“Using an Individual Based Model with four Trophic Levels to Model Fisheries Recruitment”

Fifth International Zooplankton Production Symposium
Pucón 14-18 March 2011

Matteo Sinerchia\textsuperscript{1,2}, Tony Field\textsuperscript{1}, John Woods\textsuperscript{1}, Silvana Vallerga\textsuperscript{1} and Wes Hinsley\textsuperscript{1}

\textsuperscript{1} Imperial College, London (UK)
\textsuperscript{2} Istituto per l’Ambiente Marino Costiero (IAMC-CNR), Oristano (IT)
Outline

• Background

• Scientific challenge

• Strategy

• Model description

• Results from numerical experiments
Background

- Semelparous
- Fast growing
- Opportunistic

- The abundance of cephalopods in some areas has apparently increased relative to fish
- Highly variable recruitment
Scientific challenge

- Make predictions on squid recruitment
  - Phenotypic equations from reproducible laboratory experiments under controlled conditions
    - Behaviour
    - Physiology

- Model more realistically predator prey interactions

- Testing theories about the relationship between recruitment and ecosystem
Research strategy

• Build a predictive ecosystem model based on the hard facts from marine biology
  – Lagrangian Ensemble Recruitment Model (LERM)

• Individual Based Model integrated by the Lagrangian Ensemble Metamodel (1D)

• Model food
Lagrangian Ensemble Recruitment Model
LERM

2 dissolved nutrients (N):
  Nitrogen
  Silicate

1 explicit diatom species (P)
1 explicit copepod species (Z)
1 explicit squid paralarvae species (S)
1 parametrised predator feeding on copepods (BP)
1 parametrised top predator feeding on squid (VP)

Droop pools
N,(Si), C
protein
lipid
Lagrangian Ensemble Recruitment Model (LERM)

- **Diatom**
  - Based on a midsize diatom (cross-section diameter 20µm)
  - Photoadaptation
  - Cell division (C and Si)

- **Copepod**
  - Based on Carlotti and Wolf, 1998 model for *Calanus finmarchicus*.
  - Staged growth
  - Diel migration
  - Ingestion based on gut volume, digestion, gut passage time and assimilation
  - Dynamic allocation of C to protein and lipid

- **Squid**
  - Based on the physiology and behaviour of *Loligo*
  - Temperature dependent embryogenesis
  - Endogenous and exogenous feeding
  - Ingestion based on gut volume, digestion and assimilation
  - Dynamic allocation of C to protein and lipid
  - A squid recruits when it reaches 8mm in mantle length

- **Top predators**
  - Demography is set in the scenario using a series of exogenous equations
    - Abundance, size and vertical distribution
  - Trophic interaction is expressed by ingestion equations based on squid
Experiments

Experiments set at Azores site (41°N, 27°W)
- Annual surface heat budget is in balance (i.e. solar heating equals cooling to the atmosphere)
Stability – Convergence to a stable attractor

• The ecosystem is allowed to adjust to its attractor for 15 years:
  – Stationary annual cycle of external forcing (Bunker climatology)
  – Nutrients (NOAA Ocean Atlas)

→ Virtual ecosystem follows a stationary annual cycle
Stability – Convergence to a stable attractor
Stability – Convergence to a stable attractor
Stability – Convergence to a stable attractor

- The ecosystem is allowed to adjust to its attractor for 15 years:
  - Stationary annual cycle of external forcing (Bunker climatology)
  - Nutrients (NOAA Ocean Atlas)

  Virtual ecosystem follows a stationary annual cycle

- The inter-annual variation from the multi-year mean is small
  - P, Z, S biomass on 28th May was 3.7, 8.6 and 11.3% respectively
  - Inter-annual variation in squid recruitment was 12% of the multi-year mean
Phytoplankton biomass

Base run: 2020-2030

Base run: 2029
Herbivorous zooplankton biomass

Base run: 2020-2030

Base run: 2029
Herbivorous zooplankton biomass

- Single peak in Z biomass in May
- Comparable biomasses

<table>
<thead>
<tr>
<th>Month</th>
<th>OBS gC m⁻²</th>
<th>LERM gC m⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb</td>
<td>0.57 ± 0.09</td>
<td>0.48 ± 0.03</td>
</tr>
<tr>
<td>Mar</td>
<td>0.79 ± 0.11</td>
<td>0.46 ± 0.03</td>
</tr>
<tr>
<td>Apr</td>
<td>-</td>
<td>0.84 ± 0.02</td>
</tr>
<tr>
<td>May</td>
<td>3.56 ± 1.63</td>
<td>2.72 ± 0.08</td>
</tr>
<tr>
<td>June</td>
<td>0.61 ± 0.09</td>
<td>0.87 ± 0.06</td>
</tr>
</tbody>
</table>
Experiments

- STABILITY:
- SENSITIVITY OF RECRUITMENT TO:
  - predation,
  - competition for food (basal predator),
  - spawning magnitude
• Squid mortality due to predation was the most significant factor affecting annual recruitment
• effect of predation on the squid population especially on the more abundant and slower swimming newly hatched squid
• 3 regions:
  – Density-dependent
  – Predation
  – Predation much higher than growth
Inter-population competition

• Density-dependent reduction in Z at low BP concentration
• Direct effect of food limitation at BP > 2,000 ind m\(^{-2}\)
  – less carbon was transferred to the squid population
  → reduction in squid recruitment.
  – slower growth rate → squid more vulnerable to predation for longer (Ricker and Foerster, 1948)
Recruitment as a function of number of eggs laid

• Observation:
  – increased eggs production leads to decreased recruitment for *Loligo gahi* (Agnew *et al.*, 2000).
Recruitment as a function of number of eggs laid

- Lower survival with increased intra-population competition for food
- 100-400 eggs laid: mortality exclusively by predation,
- >400 eggs laid: combination of starvation and predation

<table>
<thead>
<tr>
<th>Eggs x10^2</th>
<th>S (ind m^2 yr^-1)</th>
<th>P (ind m^2 yr^-1)</th>
<th>R (ind m^2 yr^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>95.4</td>
<td>4.6</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>195.4</td>
<td>4.6</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>295.8</td>
<td>4.2</td>
</tr>
<tr>
<td>4</td>
<td>0.0</td>
<td>395.8</td>
<td>4.1</td>
</tr>
<tr>
<td>5</td>
<td>41.4</td>
<td>457.4</td>
<td>2.2</td>
</tr>
<tr>
<td>6</td>
<td>14.8</td>
<td>584.5</td>
<td>0.8</td>
</tr>
<tr>
<td>7</td>
<td>39.5</td>
<td>660.4</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Recruitment as a function of number of eggs laid

- Lower survival with increased intra-population competition for food
- 100-400 eggs laid: mortality exclusively by predation,
- >400 eggs laid: combination of starvation and predation
Conclusions

• Annual recruitment was an emergent property of the simulation:
  – Food availability and composition
  – Inter and intra-populations competition
  – Speed of squid growth
  – Predation

• Hjort’s critical period (Hjort, 1914)

• Interaction between density-dependent growth and predation determine density-dependent survival
  – (Ricker and Foerster, 1948; Cushing and Shepherd, 1980)

• The method proved successful in providing a plausible description of the mechanisms involved in determining squid annual recruitment