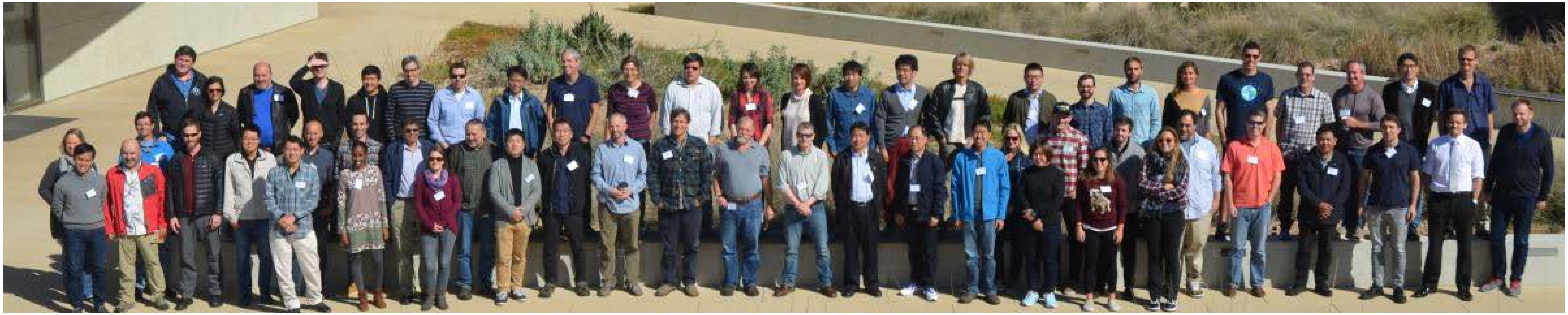
Comisión Interamericana del Atún Tropical
Inter-American Tropical Tuna Commission

Spatio-temporal modelling of fishery dependent data: its difficult

Mark Maunder
IATTC
(Jim Thorson)

2018 CAPAM Spatio-temporal modelling Workshop and special issue



http://www.capamresearch.org/Spatio-Temporal-Modelling-Mini-Workshop

CIAT IATTC

IATTC Workshop to improve the longline indices of abundance of bigeye and yellowfin tunas in the eastern Pacific Ocean

Outline

- CPUE is proportional to abundance
- Spatio-temporal modelling
- Exploring the forth dimension
- Issues
- Examples from fishing in New Zealand

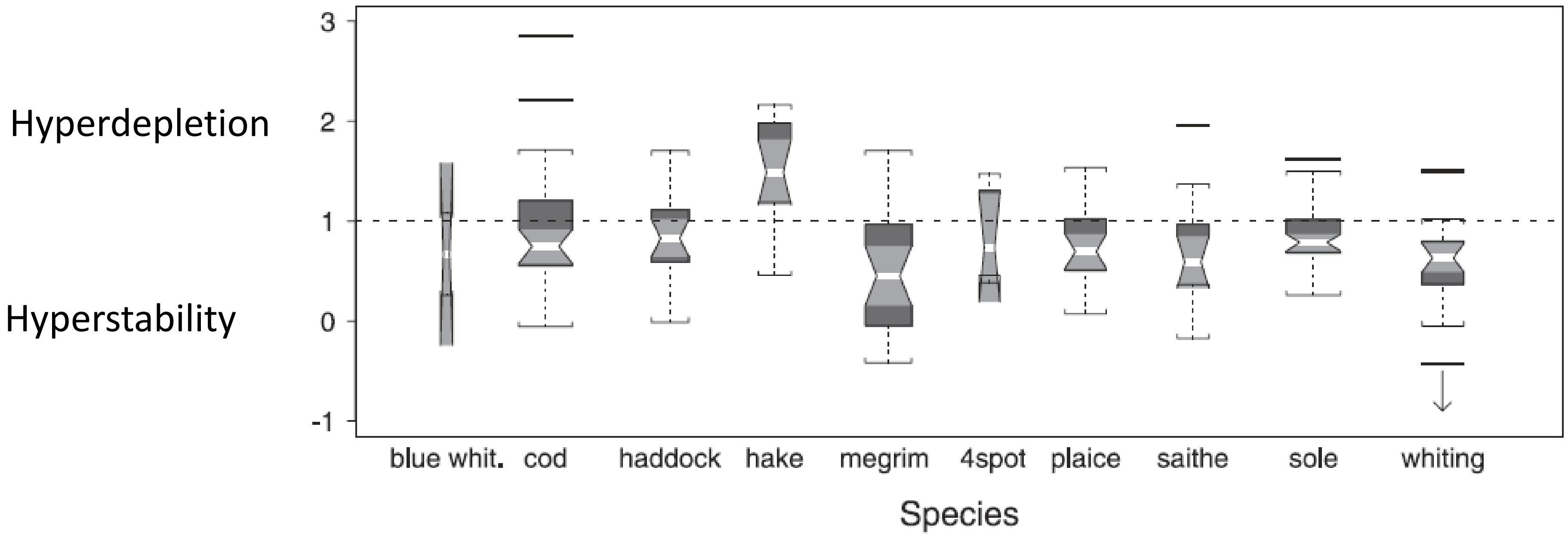
CPUE issues: CPUE is proportional to abundance

$$\frac{C_t}{E_t} = qN_t$$

Catchability is constant over time

CPUE issues: Hyperstability

Fig. 3. Summary of shape parameter β by species, age, and gear type. The boxplots show the limits of the middle half of the data (the line inside the box represents the median). The amount of data is shown as the width of the boxes that are proportional to the square root of the number of data points. The notches are the approximate 95% confidence intervals of the median. If the notches on two boxes do not overlap, this indicates a difference at a rough 5% significance level. The upper quartile and lower quartile provide the outline of the box. Whiskers are drawn to the nearest value not beyond 1.5(interquartile range) from the quartiles; points beyond are drawn individually as outliers. The arrows indicate the outlier with $\hat{\beta} = -3.23$ (details given in text). Details of the species and gear types are given in Tables 1 and 2, respectively.



Harley, S. J., Myers, R. A., and Dunn, A. 2001. Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisheries and Aquatic Sciences, 58: 1705-1772.

CPUE issues: factors that cause q to change over time

- Change in the efficiency of the fleet
  - Learning about the location and behavior of fish, or how to operate gear
  - New technology
- Changing target species
- Dependent on how effort is defined
  - Number of sets (school size proportional to abundance?)
  - Days fished
  - Vessels
- Environmental cycles and trends
- Dynamics of the population
  - Fish aggregations make it easy to find them when abundance is low
- Dynamics of the fishing fleet
  - Spatial expansion/contraction of the fleet (catchability related to whole population)
- Management measures
  - Spatial closures, gear limitations, catch quotas, size limits
- Other factors
  - Depredation, gear saturation, gear interference, misreporting, stock structure (e.g. harvesting multiple stocks together, or fishing only a small portion of a stock), capture of more vulnerable individuals in initial stages of the fishery, age- or size-specific selectivity, individual variability in natural mortality

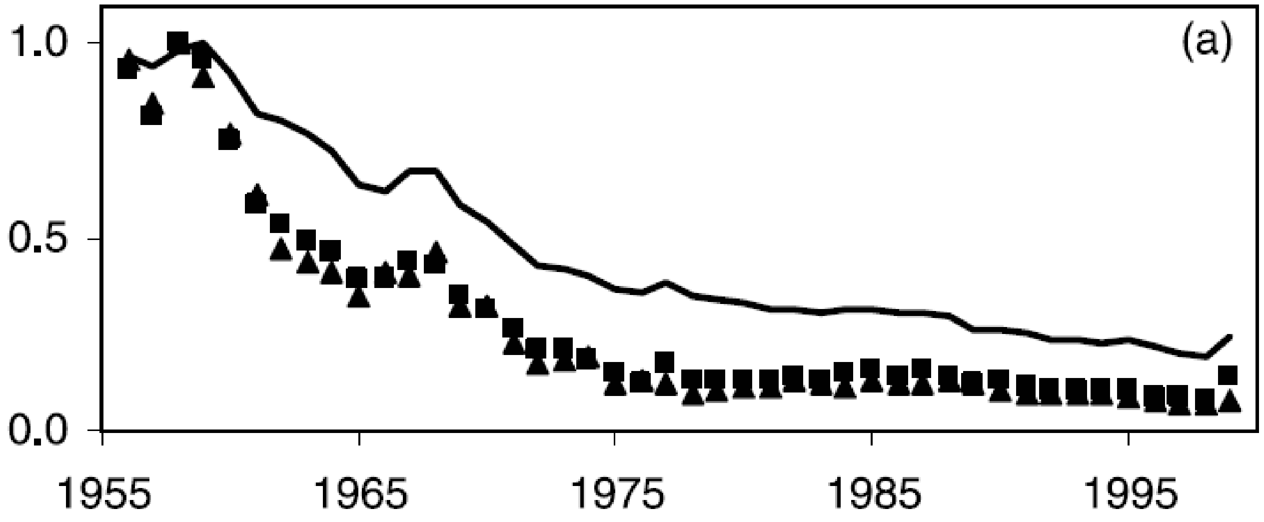
CIAT IATTC

CPUE issues: what portion of the stock does the CPUE relate?

- The proportion of the population that is vulnerable to the fishery depends on horizontal and vertical distribution of fish
- Distribution can depend on size, gender, stage, etc.
- Impact depends on the overlap of spatial distribution of fishing fleet and the fish population and how it changes over time

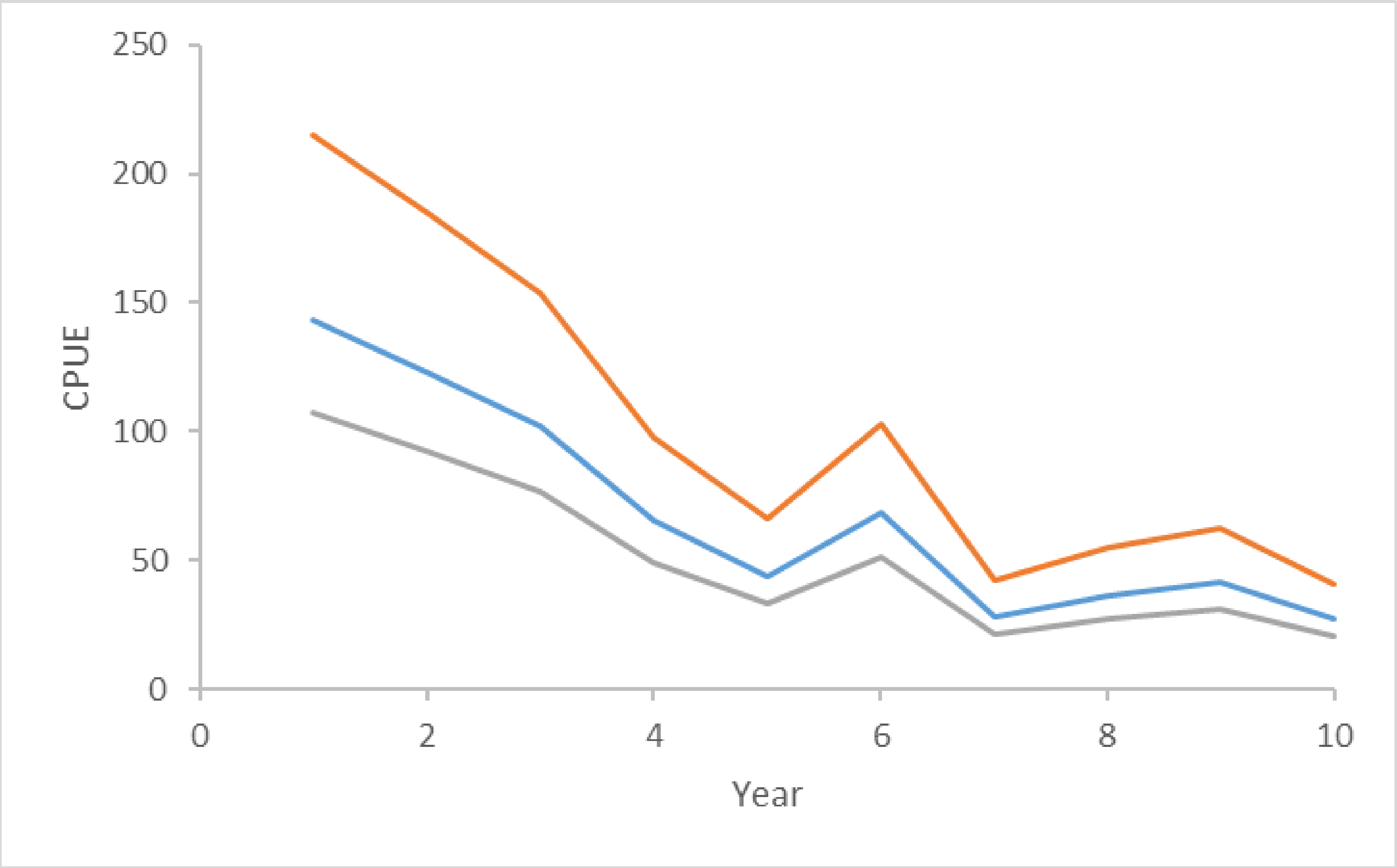
CPUE issues: Hyperstability

Fig. 1. Catch per unit effort (CPUE) trends for large tuna and billfish (total number of fish per hook) from the 5 × 5 degree cell Japanese long-line database (Myers and Worm 2003), estimated by three alternative methods for (*a*) Atlantic, (*b*) Pacific, and (*c*) Indian oceans. Full spatial (solid line) assigns mean of first three observed catch rates to each cell for years before it was first fished and the last observed catch rate for years after it was last fished. Restricted spatial (▲) is the mean catch rate over only those cells that were actually fished each year. Ratio (■) is simply total catch summed over all cells divided by total effort.

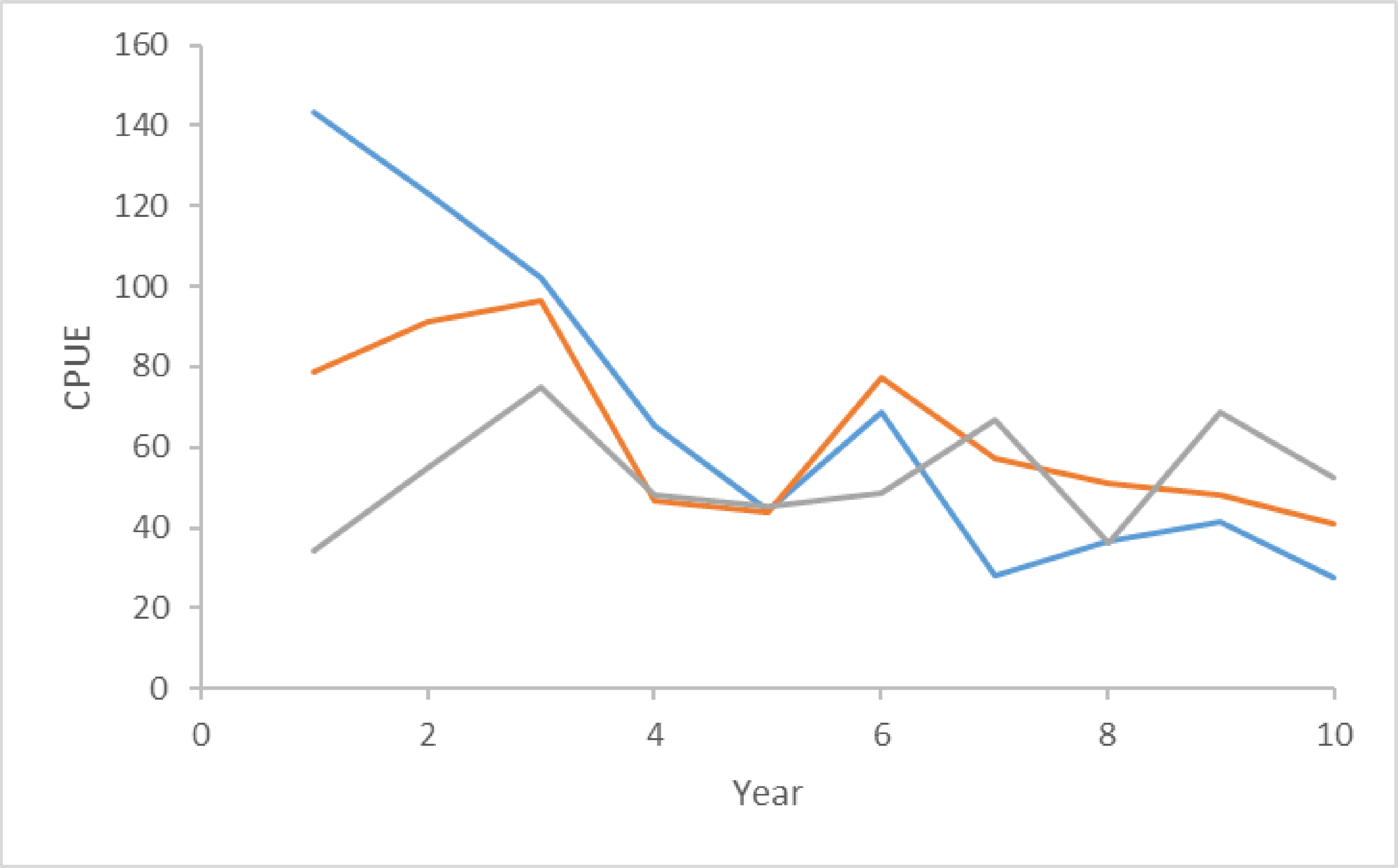


Walters, C. J. 2003. Folly and fantasy in the analysis of spatial catch rate data. Canadian Journal of Fisheries and Aquatic Sciences, 60: 1433-1436.

CPUE issues: GLM area main effect



CPUE issues: GLM area year interaction



CPUE issues: GLM area year interaction

- Area weighted average
- Treat each area as a separate population
- Model a meta-population
- Something more sophisticated that deals with space

Spatio-temporal modelling

- Fill in empty space/time cells or augment cells with low sample sizes
- Share information across space and time

- The year effect from a GLM is data weighted
  - Areas with more data get more weight
  - Fish in areas with high CPUE (preferential sampling)
  - Index of relative abundance should be generated by summing up abundance in each area (area weighting)

Spatio-temporal modelling: methods

- Conditional Autoregressive model
- Simultaneous Autoregressive model
- Kriging
- Gaussian random fields
- Flexible generalized additive (mixed effect) models
  - 3D tensor product smooth terms
  - Soap film smoothers
- Machine learning techniques (maxEnt, random forests, etc)

- All are just smoothing over space and time
- Sharing information
- Method is probably less important than other choices

CIAT IATTC

Spatio-temporal modelling: missing at random

1	0	1	1	1	0	0	0	1	1	0	0	1	1	1	0	0	0	1	1	0	1
1	1	1	1	1	1	1	0	0	0	0	1	1	0	1	1	0	1	0	1	0	0
1	1	0	1	1	0	0	1	1	0	0	1	1	0	0	0	0	1	1	1	1	1
0	0	1	0	0	1	0	0	1	1	0	0	1	1	0	0	0	1	0	0	0	0
0	1	0	1	0	1	1	0	1	0	0	0	1	0	1	0	1	0	0	0	0	1
0	0	0	1	0	0	0	1	0	1	1	0	1	0	0	0	1	0	0	1	0	0
1	1	0	0	0	1	0	1	1	1	0	0	1	1	0	0	0	0	1	0	0	0
0	0	1	1	0	1	1	1	0	0	0	0	1	1	1	1	1	1	1	0	0	0
1	1	0	0	1	0	1	0	0	0	0	0	1	0	1	0	1	1	1	1	0	1
1	0	1	1	0	1	0	0	1	0	0	1	1	0	1	1	1	0	0	1	1	1
1	1	0	1	0	1	0	0	1	0	0	0	1	0	0	0	1	0	0	1	1	0
0	0	0	0	1	1	1	0	1	0	1	0	0	1	0	1	1	0	1	0	0	0
1	1	0	1	1	0	0	0	1	1	1	1	0	1	1	1	1	1	0	0	1	0
1	0	0	1	0	1	0	0	1	0	1	0	1	0	1	1	1	0	1	1	1	1
0	1	0	0	1	1	1	1	0	1	1	0	0	1	0	0	1	1	0	1	0	1
0	0	1	0	1	0	0	1	1	1	1	0	1	0	1	1	0	0	0	1	1	0
0	0	1	1	1	1	0	1	1	1	0	0	1	1	0	0	0	0	1	1	0	1
0	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1
1	1	1	0	1	1	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0
1	1	0	1	0	1	1	0	0	0	1	0	1	1	0	0	1	0	0	0	0	1

Spatio-temporal modelling: missing on the edges

0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	0	0	0	0	0	0	0
0	0	0	0	0	1	1	0	0	1	0	1	1	1	0	1	0	0	0	0	1	1
0	1	1	1	0	0	0	1	1	1	0	0	0	0	0	0	1	1	0	0	1	1
0	0	1	0	1	0	0	0	1	1	0	1	0	0	0	1	1	0	1	0	1	1
1	0	0	0	1	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	1	0	0	1	1	1	0
1	0	0	0	0	1	1	1	0	0	0	1	0	1	1	1	0	0	1	0	1	1
1	0	1	1	1	1	0	1	0	1	1	1	0	1	1	0	1	1	1	1	1	1
0	1	1	0	0	0	1	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0
0	0	1	1	0	1	1	1	1	0	0	1	0	0	1	1	1	0	1	0	0	1
1	1	1	0	1	0	1	0	0	1	0	1	0	1	0	0	1	1	1	0	0	0
1	0	0	1	1	0	1	1	0	1	1	0	1	1	0	0	1	1	1	1	1	1
0	1	0	0	1	0	0	0	1	0	1	0	0	1	1	1	1	1	0	1	1	1
0	1	0	1	1	0	1	0	0	1	0	1	1	1	0	1	0	1	1	1	1	1
0	1	0	1	1	1	1	1	0	1	0	1	1	1	1	0	0	0	0	1	0	0
0	0	0	1	0	1	1	0	0	0	0	0	1	1	0	0	1	0	1	0	0	1

Spatio-temporal modelling: missing in patches

1	1	0	0	0	0	0	0	1	1	1	1	0	0	1	0	1	0	0	1	1	1
0	1	1	0	0	0	0	1	0	1	1	1	1	0	0	0	0	0	0	1	1	0
0	1	1	0	1	0	0	0	1	1	1	0	1	1	1	1	0	0	0	1	1	1
0	0	0	0	1	1	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	1
1	1	1	0	1	1	1	1	0	0	0	0	0	0	1	1	0	0	1	1	0	1
1	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	1	0	0
1	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	1	0
1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0
1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0
1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0
0	1	1	1	1	0	0	0	0	0	0	1	0	0	1	1	1	1	1	1	0	1
0	0	1	1	0	1	0	0	1	0	1	1	1	1	1	0	1	0	0	1	1	1
1	0	1	1	1	0	0	0	1	1	1	0	1	1	1	1	0	0	1	1	1	1
1	0	1	0	1	1	0	1	1	0	0	0	1	0	0	1	0	1	1	1	1	0
0	1	1	0	0	0	0	1	1	1	0	0	1	1	0	0	1	0	0	1	1	1
1	0	1	0	0	0	0	1	1	0	0	0	1	1	0	1	0	0	0	0	0	0
1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	0	1	0	0	0	0	0
0	0	0	1	1	0	1	1	0	0	1	0	0	0	0	0	1	1	0	0	0	1

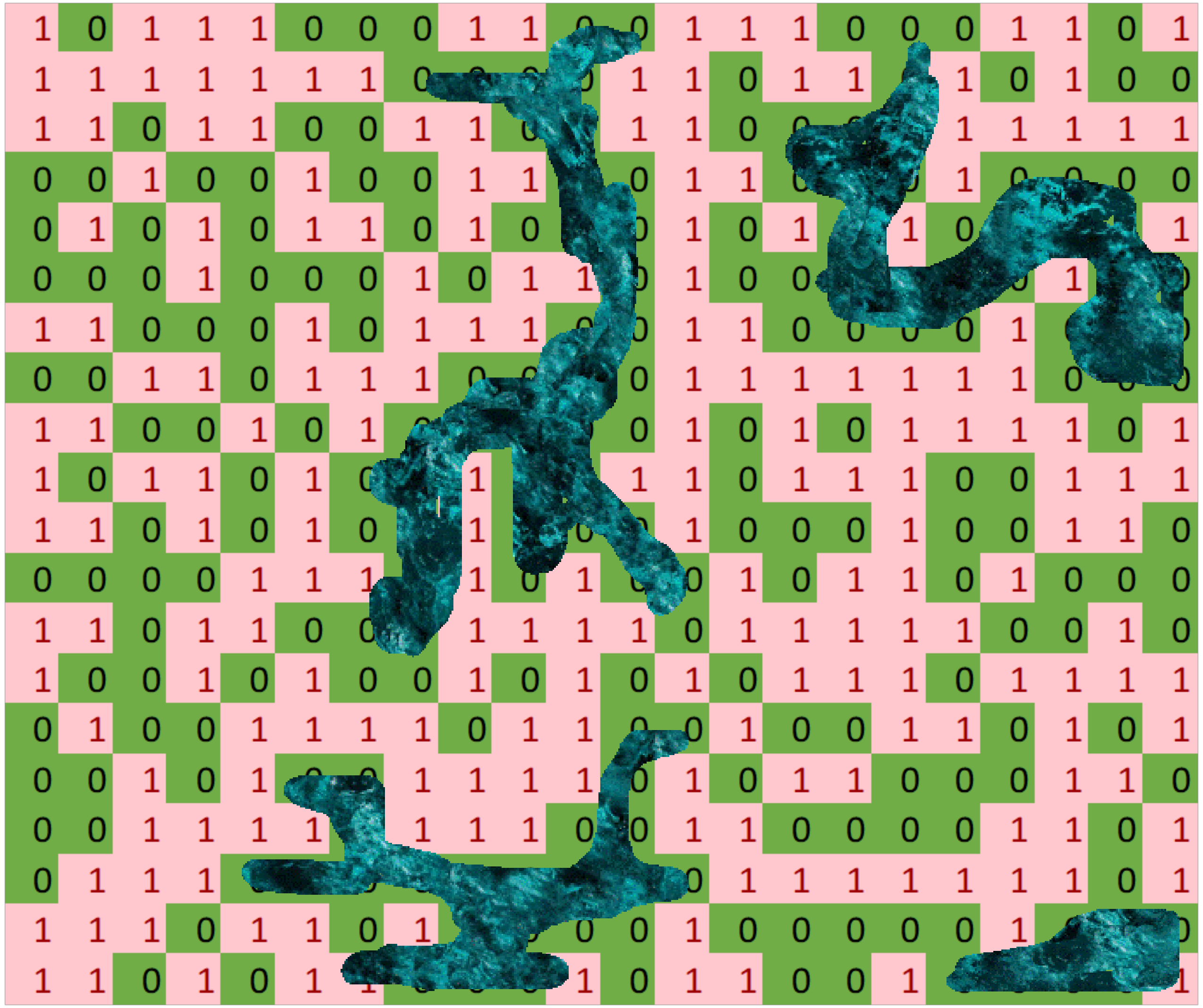
Spatio-temporal modelling: missing data

- Big gaps
  - Covariates
    - But assumes rapid mixing
    - Exploitation will keep abundance lower in fished (sampled) areas compared to unsampled with the same value of the covariate
  - Mechanistic models
  - Other science

Density vs catchability

- Separate effects into population density (e.g. spatio-temporal effect) and catchability (e.g. gear type)
- Density used to create index of relative abundance
- Complication: habitat could attract less fish or could make it harder to catch the fish

Spatio-temporal modelling: missing at random?



Spatio-temporal modelling: Testing

- Cross validation
- Use time period with wide spatial coverage
- Remove edges or patches
- Sample
- Preferential sampling

- Do it on lots of survey data sets

Exploring the forth dimension

- Depth
  - Temperature and oxygen preferences
  - Depth of gear (e.g. hooks between floats)
- Size, age, sex, stage, ….
  - Do they differ
  - Are they correlated or should they be modelled separately
- Increases the computational demands

Spatio-temporal modelling of composition data

- Both catch and the CPUE index of abundance use the age/length composition data to estimate selectivity
- “selectivity” in the stock assessment model does not simply represent contact selectivity, but also availability, which is a consequence of the spatial structure of the fleet relative to the stock.
- Fishery catch is not necessarily distributed spatially in proportion to abundance.
- In cases where the size composition differs among areas, the “selectivity” in the stock assessment model for the fishery-dependent index and the fishery catch could be different.
- Model the spatio-temporal distribution of the length composition
- Use catch weighted for the catch and density weighted for the index of abundance

CIAT IATTC

Spatio-temporal modelling: length composition

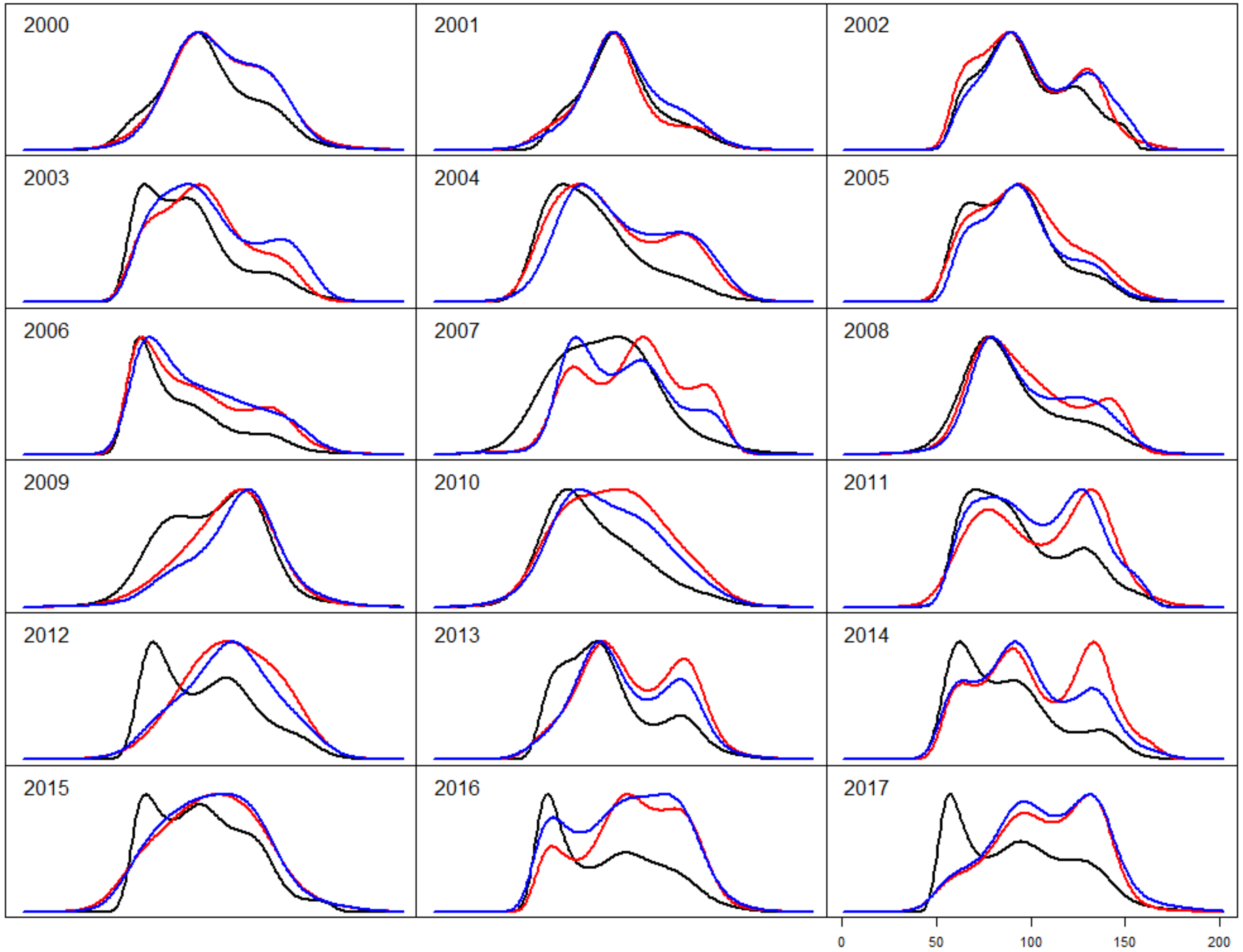


Figure 5. Length composition of the yellowfin catch calculated by the three different methods. Black = data weighting (each well sampled is given equal weight), red = spatial weighting by CPUE, blue = spatial weighting by catch.

Species targeting: multi-species model

- Latent variables
  - Habitat: Each spatial cell
  - Gear targeting: each set
- Different coefficient for each species

$$\ln(y_{j,i}) = \beta_j \varepsilon_i$$

$$\varepsilon_i \sim N(0, \sigma^2)$$

For species *j* and set or cell *i*

Thorson, J. T., Fonner, R., Haltuch, M., Ono, K., and Winker, H. 2016. Accounting for spatiotemporal variation and fisher targeting when estimating abundance from multispecies fishery data. Canadian Journal of Fisheries and Aquatic Sciences, doi: 10.1139/cjfas-2015-0598.

CIAT IATTC

Species targeting: multi-species model

- How is targeting defined (set, trip, …)
- Cluster analysis of multiple species catch
  - Include cluster effect or eliminate non-targeting data
- Habitat
  - Space
  - Space*Time
  - Confounding with spatio-temporal model
- Do other species provide enough information about spatial abundance compared to species of interest? Good for protected species

Combining fleets

- Combining commercial dolphin sightings with the marine mammal survey in the EPO
- Combine fleets of different countries to expand coverage
  - Japan and Korean longline data
  - Different catchability
  - Selectivity
  - Need overlap

Fishing in New Zealand

- Snapper in the Firth of Thames

- Yellowtail (kingfish) at the mussel farm

- Trout in Lake Tarawera

Snapper in the Firth of Thames

Snapper in the Firth of Thames

Yellowtail at the mussel farm

Yellowtail at the mussel farm

Yellowtail at the mussel farm

Yellowtail at the mussel farm: the end buoy

Yellowtail at the mussel farm

Yellowtail at the mussel farm

CIAT IATTC

Yellowtail at the muscle farm: the recipe for success

- Summer
- Light wind or not against tide
- Incoming tide preferably
- Mid to nearly high tide (buoys partly or fully under water)
- Current going into the buoys
- The end farm
- The buoys furthest offshore
- Cast at (and hit) the end buoy in the line

Fishing the drop-off for trout in Lake Tarawera

Fishing the drop-off for trout in Lake Tarawera

Spatio-temporal modelling

- Spatial patterns are complex, particularly with fishery dependent data
- They differ among stocks
- Correlation changes with space
- Correlations are Anisotropic
- Catchability has a big impact on fishery dependent data

Correlation changes with space (and time)

- Examples
  - Temperate vs tropical
  - Coastal vs off shore
  - Rocks vs sand
- Filling in the edges and patches requires correlation
- Divide by correlation pattern and analyze separately?

Thank you.

See the CAPAM workshop at http://www.capamresearch.org/Spatio-Temporal-Modelling-Mini-Workshop

Other issues

- Increased vessel efficiency
  - Model catchability using covariates
  - Vessel effect
    - Random vs fixed effect
    - Accounts for old vessels dropping out and new vessels
    - Does not account for vessels improving equipment
- Targeting
  - See later
- Preferential sampling
  - Thorson's Postdoc John Best is dealing with this
- Computational demands
  - Efficient algorithms (TMB)
  - Parallel processing
- Data weighting
  - Sample size
  - Equal for each spatial cell

Spatio-temporal mark-recapture model for tag mixing

- Tagging randomly is difficult
- Need to wait until tags mix
- Model the population abundance (N) with a spatio-temporal model
- Model the tag dispersal with an advection diffusion model
- Fit to observed catches by area using capture probability based on C/N by area