The Spatial Population Model software for management support

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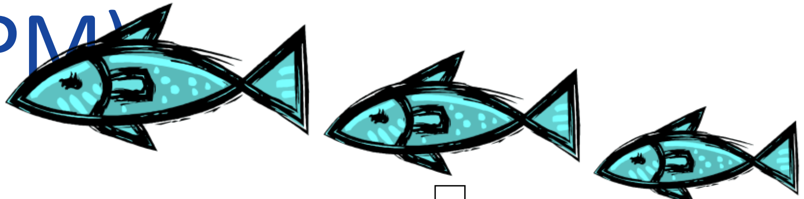
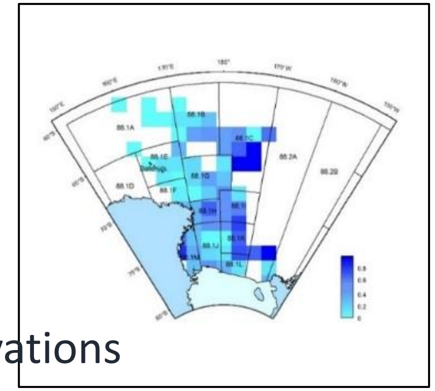
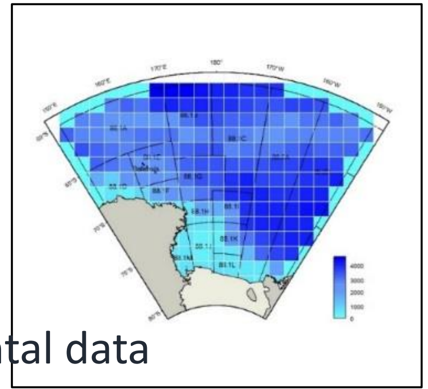
The Spatial Population Model (SPM)



- Fully Bayesian age-structured population
- Fitted to spatially- explicit observations: age distribution, relative abundance, maturity data, tagging data, …
- Movement parameterised through estimated habitat preference functions

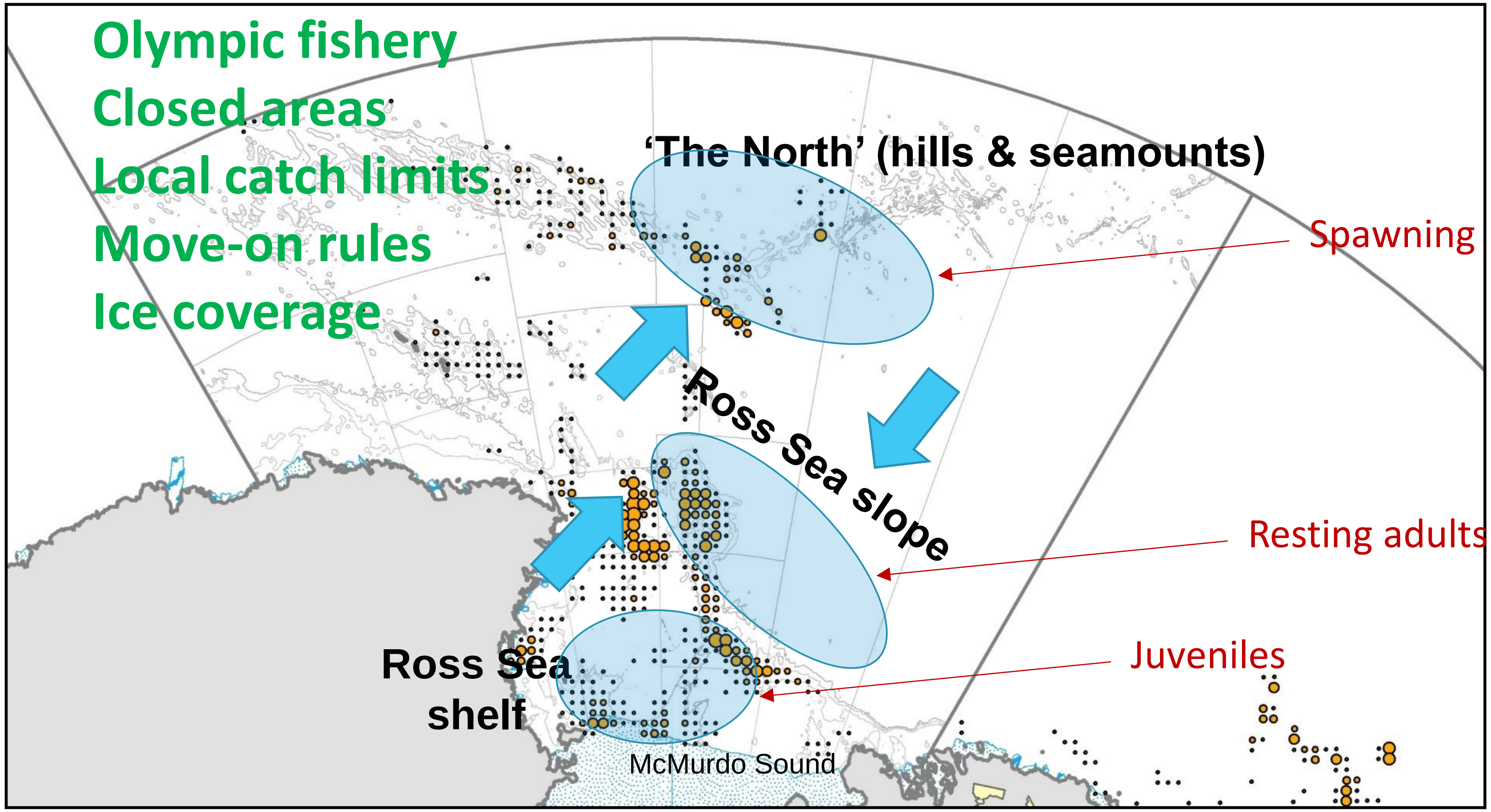


Observations



Environmental data

The Ross Sea toothfish fishery:
A spatially complex system



Also a data rich fishery

- 2 observers per vessel
- Catch and effort data per longline
- On each line 35 toothfish are sampled (length, weight, sex, maturity), 10 otoliths, 10 stomach contents, plus some bycatch
- Extra sampling returned to shore: stomachs, gonads, etc
- For each tonne caught, 1 tag is released:
  ~ 47 000 released and ~ 2700 recaptured

Why a spatial model?

- Initially designed to assess bias of the current stock assessment model (in CASAL) used for management advice
  - Fully Bayesian age-structured model, three areas as fisheries to capture ontogenetic movement and spawning migration, one stock
  - Biomass estimate based on tagging programme
  - Assumes complete tag mixing
  - There are also large variations in fishing practice between years due to ice dynamics
- Concern that this could bias estimates of stock status
- SPM has since been applied to a range of other issues

Why a different approach?

- Spatial models are usually limited to low number of areas (~ 6)
  - Many parameters needed
  - Very data hungry
  - Estimation becomes difficult
  - The case for CASAL models

- But spatial complexity is unavoidable

SPM

- C++ modular software that implements age-structured population processes, within a many-cell spatial domain
  - Model space is a grid of discrete spatial cells
  - Within each cell, records and manages a population structure
    - age by categories (e.g., age by sex, maturity, species, stock)
  - Allows a region to be split into any number of cells
    - Maximum limited by memory and time. Practically ~100-500 cells but we have a case that has ~1600 cells
  - Relatively easy to add additional functionality due to the modular C++ code structure
  - Can fit to a variety of time-specific and spatially explicit observations
  - Open source and freely available: www.niwa.co.nz/fisheries/tools-resources/spm-spatial-population-model

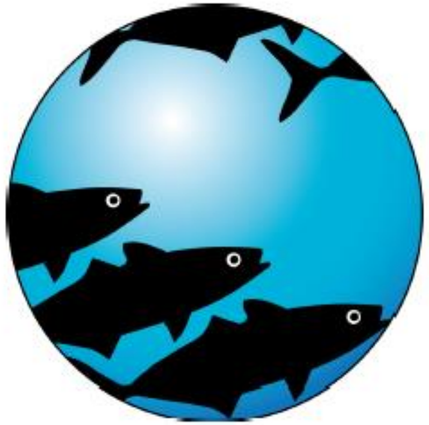
Developing SPM

- Input and observations as text files
  - Replicable, easy to peer review, …

```
# Model Structure
@model
nrows 14
ncols 21
layer Base
categories immature mature prespawning spawning postspawning immature-tag mature-tag prespa
min_age 2
max_age 30
age_plus_group True
initialisation_phases Phase1 Phase2 #Phase3
initial_year 1995
current_year 2013
cell_length 155.4679
time_steps zero one oneb two three
age_size VB VB VB VB VB VB VB VB VB VB

@age_size VB
type von_bertalanffy
size_weight basic
k      0.091
t0    -0.117
linf   174.545

@size_weight basic
type basic
a 1.051e-008
b 3.036

# Initialisation
@initialisation_phase Phase1
years 100
```

Spatial Population Model User Manual

Alistair Dunn, Scott Rasmussen, and Sophie Mormede



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Spatial Population Model User Manual (modified: 2015-11-19)
for use with SPM v1.1-2015-11-19 (rev. 1275)

SPM population processes

- Flexible, generalised population dynamic model that includes a number of standard fisheries population processes
  - Recruitment (local / global)
  - Ageing
  - Growth
  - Mortality (F+M)
  - Maturation
  - Multispecies predator-prey interactions / mortality
  - Layer-based (effort) mortality

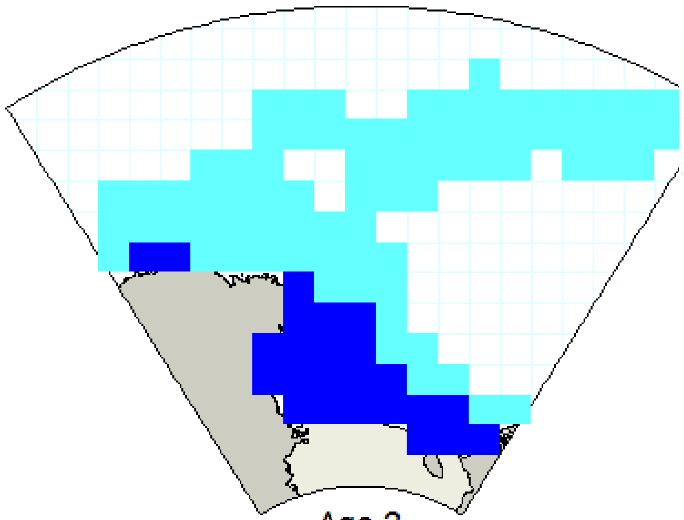
SPM movement processes

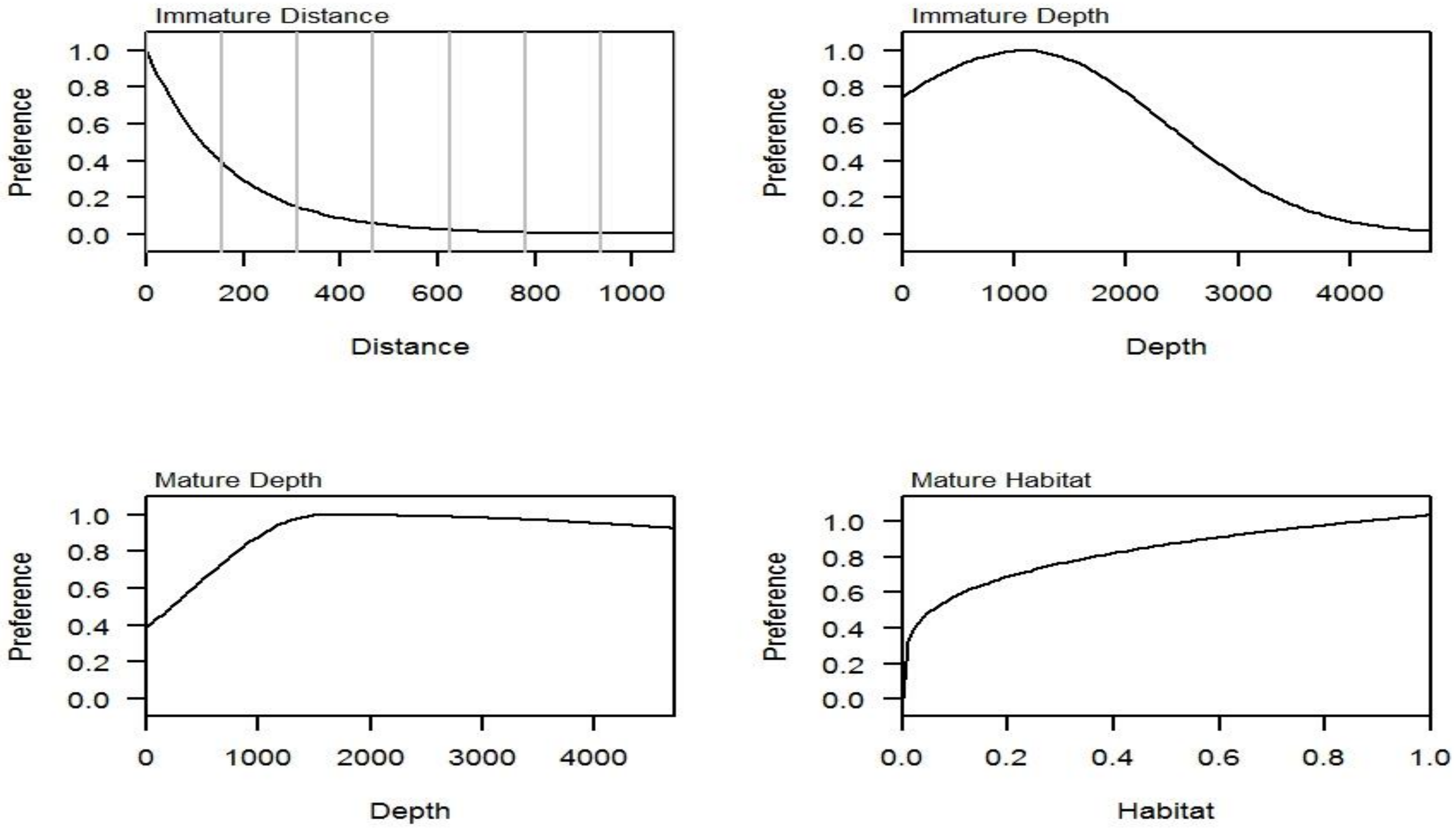
- Three movement functions included
  - Migration from cell *a* to cell *b*
  - A (very) simple diffusion process
  - Habitat preference functions:
    - The spatial distribution of cohorts at any point in time and at any location can be represented as a density function based on attributes of that location, local abundance, and/or distance from their previous location
    - Extended ideas proposed by Bentley et al. (2004) for snapper
    - Allows us to use relatively few parameters to describe complex movement over a large spatial domain

Habitat preference movement

- Movement is driven by habitat based ‘preference functions’
  - We define where each category of fish “prefers” to live
    - For example immature toothfish typically live shallower than 1000m, so we use a preference function that encourages immature fish to move to the correct depth
    - The specific parameters of the function can be estimated within the model from our observations of where fish have been found
- These ‘preference functions’ drive movement between cells
- This approach makes the solution tractable by reducing the number of unknown parameters
  - even so, we still had 34 parameters to describe the movement of immature, mature and spawning fish, maturity and fishing selectivity

Parameterising movement

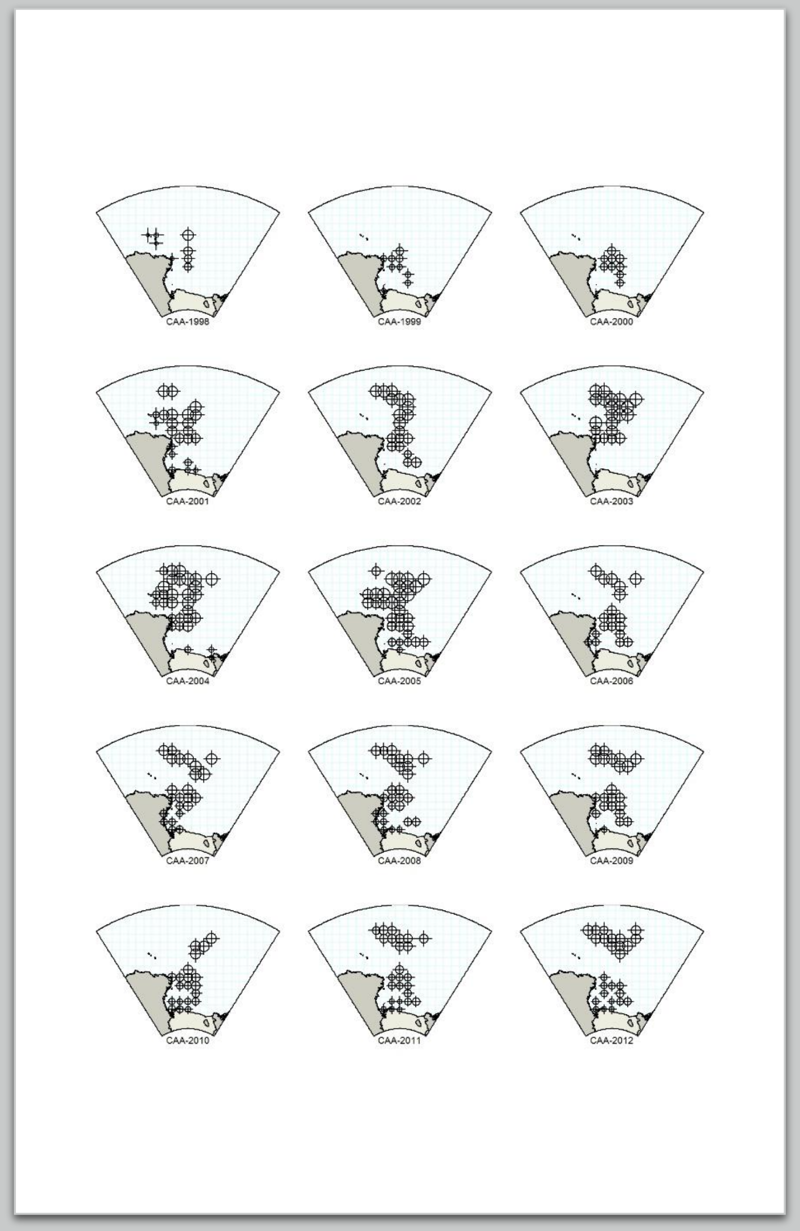




Mormede, S.; Dunn, A.; Hanchet, S.M.; Parker, S. (2014). Spatially explicit population dynamics operating models for Antarctic toothfish in the Ross Sea region. *CCAMLR Science 21*: 19-37.

How did the spatial models perform?

- Fitted the data pretty well in space and time
- Estimated maturity consistent with maturity estimated from histology
    - 50% maturity estimated at 12, measured at 13
- Estimated migration rate consistent with tag and isotope analyses
    - ~ 3 years residence time on the hills
    - ~ 1 year skip spawning when back to mature grounds
- But couldn't estimate movement and B_0 simultaneously

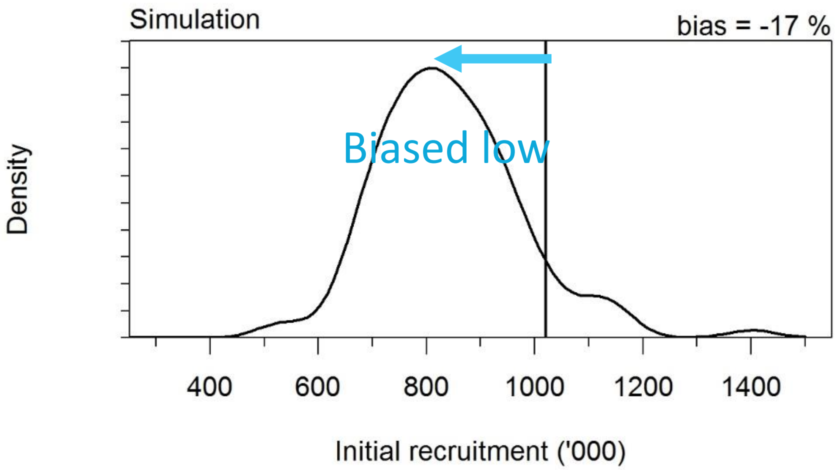


Estimating assessment bias

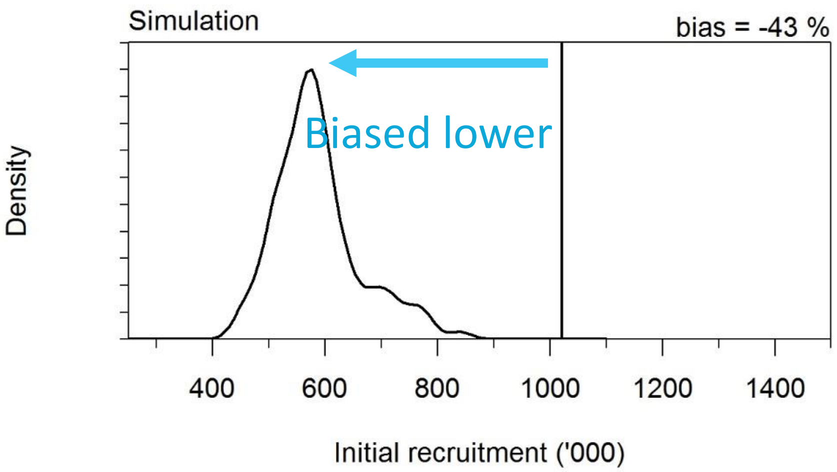
- What is the bias of the current single-area assessment under different movement and spatial extent assumptions?
  - Simulate data from various spatial models with “known” biomass
  - Fit those data in the single-area stock assessment model
  - Compare “known” biomass from the spatial models with the estimated biomass from the single-area assessment model

Estimating assessment bias

- Bias was negative: estimated biomass is 17 to 43% lower than “known” biomass



Assuming a “restricted” population range



Assuming an “unrestricted” population range

Some other uses

- Simulate the impact of spatial management options on the fish stock (MPA)
- Deepwater snapper
- Multispecies modelling
- Risk assessment of benthic organisms
- IOTC tuna model to be built to investigate the bias of the current assessment

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Using spatial population models to investigate the potential effects of the Ross Sea region Marine Protected Area on the Antarctic toothfish population

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ABSTRACT

One aim of Marine Protected Areas (MPAs) is to protect a representative portion of the environment through spatial closures to extractive practices such as fisheries. Although they usually involve the displacement of fisheries, their design rarely takes into account the effect of displacing that fishery on the target fish population. We used a spatially explicit population model of Antarctic toothfish in the Ross Sea region to investigate the effects of the endorsed Ross Sea region MPA on the fishery dynamics and the spatial distribution of the toothfish population. Our study indicates that the MPA will likely improve protection of the juvenile population residing on the Antarctic Shelf, while the number of areas with high levels of depletion is unlikely to increase compared to status quo management. Results also suggested a small increase in the catch limit under the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) harvest management rules, but with a slight reduction in catch rates. We have showed that spatial modelling tools can help inform MPA planning by simultaneously quantifying potential effects on the fish population and the ability to achieve conservation goals.

1. Introduction

Marine Protected Areas (MPAs) are increasingly used as a tool

Spatial analyses are required to understand the biological and financial implications of such closures (Sanchirico 1999). The effects of proposed spatial closures and other spatial manage-

Benthic risk assessment – method development

- To develop Spatial Population Models of biomass trajectory of benthic species based on historical, current and future fishery footprint scenarios

1. Develop spatial distribution layers based on trawl survey data (using VAST)
2. Use fishery trawl footprint as the mortality effect
3. Build into a spatial model as a platform to calculate biomass trajectory and test management plans

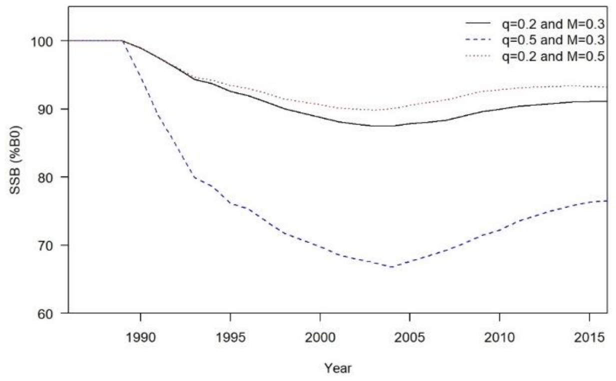
Fishing impact

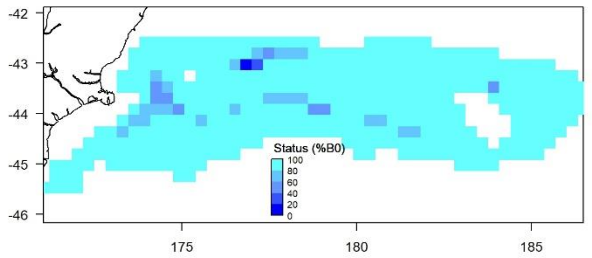
- Can be expressed as the proportion mortality at the cell level

$$I = 1 - \sum_{trawls} (1 - f_t \times s_F)$$

- Needs an assumption of species susceptibility s_F per fishery type F
  - Assume 0.1 (bottom trawl) and 0.8 (scampi) as example
  - Might be able to estimate those parameters using SPM

- Need trawl footprint trawl by trawl f_t
  - Here use total footprint (need to expand SPM further to tow by tow data)





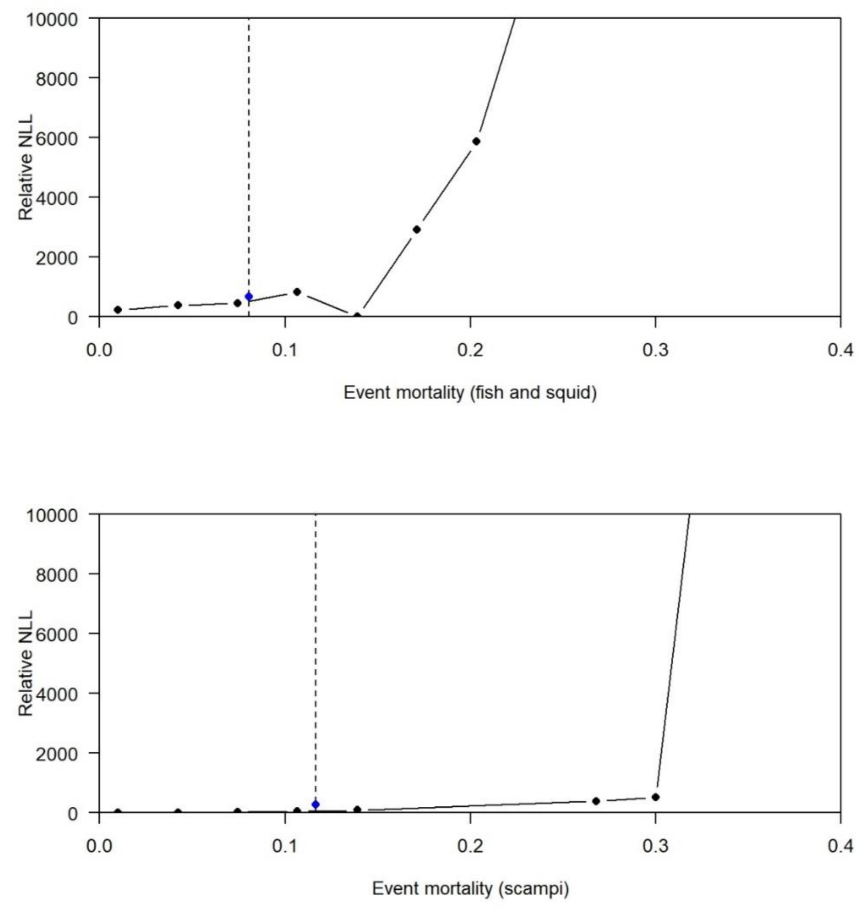
Results – as a simulator

- Can evaluate different biomass trajectories given different assumptions
  - R_0 estimated by the model, localized depletion calculated over time
  - Change trawl mortality (susceptibility) U_{fish} and U_{scampi} , survey catchability q, natural mortality M give alternative scenarios

Results – as an estimator

- Poor estimator of susceptibility at MPD level
    - Profiles on the right
    - Higher values are unlikely
    - The two values are independently estimated (not shown)
  - These depend upon values of *q* and *M*

- At MCMC level seems to be many local minima



Conclusions

- Its takes time and effort to construct good models
  - SPM helps apply spatial models to new applications quickly
  - There's many applications for which we should consider spatial structure

- We're still learning
  - how these models behave
  - what approach represents "good practice"
  - model deficiencies and when they may mislead us
  - how to plot and interpret diagnostics

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- Scott Rasmussen was responsible for the model C++ code development
- Darcy Webber, Spatial Complexity in Stock Assessment. PhD, Victoria University of Wellington
- Development of the Antarctic Toothfish spatial model was assisted by members of Ministry for Primary Industries Antarctic Working Group

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Thank you

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