored energy and metabolic rate with growth during the larval and juvenile periods. Stored energy is directly proportional to body weight through both periods (although the logarithmic abscissa distorts this trend). Metabolic rate is proportional to body weight for larvae (that 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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“Match-Mismatch” Hypothesis

- 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)

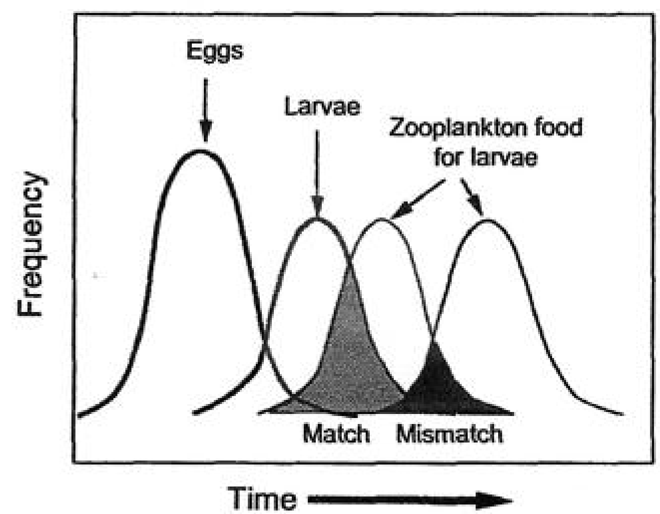

Figure 4.3 Schematic representation of Cushing's Match/Mismatch Hypothesis illustrating variability in the degree of overlap between the timing of a seasonal peak in the production of planktonic food for larvae and the co-occurrence of fish eggs and larvae. The stippled area is a match representing high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

Cowen & Shaw 2002

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.

Retention Area: Closed Life Cycle

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

  e.g., Migration Triangle Hypothesis

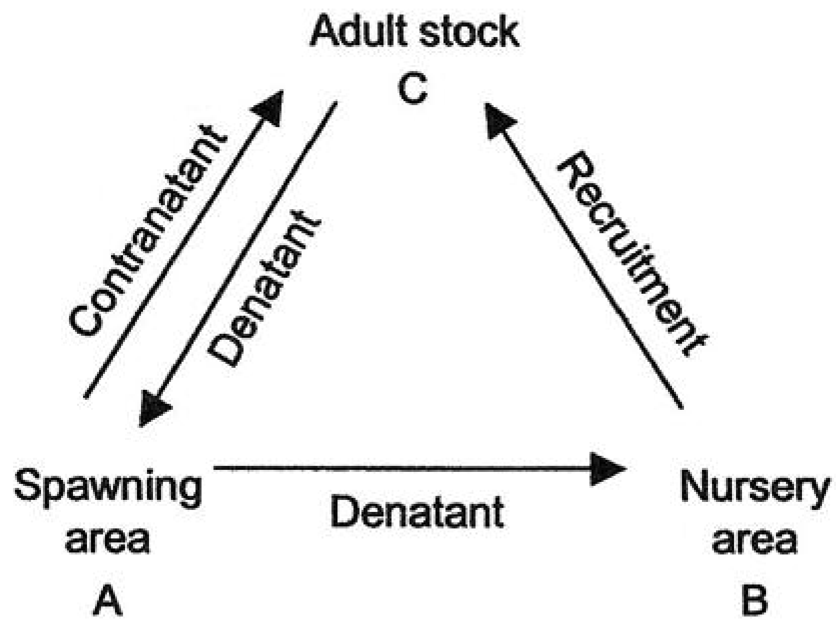

Figure 8.3 The Migration Triangle Hypothesis. In Harden Jones' (1968) original formulation, the three components of the population were spatially distinct. Completion of the life cycle required either active migration (adults) or hydrographically assisted movements (eggs and larvae).

Coastal Conveyor Belt

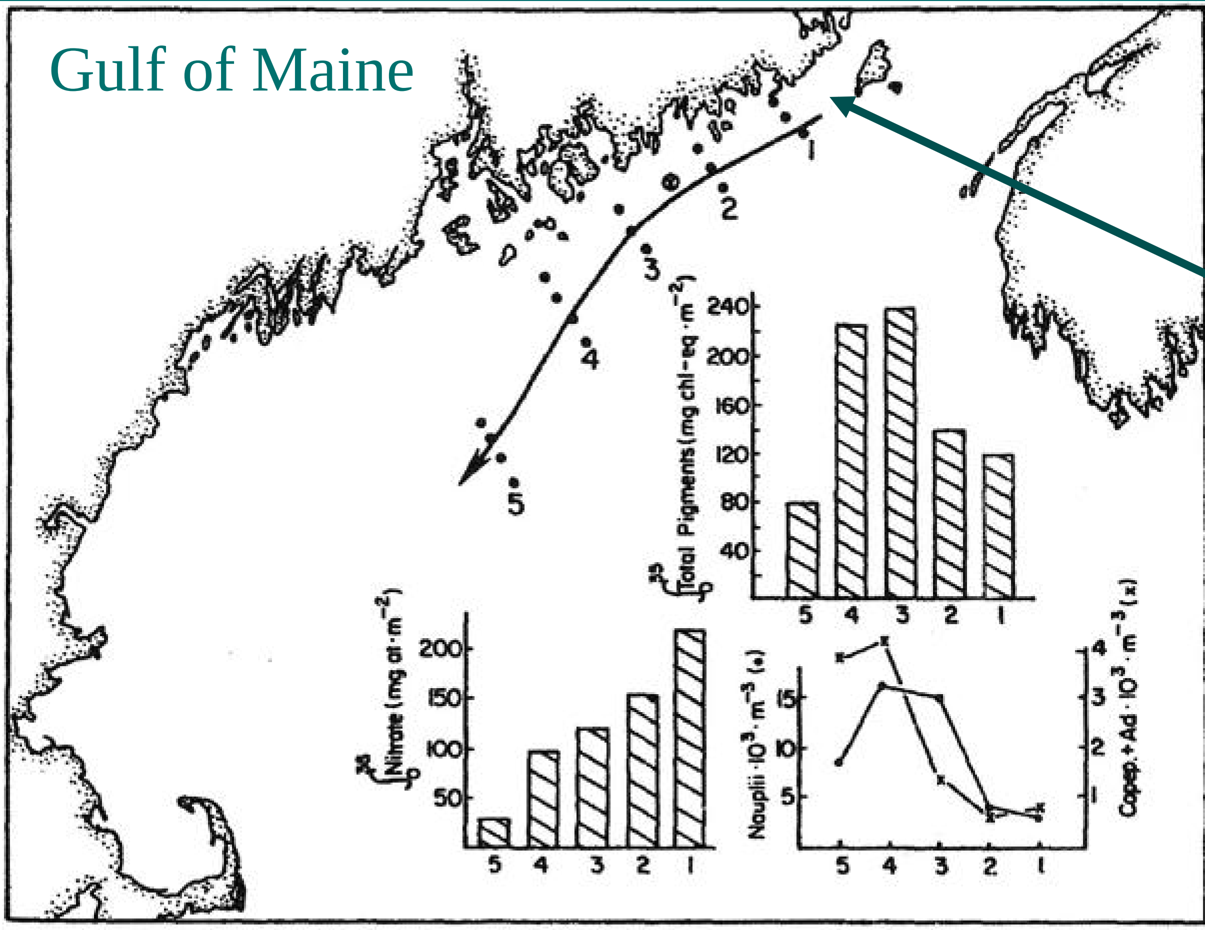

Figure 4.6 Summary plot of the changes in nitrate, chlorophyll, and naupliar and copepodid stages of copepods along the eastern Maine coastal current/plume system for July 1985, used here to illustrate the coastal conveyor belt. The nitrate and chlorophyll histograms are the averages of the vertically 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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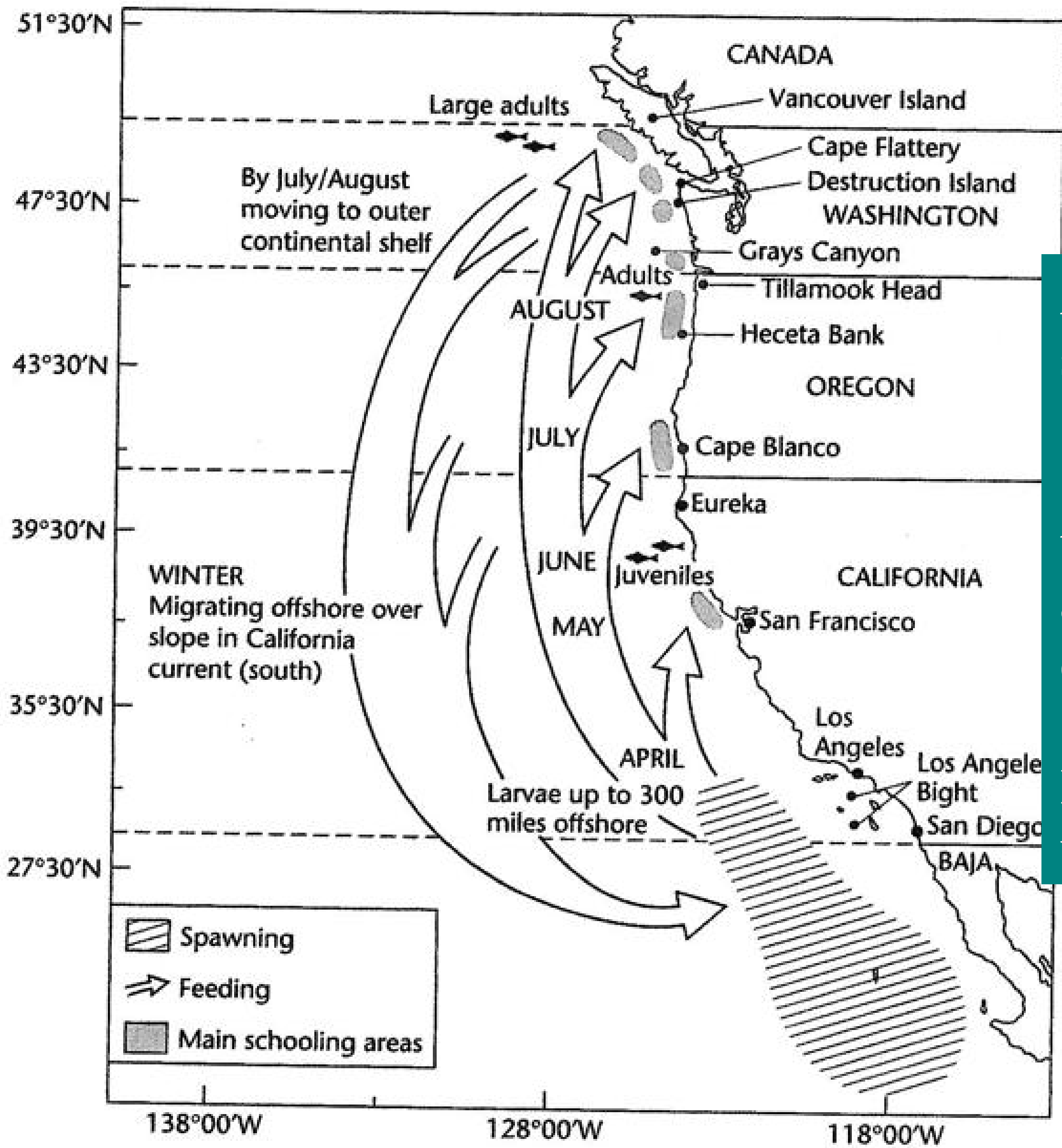
Atlantic herring spawning site

- 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.)

Mortality of Fish Larvae: 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

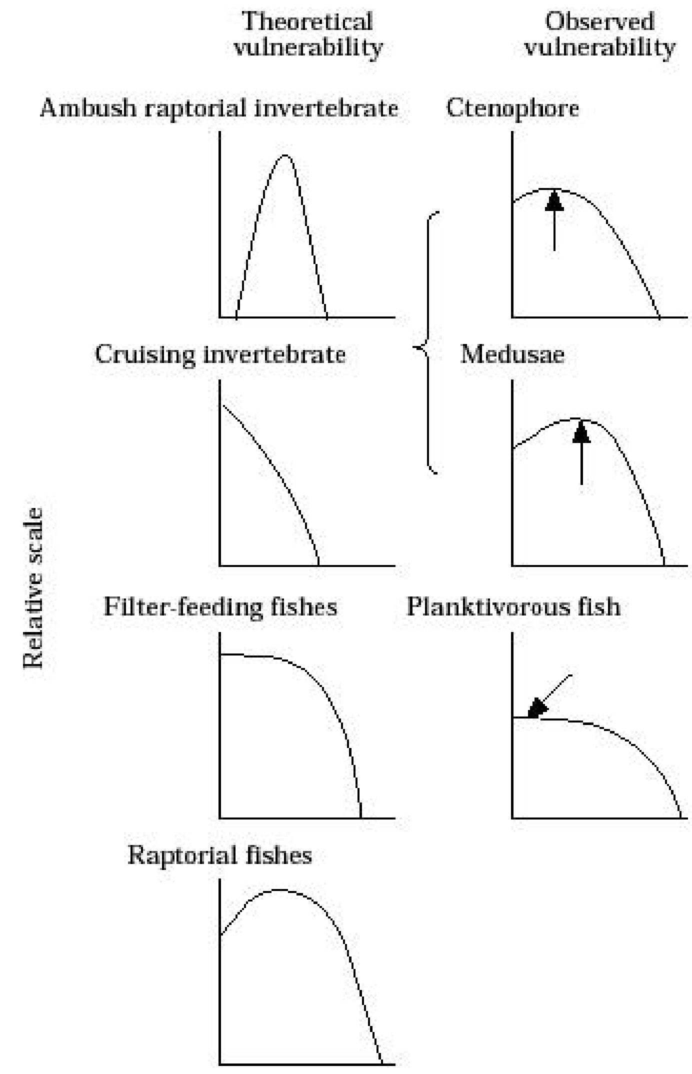


Figure 1. Vulnerability of fish larvae to different types of predators. Theoretical relationships are redrawn from Bailey and Houde (1989). Observed relationships are redrawn from Cowan and Houde (1992). Arrows indicate the relative size of maximum larval vulnerability to the predators.

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

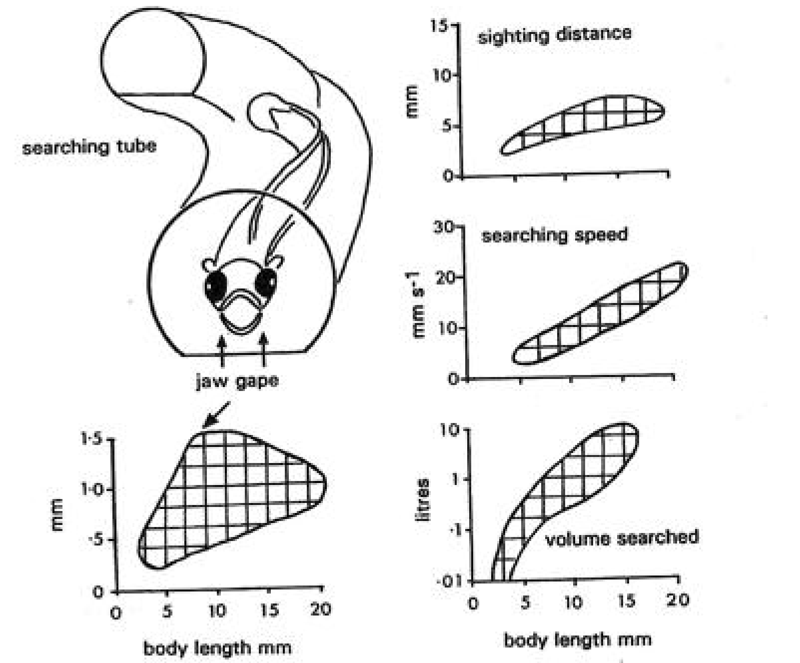


Figure 7.2 Top left: the feeding 'tube' searched by a fish larva. Bottom left: graph showing how the gape of the jaw changes as larvae grow. The shaded area in this and the other graphs is an envelope containing a number of regression lines showing the relationship between jaw gape and body length in 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

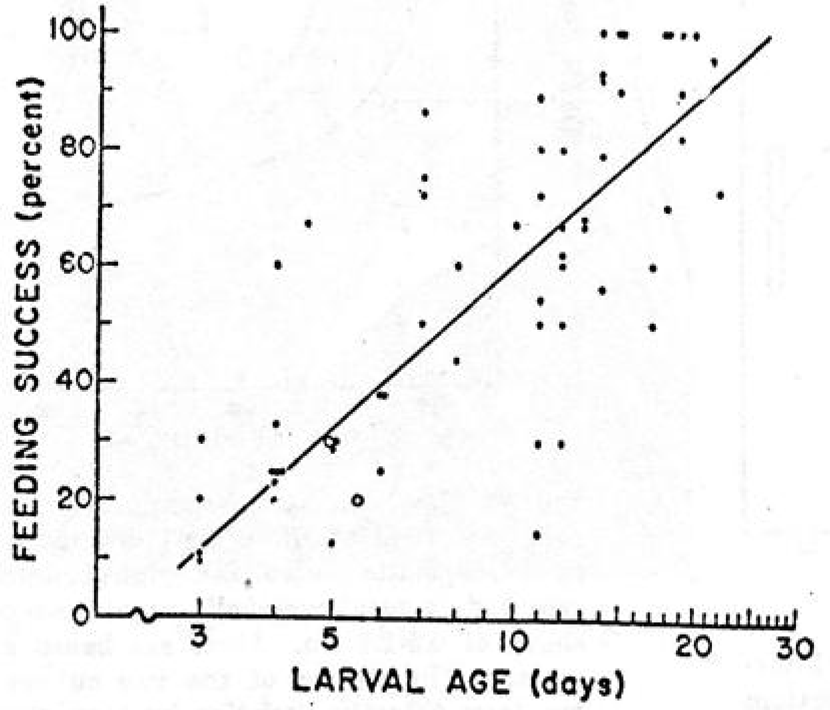


FIGURE 9.—Feeding success (percent of prey captured) of anchovy larvae of various ages fed *Brachionus*. Larval age is plotted on log scale, equation for line is percent success = 93.2(log age) − 33.30. Two open circles, larvae fed *Gymnodinium*.

Hunter 1972

Summary:
Why is recruitment variable even without fishing?

Basic species ecology with practical implications

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