Accounting for spatial structure in length-and-age-based stock assessment models: An example from South Australia

SOUTH AUSTRALIAN RESEARCH & DEVELOPMENT INSTITUTE
PIRSA

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CAPAM – spatial structure workshop

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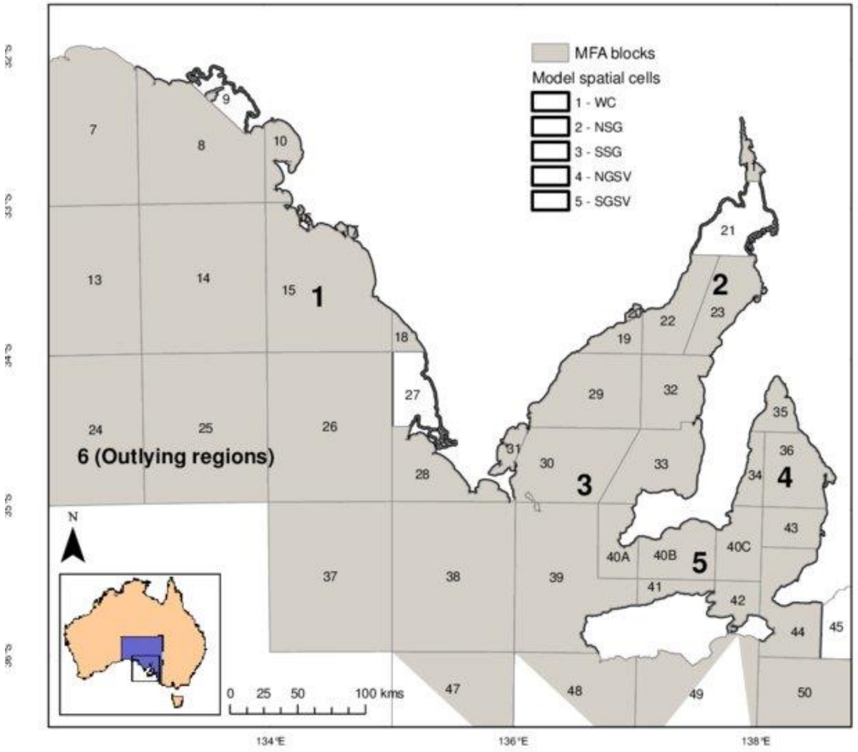
Outline

- King George Whiting (KGW) SA fishery
- Stock assessment model structure
- Slice partition formalism
- Movement submodel
- Stock Assessment outcomes
- Conclusions

Marine Scalefish Fishery (MSF)

- Multi-species, multi-gear, multi-area fishery
- Spans entire coastline of South Australia
- Stock assessments performed for three primary species:
  - King George Whiting (*Sillaginodes punctatus*)
  - Southern Garfish (*Hyporhamphus melanchoir*)
  - Snapper (*Chrysophrys auratus*)



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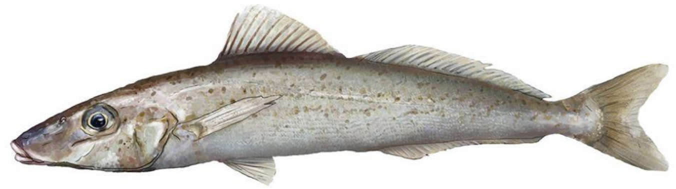

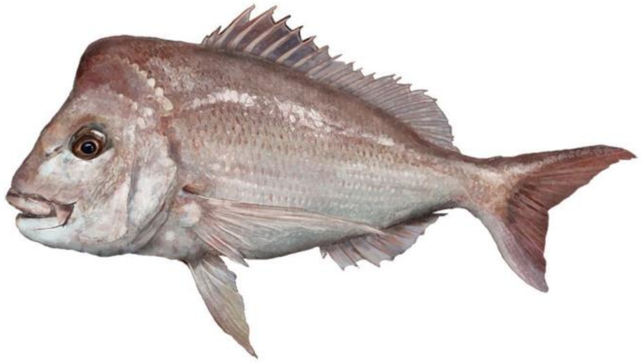

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King George Whiting (KGW) in South Australia

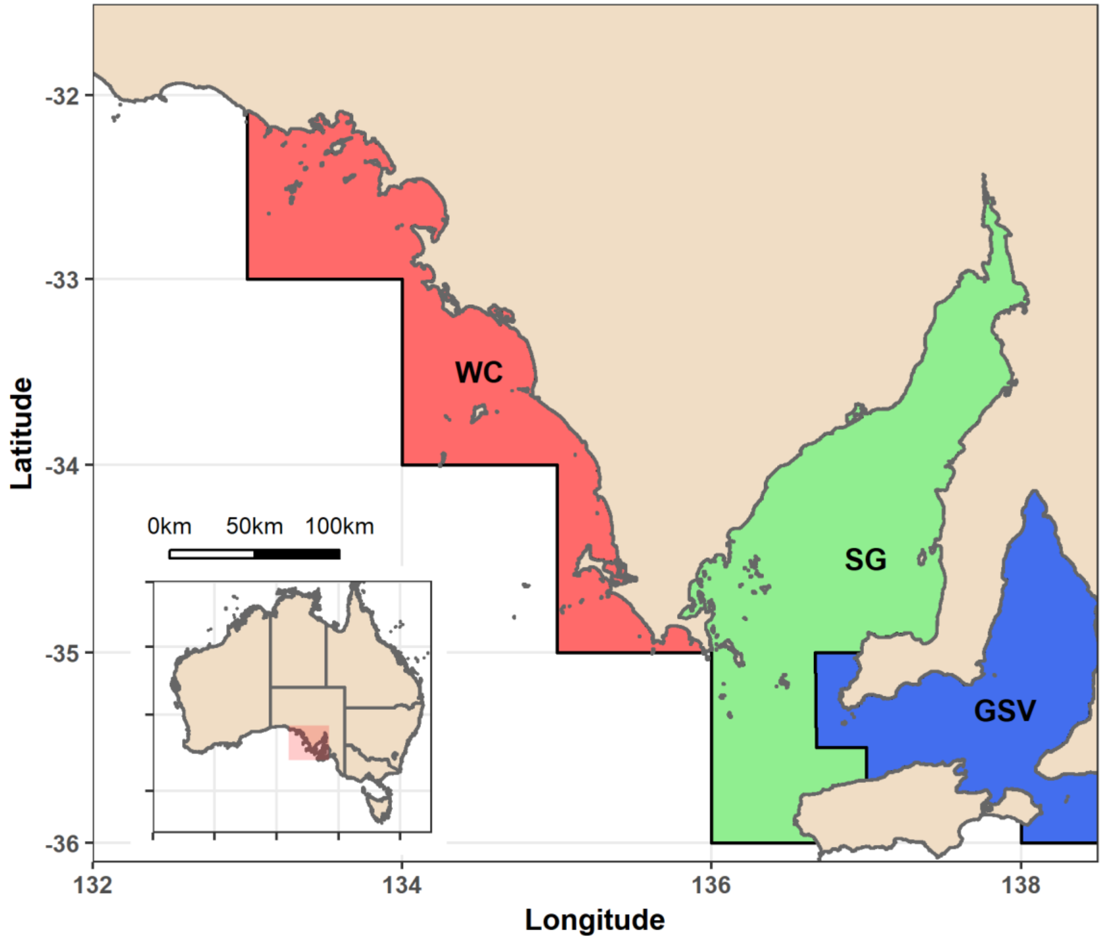
- Highest value fish by weight in South Australia

- Taken by several gear types:
  1. Hand line
  2. Haul net
  3. Gill net

- Three spatial regions:
  1. West Coast (WC)
  2. Spencer Gulf (SG)
  3. Gulf St Vincent (GSV)

- Managed by:
  – Legal minimum size (region specific)
  – Limited entry
  – Gear restrictions
  – Seasonal closures on spawning grounds

- Complex life history – ontogenetic migration



Stock Assessment Model

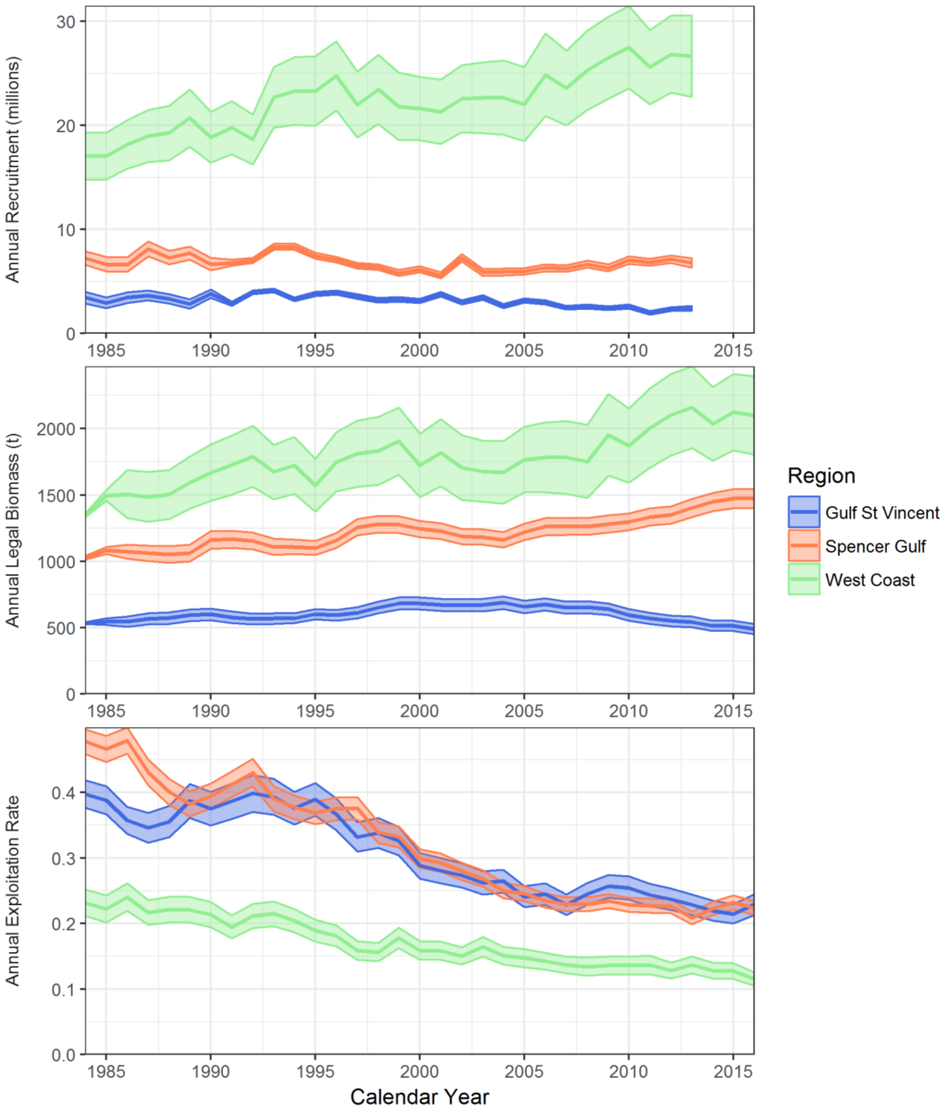
Model fits to:

- catch totals (kg)
- catch proportions-at-age-and-sex
- recreational survey data.
- Tag-recapture movement rates

Estimates key performance indicators for stock status :

- Annual harvestable biomass
- Annual harvest fraction
- Yearly recruitment.

Recruitment is a free parameter – no stock recruitment relationship



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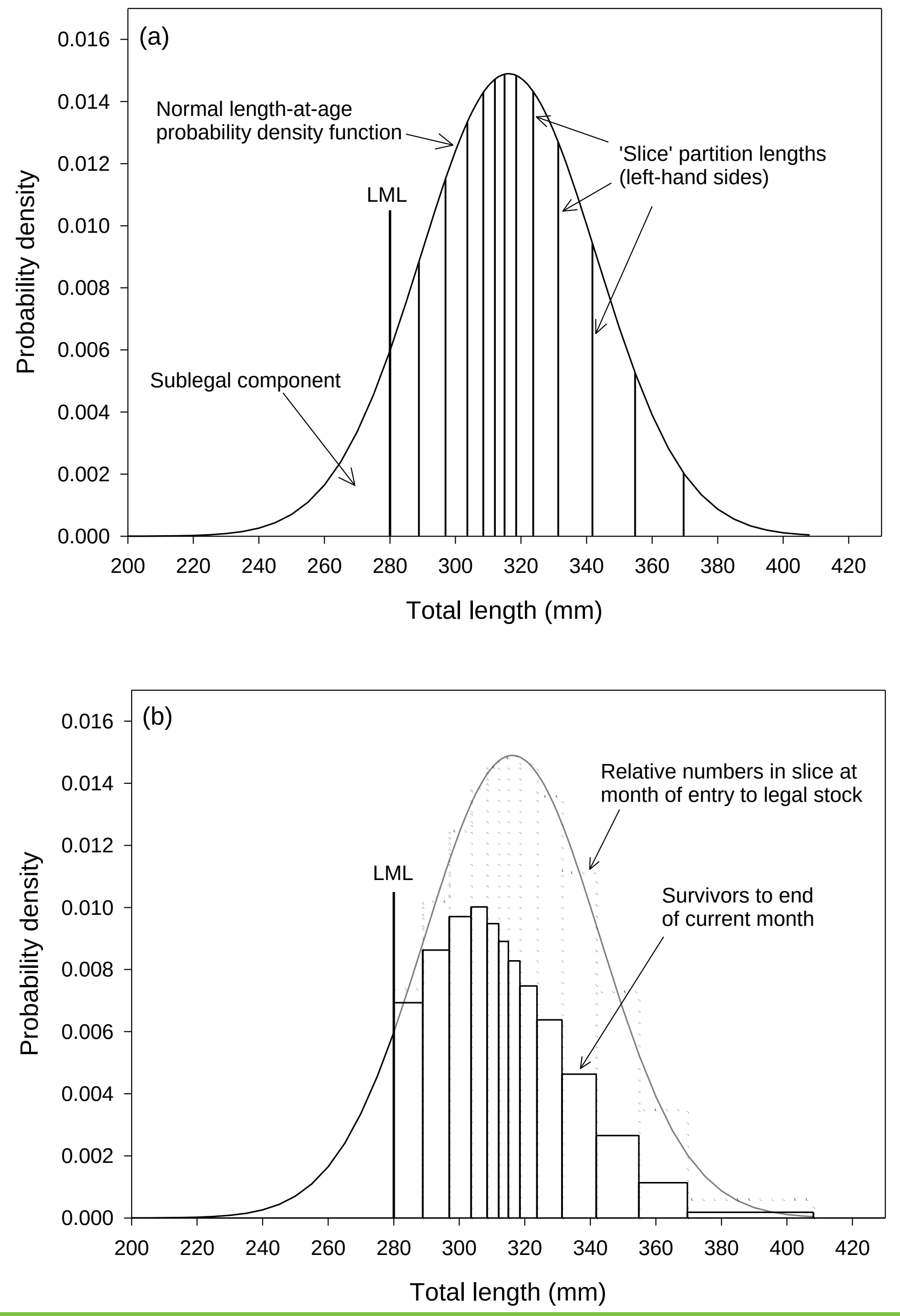
Model structure

- Monthly time steps
- Effort conditioned
- Population numbers broken into:
  - month
  - region
  - sex
  - cohort
  - length bin ('slice') within each cohort

Main reference: McGarvey R, Feenstra JE, Ye Q. 2007. Modeling fish numbers dynamically by age and length: partitioning cohorts into 'slices'. Canadian Journal of Fisheries and Aquatic Sciences 64: 1157-1173



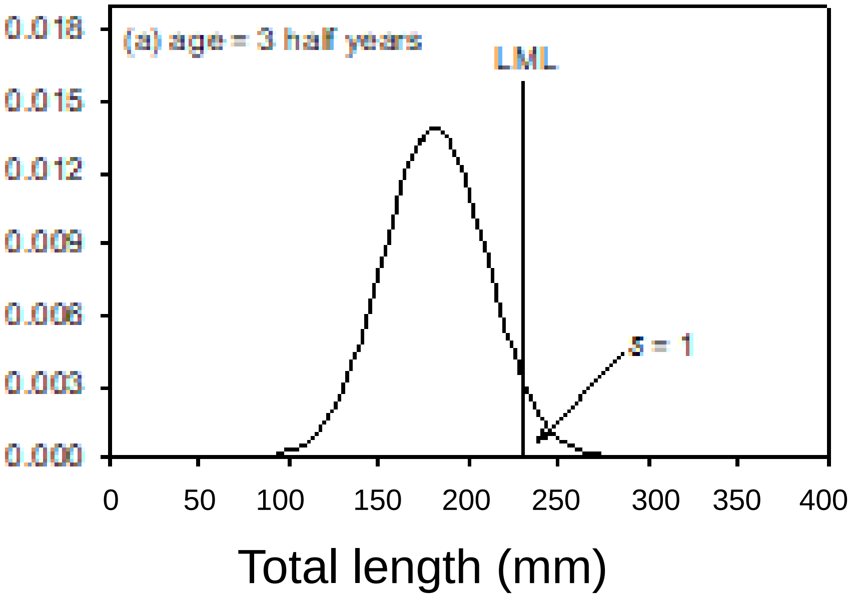
Slice Partition Approach: How does it work?

- Within each cohort length is normally distributed

- At each time step, we compute the proportion of the cohort that grown above legal size

- These slice proportions are all we need to implement a length- and age-based model

- Better account for individuals lost through mortality and either lost or gained via movement



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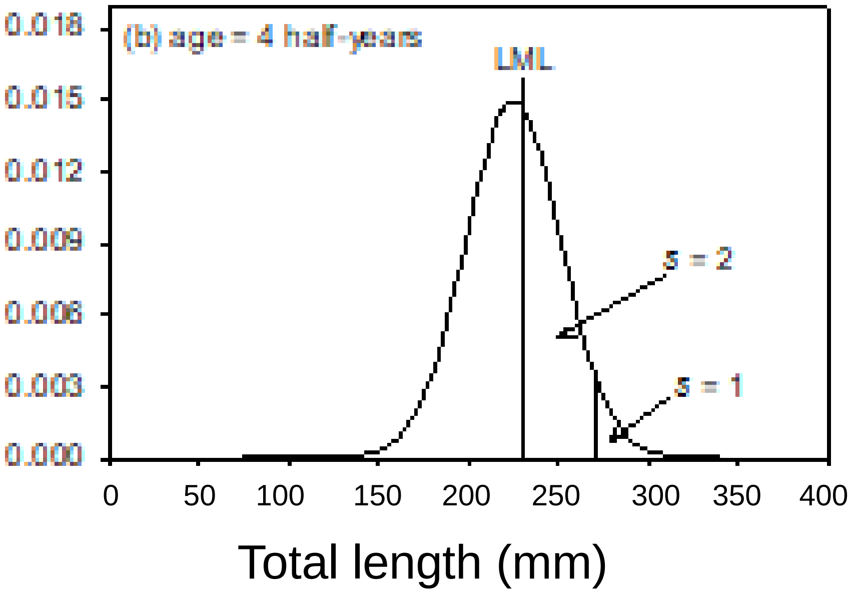

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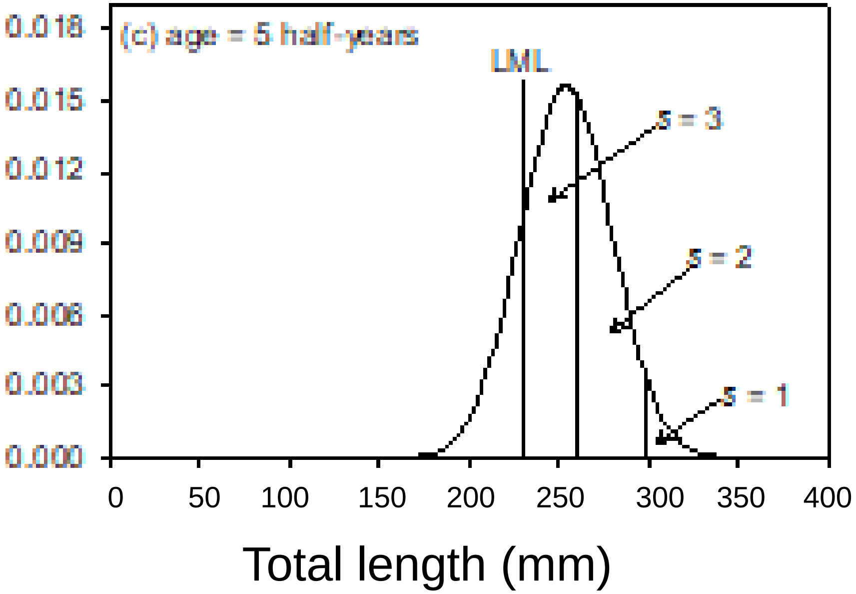

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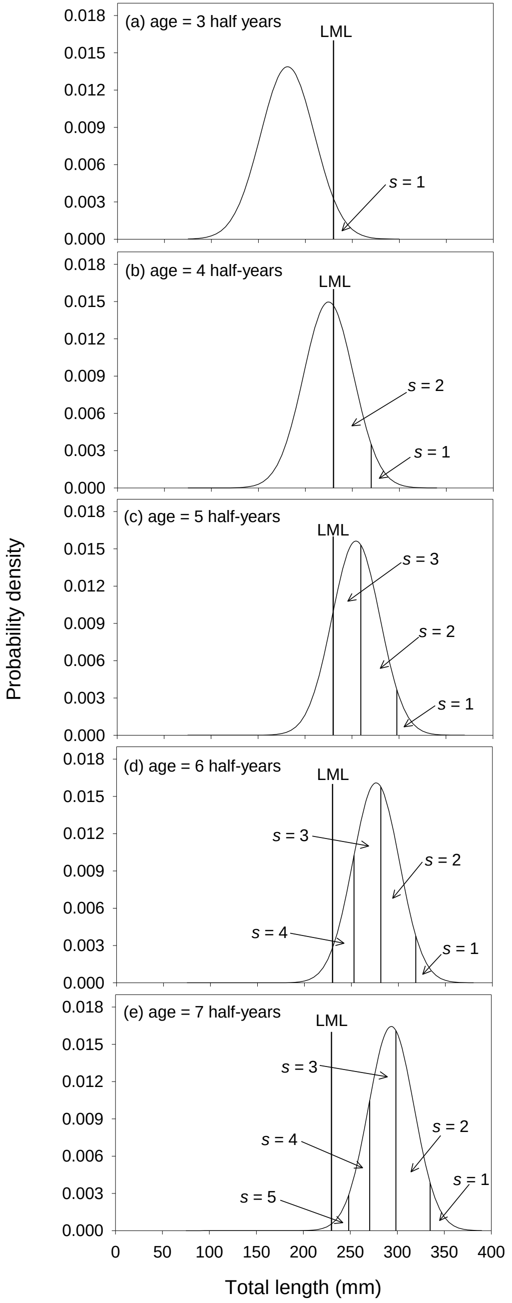
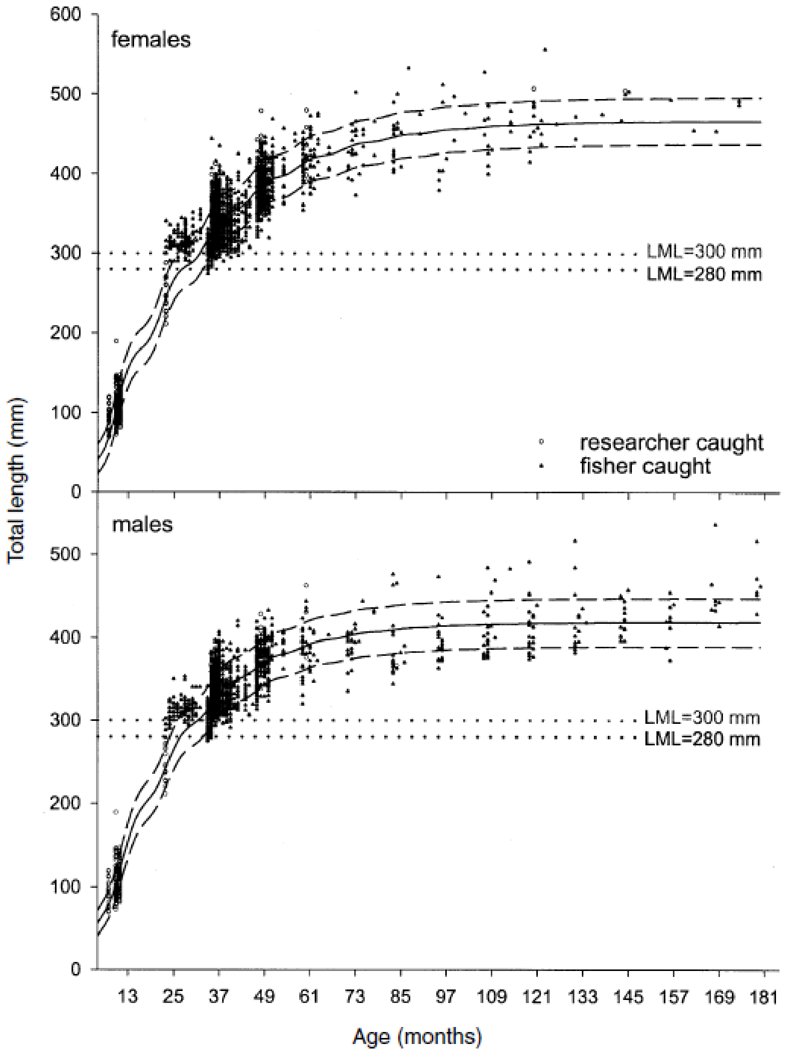
Slice Partition Approach: Advantages

- Differentiates between legal and sublegal fish in the model
- Models partial recruitment to the fishery as cohorts grow above LML
- Incorporates growth into model-predicted catch proportions-at-age
- Applied in South Australia to the 3 major fish stocks



Slice Partition Approach

- Applied to KGW as monthly time steps
  - KGW have seasonally varying growth
  - Incorporates this variability into the length-at-age pdf giving more precise slices



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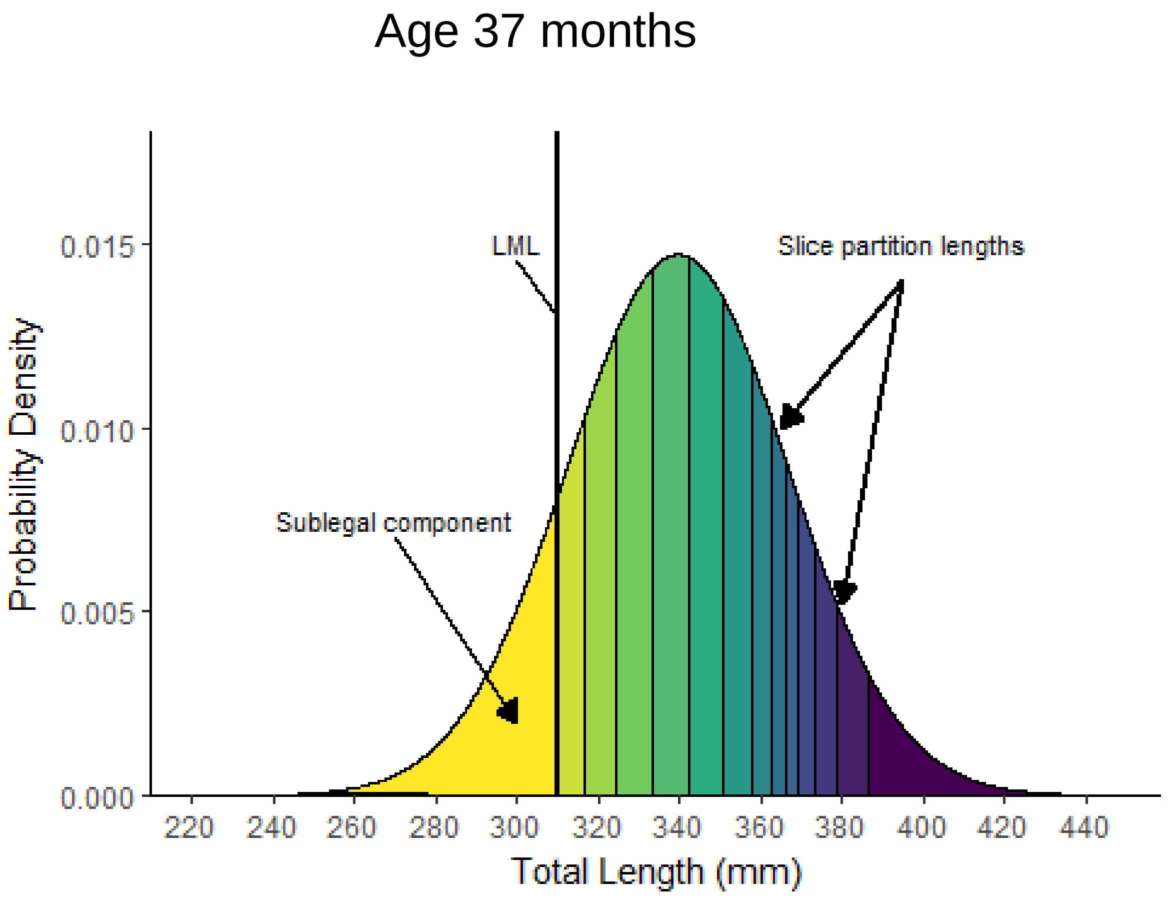
- Provides narrower slices in slow-growing months when fewer fish recruit above LML



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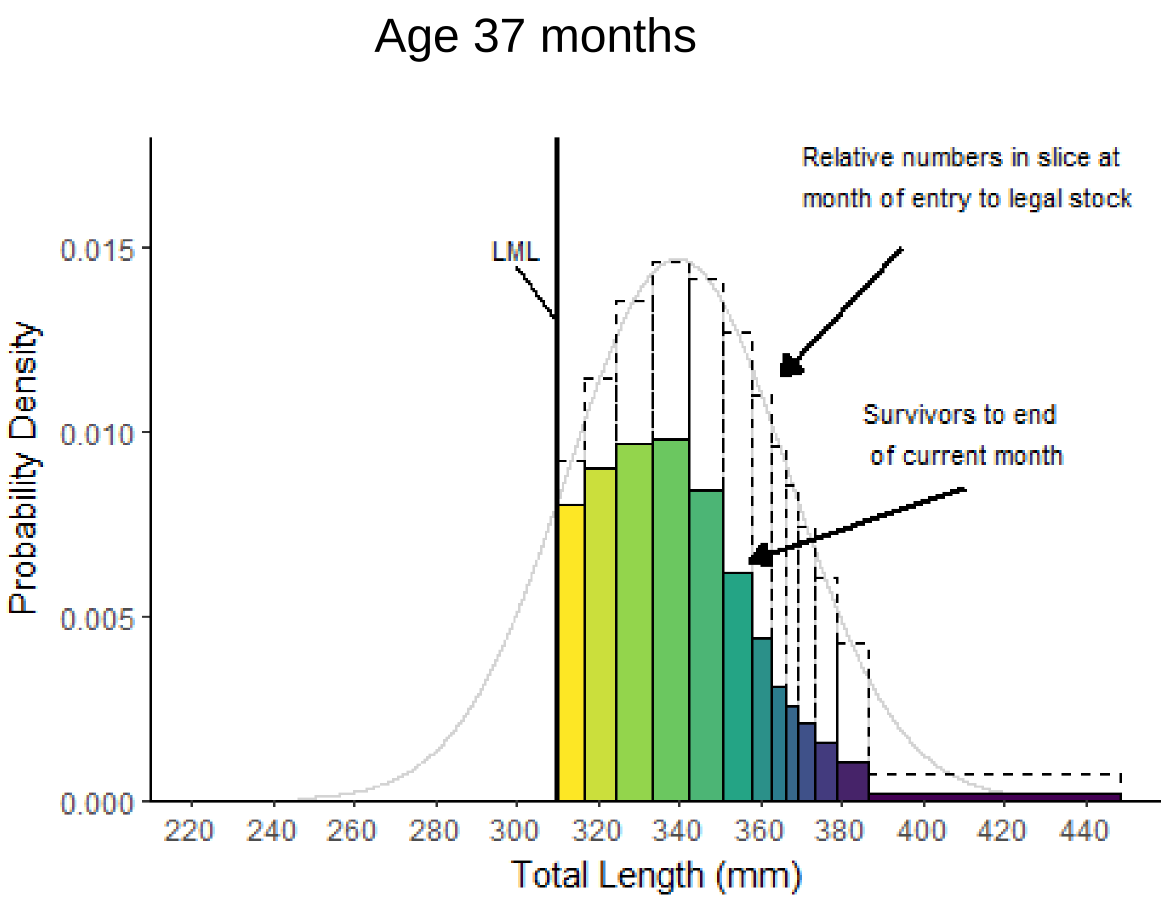
Slice Partition Approach

- Applied to KGW as monthly time steps
  - KGW have seasonally varying growth
  - Incorporates this variability into the length-at-age pdf giving more precise slices
- Provides narrower slices in slow-growing months when fewer fish recruit above LML
- Fishing mortality is then applied to each slice in each time step
- The older the slice, the greater its exposure to fishing and therefore fewer individuals remain



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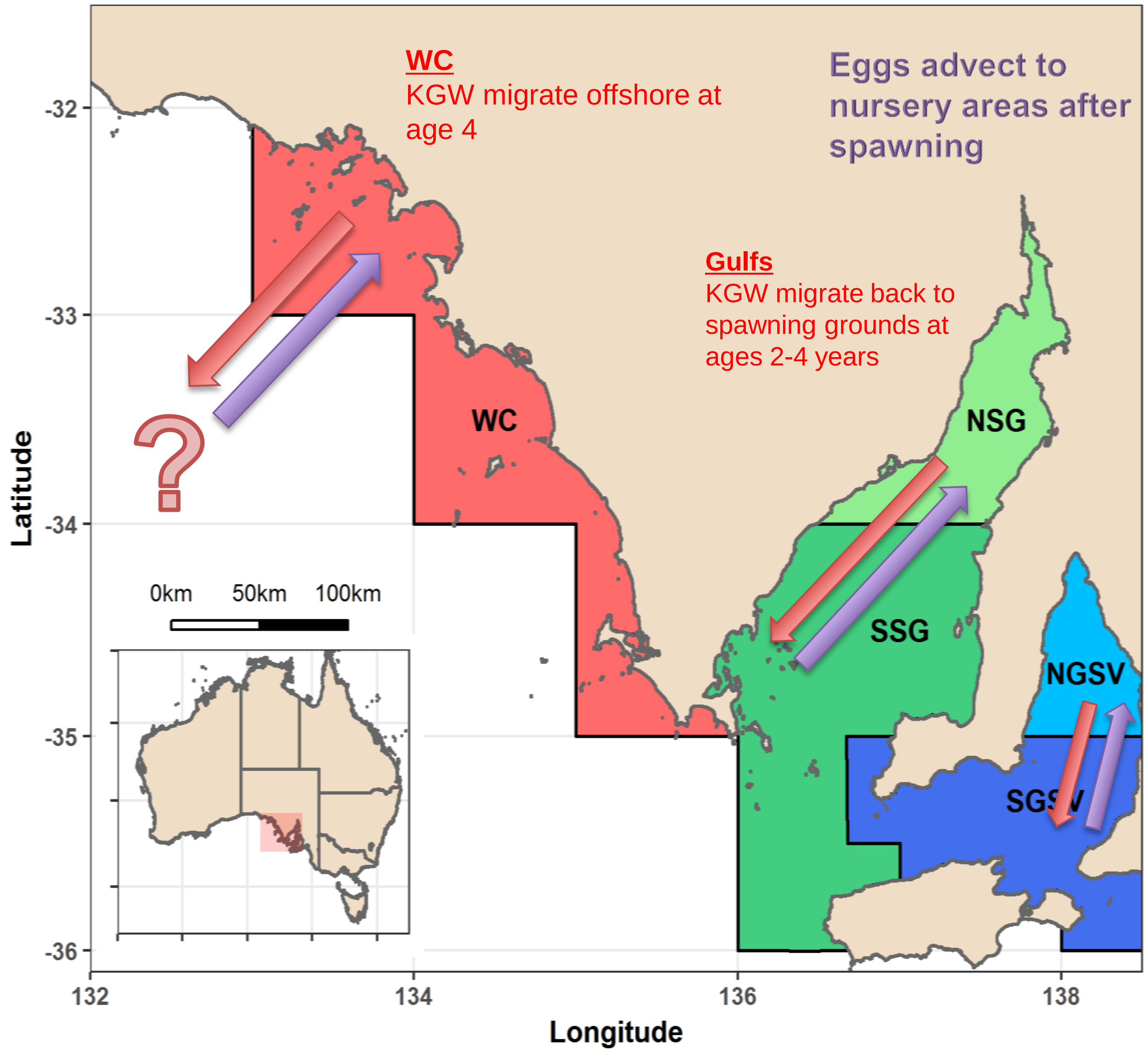
Movement Submodel



Three regions included in Stock Assessment
West Coast (WC)
Gulf St Vincent (GSV)
Spencer Gulf (SG)

KGW undergo age-dependent migration from nursery areas to spawning grounds:

- GSV and SG KGW move south at 2 – 4 years
- WC – KGW move offshore at 4 years to the “mystery cell”
- All movement occurs in summer (November – January)

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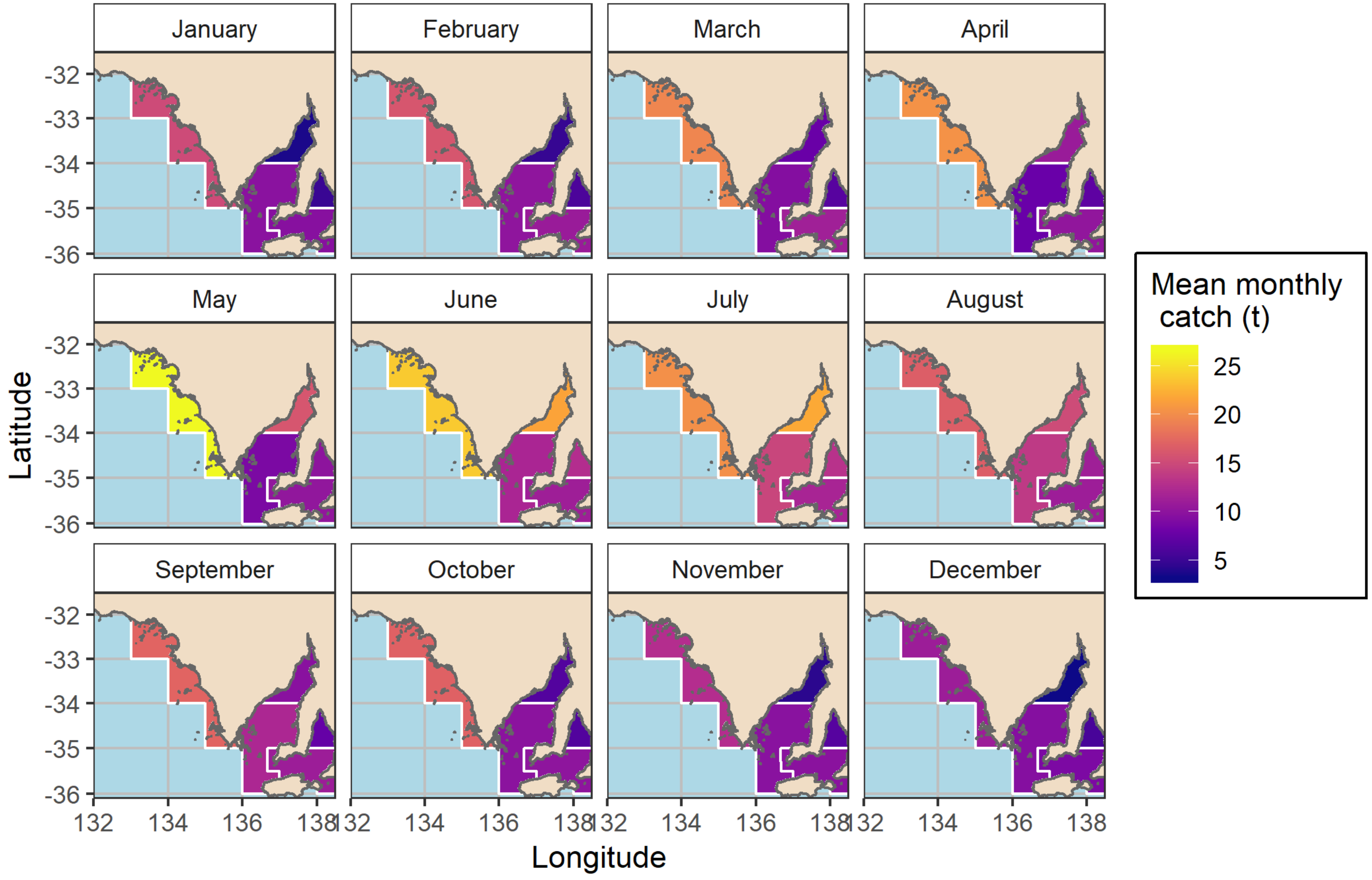
Spatial Distribution of Catches

Catches vary both spatially and temporally

- Highest in winter (May – July)
- Highest in northern gulfs
- Failure to model movement will lead to under or overestimation of F in different areas

Average monthly catch in each spatial cell 1984 - 2016



Movement Submodel

- Movement is estimated and included as a likelihood component
- Submodel is recapture conditioned
  - Mortality in original cell (until time of movement), reporting rate, tag shedding rate all cancel out
  - Key assumption is that reporting rate, tag mortality and tag loss are approximately uniform across areas
- Provides estimates of predicted movement proportions to each area
- Refines estimates of *F* and *Z* in the migration cells

N = number of individuals, *t* =month of tagging, *r* = month of recapture, *a* = age, *m* = month of movement, *P* = probability of movement, *S* = survivorship, *F* = fishing mortality, *Z* = total mortality, m_{tag} = tagging mortality, f_{report} = tag report rate

Tag and recapture data

Age Tagged (months)	Age Recaptured	Area Tagged	Area Recaptured
28	31	2	2
36	49	2	3
24	33	4	5

Predicted n. recaptures

$$\hat{N}^{r}_{i,j,a_t,a_r} = \cancel{N^{t}_{i,a_t}}\left(\cancel{1 - m_{tag}}\right)\cancel{S_i[a_t, a_m]}P_{a_m,ij}S_j[a_m, a_r] \times \left(1 - e^{-\frac{Z}{12}}\right)\left(\frac{F_j}{Z_j}\right)\cancel{f_{report}}$$

Predicted prop recaptures

$$f_1(j|i, a_t, a_r) = \frac{\hat{N}^{r}_{i,j,a_t,a_r}}{\sum_{k=1}^{n_c} \hat{N}^{r}_{i,k,a_t,a_r}}$$

$$f(j|i, a_r) = \frac{P_{ij}e^{-Z_{jm}\frac{a_r - a_m}{12}}\left(1 - e^{-\frac{Z_{jm}}{12}}\right)\frac{F_{jm}}{Z_{jm}}}{\sum_{k=1}^{n_c} P_{ik}e^{-Z_{km}\frac{a_r - a_m}{12}}\left(1 - e^{-\frac{Z_{km}}{12}}\right)\frac{F_{km}}{Z_{km}}}$$

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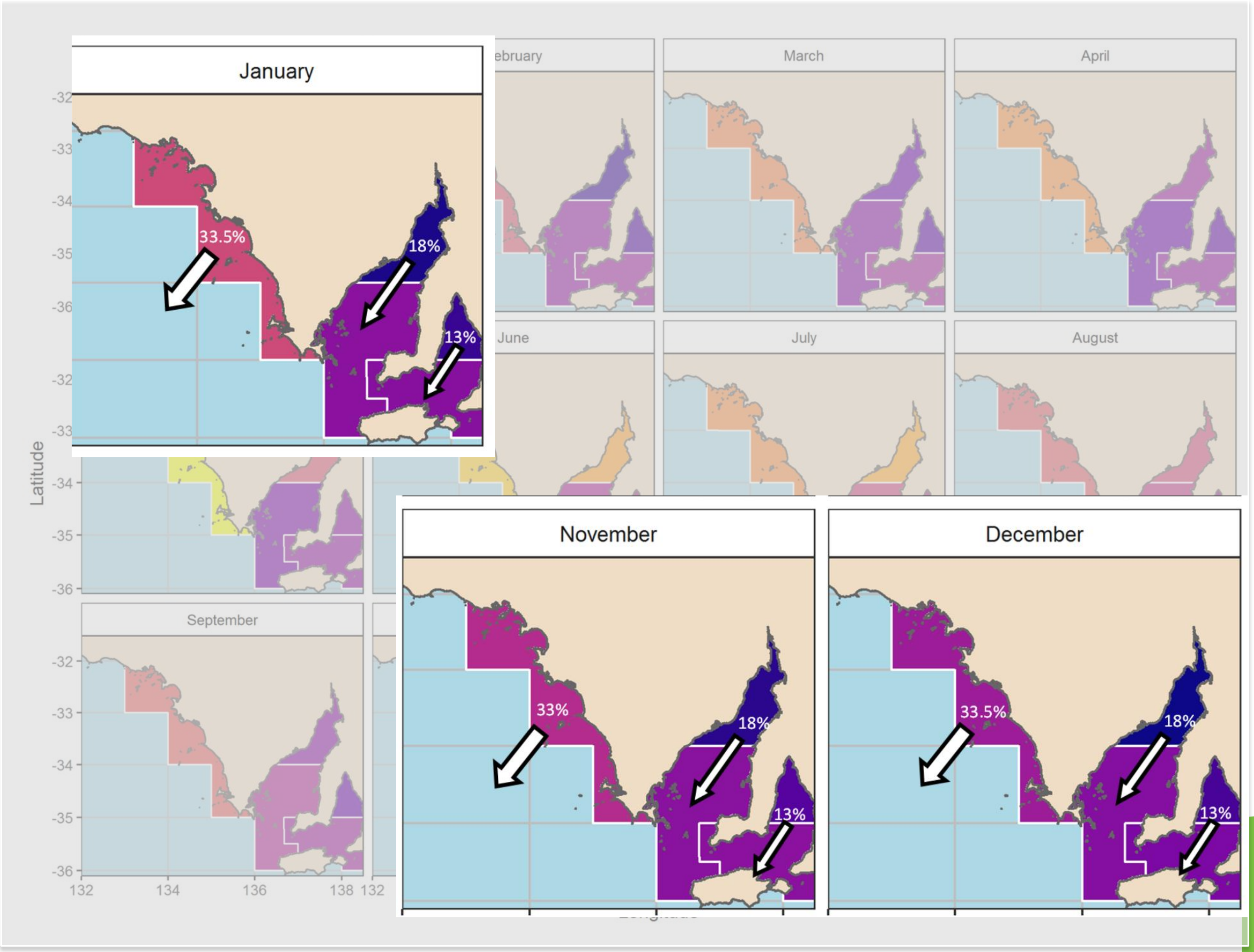
Annual time invariant movement matrix

MC	1	2	3	4	5
1	1.00	0.00	0.00	0.00	0.00
2	0.00	0.55	0.00	0.00	0.00
3	0.00	0.45	1.00	0.00	0.00
4	0.00	0.00	0.00	0.67	0.00
5	0.00	0.00	0.00	0.33	1.00

Smoothed monthly movement matrix

MC	1	2	3	4	5
1	1.00	0.00	0.00	0.00	0.00
2	0.00	0.82	0.00	0.00	0.00
3	0.00	0.18	1.00	0.00	0.00
4	0.00	0.00	0.00	0.87	0.00
5	0.00	0.00	0.00	0.13	1.00

Stock Assessment Outcomes



- Movement rates are smoothed across the 3 summer months for gradual emigration
- At age 4, all remaining fish in northern Gulfs are moved.
- West Coast movement is not estimated as this only happens at age 4

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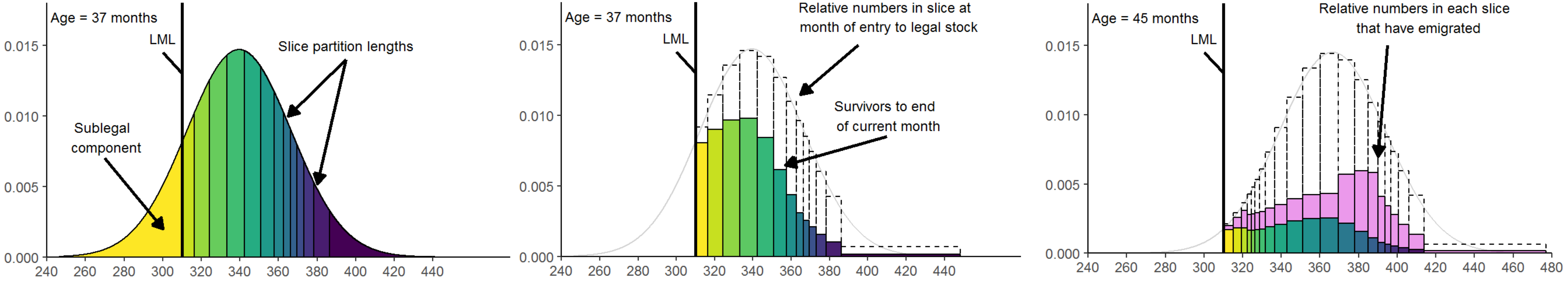
Benefits of modelling movement and using slice partitions

Accounting for movement in tandem with slice partitions, refines the mortality estimates.



Create Slices

Apply mortality

Account for movement

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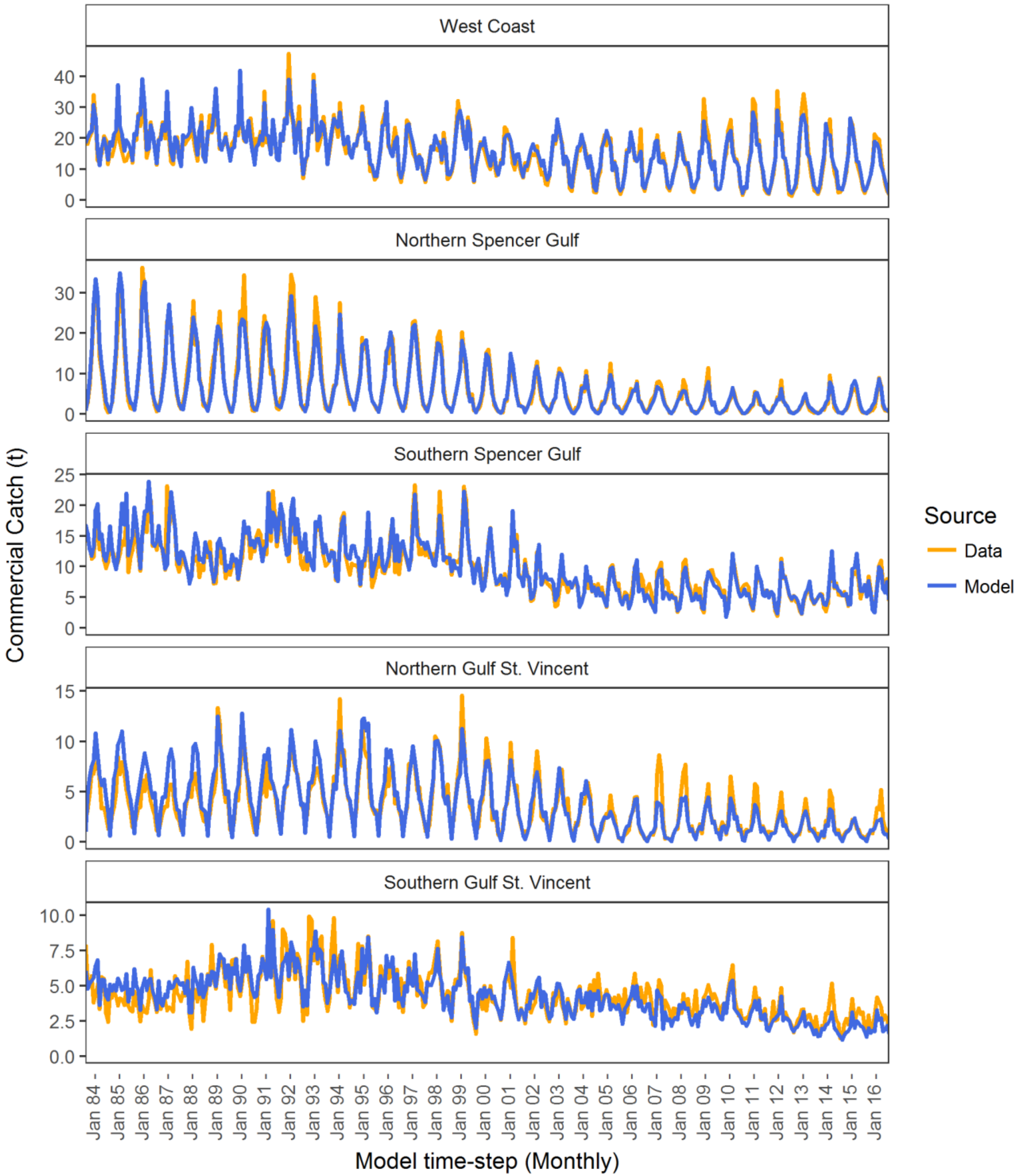
Stock Assessment outcomes

Increased precision in the population array provides:

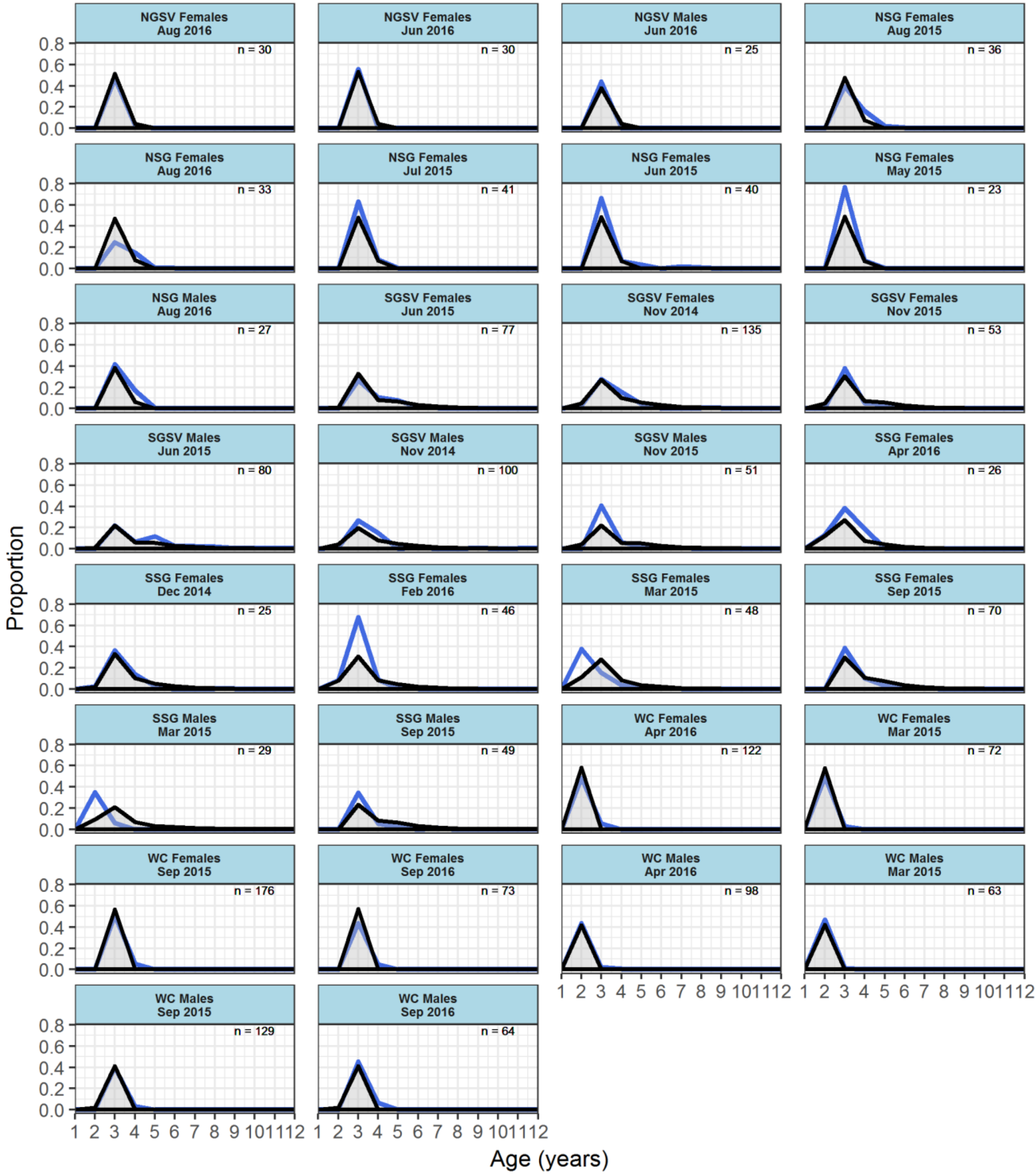
- Precise fits to catch in all areas



Stock Assessment outcomes

Increased precision in the population array provides:

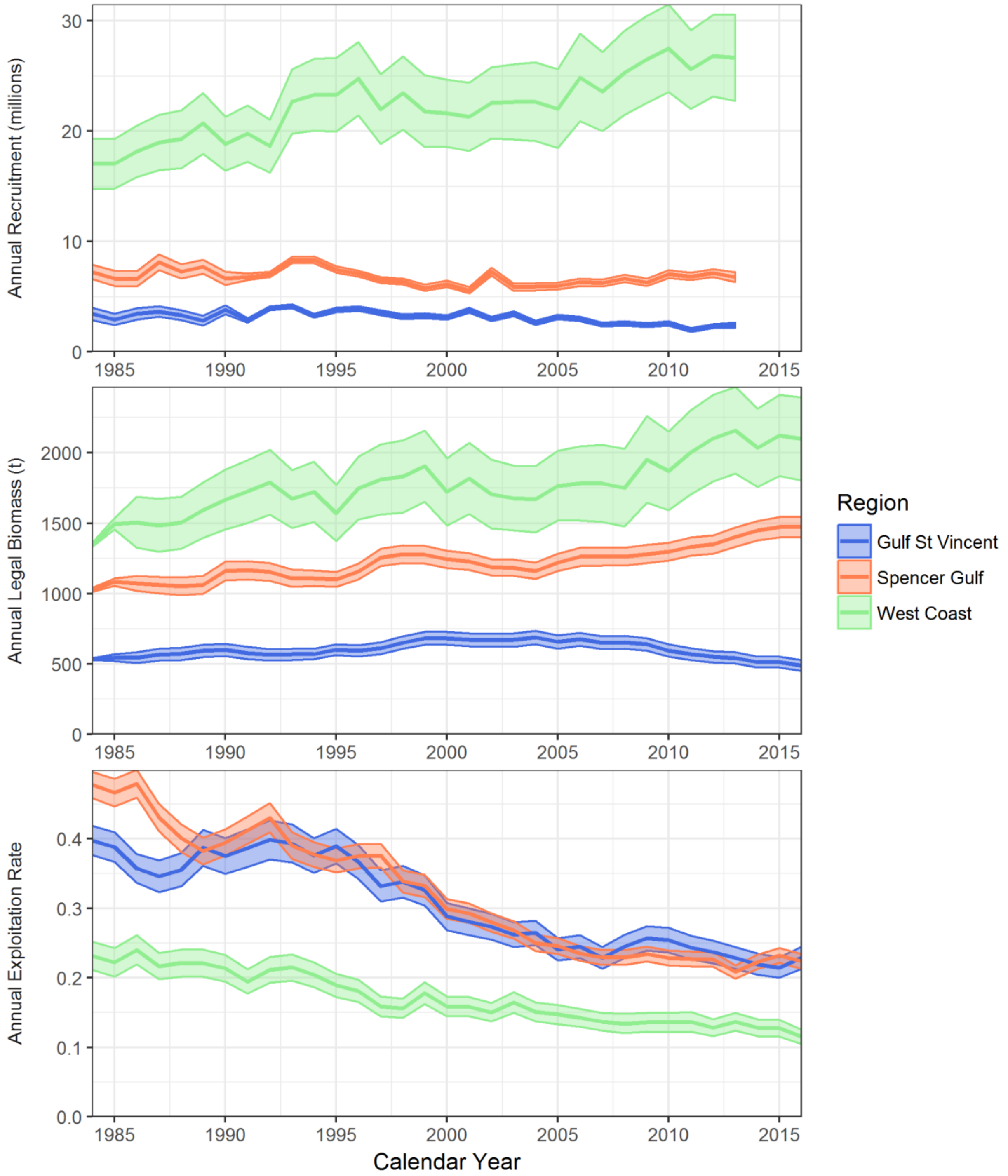
- Precise fits to catch in all areas
- Good fits to Age Comp. data
  - Note older ages occur in SSG and SGSV compositions.



Stock Assessment outcomes

Increased precision in the population array provides:

- Precise fits to catch in all areas
- Good fits to Age Comp. data
  - Note older ages occur in SSG and SGSV compositions.
- This leads to reasonable estimates of Biomass, harvest fraction and recruitment

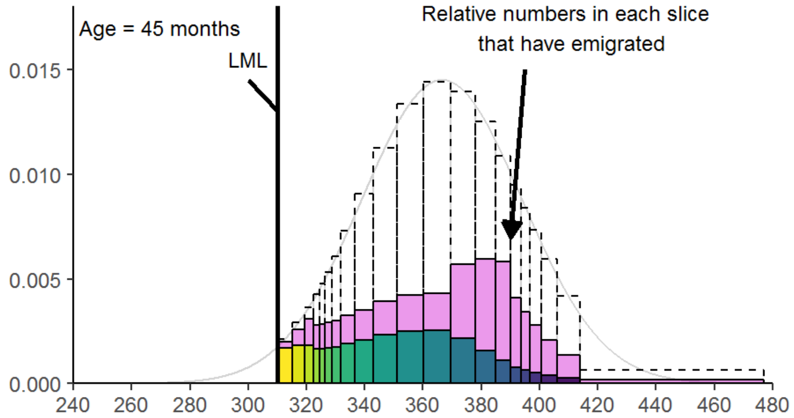


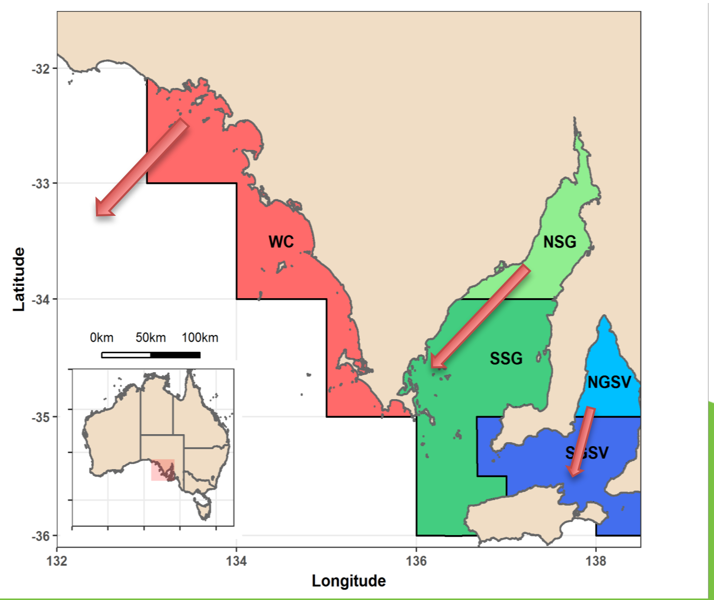
Conclusions

- Accounting for movement in this example greatly avoids issues of overestimating and underestimating *F*, leading to improved model outputs.

- The slice partition approach complements the movement submodel as the age of movement is concurrent with ages that are fished the heaviest

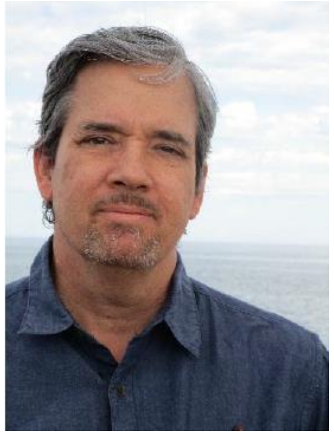
- A recapture conditioned movement model provides a simple mechanism to include tag data in stock assessments and avoids issues regarding estimation of tag reporting (if assumptions are valid)

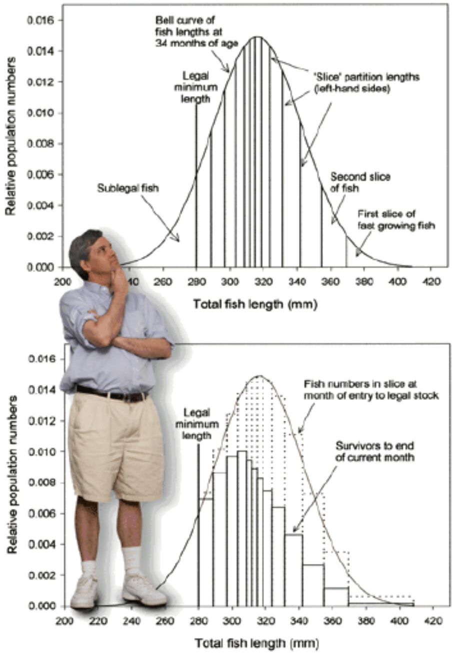




Acknowledgements

- Rick McGarvey and John Feenstra – the developers of this approach
  - McGarvey R, Feenstra JE, Ye Q. 2007. Modeling fish numbers dynamically by age and length: partitioning cohorts into 'slices'. Canadian Journal of Fisheries and Aquatic Sciences 64: 1157-1173
  - McGarvey, R., and J. E. Feenstra. 2002. Estimating rates of fish movement from tag recoveries: conditioning by recapture. Canadian Journal of Fisheries and Aquatic Sciences 59:1054-1064.
- The Marine Scalefish team – Mike Steer, Tony Fowler and all of their staff





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