Climate change, ocean acidification and individual-based models: why the little things matter

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What if.....?

Why focus on the little things?

What are the little things?
Individual vs Ecosystem

Relationship between acidification effects, socio-economic impacts and hierarchical levels of biological complexity (Le Quesne & Pinnegar, 2011)

Le Quesne and Pinnegar 2011. Fish and Fisheries (DOI:10.1111/j.1467-2979.2011.00423.x)
It’s complicated….

**Drivers**
- GHG, CO₂ Increase
- Long shore current strength
- Rainfall intensity
- Sea level Rise
- Storm intensity
- Wind speed

**Ocean Acidification**
- Indicators
  - pCO₂
  - pH
  - CaCO₃ solubility (Ω<sub>CaCO₃</sub>)

**Impacts**
- Calcification
- Enzyme activity
- Hypercapnia
- Membrane permeability
- Motility
- Proton pump
- Toxicant concentrations

**Organism Response**
- Behavior
- Condition
- Development
- Disease
- vulnerability
- Fecundity
- Fertilization
- Mating
- Survival
- Reproductive cues
- Settlement cues

**Physical Effects**
- Ω<sub>CaCO₃</sub>
- pH
- Coastal erosion
- Mixing
- Salinity
- Stratification
- Upwelling

**Ecosystem Effects**
- Dispersion (planktonic stage)
- Nutrient, sediment and toxicant loading patterns
- Phytoplankton / zooplankton community composition
- Prey availability
- Predator-prey interactions
- Habitat change (GBR, mangroves, sea grass)

**Recruitment**
- Growth
- Mortality
Individual-based models

- Explicitly model individual dynamics
- Individual variability
  - Physiology (E.g. growth, feeding, mortality, reproduction)
  - Behavioural (E.g. habitat selection, movement)
- Spatially explicit
- Integrate physical and biogeochemical
- Individual-level to Ecosystem-level
- Numerically intensive
- Difficult to calibrate / validate
Case study

- Mud crabs - Important fishery
- Lake Coombabah - Marine Protected Area
- Interested in population dynamics:
  - Efficacy of MPA
  - Impact of environment at different life stages (SST)
- Heuristic model (investigative)
- Compliment data collection
- Framework for integrating data
Lake Coombabah, Queensland
Mud Crab - life cycle

- Adult
- Juvenile
- Megalopa
- Zoa I
- Zoa IV

Locations:
- Mangrove Forest
- Estuary
- Ocean
- Mud flats

Life Cycle Stages:
Mud Crab - IBM

• **Physiological:**
  - Growth rates
  - Mortality rates

• **Movement:**
  - **Lagrangian**
  - Larvae - planktonic
  - Adults (moulting) - stationary
  - Adults (default) - random
  - Adult males (mating) - searches for females that are soft-shell, smaller, available, visible
  - Adult females (mated) - leave system to spawn, then return
Hydrodynamics

- Hydrodynamic model (larval movement)
  - Depth-averaged
  - Current velocities along transect
  - Full neap-spring cycle
  - 1 hour time steps (696 steps)

Hydrodynamics
Movement Rules

- **Larvae**
  - planktonic movement (incoming tide)
  - No movement (outgoing tide)

- **Males and females (post-larval)**
  - random movement (hard-shell stage)
  - Stationary (soft-shell stage)

- **Mature males seek out available mature females:**
  - Visible (field of network)
  - Mature
  - Soft shell state
  - Smaller
  - Not already mated
Model Scenario

- Initial empty population
- ‘Seed’ system with larvae
- Let system run for two years
- (Test harvest scenarios)
Preliminary Model Output
Preliminary Model Output
Outcomes

• Individual variability explicitly modelled
• Coupled processes:
  – physical (larval movement)
  – biological (growth / death)
  – behavioural (mating/migration) processes
• Management framework:
  – climate (SST)
  – non-climate (harvesting strategies)
Findings

• Uncalibrated
  – Census data required
  – Behavioural data

• Model expansion:
  – Ocean acidification / offshore effects
  – Habitat
  – Predator-mediated effects
  – Catchment runoff (salinity, pH, nutrients, toxicants)
Take home message

Management of marine species in the context of climate and non-climate drivers of change require models that can:

• explicitly account for individual variability,
• explicitly account for different lifecycle stages,
• explicitly account for movement (planktonic, motile),
• integrate physical-biogeochemical processes, and
• incorporate management scenarios.

Individual-based models