Evaluating how food webs and the fisheries they support are affected by fishing closures in temperate Western Australia

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Motivation

Rationale:
· Explore the ecosystem impacts of fishing

Goal:
· Evaluate how food webs and the fisheries they support are likely to be influenced by fishing closures
· Investigate how changes in abundance of key fished species (e.g. rock lobster, snapper, dhufish) are likely to influence other species

Applications:
· Dynamics of target species
· Commercial vs Recreational fishing
· Climate variability scenarios
· Provide useful ecosystem indicators
Ecopath model: 2006

• Boundaries of the model:
  Marine Park to 30m depth
  Area = 823 km$^2$

  Management Zones
  (WA Department of Environment and Conservation)
  • 80 groups (> 200 species)

• Fishing gears
  \[\begin{aligned}
  &8 \text{ commercial } \sim 480 \text{ tonnes } \cdot \text{year}^{-1} \text{ (70\% Lobster)} \\
  &6 \text{ recreational } \sim 38 \text{ tonnes } \cdot \text{year}^{-1}
  \end{aligned}\]
Functional groups

- Fish = 24
- Special interest = 10
- Invertebrates = 19
- Primary producers = 11
- Zooplankton = 4
- Non-Fish = 5
- Non-Living = 7

Iconic/special interest

- Pink snapper
- Dhufish
- Baldchin grouper
- Breaksea cod
- Foxfish
- King wrasse
- 4 stages of rock lobster
Ecopath & Ecosim core equations:

1) Mass-balance (within groups):

\[ B_i \cdot (P / B)_i = Y_i + \sum_{j=1}^{n} B_j \cdot (Q / B)_j \cdot DC_{ji} + E_i + B_A_i + B_i (P / B)_i \cdot (1 - EE_i) \]

Production = Yield + Predation + Biomass Acc. + Migration

2) Conservation of energy (between groups):

\[ B \cdot (Q / B) = B \cdot (P / B) + (1 - GS) \cdot Q - (1 - TM) \cdot P + B \cdot (Q / B) \cdot GS \]

Consumption = Production + Respiration + Unassimilated food

3) Biomass dynamics:

\[ \frac{dB_i}{dt} = g \sum_j C_{ji} - \sum_j C_{ij} + I_i - (M_i + F_i + e_i) B_i \]

D Biomass = Growth + Immigration – Predation - Mortality
Model Calibration: Wester Rock Lobster (data from Department of Fisheries, WA)

- Model captures general variability
- Model can reproduce known history

Biomass estimated by depletion analysis
Biomass predicted by the model

Panulirus cygnus
Results: trophic role of *Ecklonia* (kelp)

- *Ecklonia*, seagrasses and macroalgal assemblages are the major sources of habitat and food for marine invertebrates and fish.

- *Ecklonia* provided substrata for food (epiphytes and epifauna) and shelter from predators.
Ecosim scenario: Reduction of F by 50% over 20 years (2.5% year$^{-1}$) of dhufish and pink snapper
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Ecospace: Spatial modelling of Jurien Bay

Scenario 1: ~10% of the park

Scenario 2: No fishing closures

Scenario 3: Fishing closures up to 30%
Ecopath models are like cubism art....abstract, ambiguous, with random angles, but (probably/possibly) realistic.
Scenario: Reduction of F by 50% (2.5% year$^{-1}$) of dhufish, pink snapper & baldchin grouper
Model’s Performance: Mortalities

Mortalities predicted by the model

Fishing mortality (F) Natural Mortality (M)

Production = Fishery yield + Natural Mortality

\[ P/B = Z = F + M \]

\[ F = C/B \]
Sensitivity Analysis - (change biomass of each living group)

- **Index of Sensitivity** = the number of groups affected (± 30%) by 50% of biomass for each group.

- The Ecopath model is relatively insensitive to parameter values for most living groups (only 34 groups produced Index sensitivity >10).

- Changes in parameters of Dead carcasses and sediment detritus exert the greatest influence (living groups) in the system.

- The importance/sensitivity of the model to sediment detritus emphasises the ultimate desirability of developing Atlantis type model.
Ecosystem attributes of Jurien Bay

• Jurien Bay is a relatively complex ecosystem.

• Medium/High productive system. More energy produced than respired within the system (*Primary Production/Respiration = 1.23*).

• Dynamic system. There is a low-medium level of biomass accumulation (*Primary Production/Biomass = 1.68*).

• Low rates of cycling (*proportion of flows originated from detritus ~ 10%*).

• Ecosystem dominated by the benthic community (*Ratio of biomass benthic/pelagic groups = 1.27*).

• Ecosystem function related to *Bottom-up control*, but wasp-waist predator-prey and top-down interactions were identified.

• This ecosystem could be considered in an Intermediate-Low development stage, dominated by lower trophic levels. (*overall network analysis results*).
Trophic structure and fisheries

- Mean trophic level of the catch = 2.96
- Gross Efficiency (Catch/Primary Production) = 0.00041
- Total Catch = 0.68 t/km² (560 tonnes taken within the park in 2005, where almost 90% was removed by commercial fishing)

Jurien Bay Marine Park

Some of these attributes could be used as ‘indicators’ to identify overfishing in the future.
### Ecosim

- **Scenario evaluation:**

  Workshop November, 2007: Participants + Steering group

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Species</th>
<th>Fishing effort (% year(^{-1}))</th>
<th>Duration (years)</th>
<th>Rationale</th>
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<tr>
<td></td>
<td></td>
<td>Commercial (C)</td>
<td>Recreational (R)</td>
<td></td>
</tr>
<tr>
<td>1</td>
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<td>↓2.5</td>
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<td>20</td>
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<td>6</td>
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<td>↓2.5</td>
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</table>
Role of western rock lobster

Fishing mortality in 2006 (F=0.62) ↓ Biomass prey up to 20% ↓

Fishing mortality in 2026 (F=0.3)

Lobster adult ~ 30%

Scenario 1: Reduction of lobster fishing mortality from 0.6 to 0.3 in 20 years

Its prey have high productivity and short life cycles (i.e., coralline algae and crustaceans).

Low impact on other groups

Reduction in fishing mortality of the western rock lobster is unlikely to produce important trophic cascade effects in the system.
↓ Lobster ~ 20%
↓ Dhufish, pink snapper, king wrasse, up to ~ 20%
↓ Sharks & Rays ~ 30%
↓ Ecklonia/seagrass <5%
↓ Total catch ~ 20%
↑ Herring, Mullets, Cardinal-fishes ~20%
↑ Sea urchins ~ 20
Pink snapper >90%
Herring ~ 30%
Fox fish, Breaksea cod, Octopus, Squid ~ 20%
Lobster ~10%
Sea urchins ~ 70%
Dhufish ~ 40%
Sharks ~ 20%
Rays ~ 90%
Pink snapper ~ 2.5x
↑ Sea urchins ~ 70%
↑ Dhufish & Sharks ~ 30%
↓ Squid, Octopus ~ 40%
↓ Baldchin grouper, Breaksea cod, Western Foxfish < 20%
Lobster no change
↑ Pink snapper ~ 3x
↑ Sea urchins ~ 20%
↑ Dolphins
↓ Squid, Octopus ~ 50%
↓ Baldchin grouper, Breaksea cod, Western Foxfish < 10%
Lobster no change
↑ Large sharks ~ 30%
↑ Carangids, Clupeids ~ 25%
↑ Sea urchins, seagrass ~ 20%
↓ Sea lions ~ 40%
↓ Dhufish, pink snapper ~ 30%
↓ Small sharks ~ 40%
Lobster no change
Total catch ~ 40%
↑ Breaksea cod, Foxfish ~ 30%
↑ Octopus, squid ~ 30%
↓ Pink snapper ~ 50%
↓ Dhufish ~ 40%
↓ Lobster adult ~ 30%
↓ Sea urchins ~ 25%
↓ Sharks ~ 20%
↑ Foxfish ~ 30%
↑ Blennies ~ 20%
↑ Octopus ~ 10%
↓ Total catch ~ 30%
↓ Sharks ~ 60%
↓ Lobster adult ~ 90%
↓ Pink snapper, Dhufish, >90%
↓ Sea urchins > 90%
Total catch ~ 90%

↑ Lobsters ~ 80%

↑ Pink snapper ~ 100%

↑ Dhufish & Sharks ~ 50%

↑ Sea urchins ~ 70%
Total catch ~ 10%

Pink snapper ~ 25%

Sharks ~ 20%

Baldchin grouper, Foxfish, Breaksea cod ~ 10%

• Lobsters ~ no change

Octopus ~ 10%

Sardines ~ 60%
↑ Lobster ~ 20%
↑ Dhufish, Pink snapper ~ 80%
↓ Octopus, Western fox fish ~ 30%
↓ Breaksea cod, Squid ~ 10%
Relative fishing mortality imposed by all gears (2006)

↓ Total catch ~ 30%
↓ Zoop. Feed. (clupeids) ~ 20%
↑ Lobster adults ~ 10%
↑ Sharks ~ 30%
↑ Pink snappers ~ 40%

Inshore pelagic zooplankton feeders (clupeids, atherinids)

Non depth restricted Benthopelagic carnivores (Carangids, Urolophids)

Large Sharks

Lobster Adult

Pink snapper

Total catch
↓ Large sharks reduced by 70% after 20 years.
↑ Sea lions ~ 50%
↓ Lobster ~ 20%
↓ Lower trophic levels up by 30% (Potential cascade of effects).
Energy flow in Jurien Bay

Total system flow was 22,067 ton km\(^{-2}\) year\(^{-1}\)

- Internal consumption 56%
- Respiration 25%
- Detritus 10%
- Export 11%