Recruitment Variability, cont’d:

H₀: 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>
<thead>
<tr>
<th>Condition</th>
<th>Initial number in cohort</th>
<th>Instantaneous mortality coefficient (d⁻¹)</th>
<th>Age at metamorphosis (d)</th>
<th>Number of recruits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>$1 \times 10^6$</td>
<td>0.100</td>
<td>45.0</td>
<td>11,109</td>
</tr>
<tr>
<td>Bad-1</td>
<td>$1 \times 10^6$</td>
<td>0.125</td>
<td>45.0</td>
<td>3,607</td>
</tr>
<tr>
<td>Bad-2</td>
<td>$1 \times 10^6$</td>
<td>0.100</td>
<td>56.2</td>
<td>3,625</td>
</tr>
<tr>
<td>Bad-3</td>
<td>$1 \times 10^6$</td>
<td>0.125</td>
<td>56.2</td>
<td>889</td>
</tr>
</tbody>
</table>

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.
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).
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
**H₀: 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).
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.

Fuiman & Werner 2002
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. 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 and metamorphoses in estuaries. 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

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

K.E. Selph, OCN 621, Spring 2008
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

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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\textsubscript{2} levels than fish - indication of eutrophication
Benguela Upwelling Zone - shift from fish to jellies

jellyfish biomass = 12.2 MT
fish biomass = 3.6 MT

mainly sardines/anchovies

K.E. Selph, OCN 621, Spring 2008

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

- Other good refs:

K.E. Selph, OCN 621, Spring 2008