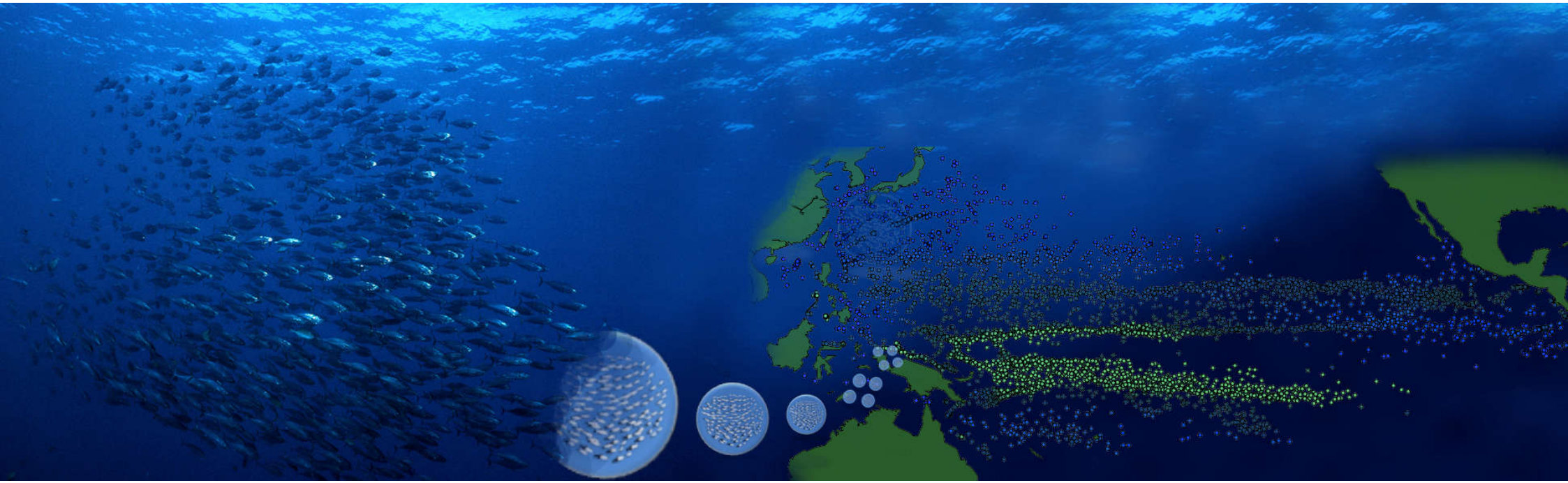

The Role of Simulation Tools

Joe Scutt Phillips

Utrecht University

University of New South Wales

Why use simulation models?

- **Description**

"…the study of the patterns of nature…

- **Dynamics**

…how they change in space and time…

- **Processes**

…how those patterns came to be…"

Sharon E. Kingsland (1985) "Modelling Nature"

Why use simulation models?

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Sharon E. Kingsland (1985) "Modelling Nature"

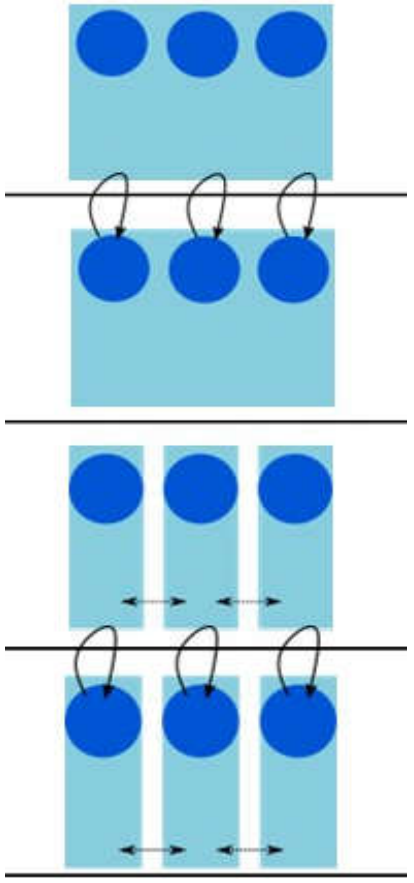
Simulation models as assumption busters

Using simulation tools to explore

> *"…how those patterns came to be…"*

as

- Opaque thought experiments
- Assumption analysers
- Create quantitative scenarios
- Design experiments/monitoring programmes
- Guide further research



Models of adult tuna movement

Many of the observed patterns in the data we have are a function of movement

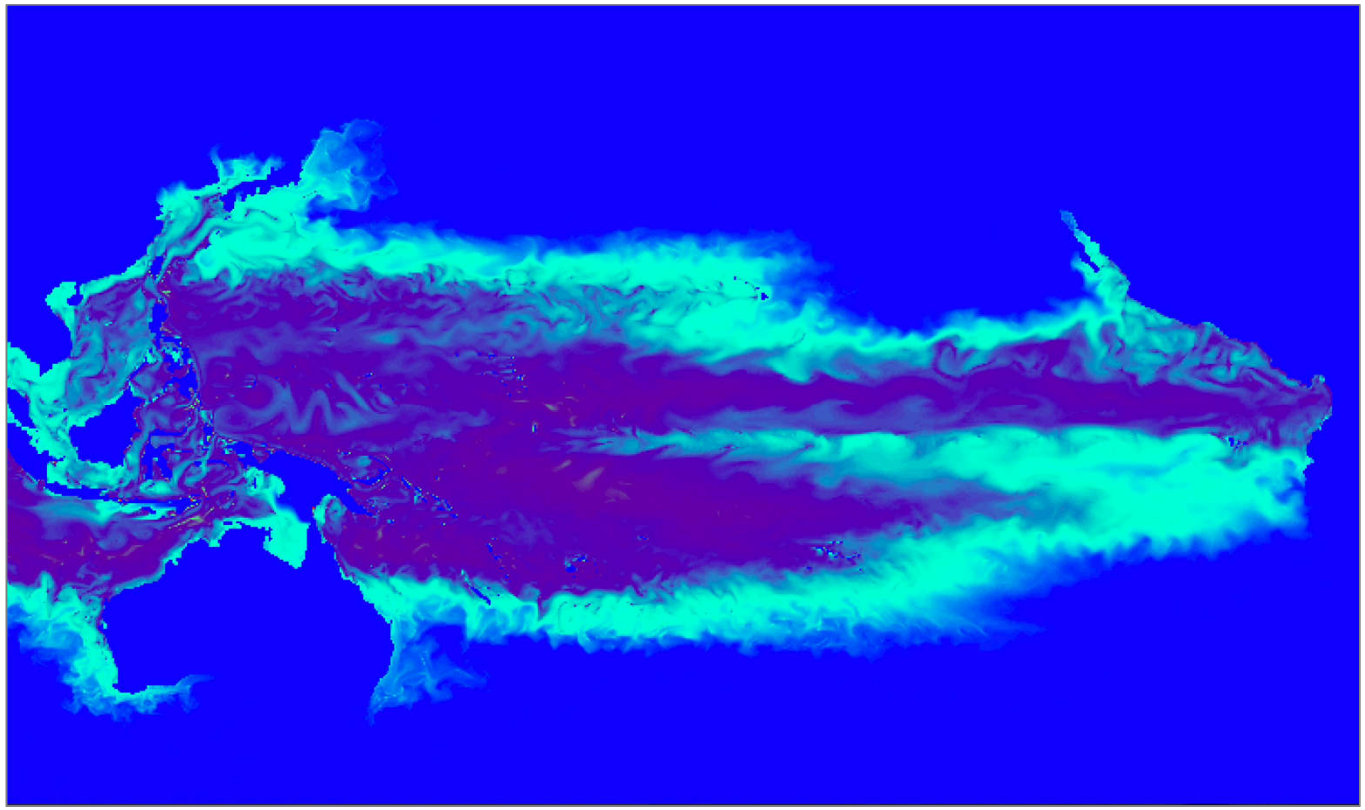
Two examples of models that can potentially help us understand the effect of movement on stock structure

- SEAPODYM – Ecosystem and population dynamics model
- Ikamoana – Individual-based movement model

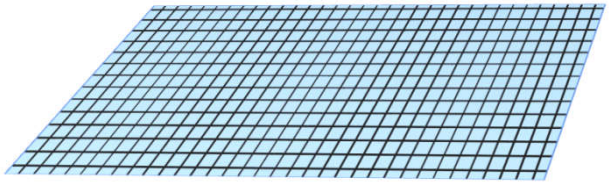
Models of adult tuna movement - SEAPODYM

Advection-Diffusion-Reaction Ecosystem Model

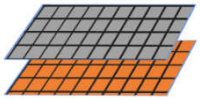
- Simulates population dynamics of marine species
- Density of animals represented by tracer
- Regular grid spatial structure
- Equations govern the change in density/biomass
- Estimated using tagging and fisheries data



Models of adult tuna movement - SEAPODYM

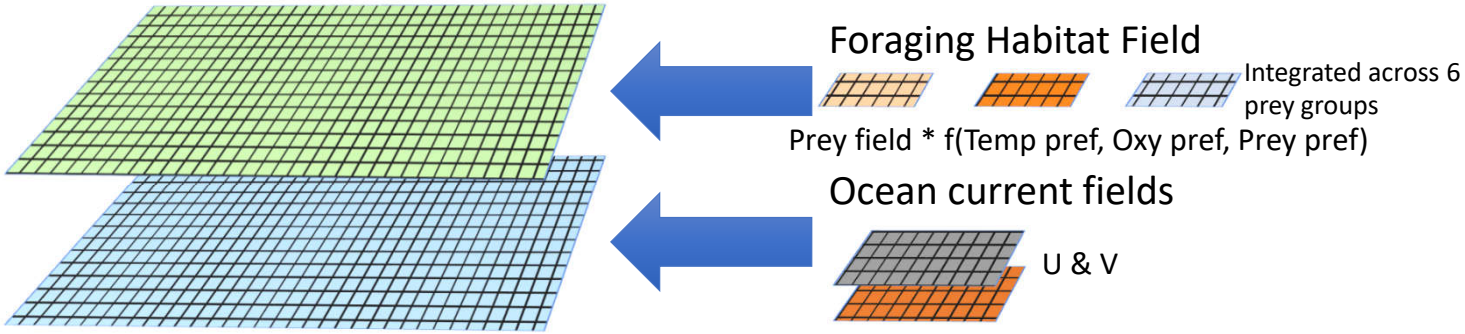


Ocean current fields

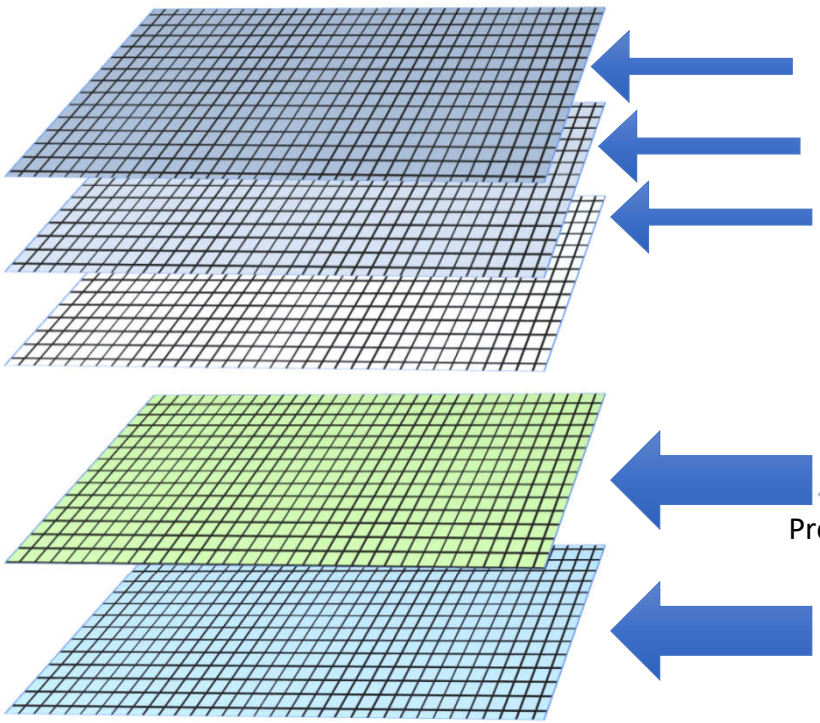


U & V

Models of adult tuna movement - SEAPODYM



Models of adult tuna movement - SEAPODYM



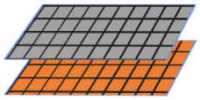
Tuna Density
(each age-class)

Foraging Habitat Field

Integrated across 6 prey groups

Prey field * f(Temp pref, Oxy pref, Prey pref)

Ocean current fields

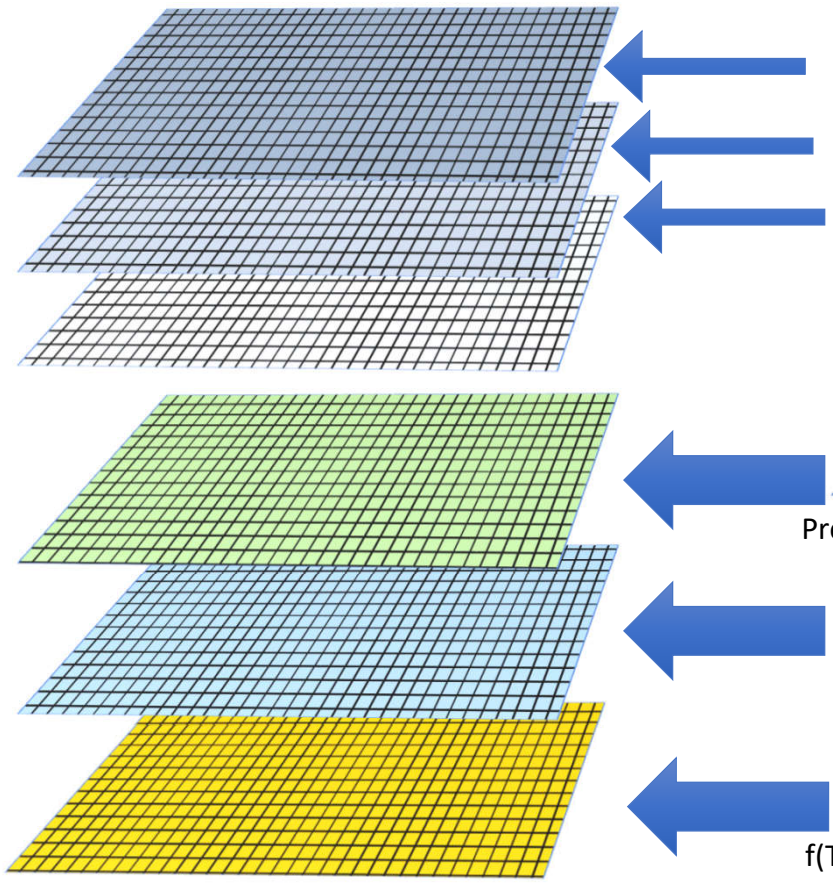


U & V

Behaviour

- Advection by ocean currents
- Active movement follows foraging habitat gradients
- Greater diffusion in poor habitat

Models of adult tuna movement - SEAPODYM



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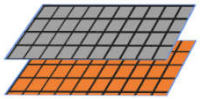
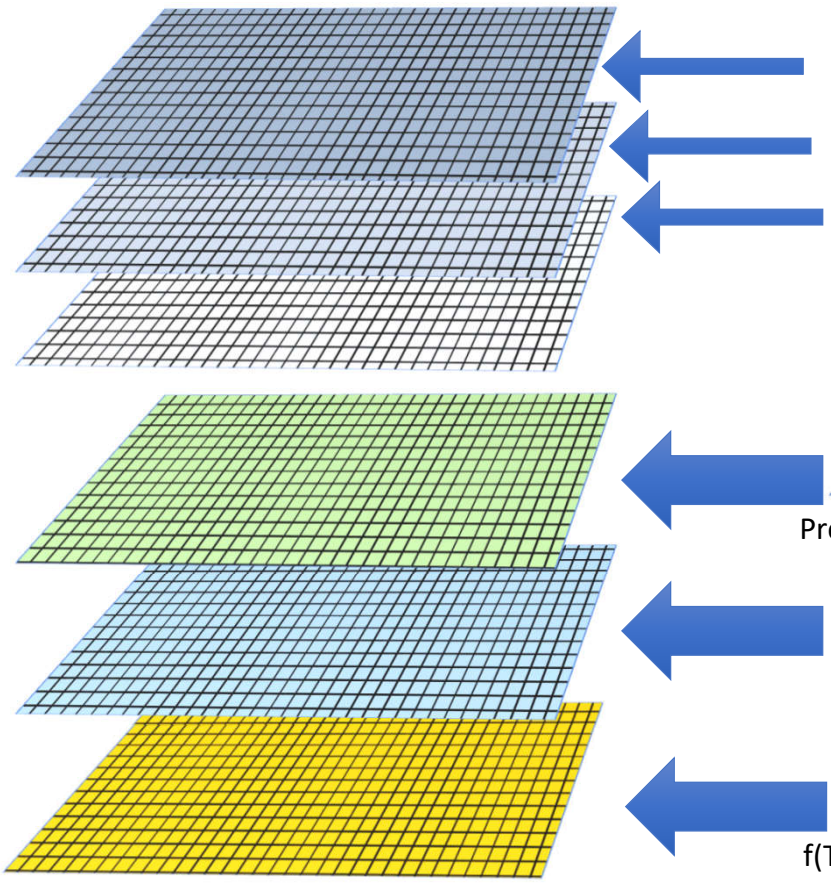


U & V

Spawning Habitat Field

f(Temp pref, Larval food, Larval prey)

Models of adult tuna movement - SEAPODYM



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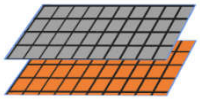


U & V

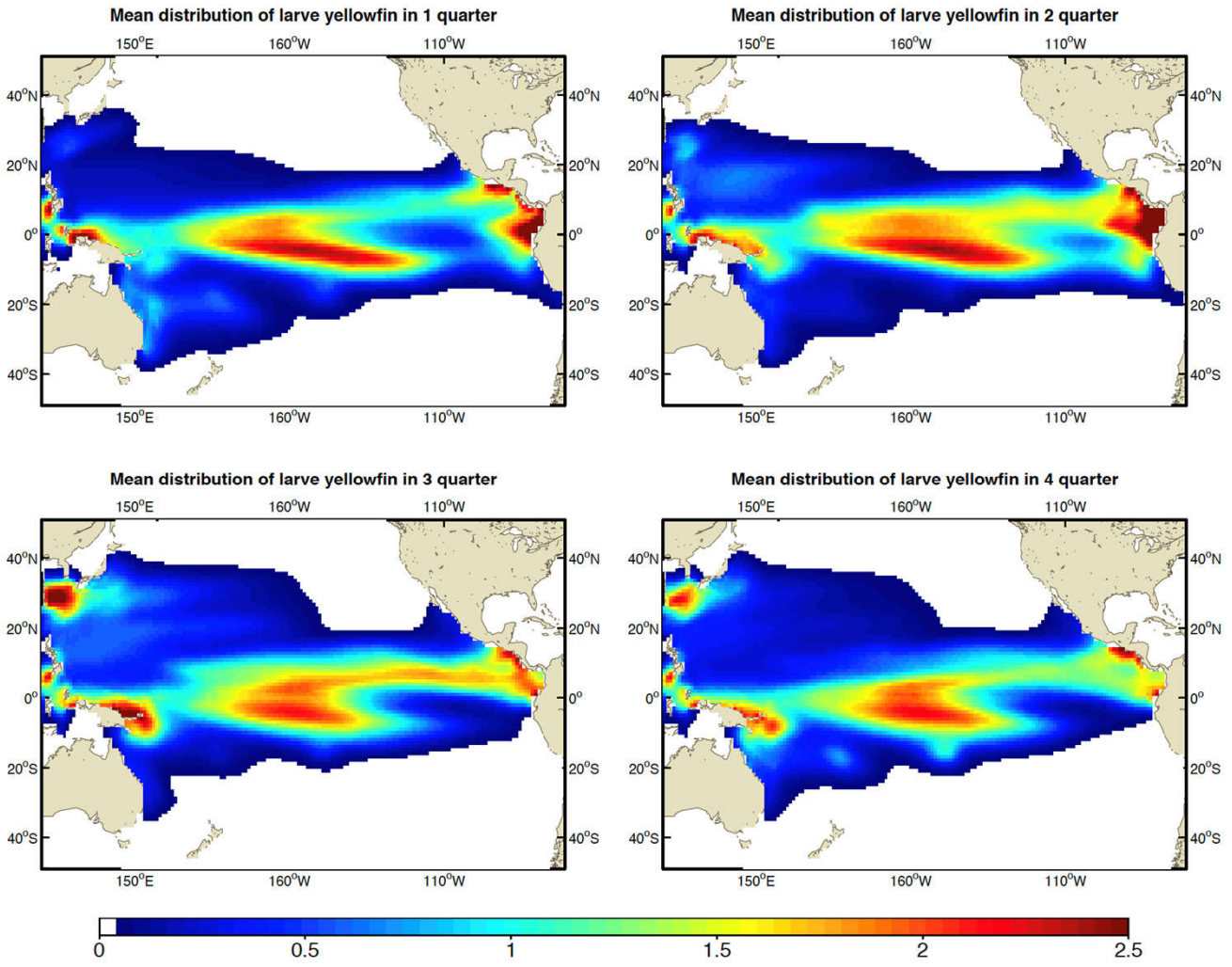
Spawning Habitat Field

f(Temp pref, Larval food, Larval prey)

- Reproduction a function spawning habitat and adult biomass
- Switch in movement preference between foraging and spawning

Models of adult tuna movement - SEAPODYM

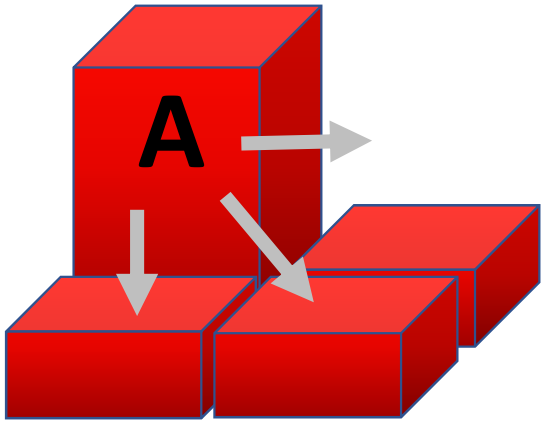
Simulate potential spawning grounds/successful spawning areas



Models of adult tuna movement - SEAPODYM

Tracking the movement of biomass in SEAPODYM

- Broad scale connectivity

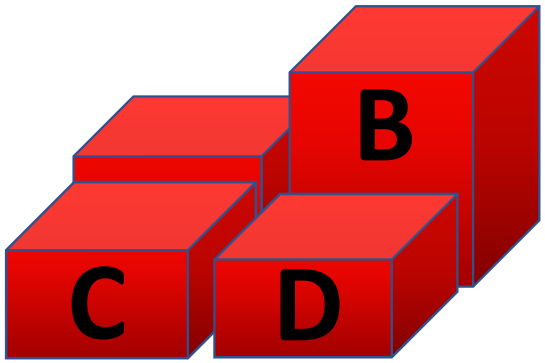


Tuna density by region

Models of adult tuna movement - SEAPODYM

Tracking the movement of biomass in SEAPODYM

- Broad scale connectivity
- Where do fish move over some time-period?



Tuna density by region

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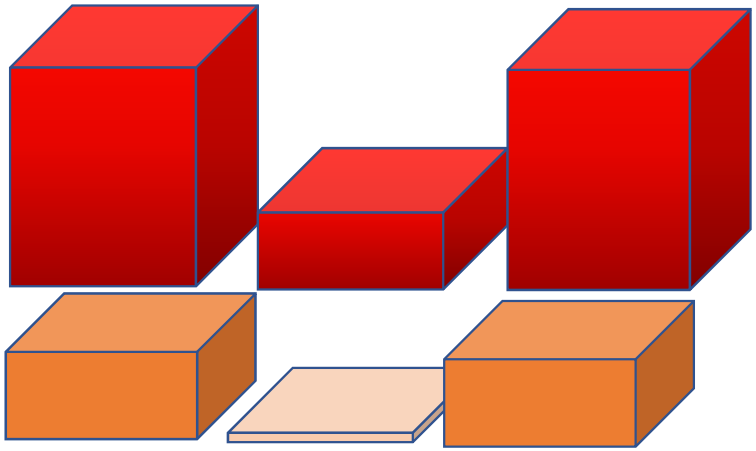


Potentially separate spawning areas

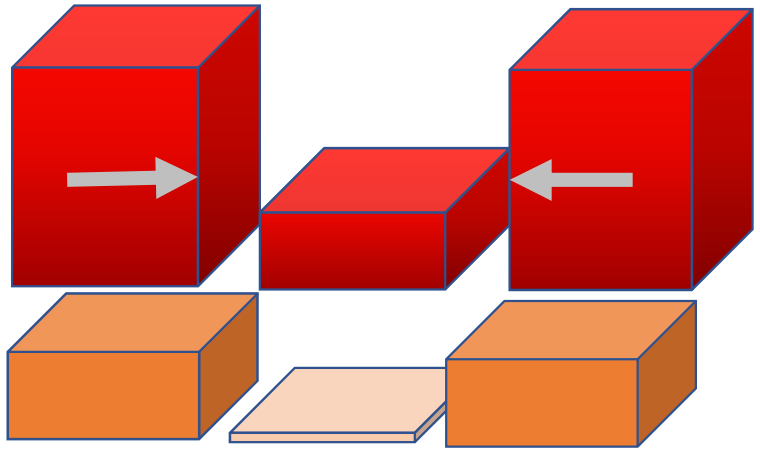
Tuna Density

Spawning Habitat Field

Models of adult tuna movement - SEAPODYM

Tracking the movement of biomass in SEAPODYM

- Adult biomass contributes to larval recruitment



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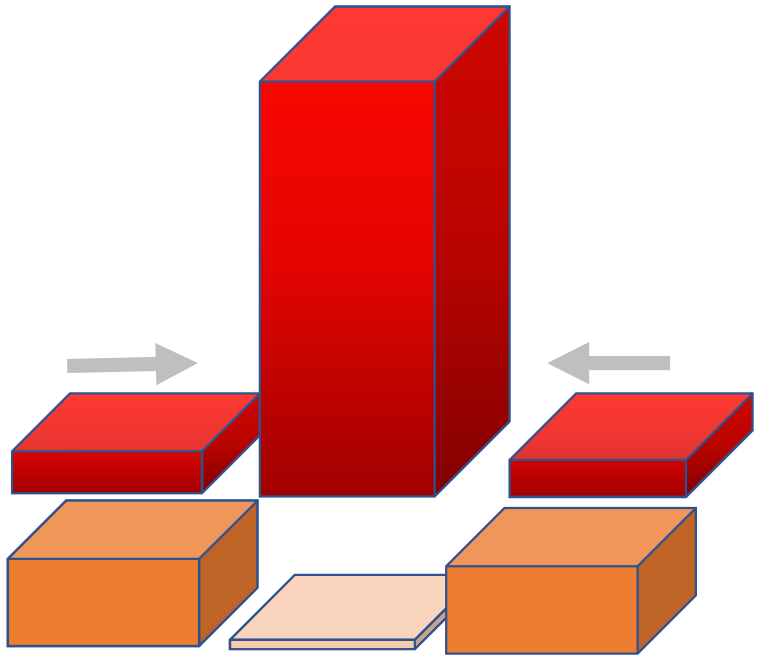
Models of adult tuna movement - SEAPODYM

Tracking the movement of biomass in SEAPODYM

- Adult biomass contributes to larval recruitment
- Biomass advects/diffuses through domain



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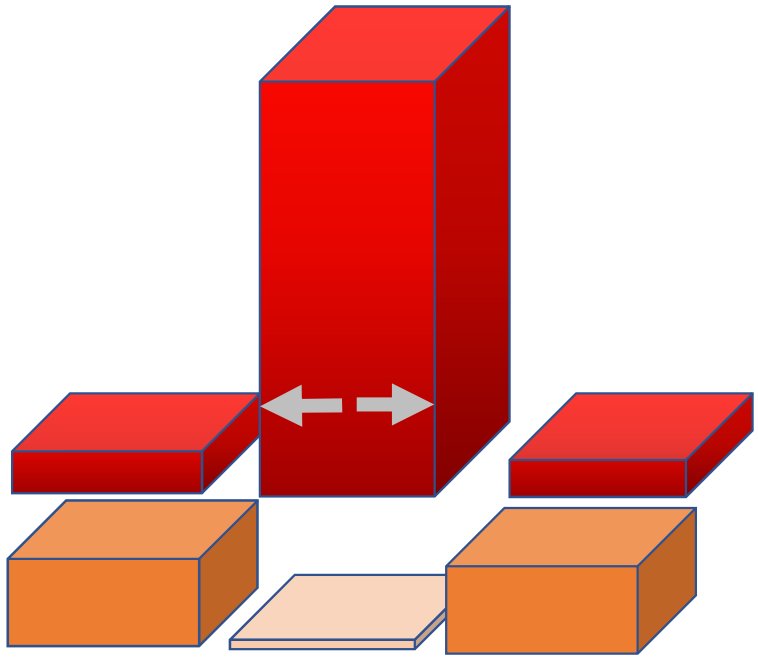


Potentially separate spawning areas

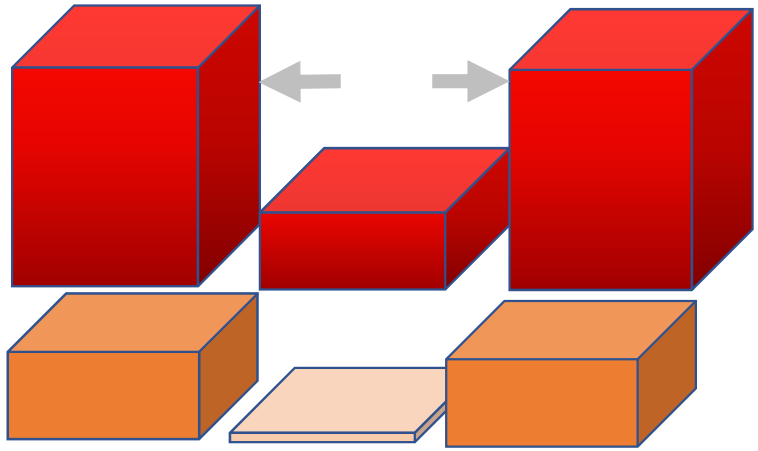
Tuna Density

Spawning Habitat Field

Models of adult tuna movement - SEAPODYM

Tracking the movement of biomass in SEAPODYM

- Adult biomass contributes to larval recruitment
- Biomass advects/diffuses through domain
- Cannot track conditional pathway of tracer representing the biomass



Potentially separate spawning areas

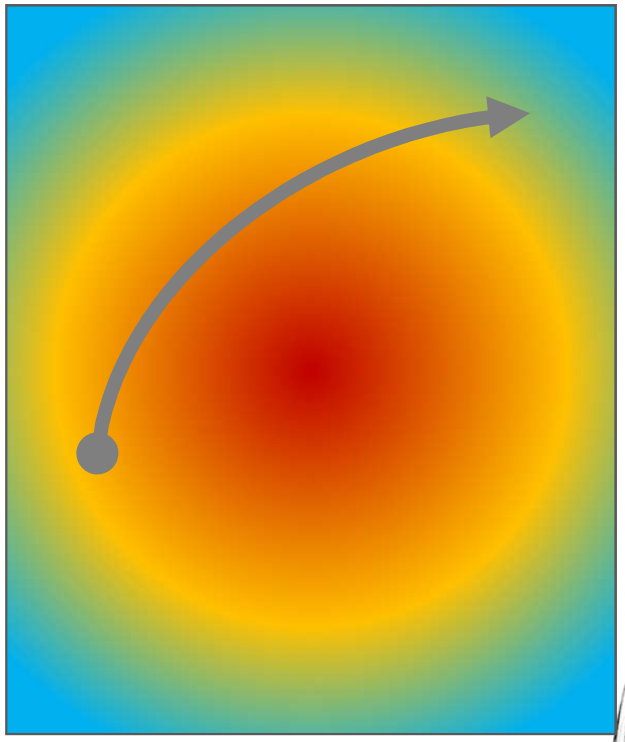
Tuna Density

Spawning Habitat Field

Models of adult tuna movement - Ikamoana

Questions regarding the tracking of biomass at the individual level

- Connectivity between regions- source/sink dynamics?
- Differing growth rates of larvae and young fish
- Where might sampled YOY have come from at time-of-spawning?
- Mixing of tagged fish with the untagged population
- Mixing of genetically distinct sub-populations
- Accretion of isotopes/trace metals during lifetime of an individual



Models of adult tuna movement - Ikamoana

Individual-based Kinesis, Advection and Movement of Ocean ANimAls

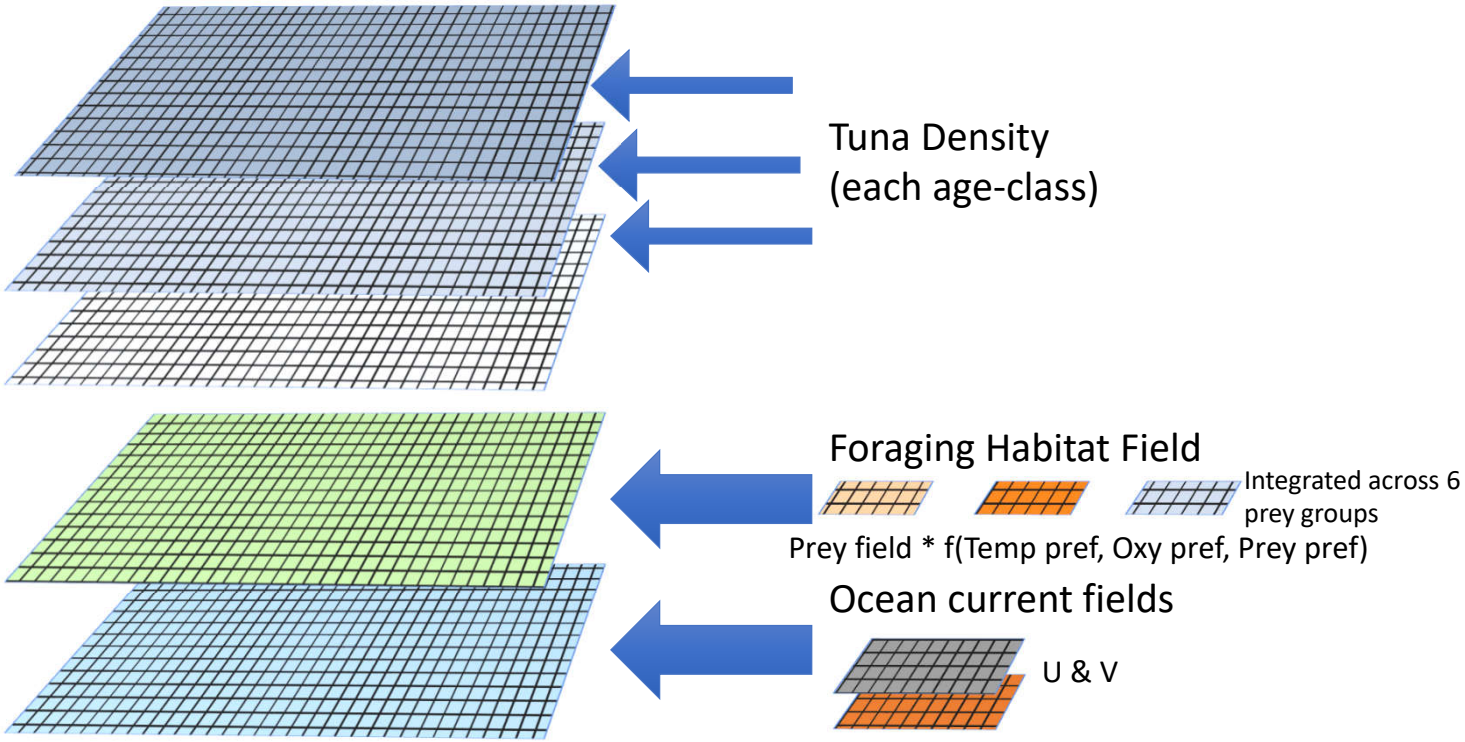
— Extends a recently developed Lagrangian particle simulator (Parcels) which **advects** individuals using physical forcing

— Adds non-directional **kinesis** movements, such as Lagrangian diffusion, random walks, internal states of individuals etc.

— Active **movements** that cause individuals to follow habitat gradients, or move in response to other individuals, environment etc.

— Not a population dynamics model!

Models of adult tuna movement - Ikamoana



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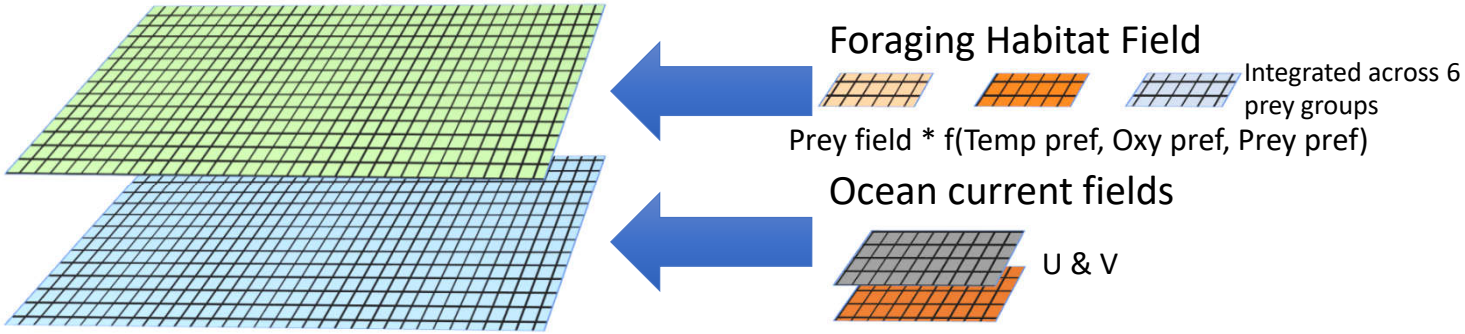

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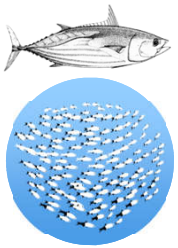
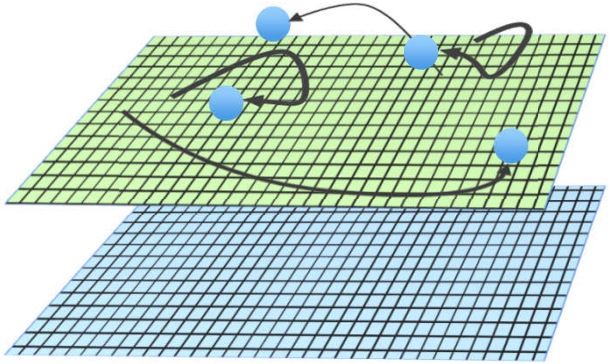


Particle
"Individuals"

- Number of individuals in school
- Continuous age (and mortality)
- Continuous position
- Recorded trajectories
- Memory of fields sampled (e.g. spawning habitat index)
- Variable behaviours (e.g. those estimated by SEAPODYM)



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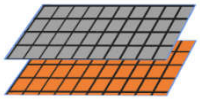


U & V

Models of adult tuna movement - Ikamoana

Models of adult tuna movement - Ikamoana

Quantifying connectivity through stock assessment regions

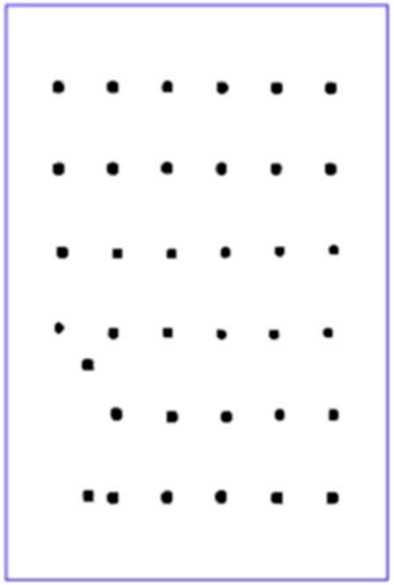
- Transfer rates under a given behavioural scenario
- Use individual-scale pathways

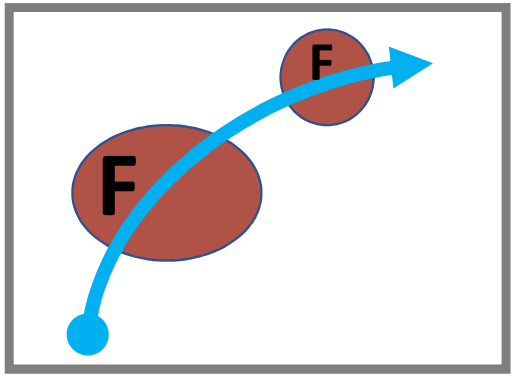
- Early origins of fish recruiting into purse seine fishery in each stock assessment regions

Models of adult tuna movement - Ikamoana

Quantifying tag mixing

- Probability of capture for tagged fish vs untagged fish
- Changes across release scenarios
  - Temporal
  - Location
  - Release size
- Examine spatially varying F along pathways of individuals
- Compare the F experienced by a whole cohort in a region with that of a ‘tagged’ subset



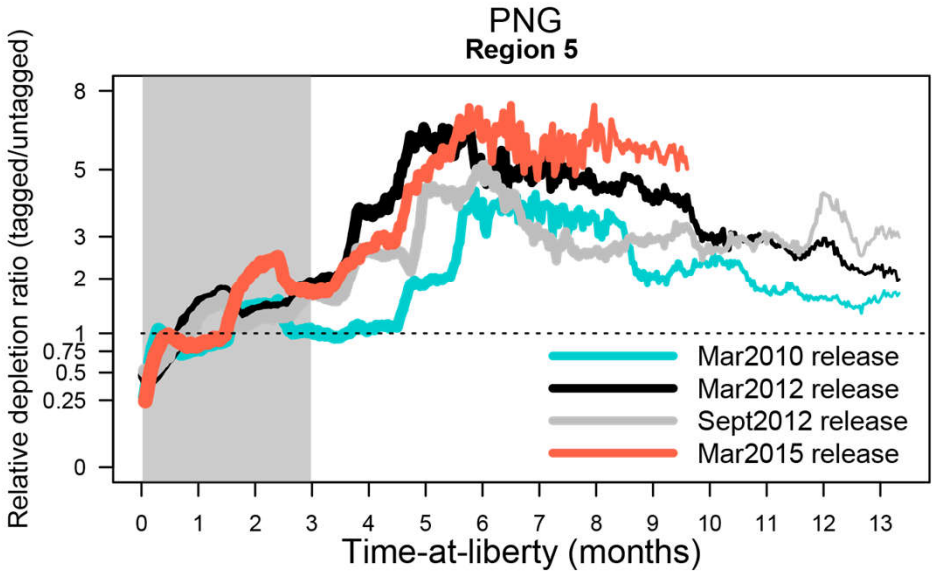


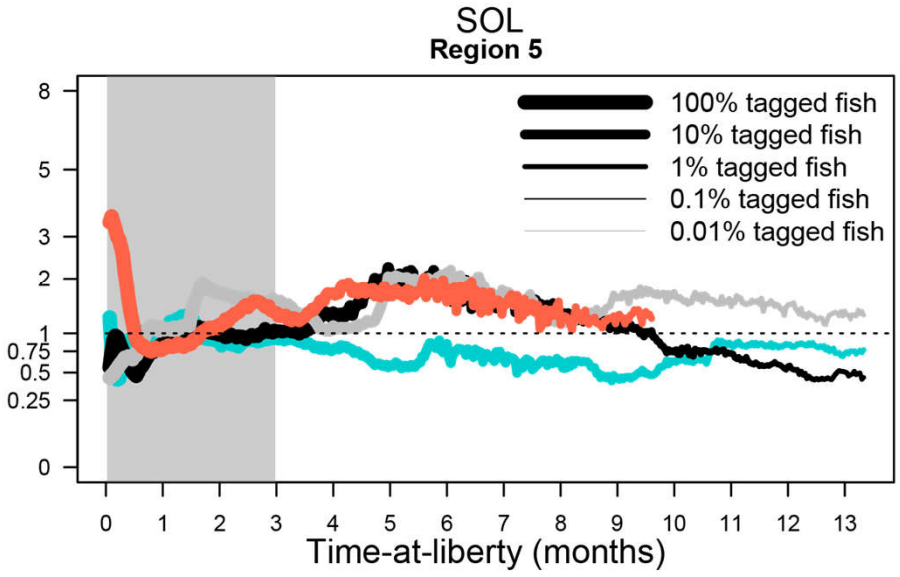
Models of adult tuna movement - Ikamoana

Models of adult tuna movement - Ikamoana

When we compare with a tagged subset, originating from a specific location

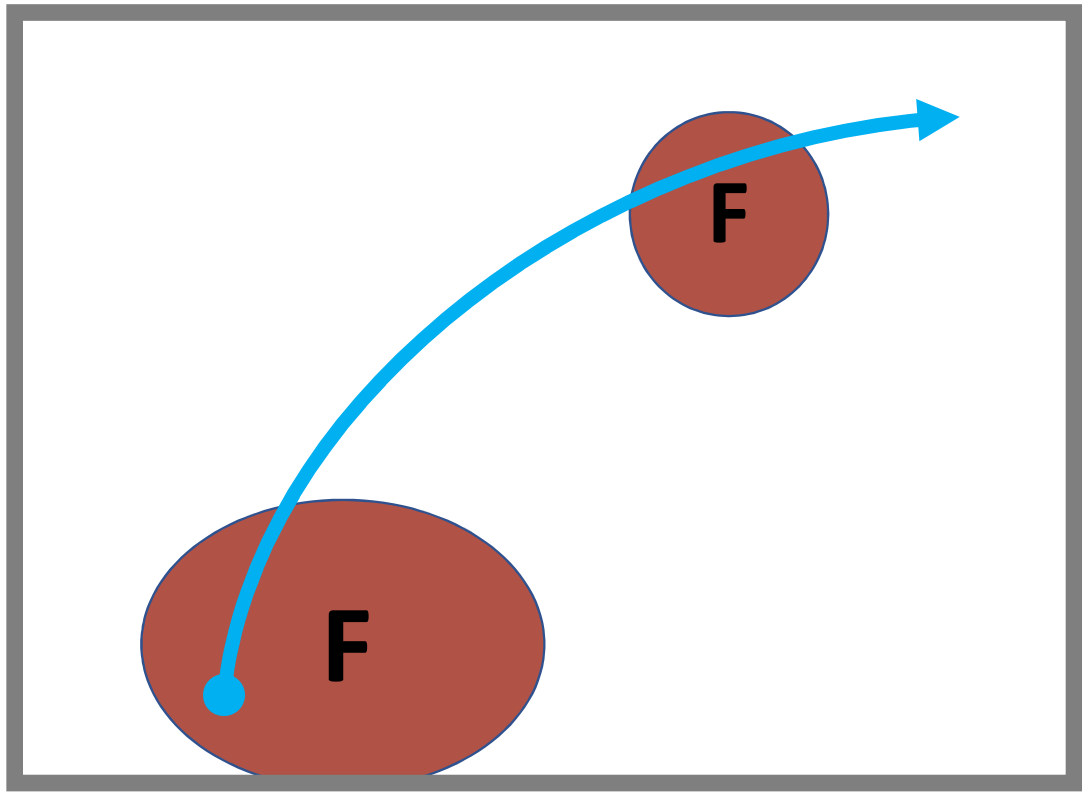
- Difference in depletion due to fishing highly variable through time
- Depends on time/location/region
- Suggests implications for how we might use tagging data from different releases





Models of adult tuna movement - Ikamoana

Tag mixing simulations an example of testing a movement hypothesis on capture probability

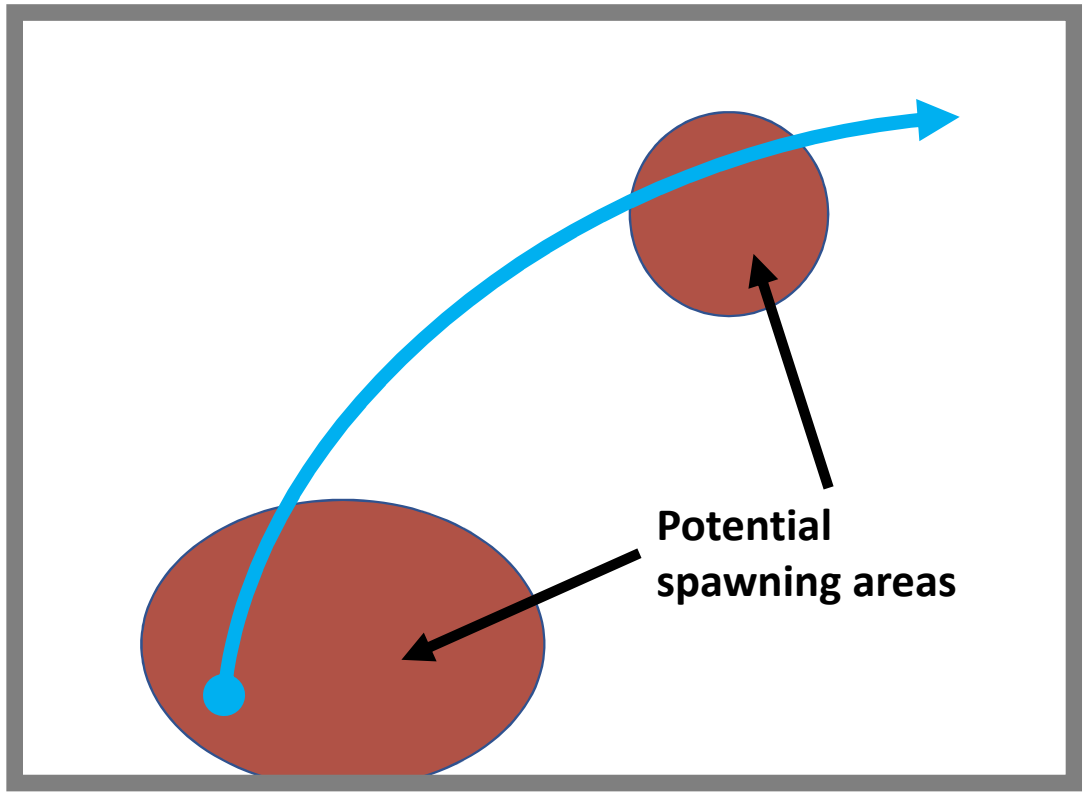


Models of adult tuna movement - Ikamoana

Tag mixing simulations an example of testing a movement hypothesis on capture probability

Could similarly use:

- Spawning areas



Models of adult tuna movement - Ikamoana

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Could similarly use:

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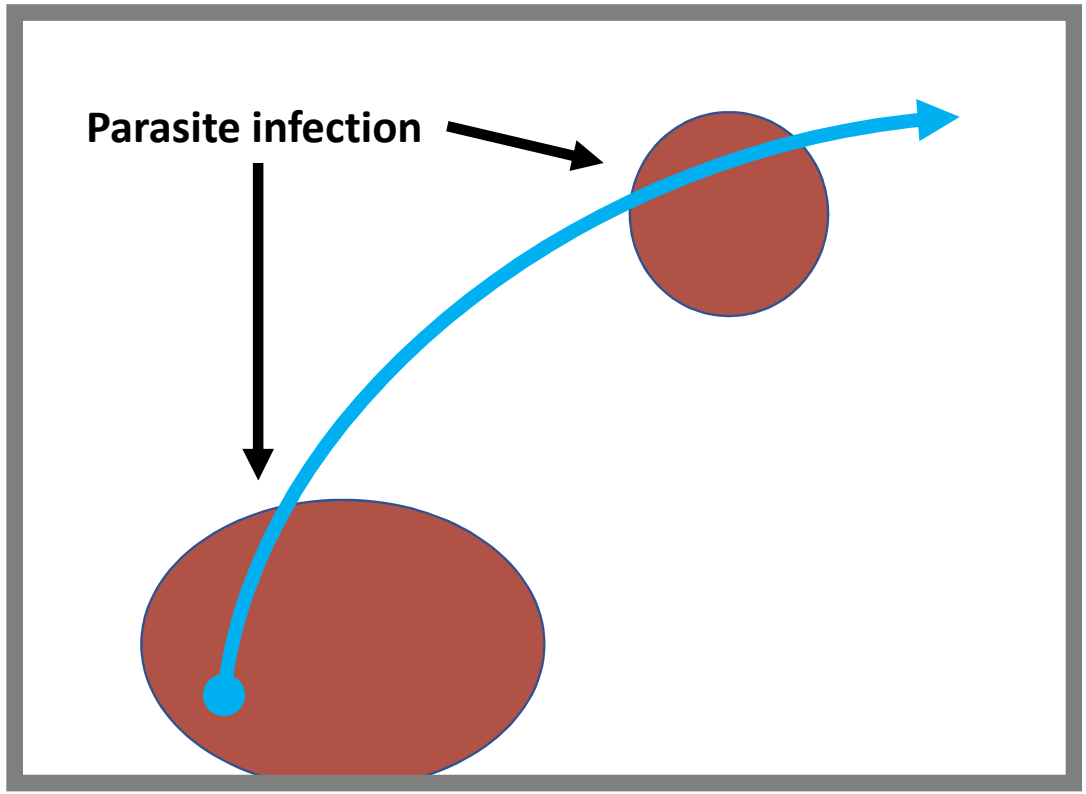

Models of adult tuna movement - Ikamoana

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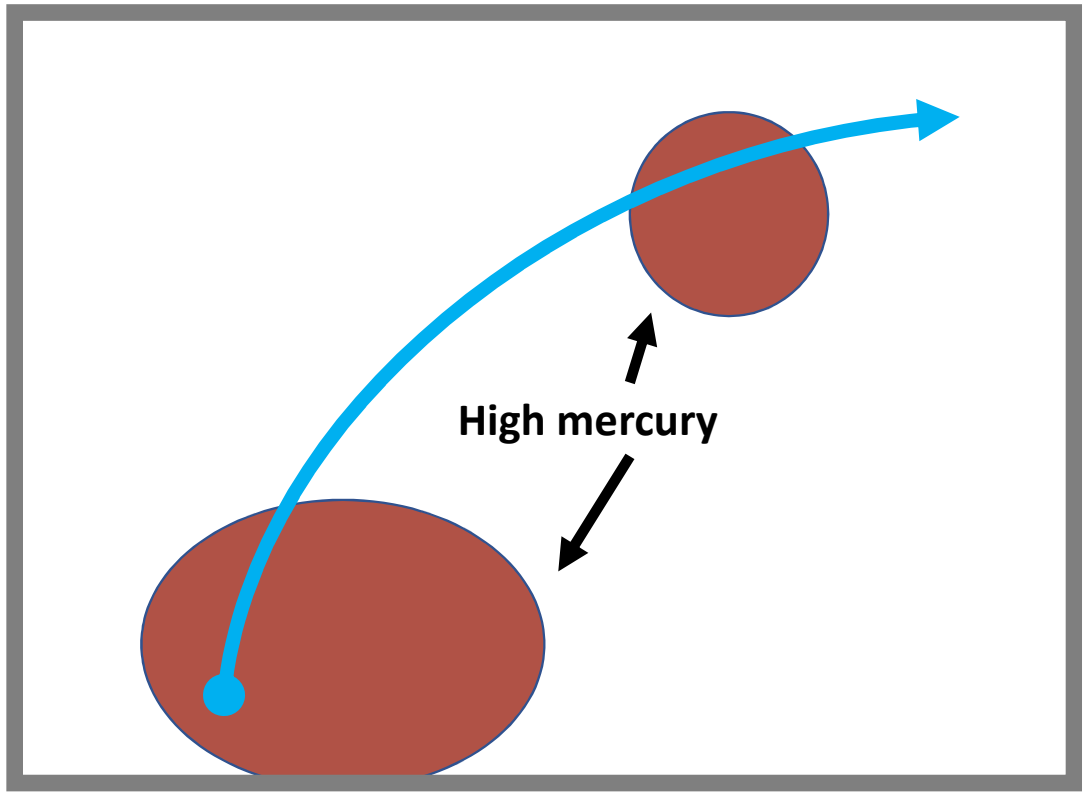
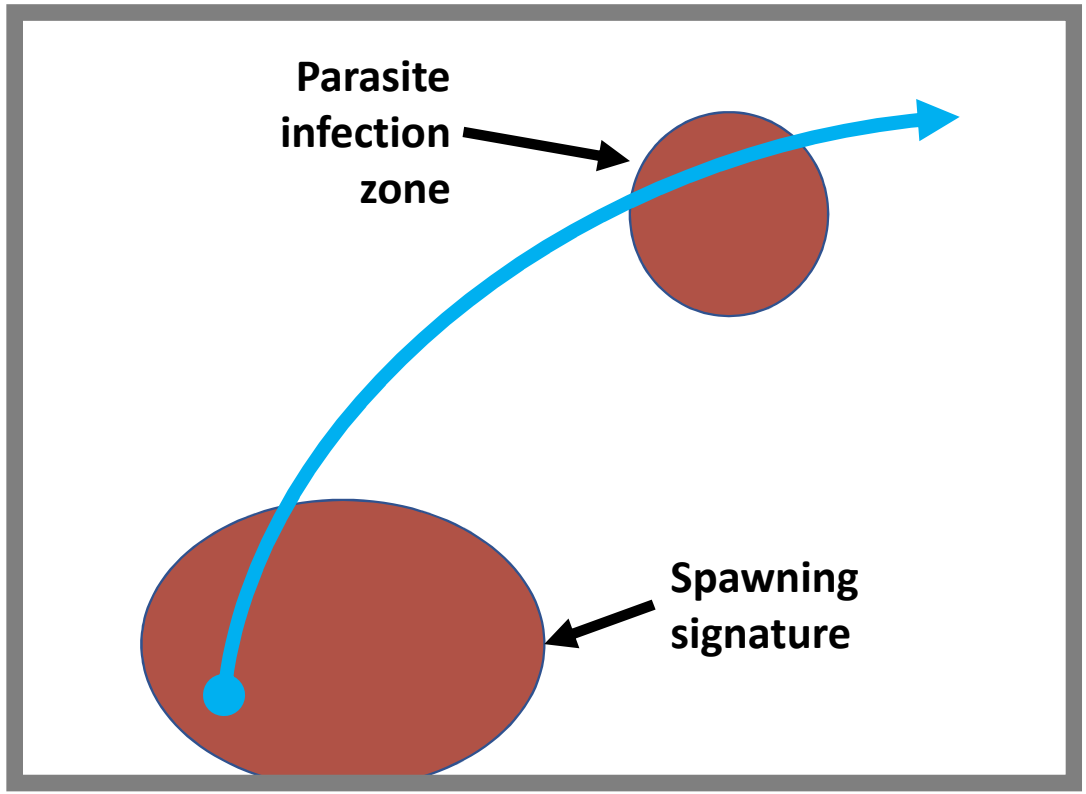


Models of adult tuna movement - Ikamoana

Tag mixing simulations an example of testing a movement hypothesis on capture probability

Could similarly use:

- Spawning areas
- Parasite infection sources
- Microchemistry accretion
- Combine observed patterns



Points for discussion

1. Given these, and other tools, are there specific hypotheses we would like to test in a movement model?
   - Specific observations
   - What are your hunches?

2. Is there any consensus on bracketing the extremes of behavioural hypotheses?
   - All fish are random walkers – one extreme
   - Strong, natal homing to fixed, discrete spawning areas – another extreme

3. Where can we constrain hypotheses from multiple datasets/patterns?
   - Where do data overlap spatially and temporally?
   - Which patterns are most clear?

4. Are there simulation tools to test hypotheses regarding mechanisms other than movement?