Fisheries Oceanography

OCN 621

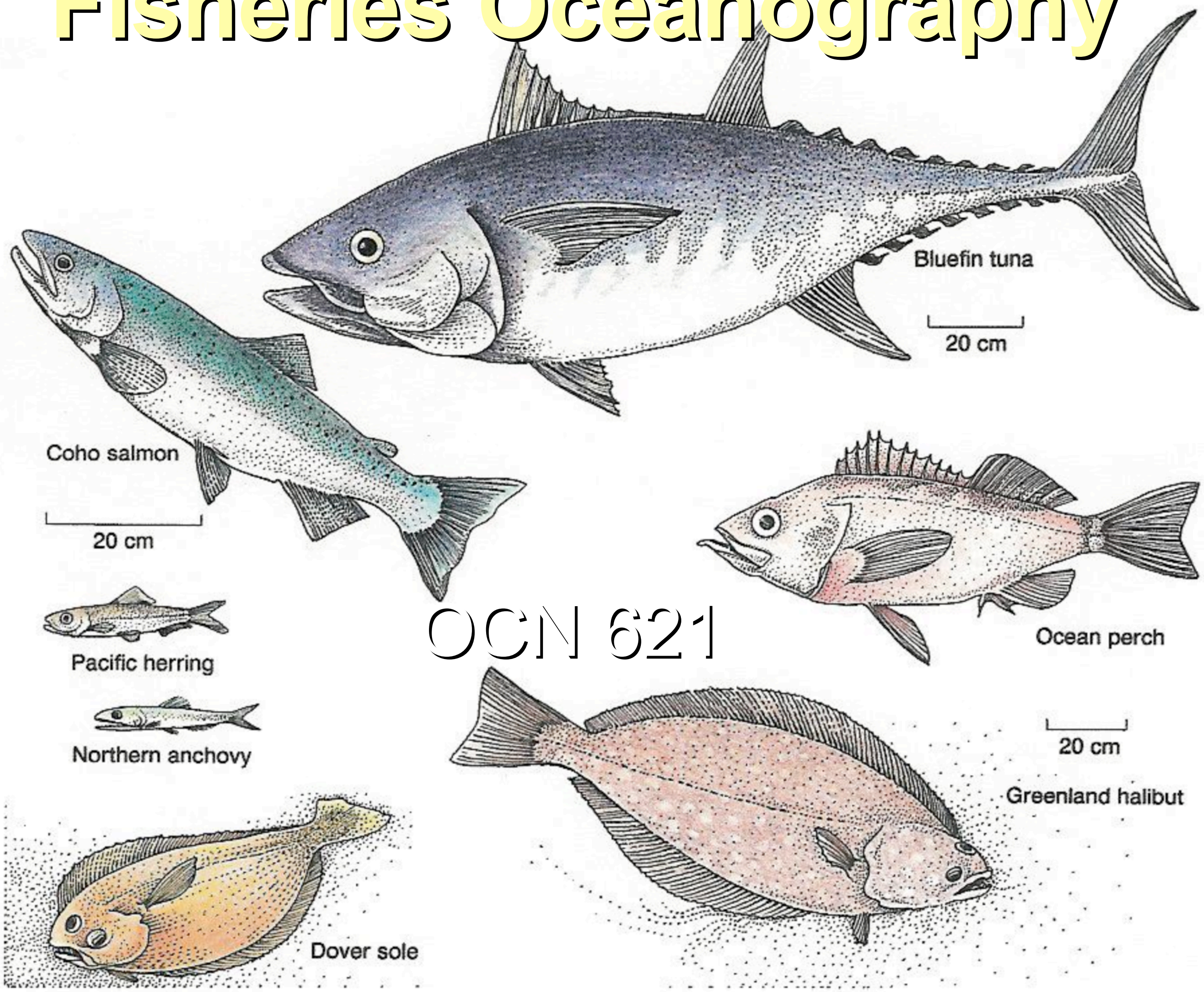


Figure 16.12
Commercially harvested members of the bony fish.

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, ~$70 billion industry, ~15 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)

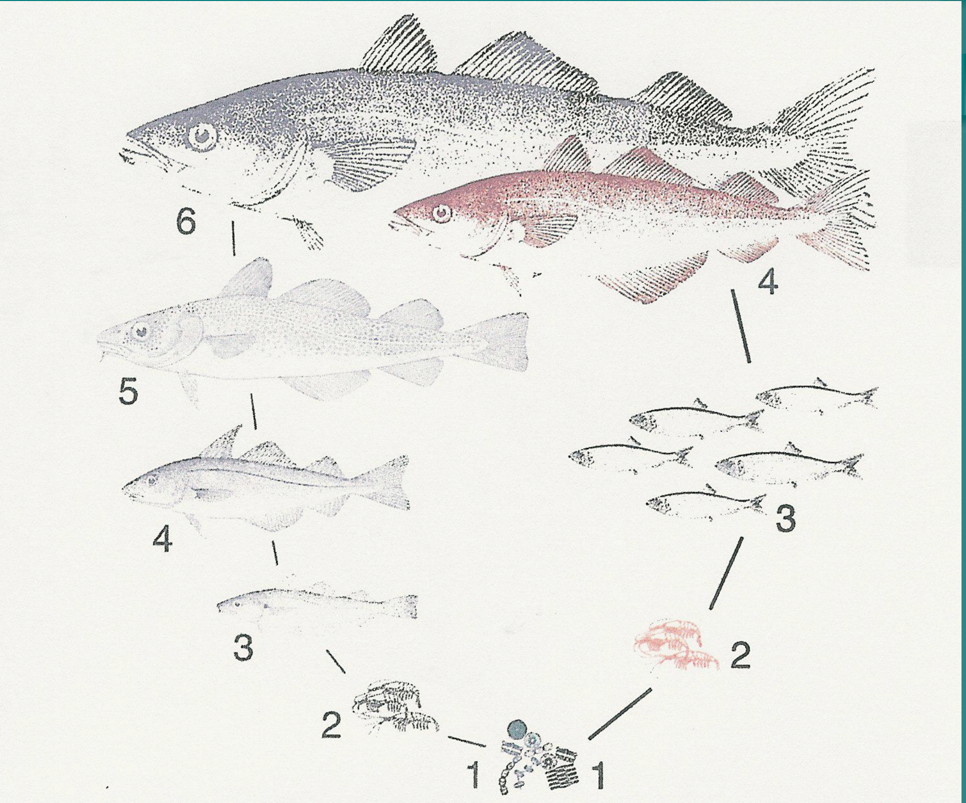


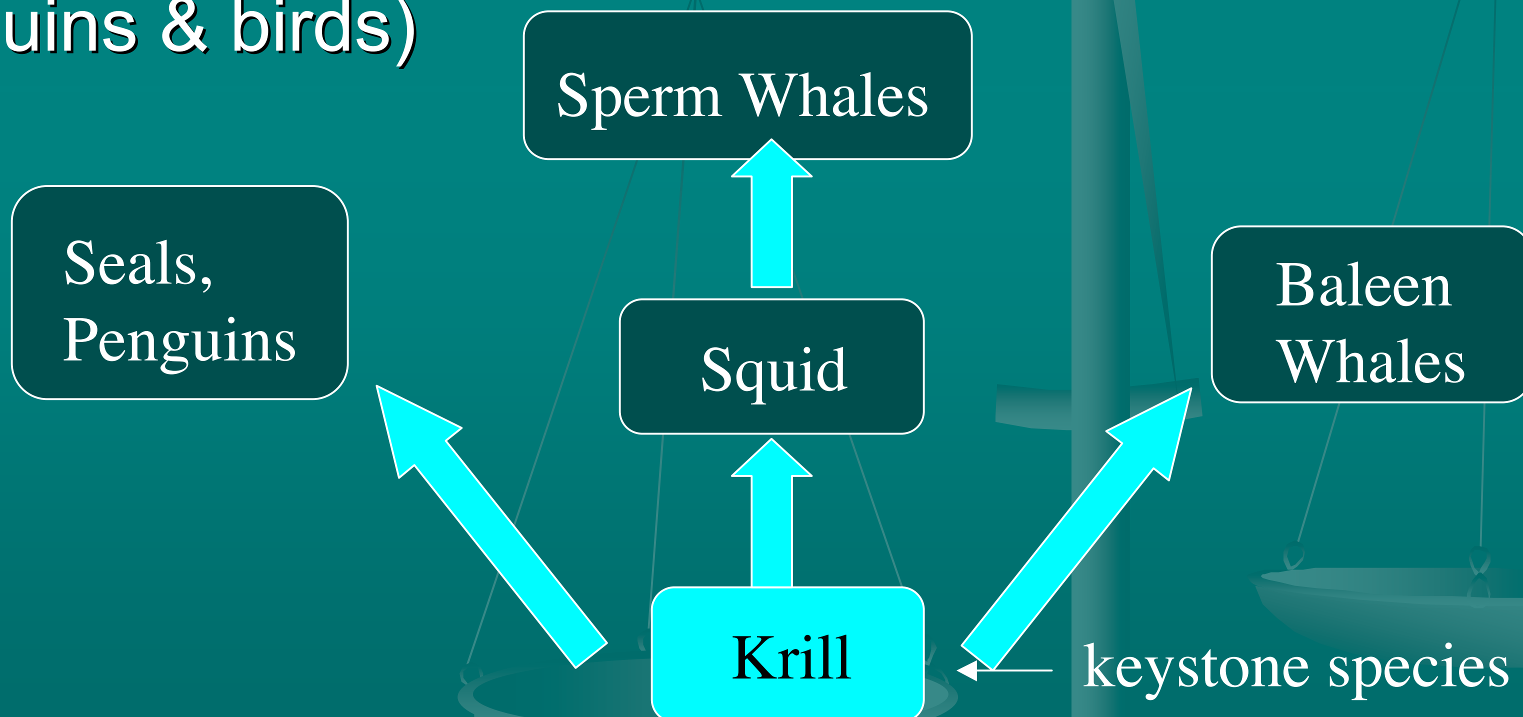
FIGURE 19. WHAT FISHING DOWN THE FOOD WEB MEANS FOR A TYPICAL PREDATOR.
As once-abundant large prey become scarcer, smaller prey must be consumed. This then affects the whole food web, resulting in fewer steps between the extremes of the predators and the plankton.

Pauly & Maclean 2003

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**

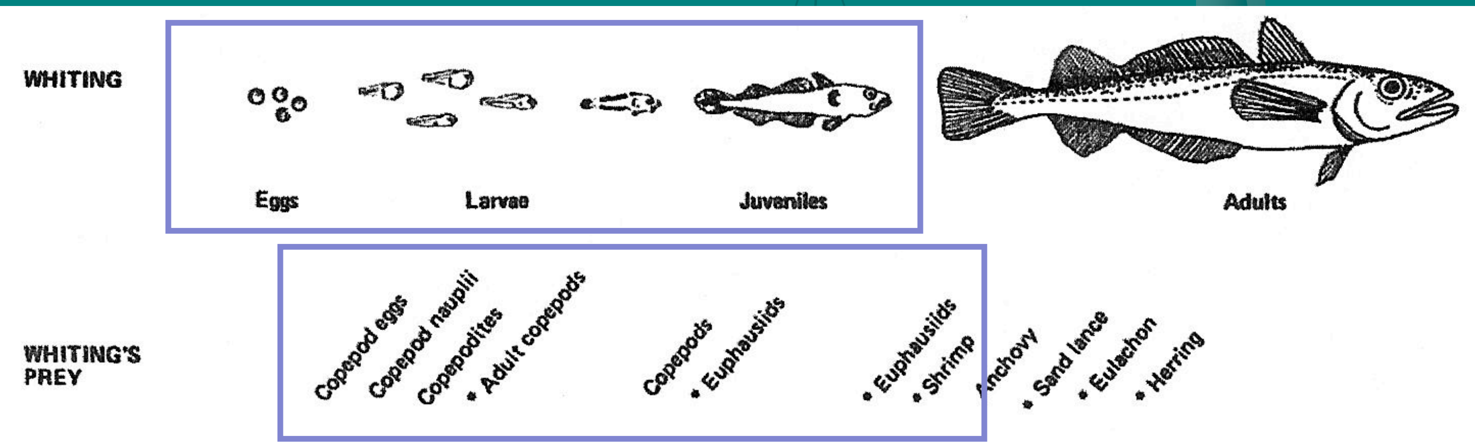


Figure 6.11. Pacific whiting prey fish eaten at various life history stages. (Asterisk indicates major prey species.) Modified from Livingston and Bailey (1985). Mar. Fish. Rev. 42(2):16–22.

Developmental Stages

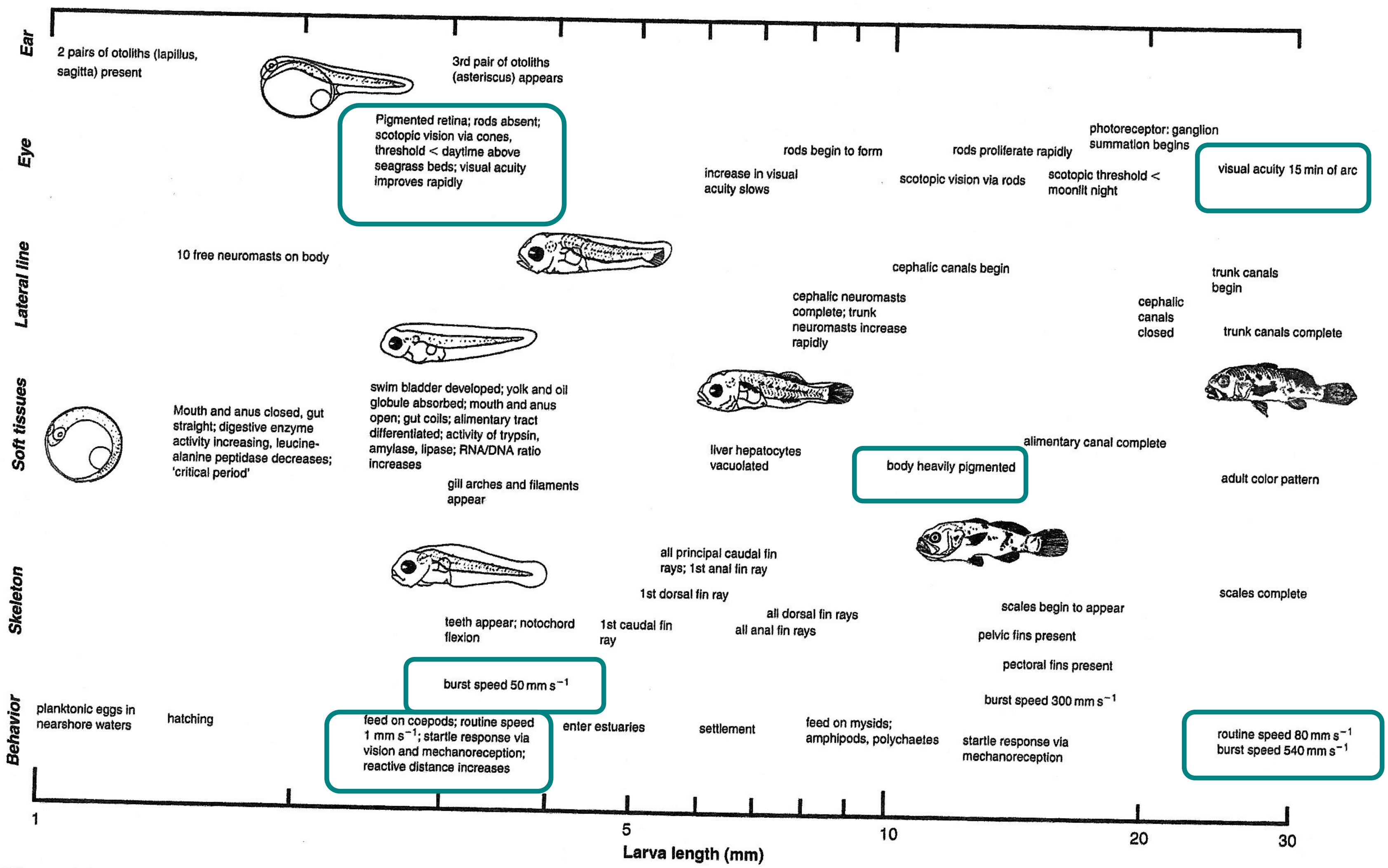


Figure 1.13 Composite of developmental changes in body form, function, and ecology in red drum (*Sciaenops ocellatus*). Data from numerous sources. Drawings from Holt *et al.* (1981) and Pearson (1929).

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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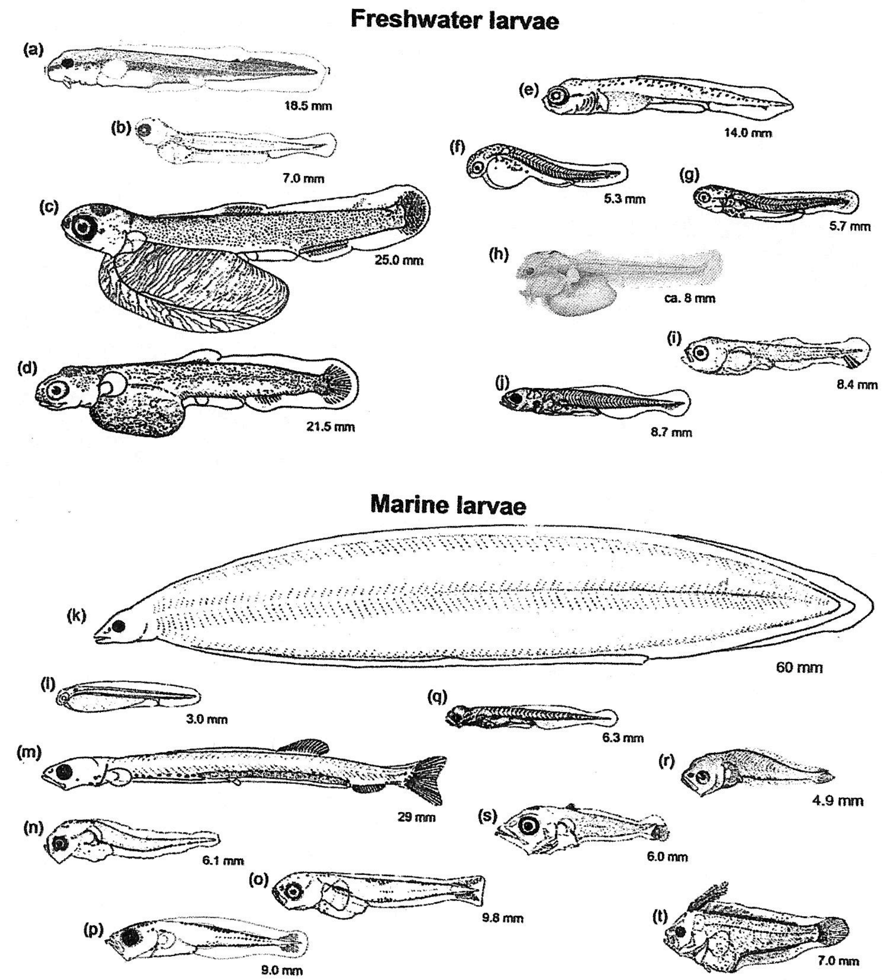


Figure 1.3 Representative stages of larvae for selected species of freshwater and marine fishes. Sources are given in parentheses: (a) lake sturgeon, *Acipenser fulvescens* (Jude 1982); (b) bloater, *Coregonus hoyi* (Auer 1982); (c) chinook salmon, *Oncorhynchus tshawytscha* (Kendall & Behnke 1984);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

Metabolic rate & Stored Energy

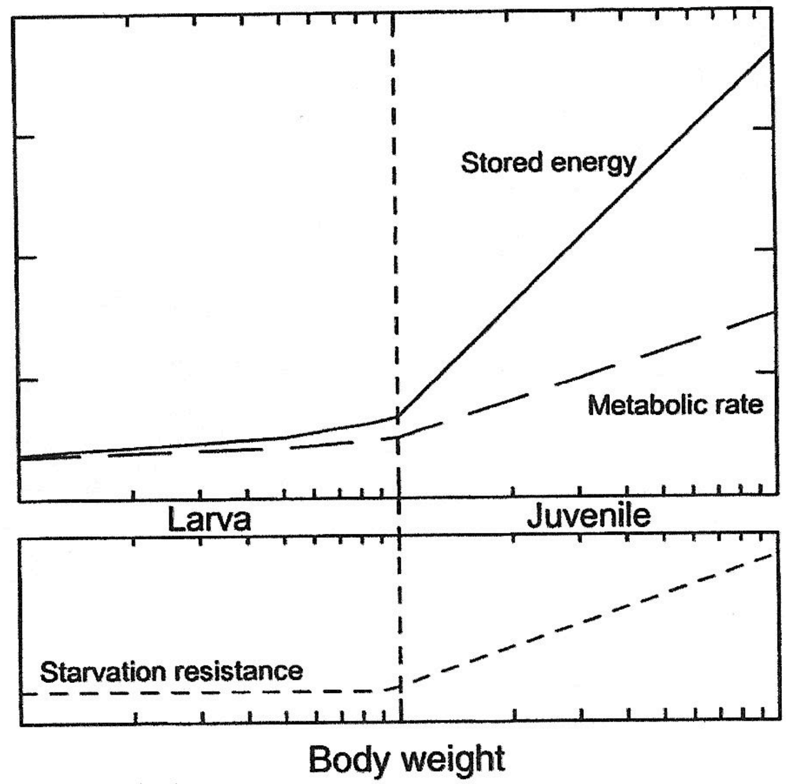


Figure 1.11 Changes in stored energy and metabolic rate with growth during the larval and juvenile periods. Stored energy is directly proportional to body weight through both periods (although the logarithmic abscissa distorts this trend). Metabolic rate is proportional to body weight for larvae (that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

Fuiman & Werner 2002

“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 $\longrightarrow$ low reproduction $\longrightarrow$ 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.

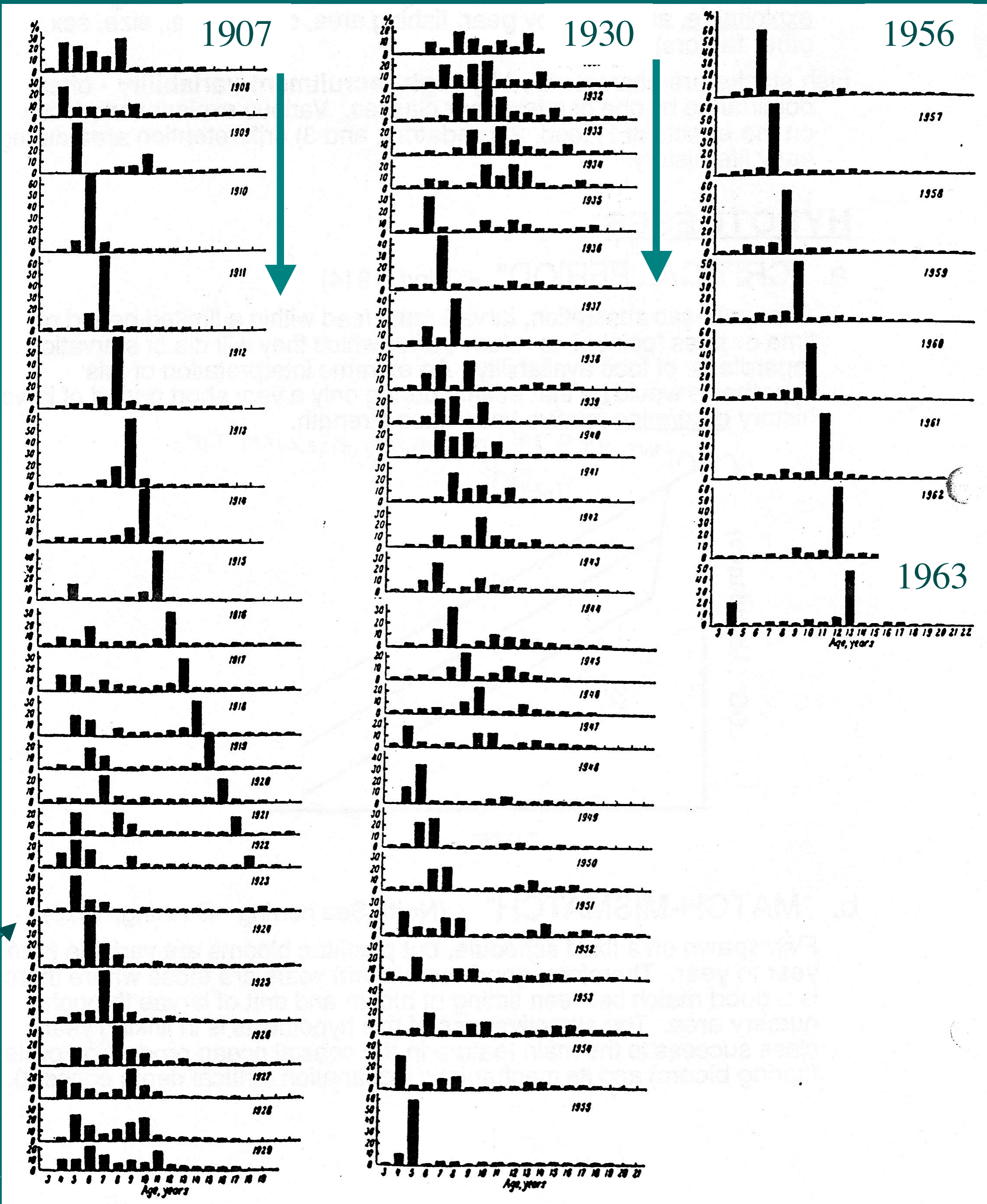
Atlanto-Scandian Herring

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.



Abundance vs. Age

Why is there a natural variation in recruitment?

- Various explanations focus on the effects of
  1) food,
  2) predators, and
  3) drift/retention area during early life history

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.

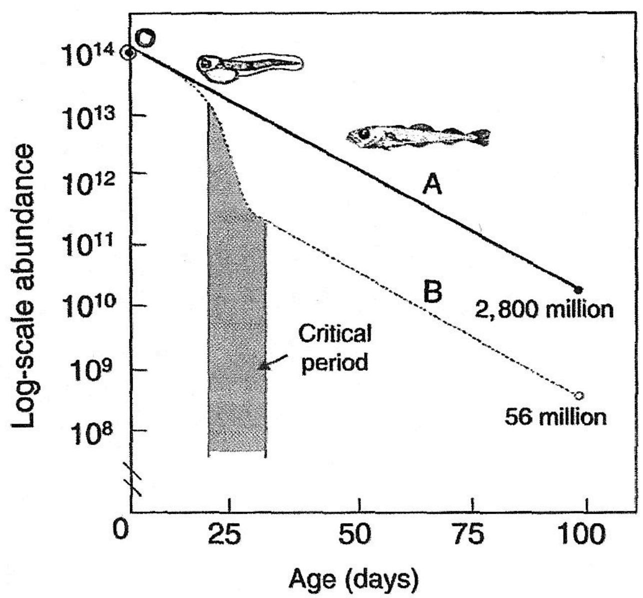


Figure 3.4 Survivorship curves showing effect of a “critical period” on abundance of survivors at 100 days post-hatching. Both populations have an initial mortality rate of $M = 0.10$ day^{-1}. The population that experiences high losses in the “critical period,” although recovering to experience the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

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)

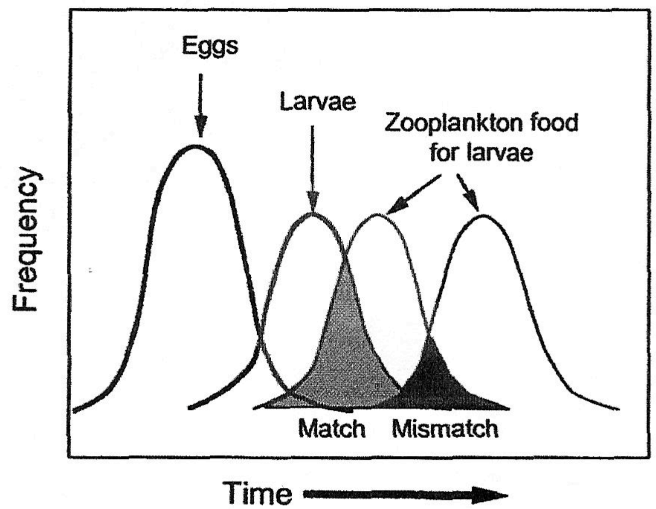


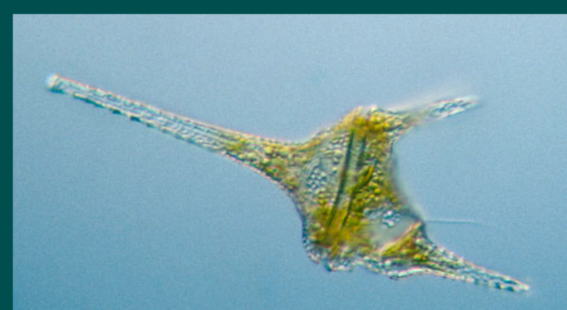
Figure 4.3 Schematic representation of Cushing's Match/Mismatch Hypothesis illustrating variability in the degree of overlap between the timing of a seasonal peak in the production of planktonic food for larvae and the co-occurrence of fish eggs and larvae. The stippled area is a match representing high 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 <u>appropriate</u> 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

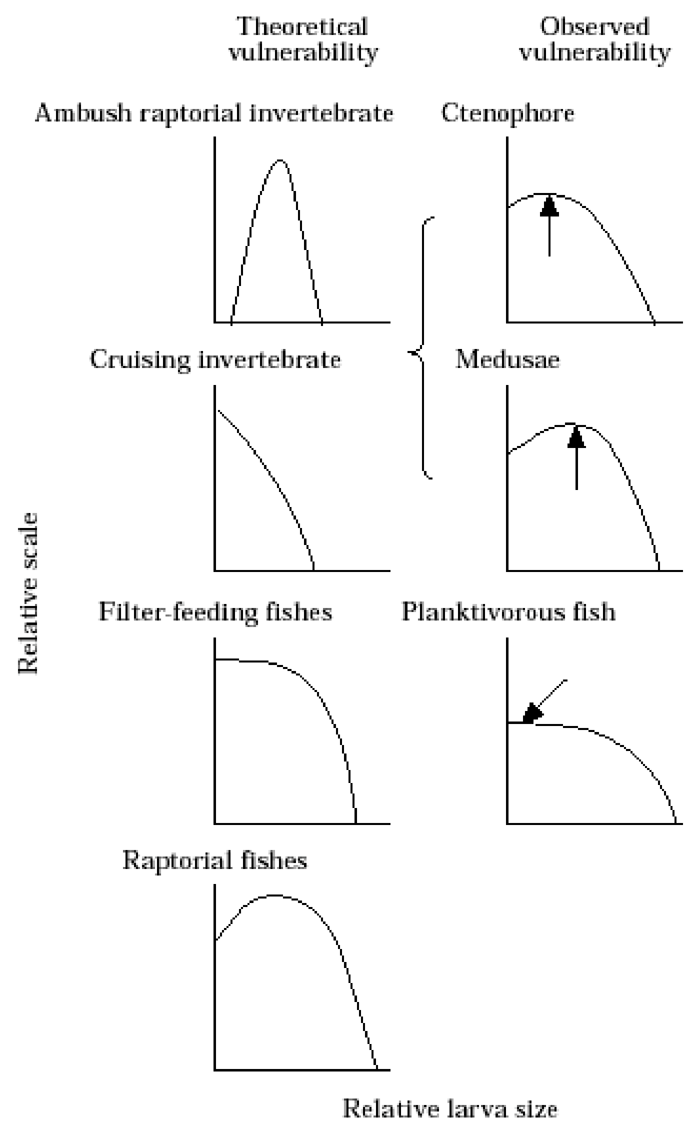


Figure 1. Vulnerability of fish larvae to different types of predators. Theoretical relationships are redrawn from Bailey and Houde (1989). Observed relationships are redrawn from Cowan and Houde (1992). Arrows indicate the relative size of maximum larval vulnerability to the predators.

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

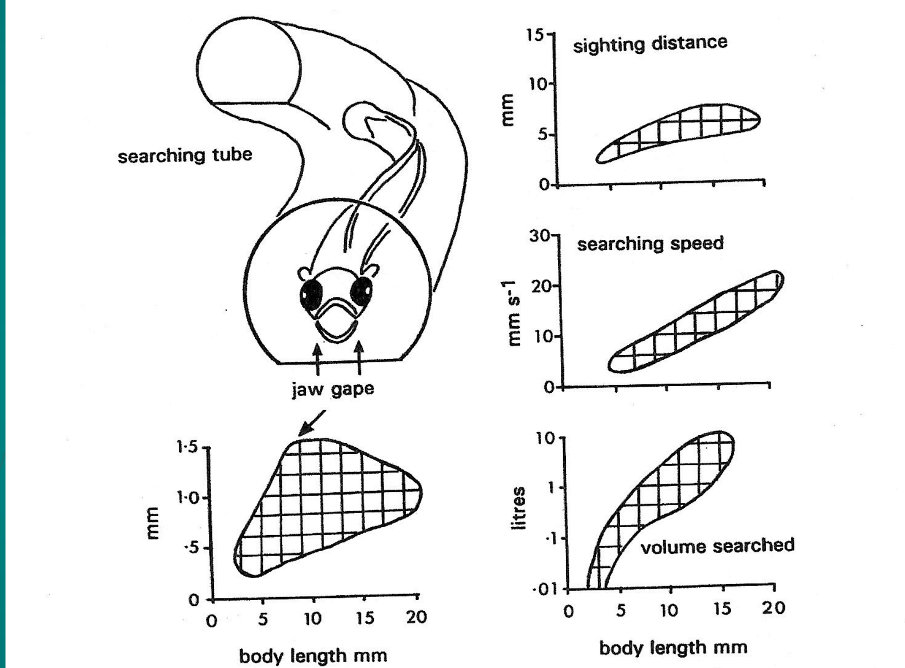


Figure 7.2 Top left: the feeding ‘tube’ searched by a fish larva. Bottom left: graph showing how the gape of the jaw changes as larvae grow. The shaded area in this and the other graphs is an envelope containing a number of regression lines showing the relationship between jaw gape and body length in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

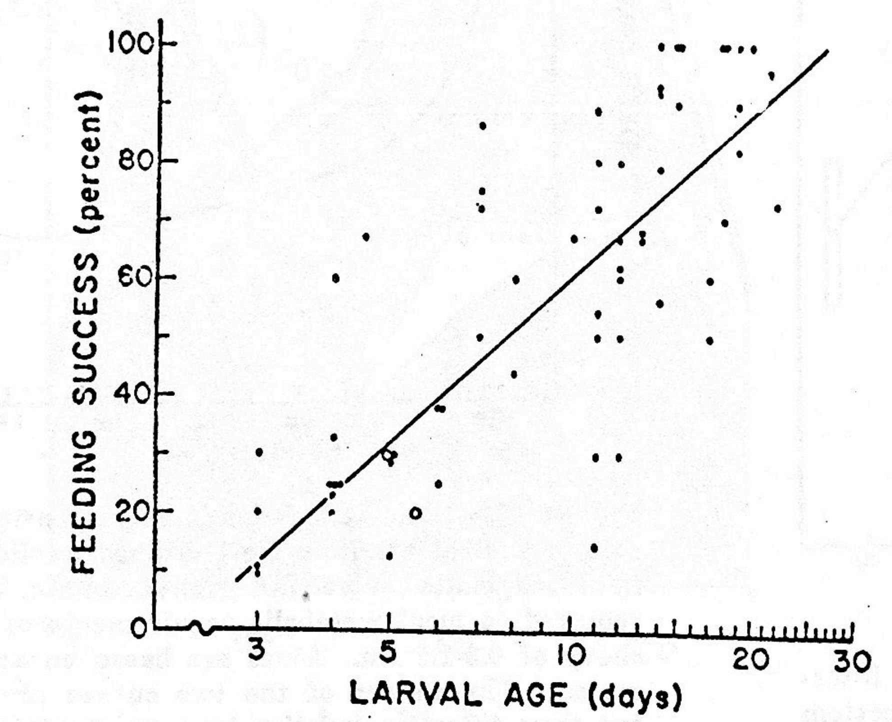


FIGURE 9.—Feeding success (percent of prey captured) of anchovy larvae of various ages fed *Brachionus*. Larval age is plotted on log scale, equation for line is percent success = 93.2 (log age) − 33.30. Two open circles, larvae fed *Gymnodinium*.

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

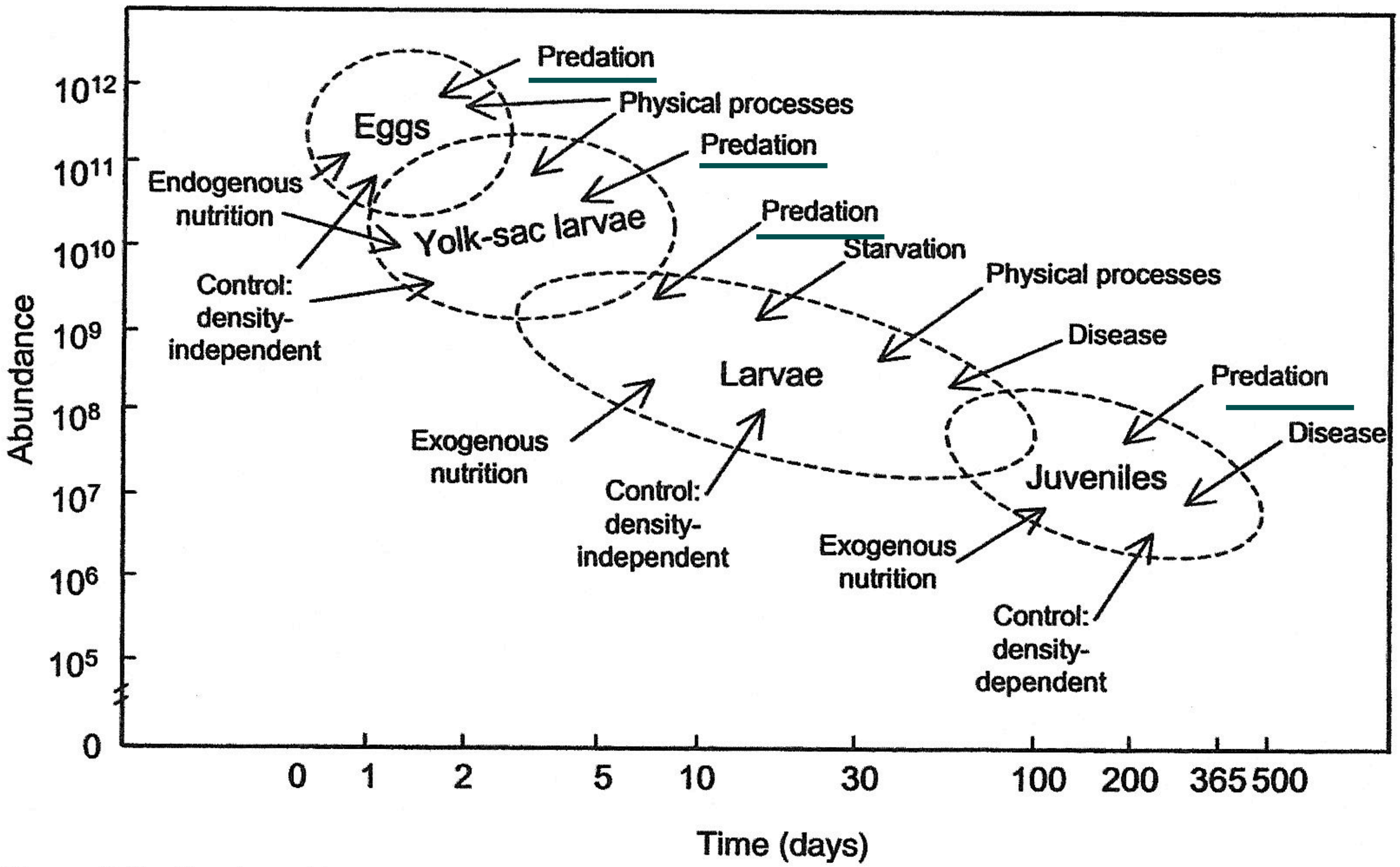


Figure 3.5 Survivorship curve conceptualizing the recruitment process in fishes, including factors that affect mortality and growth. Hypothesized mechanisms of control are indicated (reproduced from Houde 1987 with permission of the American Fisheries Society).

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

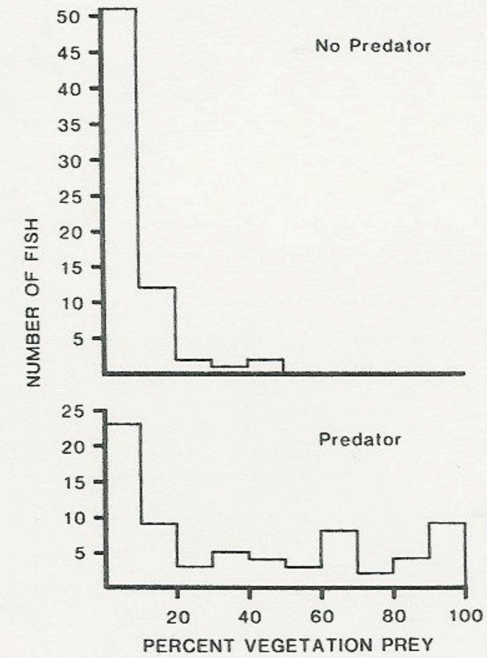
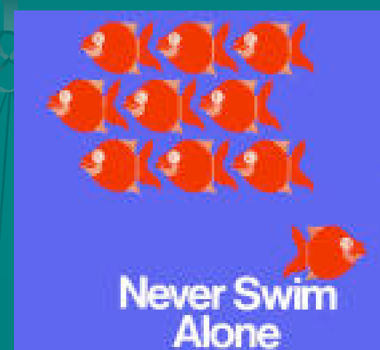


Fig. 1. Prey fish can shift their distribution and foraging patterns in response to changing predation. The number of small, vulnerable bluegill sunfish that foraged in the less profitable, vegetated region of a pond increased when predatory largemouth bass were present, as indicated by the percent of 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

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

Agents of Mortality for Young Fish

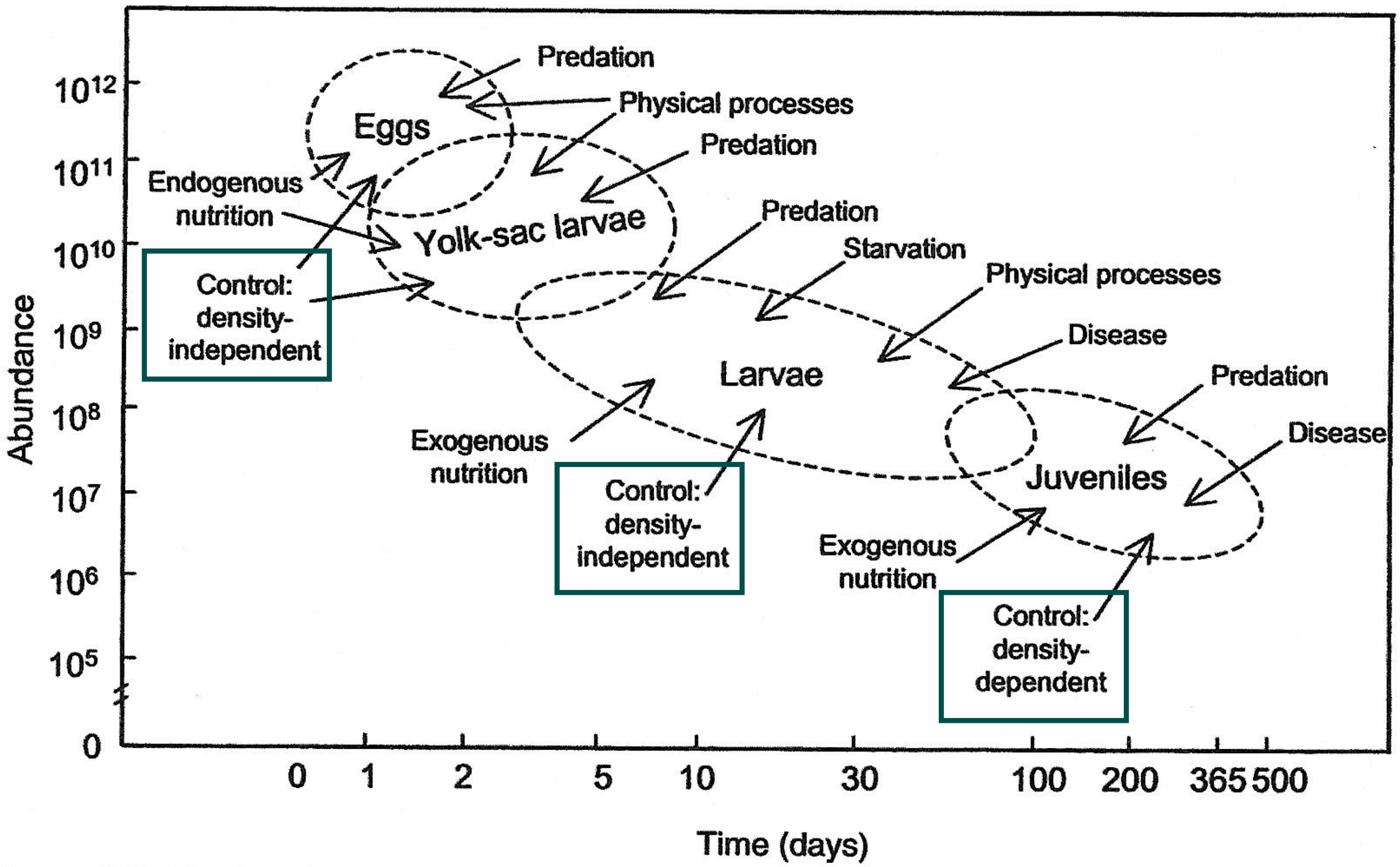


Figure 3.5 Survivorship curve conceptualizing the recruitment process in fishes, including factors that affect mortality and growth. Hypothesized mechanisms of control are indicated (reproduced from Houde 1987 with permission of the American Fisheries Society).

Fuiman & Werner 2002

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

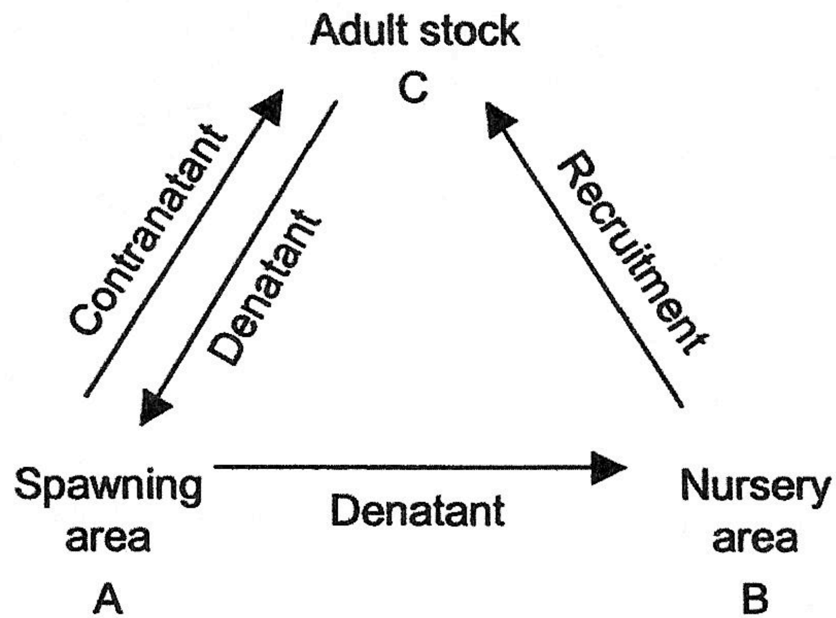


Figure 8.3 The Migration Triangle Hypothesis. In Harden Jones' (1968) original formulation, the three components of the population were spatially distinct. Completion of the life cycle required either active migration (adults) or hydrographically assisted movements (eggs and larvae).

Coastal Conveyor Belt

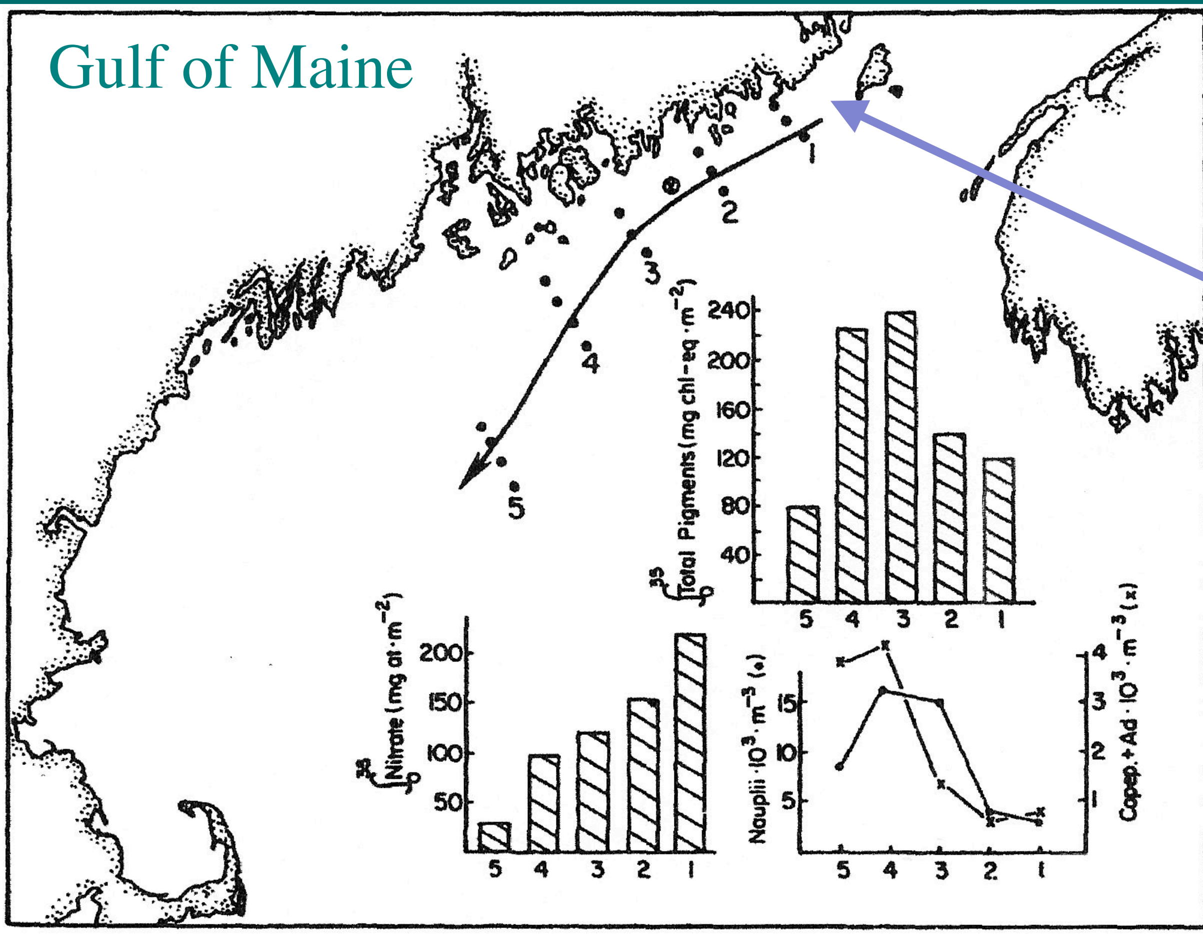


Figure 4.6 Summary plot of the changes in nitrate, chlorophyll, and naupliar and copepodid stages of copepods along the eastern Maine coastal current/plume system for July 1985, used here to illustrate the coastal conveyor belt. The nitrate and chlorophyll histograms are the averages of the vertically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

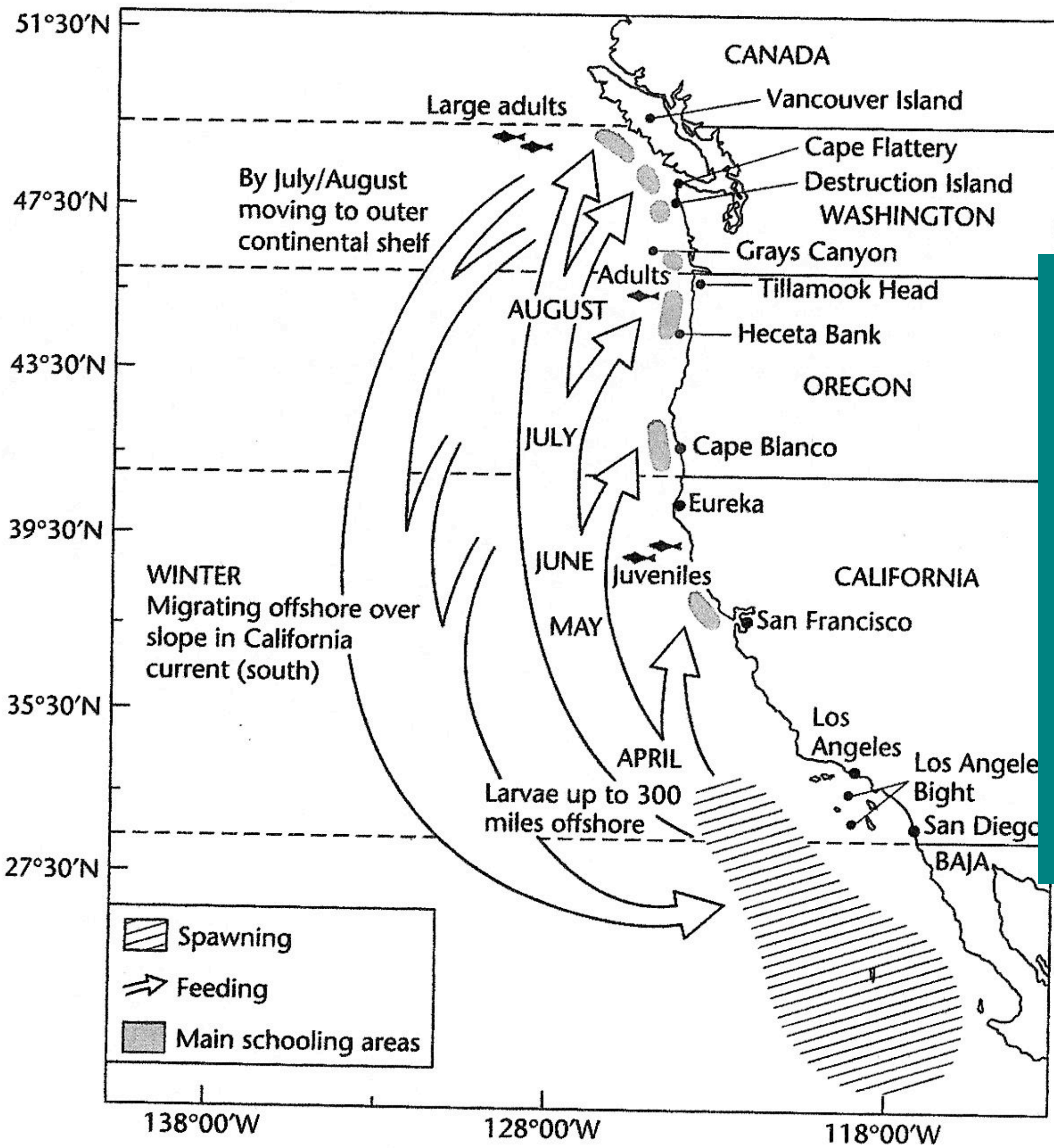


Fig. 15.3 General routes and timing of the spawning and feeding migrations of Pacific hake. (After Bailey *et al*. 1982.)

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

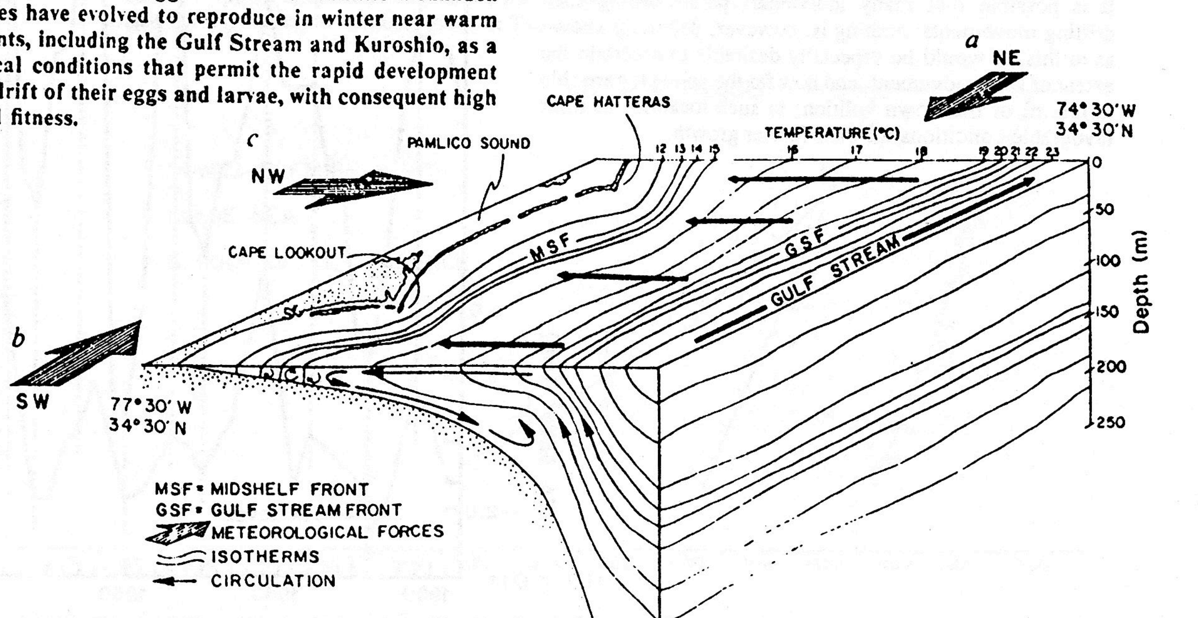
Member/Vagrant Hypothesis

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

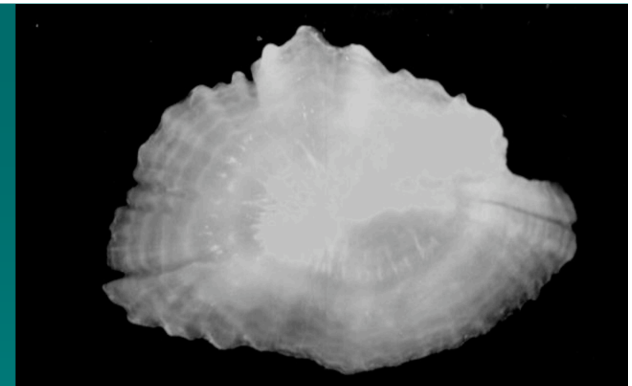
Menhaden off N. Carolina in winter: spawn

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

Coral Reef Fish



Broadcast spawners --
Larvae spend several weeks in the plankton
How do they find the reef, or any reef, after such dispersal time?

Swearer et al. (Nature 1999) used the elemental composition of Caribbean wrasse otoliths to show their origins (coastal vs. open ocean) and found that >50% of recruits were from locally spawned larvae

Jones et al. (Nature 1999) marked 10 million damselfish embryo otoliths. Later, examined 5,000 juvenile settlers and found 15 marked fish. This translated to 15 - 60% of juveniles returning to same site, since only 0.5 - 2% of total embryos were marked.

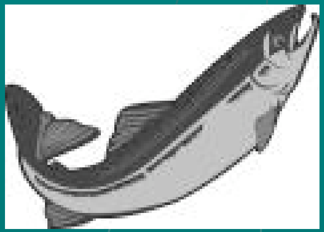
Fish Otoliths

- fish “ear bones” -- bony fish have 3 pairs of these -- sense of balance and aid in hearing
- natural data logger -- grow throughout the fish’s lifetime
- daily and annual growth rings (like in trees)
- composed mainly of calcium carbonate, but incorporates trace elements, too.
- composition records age of fish, growth patterns, and chemical environment

- fossilized otoliths also used by paleontologists to infer past conditions, such as water temperature through stable O2 isotopes.

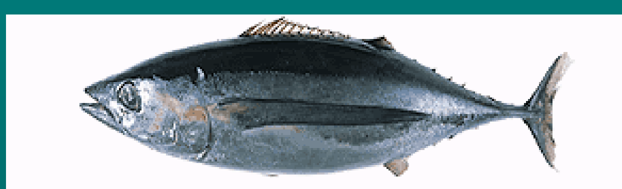
Fish Migrations

- Migrate to seek favorable food supply or ideal reproduction sites
- Some migrations several hundred to several thousand kilometers
- Some migrations between salt and fresh water (spawning feeding grounds).
  - Anadromous fish: breed in fresh, spend most of rest of life in the sea (e.g., salmon)
  - Catadromous fish: breed in the sea, spend life in fresh water (e.g., freshwater eels)



Migration example

Pacific Albacore Tuna:
from Pacific coast of the US, across the Pacific well north of Hawaii, then southward across along the east coast of Asia to Japan
i.e., generally along major current systems.



And: within 14.4° - 16.1°C waters

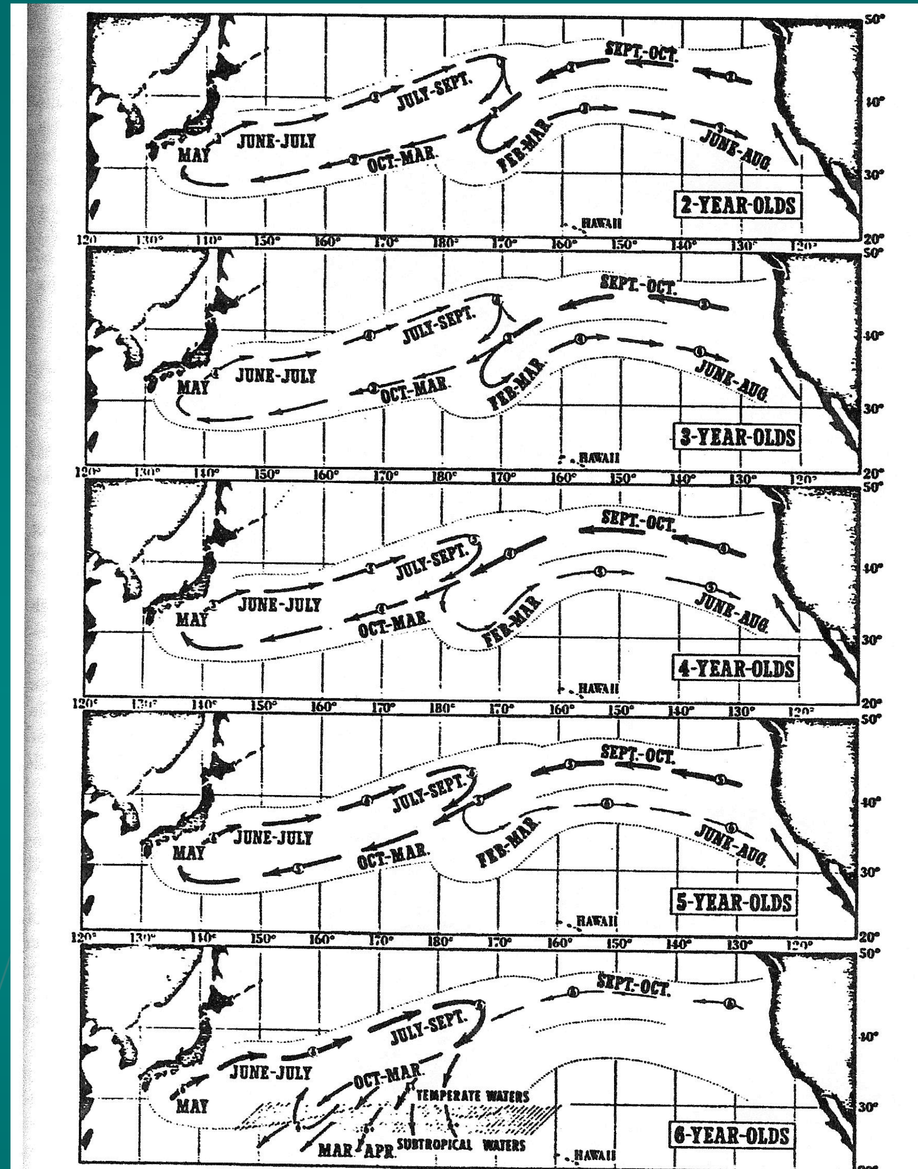


Figure 6.8. Model of albacore migration in the North Pacific Ocean, by age groups. From Otsu and Uchida (1963). U.S. Fish and Wildlife Service, Fish. Bull. 63(1):33–44.

How do they find their way?

Sun: Use the sun to aid orientation, “sun compass”

Geomagnetic and Geoelectric Fields: movement of ocean currents through the earth’s magnetic field generates electric fields that some fish can sense (salmon, eels).

Random walks? Some studies show that if salmon swim in random directions in the open ocean, but then get near the river mouth where they originated, and presumably can then “smell home”, then no other directional sense is required, other than maybe use of the sun for orientation

Conclusion: relatively low degree of orientation probably involved in migrations and not all migrants make it “home”

Olfaction

- "smelling home" evidence
  - many fish (eels, salmon, carp, trout) can distinguish between home and non-home waters
  - what chemicals? those associated with sex (pheromones), food (amino acids), and avoidance and migration behavior (e.g., bile salts)

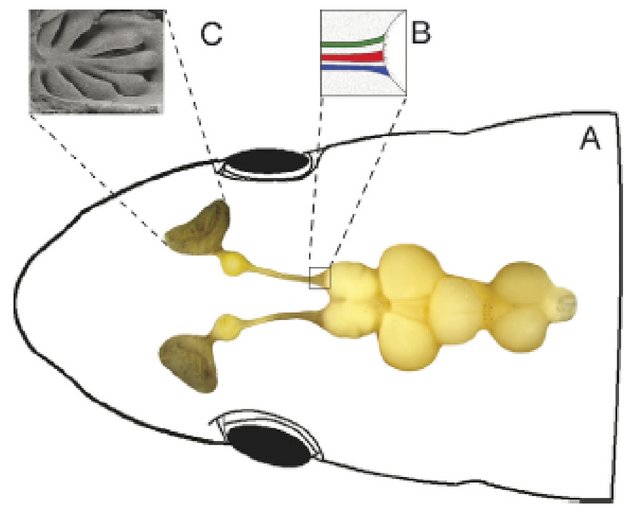


Fig. 1. Overview of the fish brain. (A) Dorsal view of the head of a crucian carp showing the brain and the olfactory system. (B) Schematic drawing of the olfactory tract as it enters the telencephalon, demonstrating three distinct bundles. The medial part of the medial olfactory tract in blue, the lateral part of the medial olfactory tract in red, and the lateral olfactory tract in green. (C) Scanning micrograph of the olfactory rosette.

Hamdani et al. 2007

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

The role of the jellyfish - medusoid

- Increasingly important in many ecosystems worldwide

    regime shifts? over-fishing?

- Competitors and predators of fish: perhaps represent an alternate guild of predators to fish in marine ecosystems

- Adapted to patchy and diffuse food resources

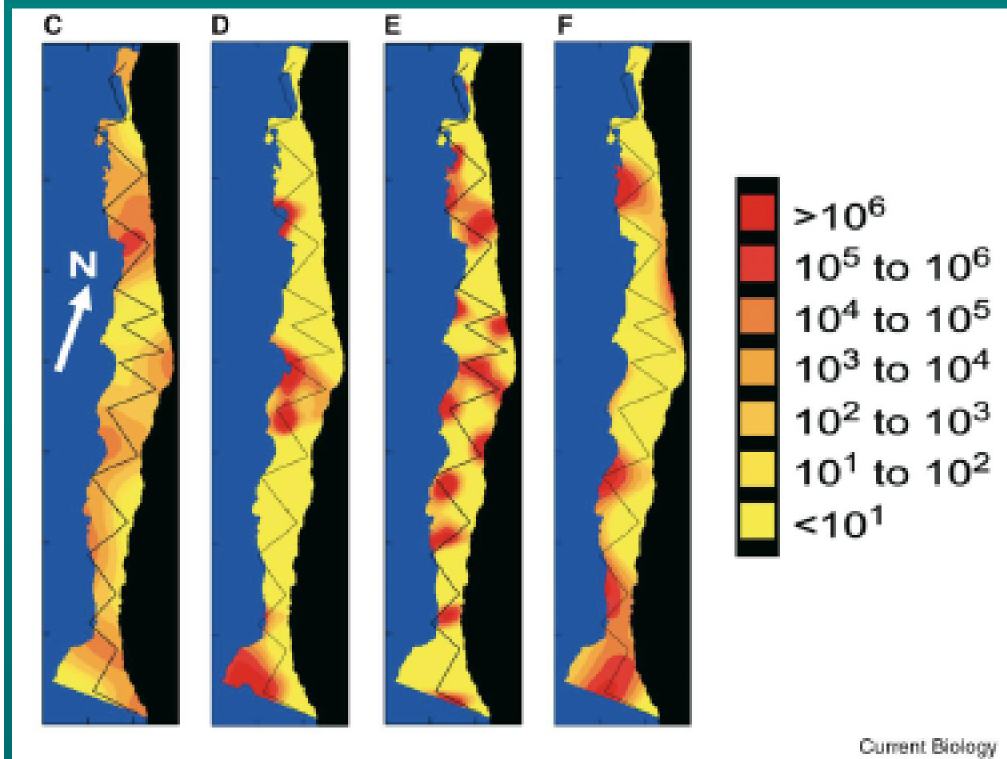
    can grow rapidly if food available or subsist on little or no food (able to shrink when starved)

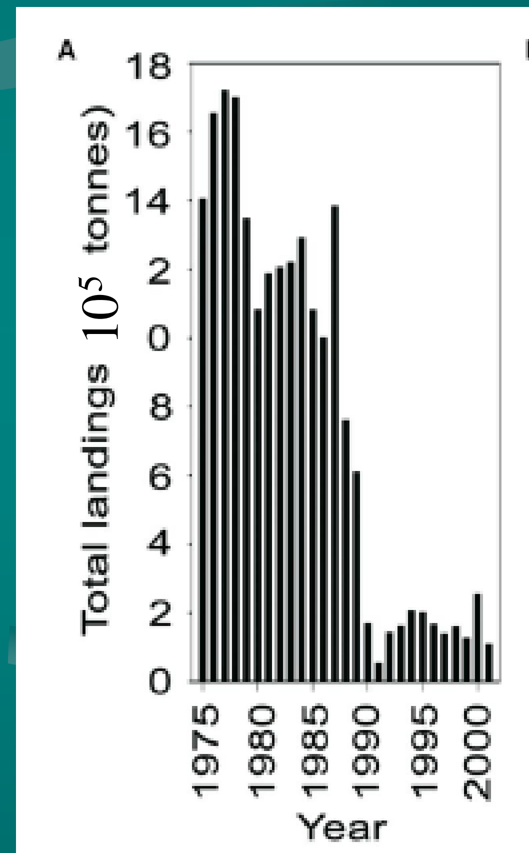
- Can survive at lower O_2 levels than fish - indication of eutrophication

Benguela Upwelling Zone - shift from fish to jellies

mainly sardines/anchovies

jellyfish biomass = 12.2 MT
fish biomass = 3.6 MT





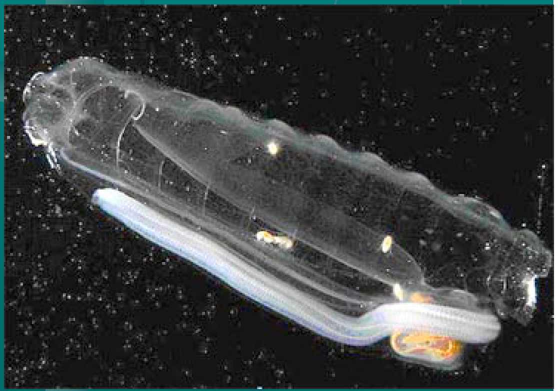
c,d = jellyfish, e,f = fish

Lynam et al. 2006

Salps

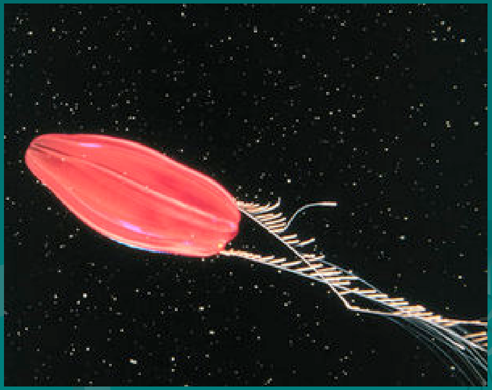
- Abundant in equatorial and Antarctic waters
- Filter feeders with fecal pellets sinking ~1,000 m/day
- Decrease in krill in Antarctica coincides with increase in salps

- Why? Both consume similar food but salps tolerate higher temperatures so can live in open water whereas krill need sea ice to over-winter and as nursery grounds



Larry Madin, WHOI

Ctenophores



- "comb jellies": carnivores -- use tentacles to entangle prey
- usually do not have a big effect on ecosystem function
- Big exception: introduction of a North Atlantic species into the Black Sea -- out-competed anchovies for copepod prey and contributed to collapse of fishery

Siphonophores

- colonial organism, carnivore
- feed on fish larvae, crustaceans
- movement: air bladder pushed by the winds/currents
- most famous member: Portuguese Man O'War

References

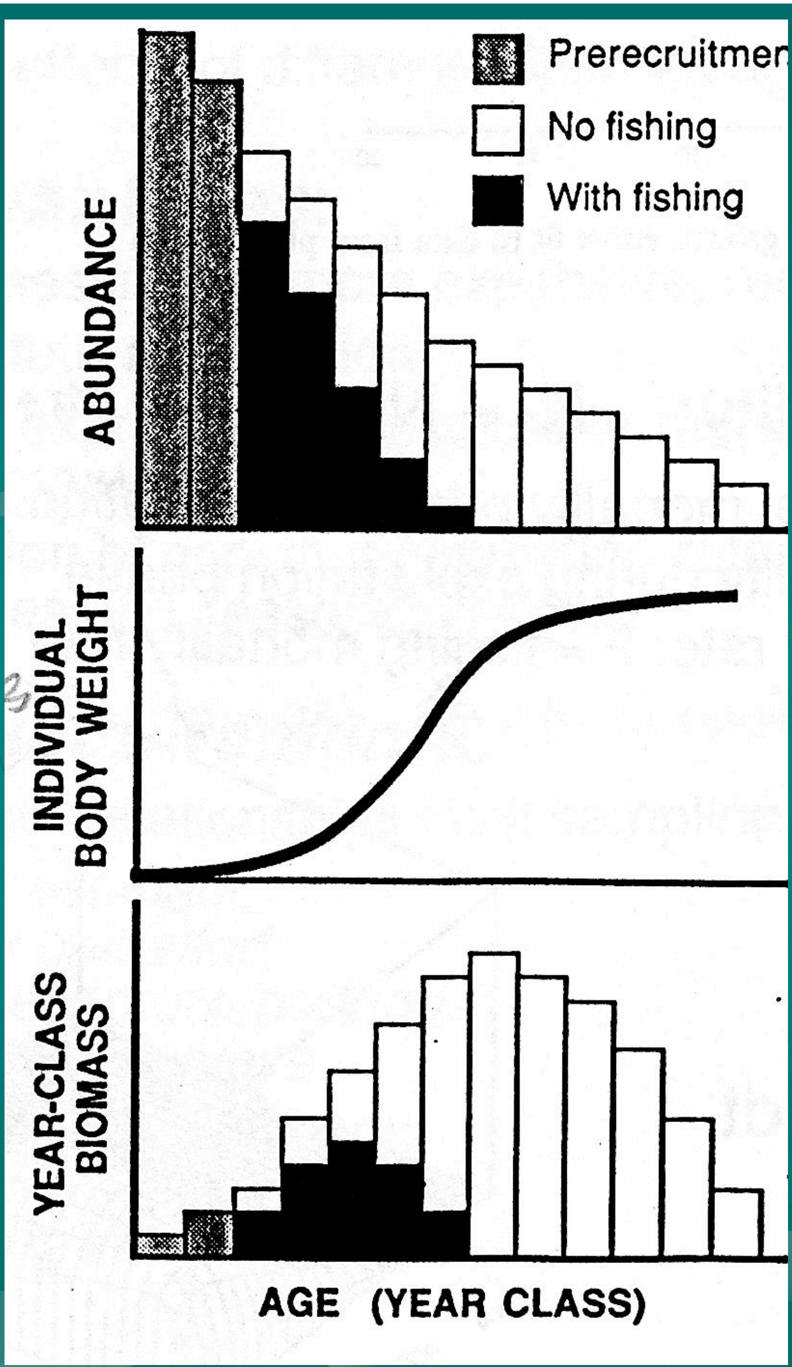
- Bailey, K.M., R.C.C Francis, P.R. Stevens. 1982. The life history and fishery of Pacific whiting, *Merluccius productus*. CalCOFI Rep. 23:81-98.
- Bone, Q., N.B. Marshall, J.H.S. Blaxter. 1995. Biology of Fishes. 2nd edition, Blackie Academic & Professional, London.
- Checkley, D.M., Jr., S. Raman, L. Maillet, K.M. Mason. 1988. Winter storm effects on the spawning and larval drift of a pelagic fish. Nature 335:346-348.
- Cowan, J.H., E.D. Houde, K.A. Rose. 1996. Size-dependent vulnerability of marine larvae to predation: an individual-based numerical experiment. ICES J. Mar. Sci 53:23-37.
- Cushing, D.H. 1975. Marine Ecology and Fisheries. Cambridge University Press, Cambridge.
- Fuiman, L.A. & R.G. Werner. 2002. Fishery Science: The unique contributions of early life stages. Blackwell Scence.
- Hjort, J. 1914. Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. *Rapports et Proces-Verbaux Des Reunions, Conseil International pour L'Exploration de la Mer* 20:1-228.
- Houde, E.D. 1987. Fish early life dynamics and recruitment variability. Amer. Fish. Soc. Symp. 2:17-29.
- Hunter, J.R. 1972. Swimming and feeding behavior of larval anchovy, *Engraulis mordax*. U.S. Fish. Bull. 70:821-838.
- Lasker, R. 1975. Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. U.S. Fish. Bull. 73:453-462.
- Lasker, R. 1978. The relation between oceanographic conditions and larval anchovy food in the California Current: identification of factors contributing to recruitment failure. Rapp. P.-v. Reun. Cons. int. Explor. Mer, 178.
- Paine, R.T. 1969. A note on trophic complexity and species diversity . American Naturalist 100:91-93.
- Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, F.C. Torres Jr. 1998. Fishing down marine food webs. Science 279:860-863.
- Pauly, D., J. Maclean. 2003. In a perfect ocean: The state of fisheries and ecosystems in the north Altantic Ocean. Island Press, Washington.
- Werner, E.E., J.F. Gilliam, D.J. Hall, G.G. Mittelback. 1983. An experimental test of the effect of predation risk on habitat use by fish. Ecology 64:1540-1548
- Other good refs:
  - Jennings, S., M.J. Kaiser, J.D. Reynolds. 2001. Marine Fisheries Ecology. Blackwell Publishing.
  - Iversen, E.S. 1996. Living Marine Resources: Their utilization and management. Chapman & Hall.

Fisheries Oceanography: Fisheries Management

OCN 621

Fisheries as Predation

- From a fisherman's perspective, natural mortality is "wasted."
- Fisheries compete with natural losses by catching fish before they are eaten or die of old age.
- Fishing changes the size and age structure of the stocks, thereby reducing the "resiliency" of stock to environmental fluctuations.



Fisheries Management Approaches

- Goals to Balance:
  - Socio-economic -- maximize "benefit" to society, i.e., optimize physical yield without jeopardizing ability of stock to reproduce
  - Biological -- protect genetic diversity, population integrity, habitat
  - Economic -- optimize economic gain; efficiency

Theory of Fisheries Management

- Unfished, “virgin” stock

Growth → Stock
Recruitment → Stock
Stock → Natural Mortality

- Fished stock

Growth → Stock
Recruitment → Stock
Stock → Natural Mortality
Stock → Fishing Mortality

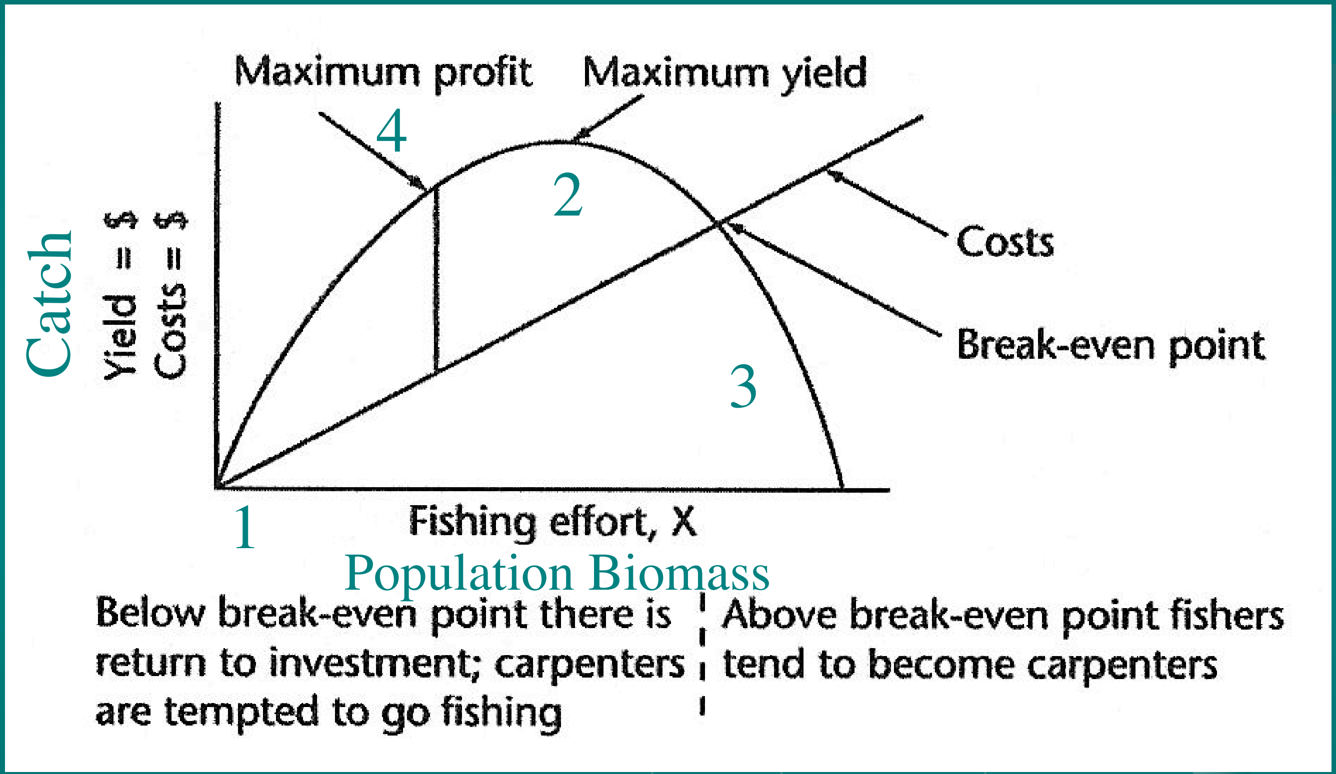
Compensating mechanisms for Fishing Mortality leading to lower Natural Mortality (Density-dependence):

-- growth increases (less competition for resources)

-- recruitment increases (less competition, more survivorship, less predation)

What is a suitable (sustainable) amount of Fishing Mortality?

MSY = Maximum Sustainable Yield



Zone 1: under-fished (catch good, cost low, profits high)
Zone 2: MSY (catch more, costs more, profit good)
Zone 3: over-fished (catch less, costs high, profit negative)
Zone 4: optimum yield (catch vs. cost best, max. profit)

CPUE

Catch Per Unit Effort

- Catch/Fishing Effort: really the only relationship we know well
- If this ratio is declining, we are over-fishing
- World CPUE in decline since 1980s
- Estimate that 45% of fisheries over-fished at present

CPUE

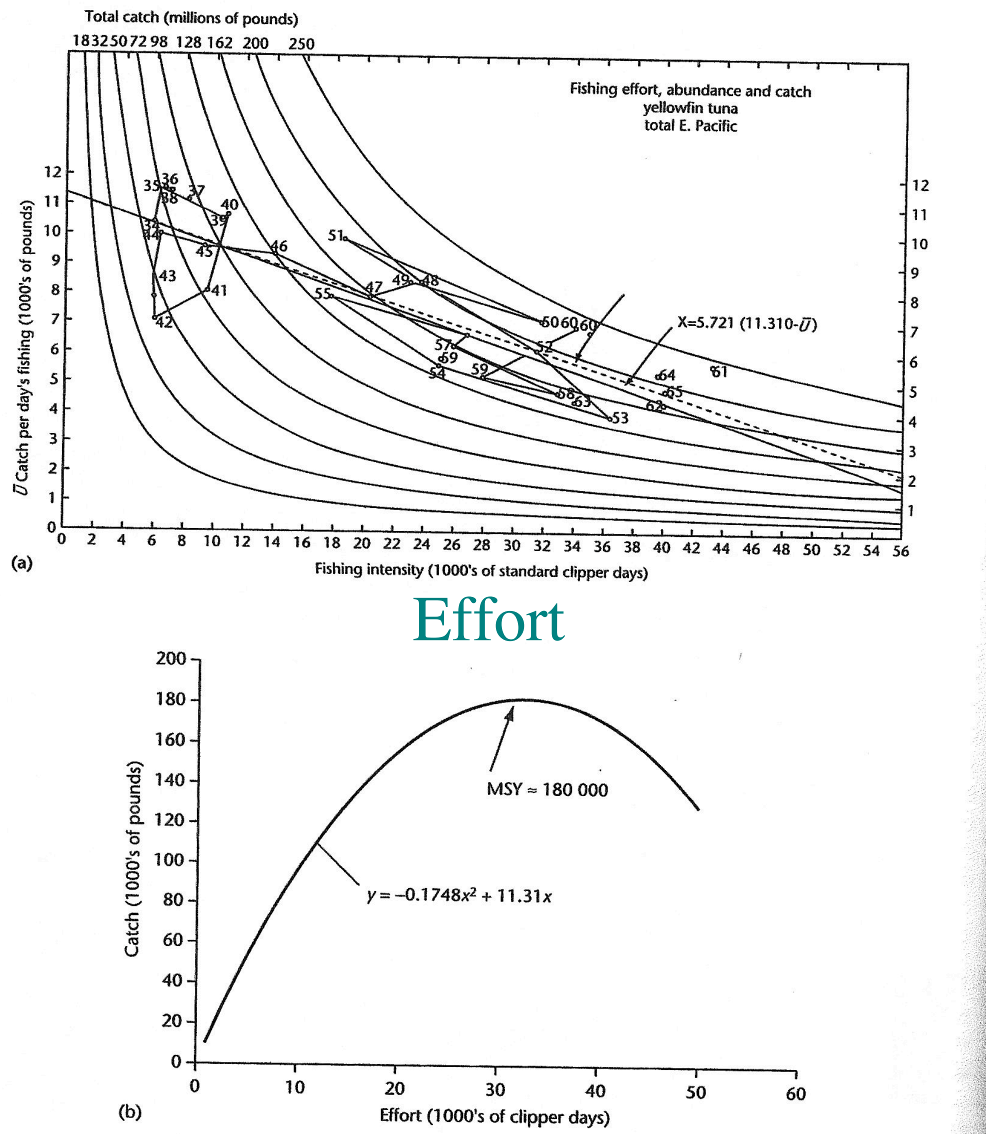


Fig. 15.7 (a) CPUE (catch per unit effort) for yellowfin tuna in the eastern tropical Pacific, 1934–1965. (b) Line in (a) converted to show catch vs. effort, a parabola. (a,b after Schaefer 1967.)

Miller 2004

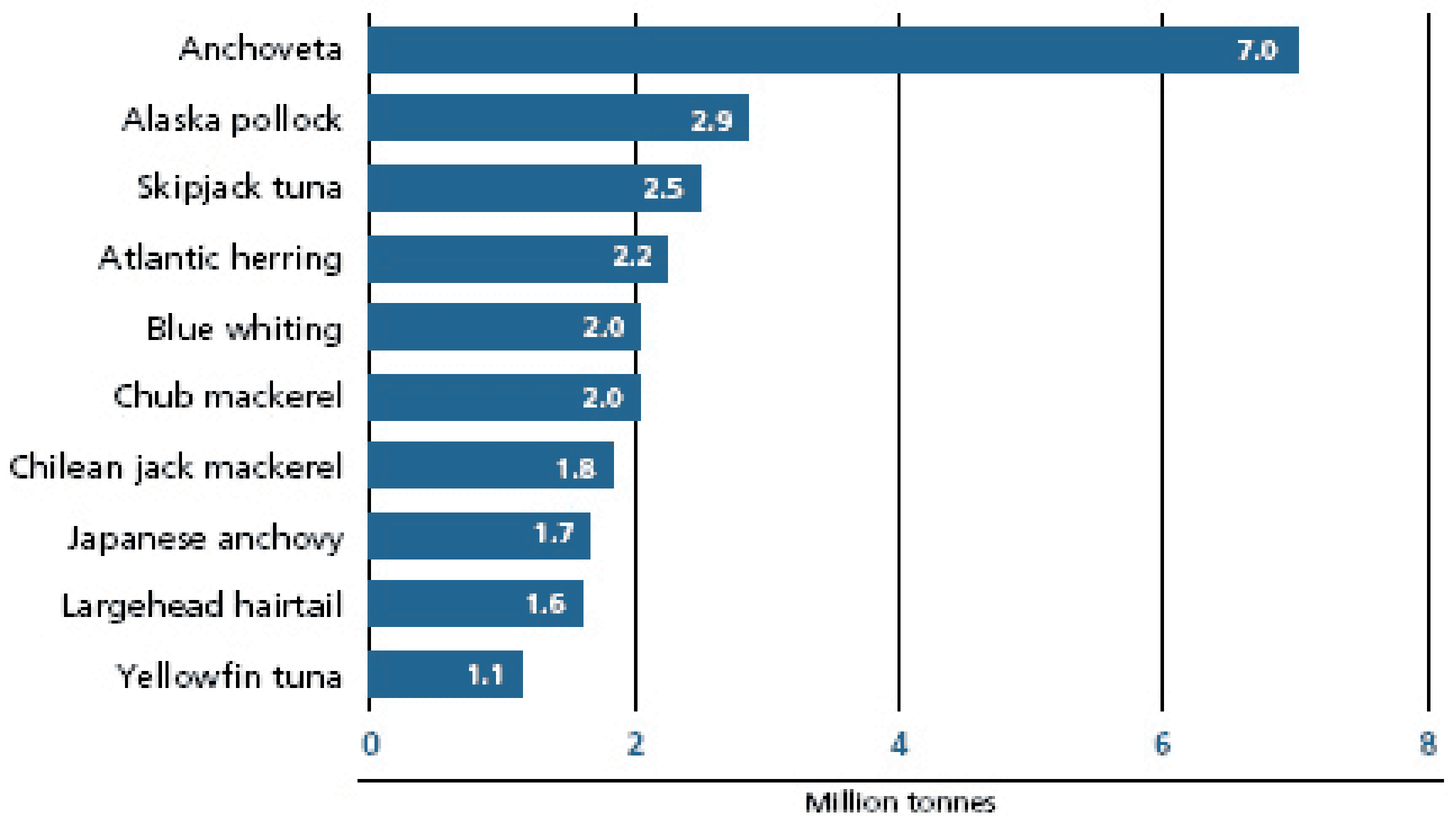
Single Species Management

Usual method, but, too narrowly focused, as fishing for one species can affect other exploited fish

- Discards/bycatch usually discarded dead
  - dead mammals, reptiles, etc. in gill nets
  - example: Shrimp trawling: 125 - 830% by catch excess over shrimp and bycatch is snapper

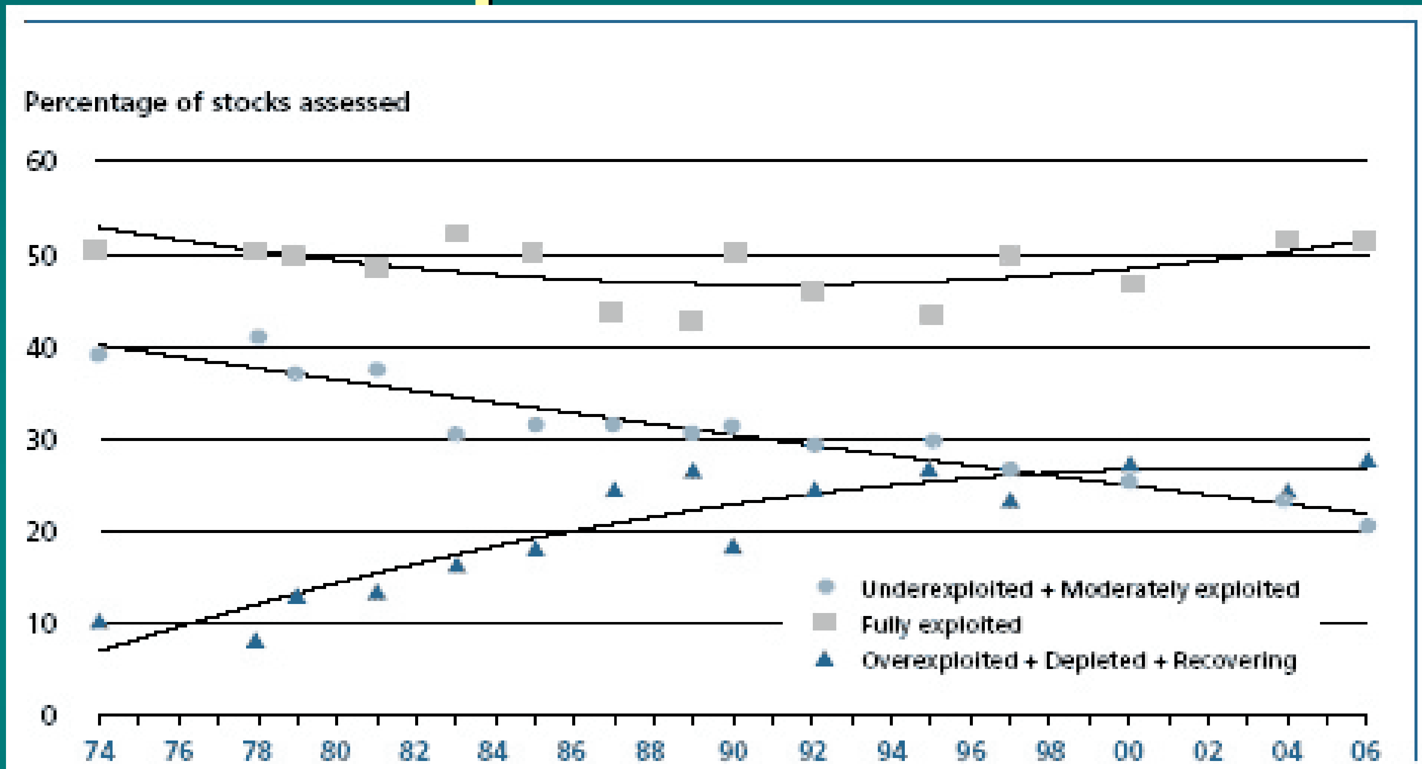
NOAA Photo library

Top 10 Fish of 2006 (30% of fisheries production)



Source: FAO Fisheries ***– The State of World Fisheries and Aquaculture, 2008 PART 1:World review of fisheries and aquaculture, p. 12***

Current state of world fisheries production



Source: FAO Fisheries ***– The State of World Fisheries and Aquaculture, 2008***
PART 1:World review of fisheries and aquaculture, p. 33

~50% of world stocks fully exploited
Previously over-exploited, depleted or recovering stocks have been stable for 10-15 years

Commercially harvested marine fish

- Anchovy, herring and sardines: all small pelagic fish, represent by far the largest fisheries in the world
- Live in highly productive areas (upwelling regions & off Japan & Argentina)
- Unstable populations (time scale of 10 - 30 yrs)

Unstable populations: collapse of fisheries is a function of over-fishing & natural environmental change

Peruvian anchoveta: #1
Engraulis ringens

- Vital statistics
  - Max size: 20 cm
  - Max reported age: 3 years; time to maturity: 1 year
  - Depth range found: 3 - 80 m
  - Distribution
  - Ecosystem role: eats phytoplankton & zooplankton, preyed upon by man and seabirds
  - Spawn near shore; Behavior enabling high success of fishery? Schooling

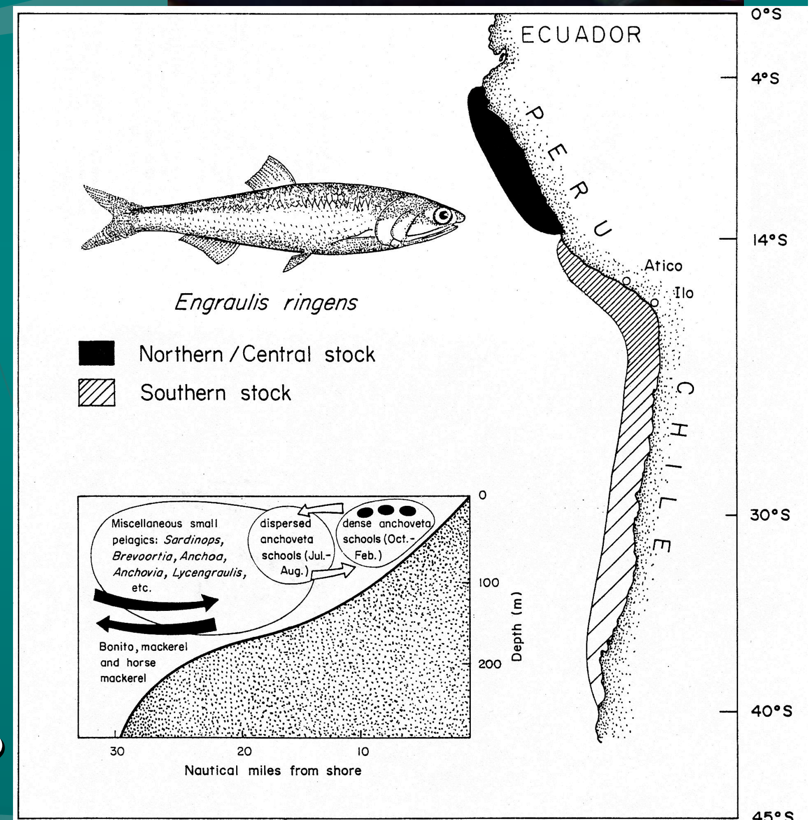


Fig. 1. Distribution of anchoveta stocks along the Eastern Coast of South America. Based on FAO (1981), Jordan (1971), Chirichigno (1974), Brandhorst (1963) and IMARPE (1973).

History

mid-1950 Fishery begins and rapidly expands (fish meal for livestock)

1964 Catch = 8.7 MMT (17% of world catch); Schaefer (FAO study) estimates MSY at 9.5 MMT, but guano birds and other predators took 2 MMT leaving 7.5 MMT for man

1965 El Nino - low reproductive success, schools dispersed, bird predators gone (Cormorants)

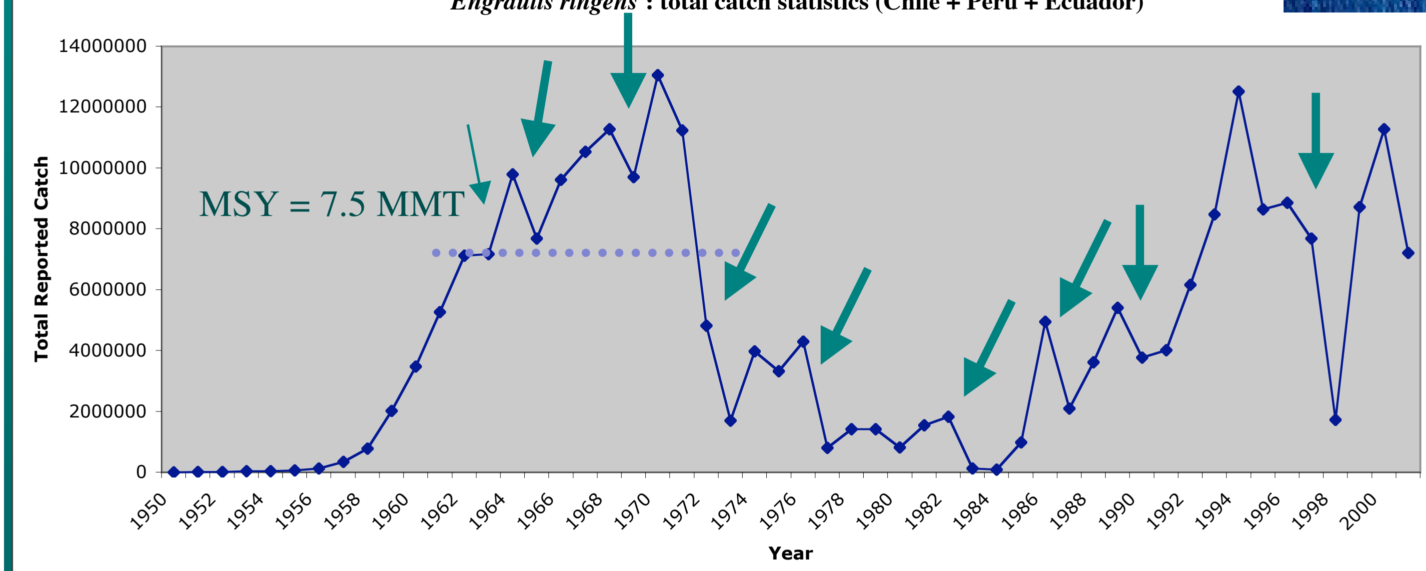
1970 Harvest 12.5 MMT; 50% greater than MSY; fishing efficient, ~95% of fish caught before reaching reproductive age (*overcapitalization*)

1971-2 Bad recruitment years (El Nino, too): collapse of fishery

1986-96 Recovery

1997-98 El Nino collapse, recovering now

2004: 10.7 MMT (FAO)



Arrows = El Niño years

Overcapitalization

- When fishing is good, more boats are built, people employed
- When yield declines, it is hard to cut back
- Subsidies are paid to fisherman
- Fishing continues, even though not commercially viable
- Exacerbates over-fishing problems, but not a surprising consequence of economic pressures

http://www.nationmaster.com

Map & Graph: Economy: Top 10 Fishing subsidies

Scroll down for more information

Show map full screen

	Country	Description
1.	Japan	$2935.30 million (1997)
2.	United States	$867.90 million (1997)
3.	Canada	$768.55 million (1997)
4.	Russia	$633.00 million (1997)
5.	Korea, South	$346.70 million (1997)
6.	Indonesia	$254.40 million (1997)
7.	Spain	$170.45 million (1997)
8.	Norway	$160.40 million (1997)
9.	France	$108.00 million (1997)
10.	United Kingdom	$99.03 million (1997)
	Weighted Average	$803.99 million million

Definition: Subsidies to the commecial fishing sector
Units: US Dollars (Millions)
Units: Data on itemized fishing subsidies were combined from Annex 1 of the WWF report. Where estimated rangeswere given, the mid-point of the range was used. In calculating the ESI, the base-10 logarithm of this variablewas used.

Source: World Wildlife Fund (WWF-US). Hard Facts, Hidden Problems: A Review of Current Data on FishingSubsidies, A WWF Technical Paper, October 2001, Annex 1. via ciesin.org

Peruvian Anchovy

- Effects of El Niño
  - anchovy feeds on phytoplankton/zooplankton
  - during El Nino, no upwelling, fewer phytoplankton, fewer zooplankton, fewer fish
- Other ecosystem effects of fishing
  - Depleting anchovy stocks results in reduced populations of fish-eating sea birds

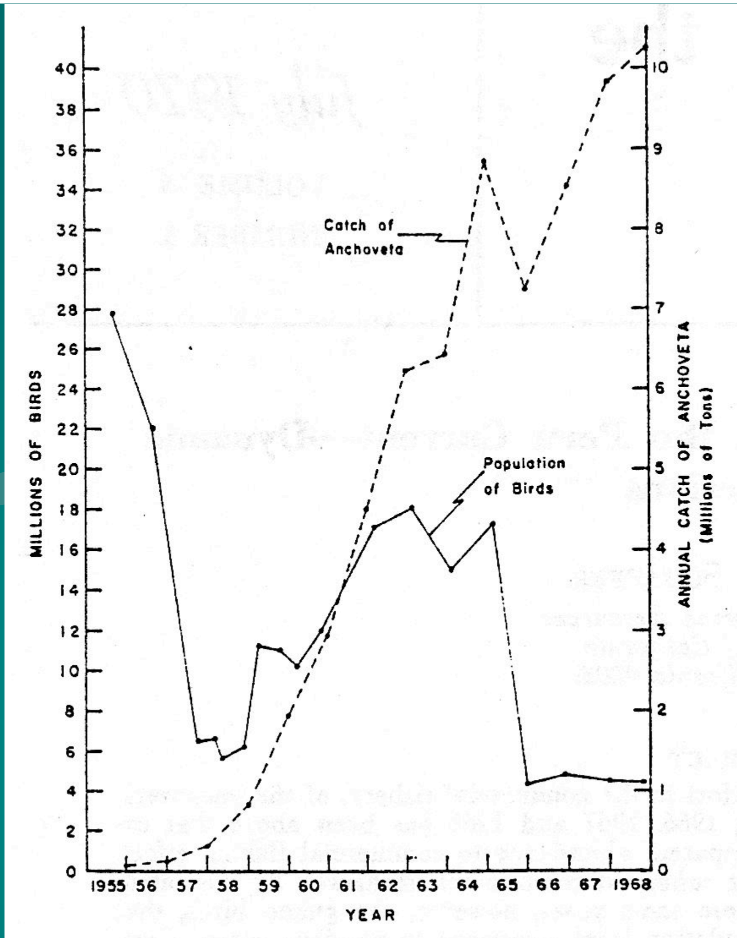


FIGURE 1.—Commercial catch of anchoveta by calendar years, and population of guano birds from censuses at indicated dates.

Schaefer 1970

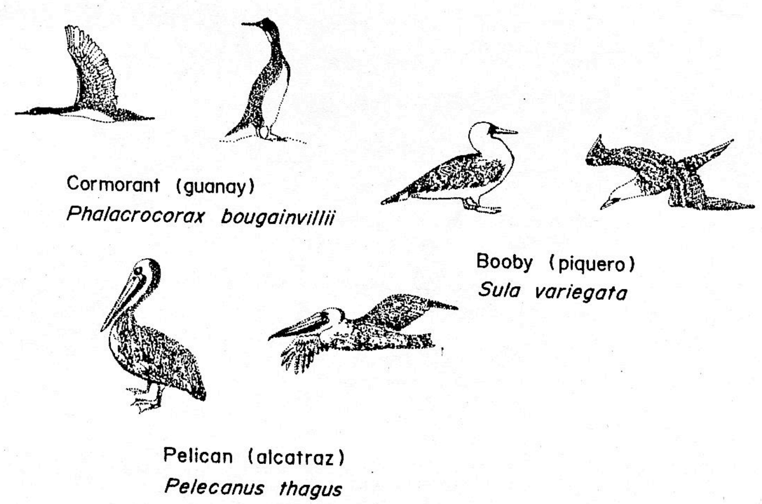
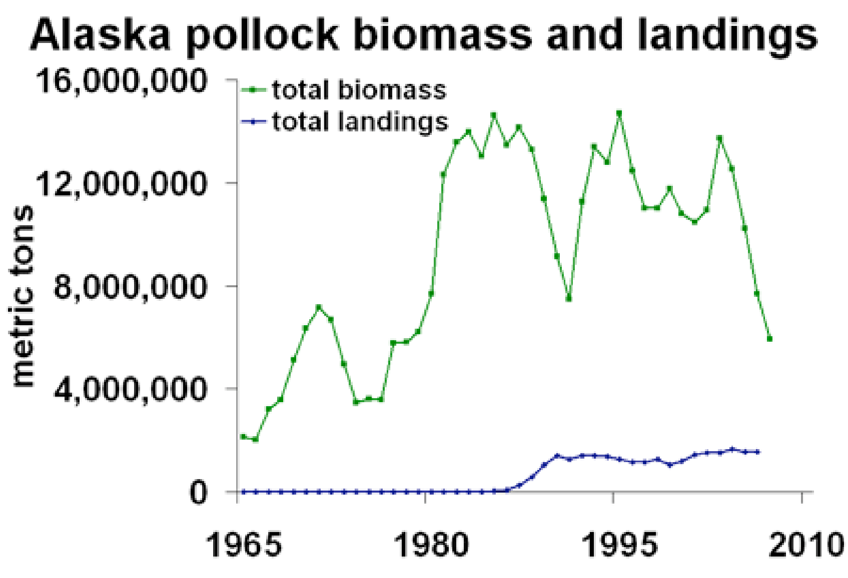
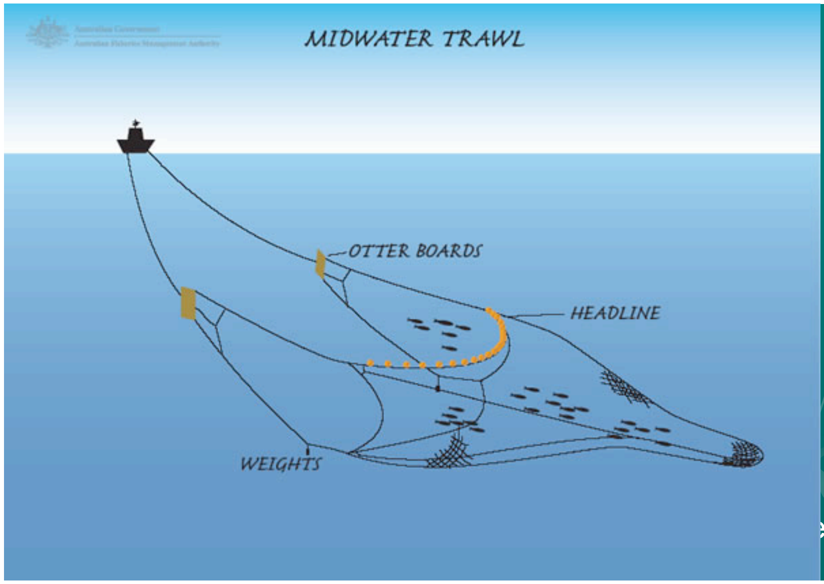


Fig. 1. The three main species of fish-eating birds of the Peruvian upwelling ecosystem (Spanish names in brackets).

Alaska Pollock
Theragra chalcogramma



- max size/age: 91 cm, 15 years, age at 1st maturity: 3 - 5.5 yr
- benthopelagic, brackish/marine waters, usually found from ~300 - 1000 m depth
- DVM, feeds on fish and crustaceans (esp. krill), TL = 2.8+
- Prey for Stellar Sea Lion (Alaska) & other marine mammals, seabirds, bigger fish
- Well managed fishery, use midwater trawl nets with little by-catch



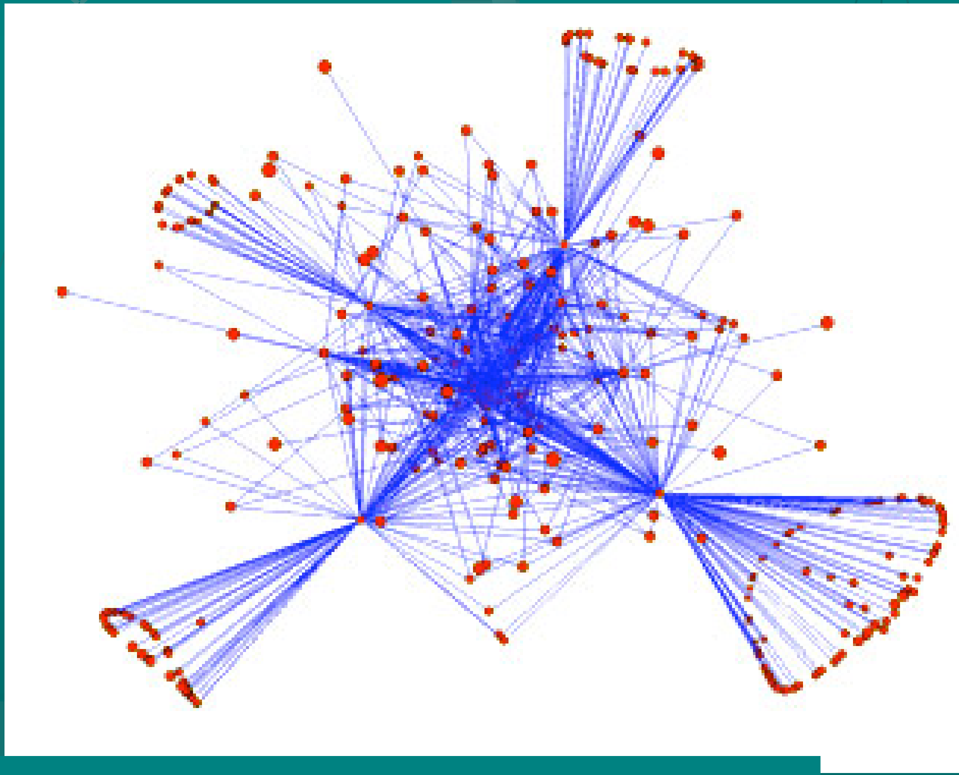
Alaska Pollock Fishery

- Currently well managed, but not managed as a multispecies fishery
- Efforts are going into ecosystem modelling, including physical forcing, to better predict all fisheries in region

<u>GOA Ecosystem</u>

Each species is a node (dots) and each predator-prey interaction is a link (line).

Four hubs are cod, pollock, halibut and arrowtooth flounder.

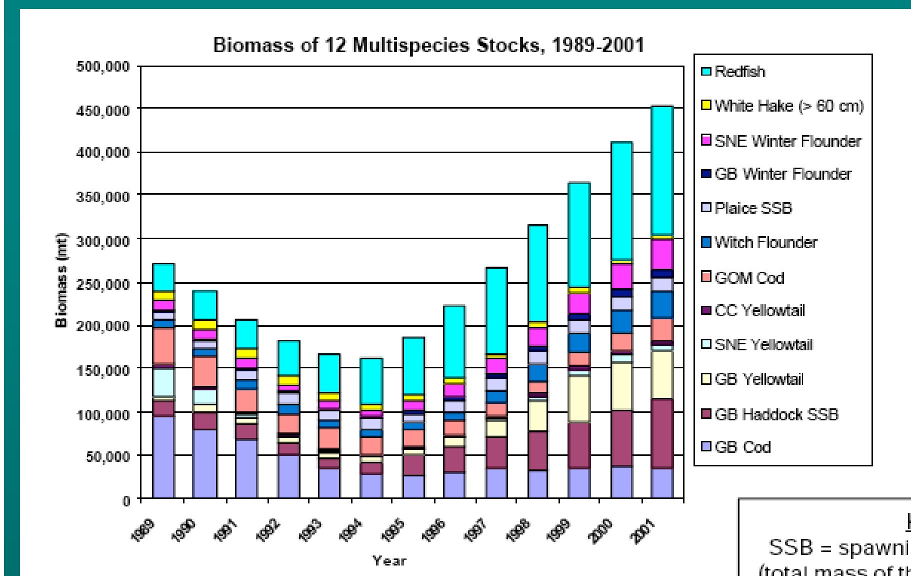


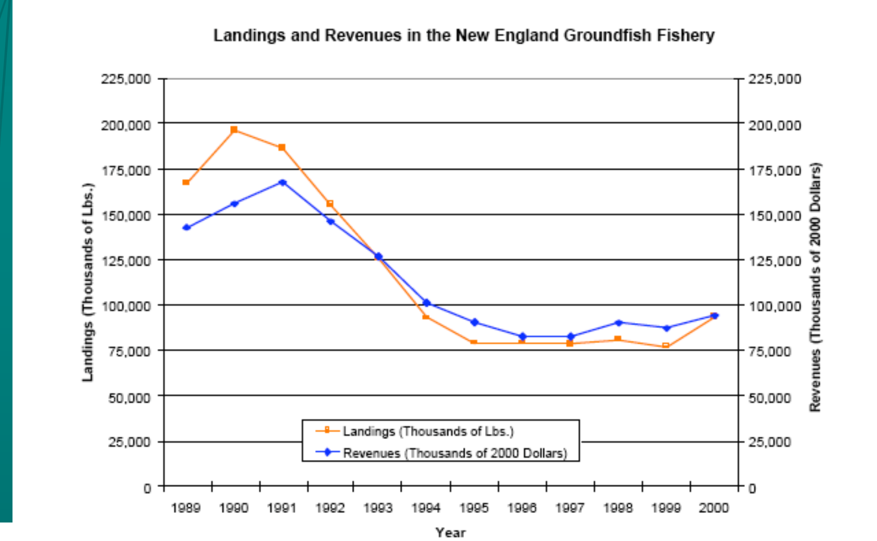
S. Gaichas, NOAA, www.afsc.noaa.gov

Multispecies Management

Example: New England Groundfish Fisheries

- 15 species managed
- implemented in 1986, but did not include catch or fishing effort restrictions
- 1994: Amended management plan to address these problems





Key:
SSB = spawning stock biomass (total mass of the stock capable of spawning)
GB = Georges Bank
GOM = Gulf of Maine
SNE = Southern New England
CC = Cape Cod

www.nefmc.org

Application to Anchovy Fishery

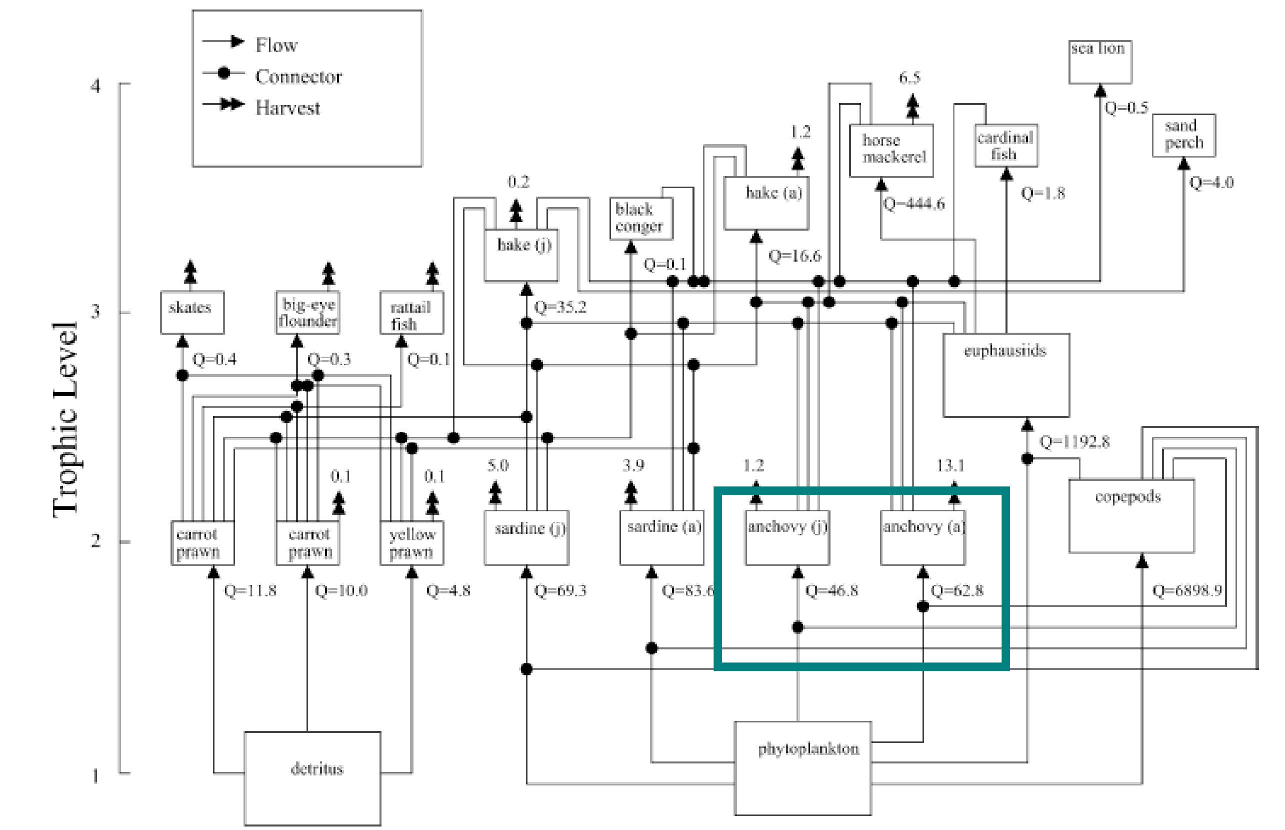
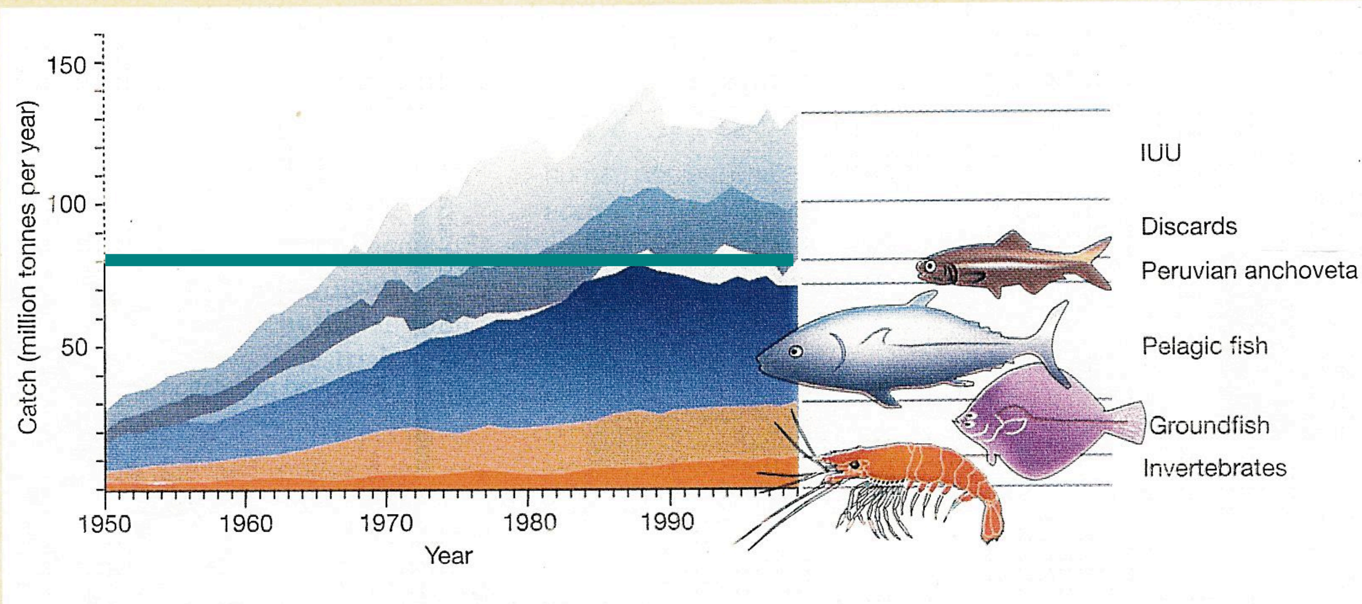


Fig. 4. Flow diagram of the Central Chile marine ecosystem (33°–39°S), 1992. Q: consumption. Flows are expressed in t km^{-2} per year.

Niera et al. 2004. Comparative analysis of trophic structure of commercial fishery species off Central Chile in 1992 and 1998. Ecol. Model. 172:233-248

Global Fish Catch

Figure 1 Estimated global fish landings 1950–1999. Figures for invertebrates, groundfish, pelagic fish and Peruvian anchoveta are from FAO catch statistics, with adjustment for over-reporting from China[26]. Fish caught but then discarded were not included in the FAO landings; data relate to the early 1990s[83] were made proportional to the FAO landings for other periods. Other illegal, unreported or unregulated (IUU) catches[65] were estimated by identifying, for each 5-year block, the dominant jurisdiction and gear use (and hence incentive for IUU)[84]; reported catches were then raised by the percentage of IUU in major fisheries for each 5-year block. The resulting estimates of IUU are very tentative (note dotted *y*-axis), and we consider that complementing landings statistics with more reliable estimates of discards and IUU is crucial for a transition to ecosystem-based management.



Pauly et al. 2002

Global Catch

"Corrected" global catch: ~80 MMT

How do they gather the data?

Individual countries tell the FAO how much was caught by their fishermen

Usual Problem: under-reporting

Apparent Problem with China: over-reporting

Particularly misleading for overall picture of fisheries health, as China's catch is a high proportion of the total world catch

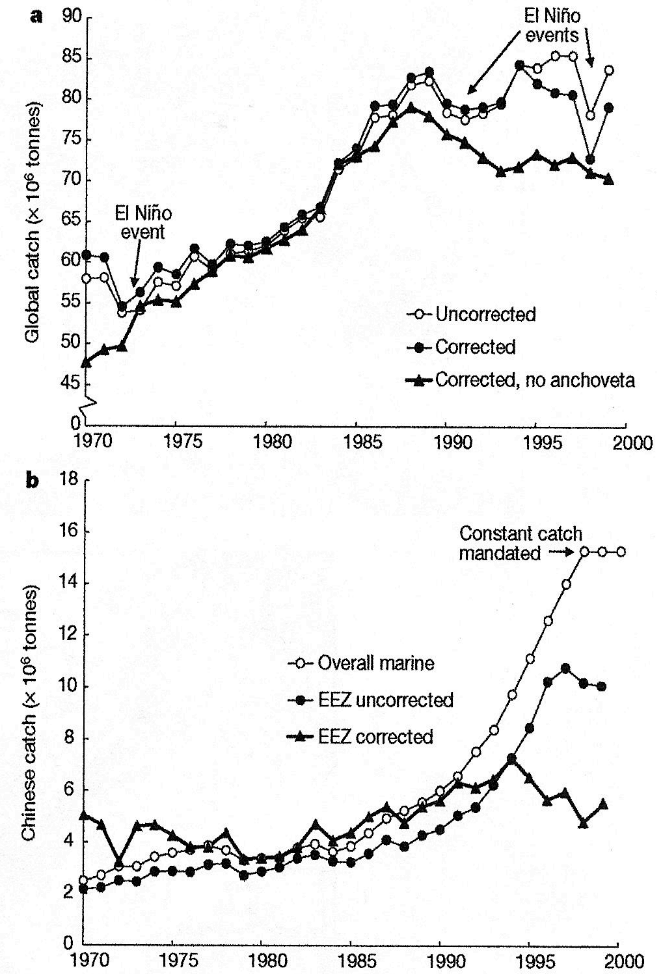


Figure 1 Time series of global and Chinese marine fisheries catches (1950 to present). **a**, Global reported catch, with and without the highly variable Peruvian anchoveta. Uncorrected figures are from FAO (ref. 3); corrected values were obtained by replacing FAO figures by estimates from **b**. The response to the 1982–83 El Niño/Southern Oscillation (ENSO) is not visible as anchoveta biomass levels, and hence catches were still very low from the effect of the previous ENSO in 1972 (ref. 4). **b**, Reported Chinese catches (from China's exclusive economic zone (EEZ) and distant water fisheries) increased exponentially from the mid-1980s to 1998, when the 'zero-growth policy' was introduced. The corrected values for the Chinese EEZ were estimated from the general linear model described in the Methods section.

Watson & Pauly 2001

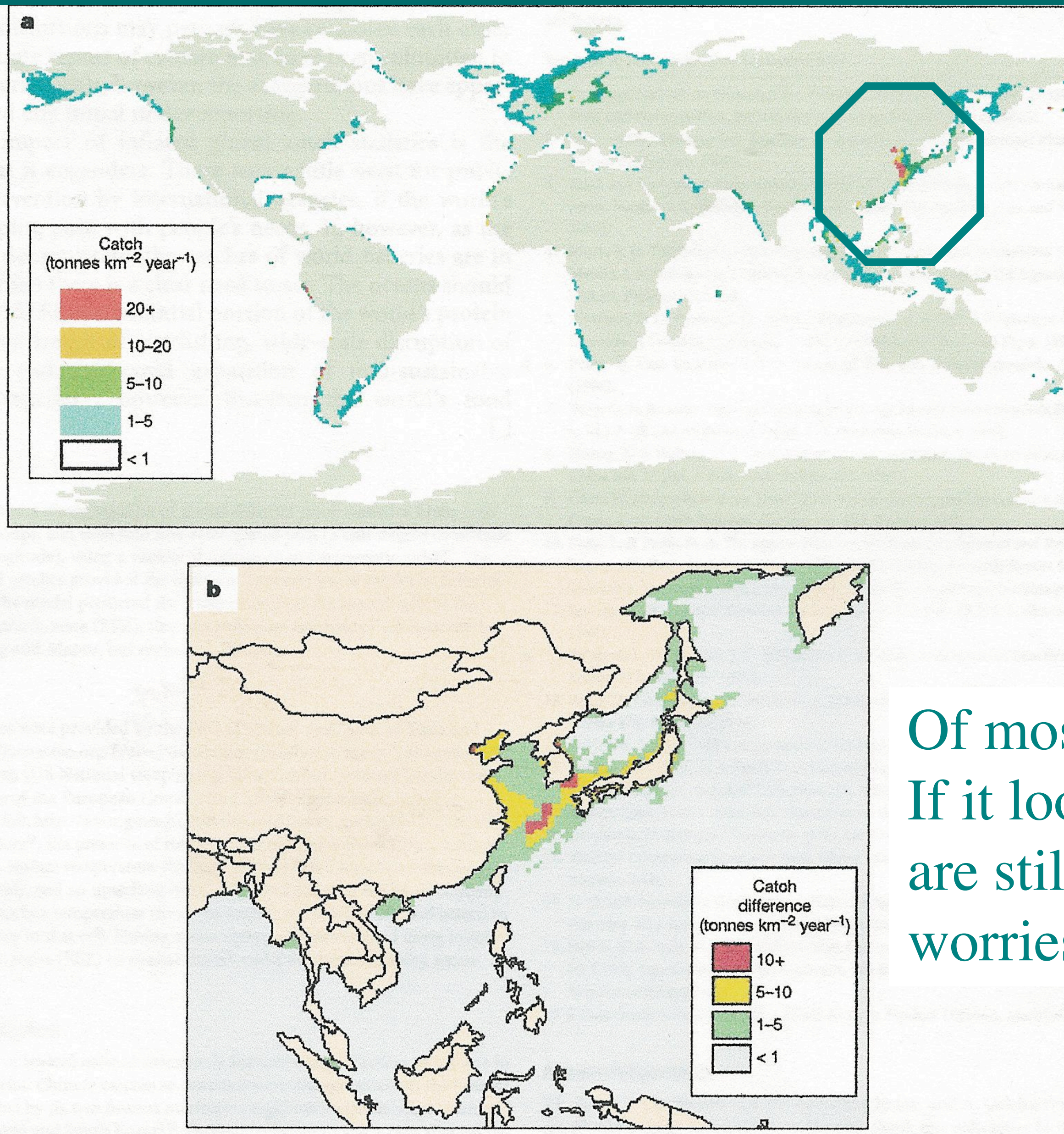
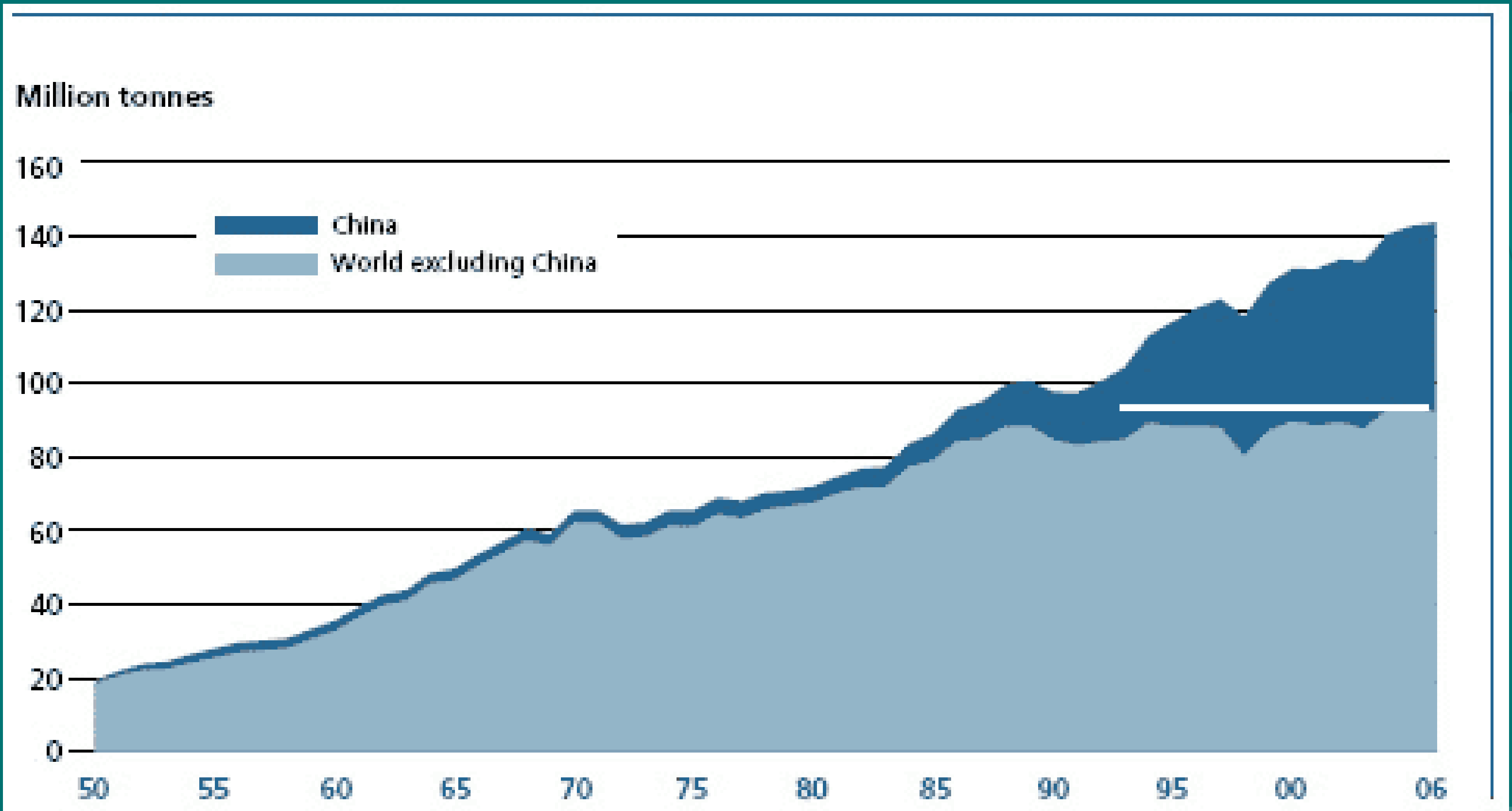


Figure 2 Maps used to correct Chinese marine fisheries catch in Fig. 1b. **a**, Map of global catches reported by FAO for 1998, generated by the rule-based algorithm described in the Methods section. We note the anomalously high values along the Chinese coast, comparable in intensity (not area covered) to the extremely productive Peruvian upwelling system. **b**, Map of differences in southeast and northeast Asia between the catches reported in **a** and those predicted by the model described in the Methods section.

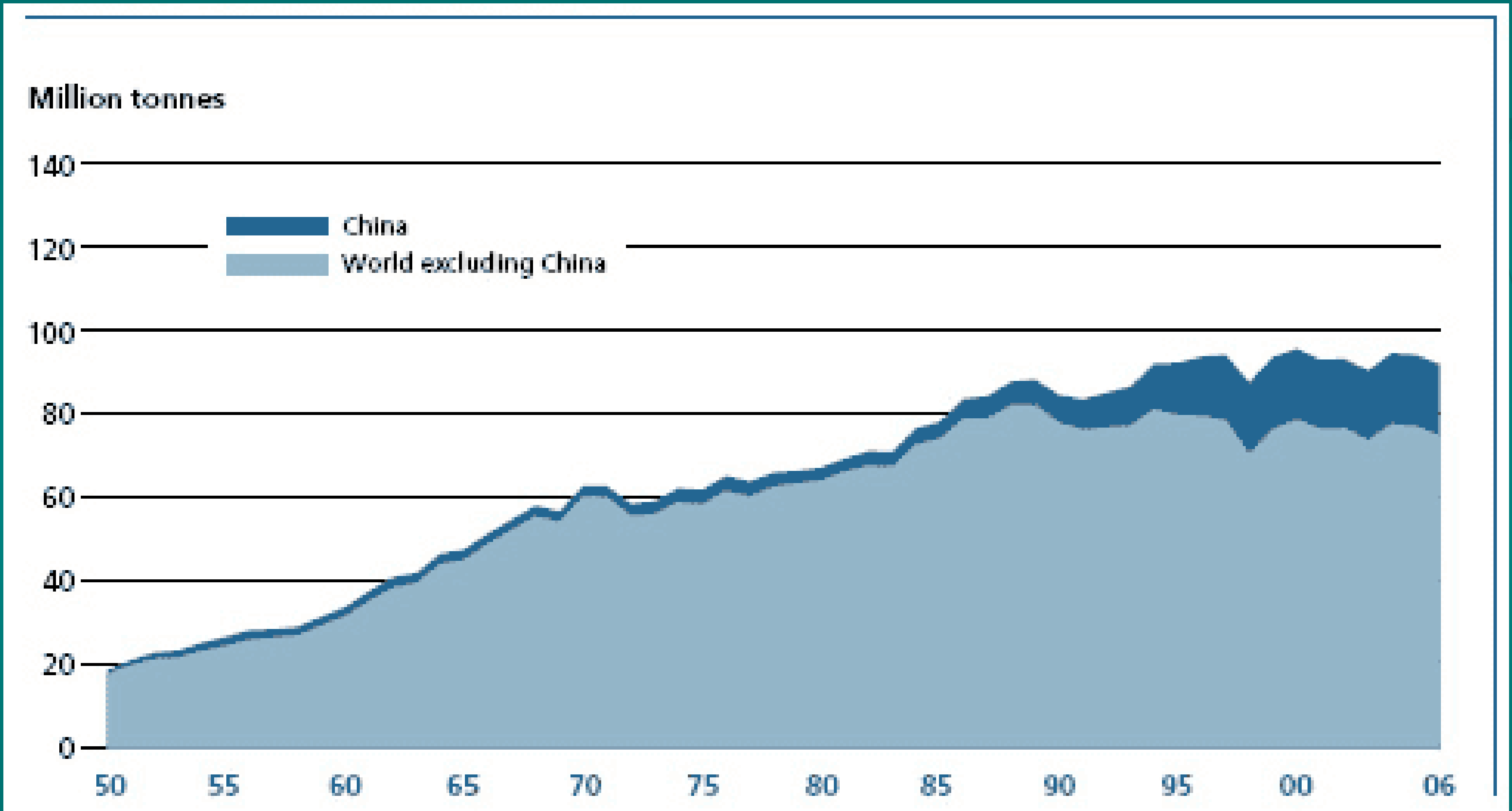
Of most concern:
If it looks like catches are still rising, no one worries...

Most recent data (released March 2, 2009): World Capture and Aquaculture Production



Source: [FAO Fisheries](#) ***– The State of World Fisheries and Aquaculture, 2008 PART 1:World review of fisheries and aquaculture, p. 4***

World Capture Fisheries Production



Source: FAO Fisheries ***– The State of World Fisheries and Aquaculture, 2008 PART 1:World review of fisheries and aquaculture, p. 6***

Global MSY

- Best estimate for global MSY = 100 - 135 MMT (all species, all oceans)
- Most recent compilation of world fisheries:

92 MMT (Present Harvest)

+ Discards (by-catch), ~30% of total catch

+ IUU (Illegal, unreported or unregulated catch),

All together, ~130 MMT

  - So, Global MSY reached already

Aquacultured Fish on the rise, however...

- Because top, or higher, trophic levels vanishing due to over-fishing, fishermen are exploiting lower trophic levels

- Note that dip in marine curve in 60's was due to extremely large catches of Peruvian anchovetta with low trophic level of 2.2 (TL = 2 is that of primary herbivores)

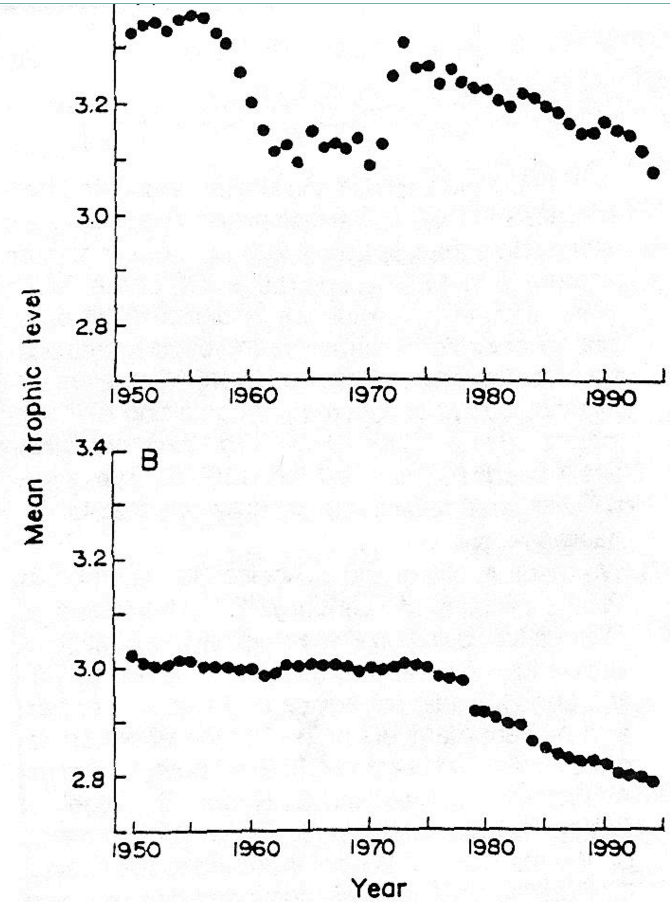


Fig. 1. Global trends of mean trophic level of fisheries landings, 1950 to 1994. (**A**) Marine areas; (**B**) inland areas.

1998

Fishing Down Marine Food Webs

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The mean trophic level of the species groups reported in Food and Agricultural Organization global fisheries statistics declined from 1950 to 1994. This reflects a gradual transition in landings from long-lived, high trophic level, piscivorous bottom fish toward short-lived, low trophic level invertebrates and planktivorous pelagic fish. This effect, also found to be occurring in inland fisheries, is most pronounced in the Northern Hemisphere. Fishing down food webs (that is, at lower trophic levels) leads at first to increasing catches, then to a phase transition associated with stagnating or declining catches. These results indicate that present exploitation patterns are unsustainable.

Fishing down the food web

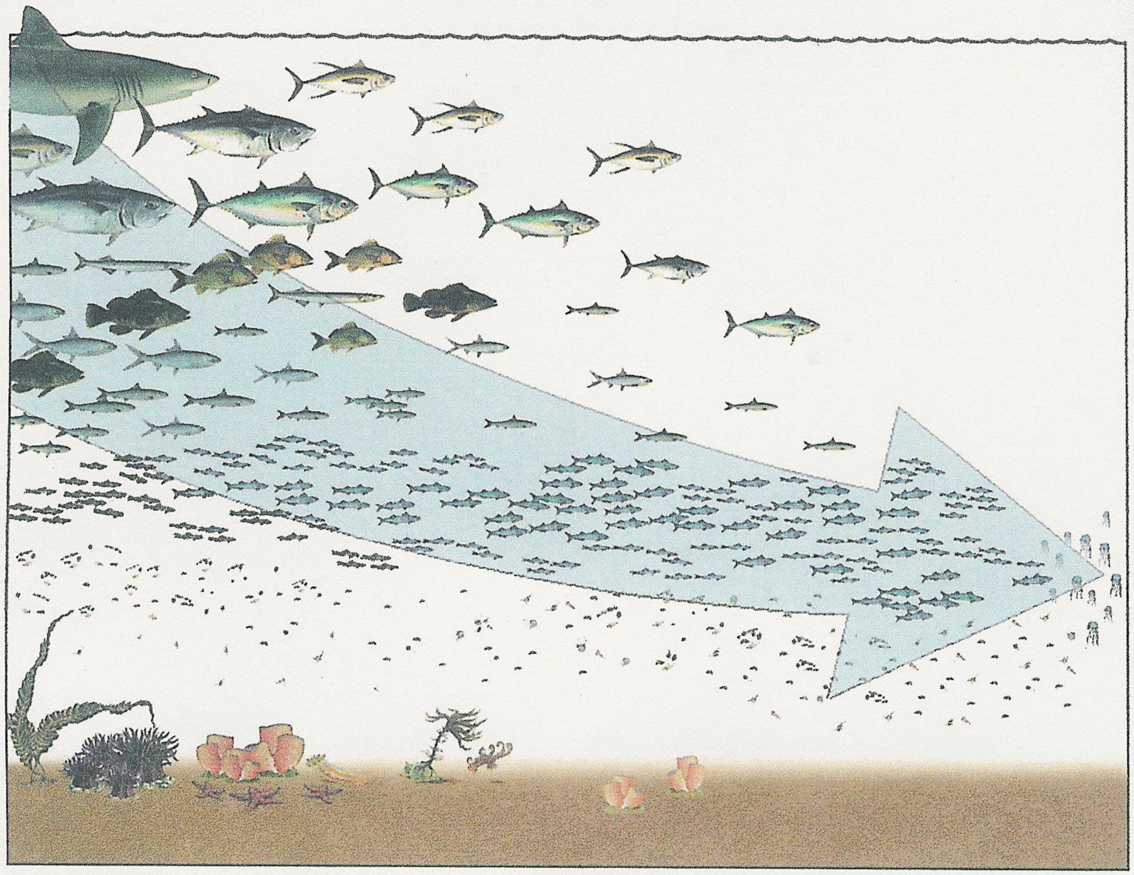


FIGURE 17. FISHING DOWN: WHAT IT ACTUALLY MEANS.
Fishing down marine food webs means that the fisheries (blue arrow), having at first removed the larger fishes at the top of various food chains, must target fishes lower and lower down, and end up targeting very small fishes and plankton, including jellyfish.

Pauly & Maclean 2003

One step in the right direction: Marine Protected Areas (MPA)

- Can "seed" fished areas
- Success dependant upon mobility of fish and size of MPA
- Wouldn't help wide-roaming fish like tuna or other pelagic fish, but would help coastal-based fisheries

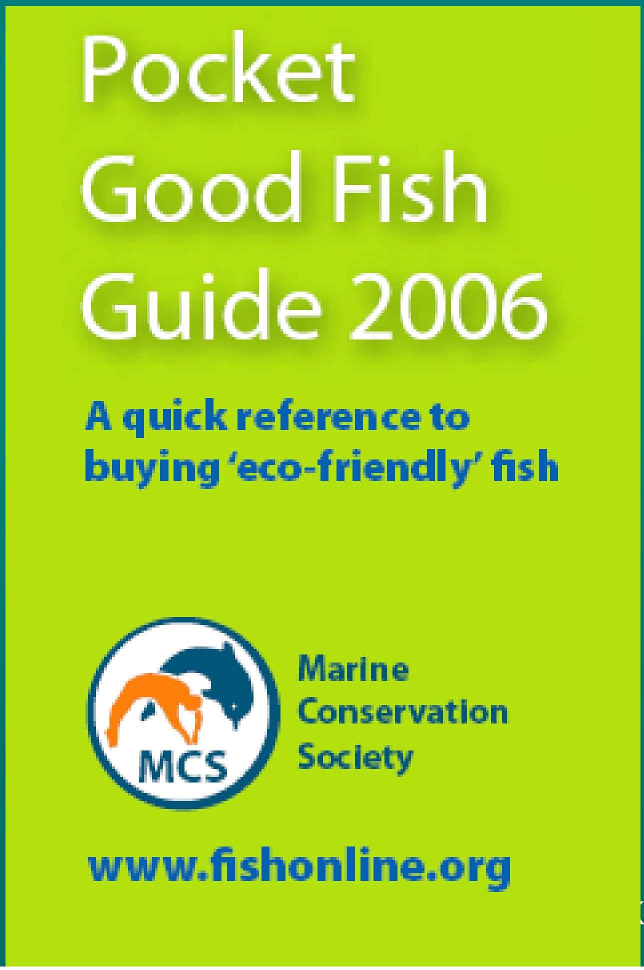
(unless they stop at "oases" in the open ocean and these are included)

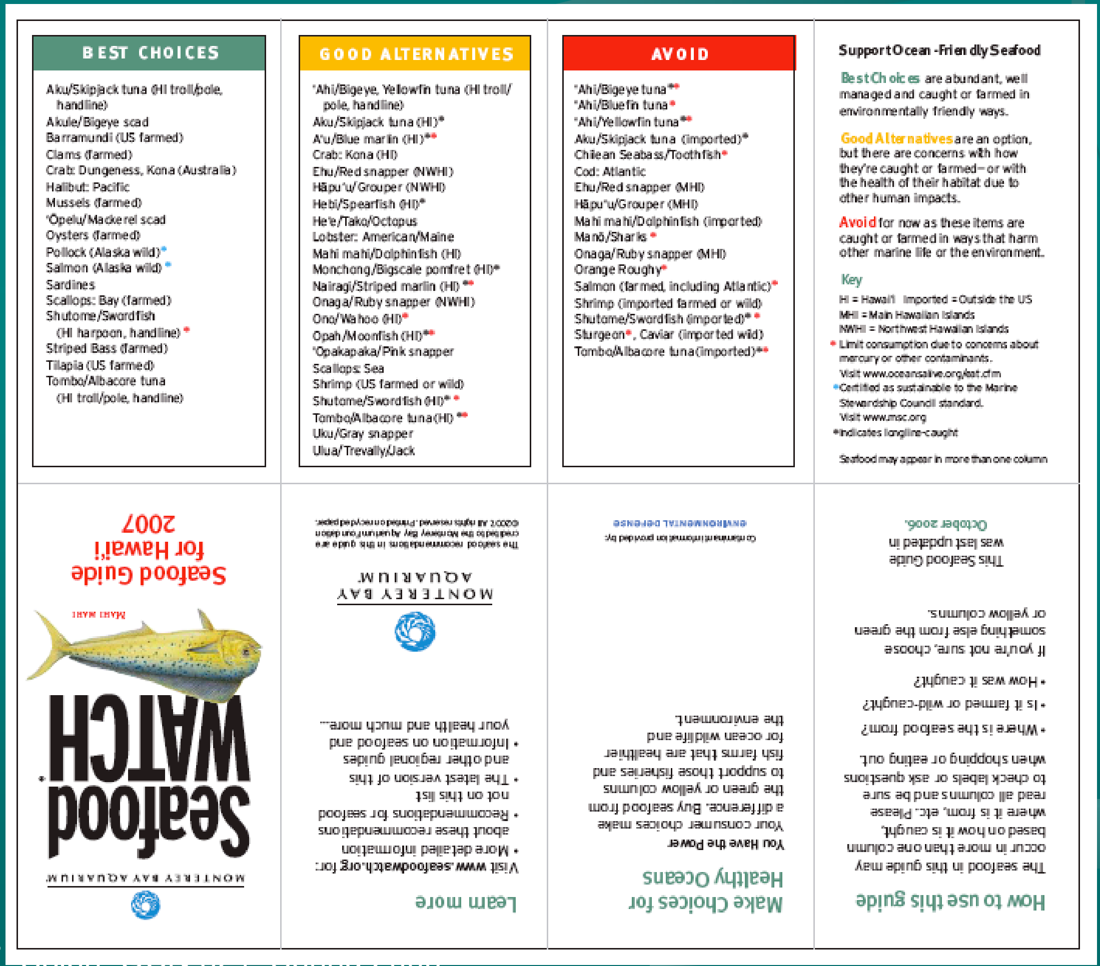
- Also preserves habitat in case of destructive fishing (i.e., trawling which destroys bottom populations)
- Currently , 1300 marine reserves globally, but only 0.01% of world's ocean areas are closed to fishing: need to have significantly more protection to make a global difference

http://www.fishbase.org

http://www.fishonline.org/

http://www.mbayaq.org/cr/cr_seafoodwatch





BEST CHOICES

Aku/Skipjack tuna (HI troll/pole, handline)
Akule/Bigeye scad
Barramundi (US farmed)
Clams (farmed)
Crab: Dungeness, Kona (Australia)
Halibut: Pacific
Mussels (farmed)
'Ōpelu/Mackerel scad
Oysters (farmed)
Pollock (Alaska wild)*
Salmon (Alaska wild) *
Sardines
Scallops: Bay (farmed)
Shutome/Swordfish (HI harpoon, handline) *
Striped Bass (farmed)
Tilapia (US farmed)
Tombo/Albacore tuna (HI troll/pole, handline)

GOOD ALTERNATIVES

'Ahi/Bigeye, Yellowfin tuna (HI troll/pole, handline)
Aku/Skipjack tuna (HI)*
A'u/Blue marlin (HI)**
Crab: Kona (HI)
Ehu/Red snapper (NWHI)
Hāpu'u/Grouper (NWHI)
Hebi/Spearfish (HI)*
He'e/Tako/Octopus
Lobster: American/Maine
Mahi mahi/Dolphinfish (HI)
Monchong/Bigscale pomfret (HI)*
Nairagi/Striped marlin (HI) **
Onaga/Ruby snapper (NWHI)
Ono/Wahoo (HI)*
Opah/Moonfish (HI)**
'Opakapaka/Pink snapper
Scallops: Sea
Shrimp (US farmed or wild)
Shutome/Swordfish (HI)* *
Tombo/Albacore tuna (HI) **
Uku/Gray snapper
Ulua/Trevally/Jack

AVOID

'Ahi/Bigeye tuna**
'Ahi/Bluefin tuna*
'Ahi/Yellowfin tuna**
Aku/Skipjack tuna (imported)*
Chilean Seabass/Toothfish*
Cod: Atlantic
Ehu/Red snapper (MHI)
Hāpu'u/Grouper (MHI)
Mahi mahi/Dolphinfish (imported)
Manō/Sharks *
Onaga/Ruby snapper (MHI)
Orange Roughy*
Salmon (farmed, including Atlantic)*
Shrimp (imported farmed or wild)
Shutome/Swordfish (imported)* *
Sturgeon*, Caviar (imported wild)
Tombo/Albacore tuna (imported)**

Support Ocean-Friendly Seafood

Best Choices are abundant, well managed and caught or farmed in environmentally friendly ways.

Good Alternatives are an option, but there are concerns with how they're caught or farmed—or with the health of their habitat due to other human impacts.

Avoid for now as these items are caught or farmed in ways that harm other marine life or the environment.

Key

HI = Hawai'i Imported = Outside the US
MHI = Main Hawaiian Islands
NWHI = Northwest Hawaiian Islands
* Limit consumption due to concerns about mercury or other contaminants. Visit www.oceansalive.org/eat.cfm
* Certified as sustainable to the Marine Stewardship Council standard. Visit www.msc.org
* Indicates longline-caught

Seafood may appear in more than one column