Implications of *Entrainment* for Stock Assessment

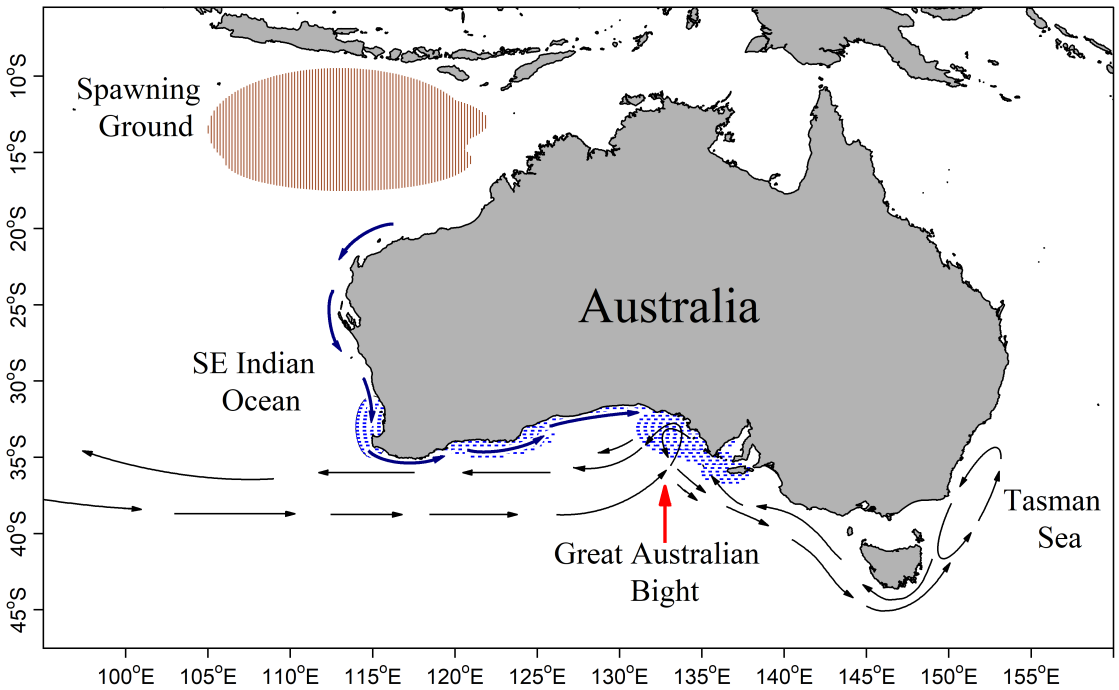
CAPAM Workshop: Developing the next generation of stock assessment models.

Mark Chambers

mark.stanley.chambers@gmail.com

Wednesday 6th November, 2019

Juvenile southern bluefin tuna in Great Australian Bight



- Population is genetically homogeneous.
- GAB a key region.
- 2 – 5-year-olds undertake alternative overwintering migrations.
- Destinations beyond the experience of 2-year-olds.

- Migrants *home* to overwintering grounds [Chambers et al. 2017].

What mechanism could explain this behaviour?

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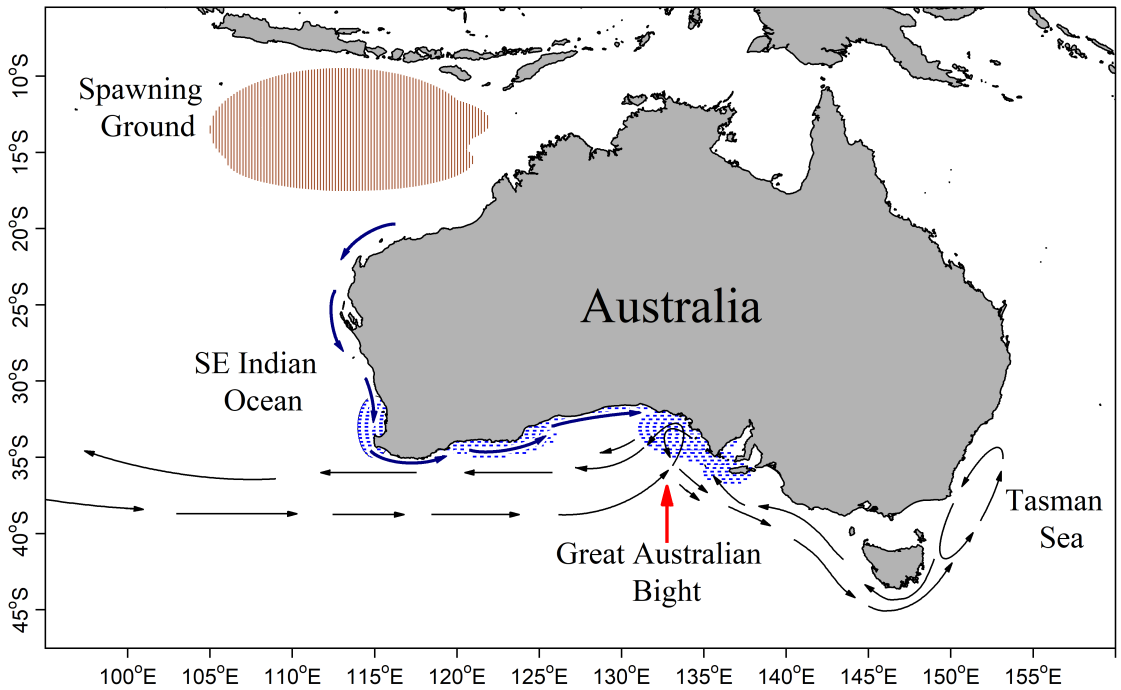

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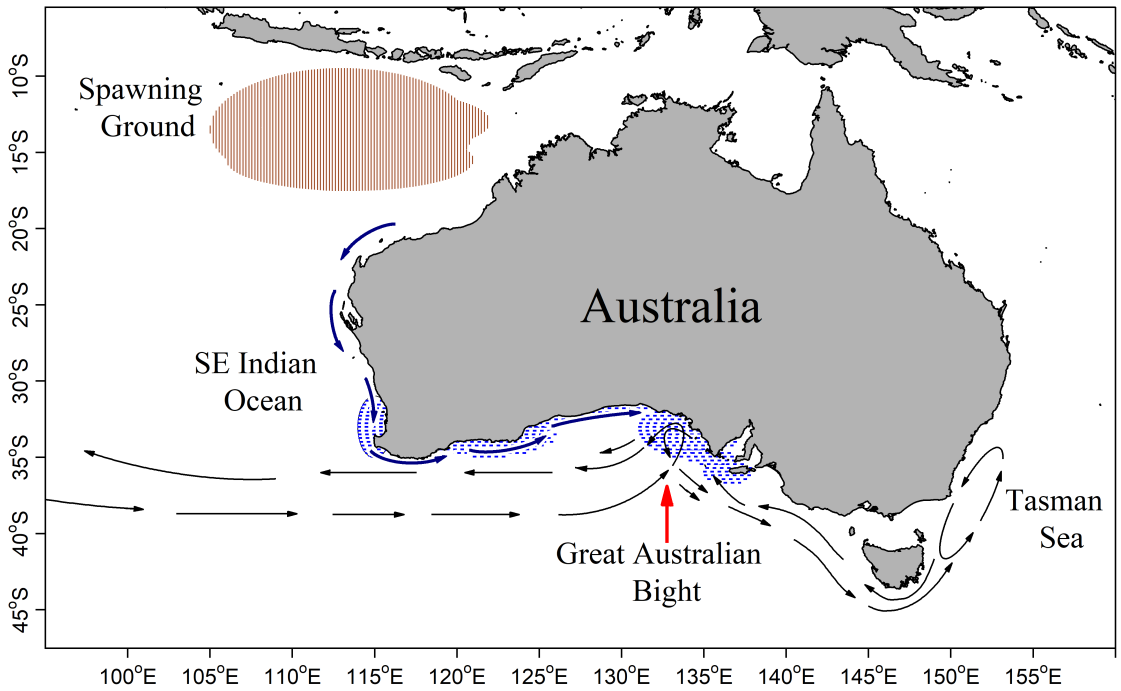

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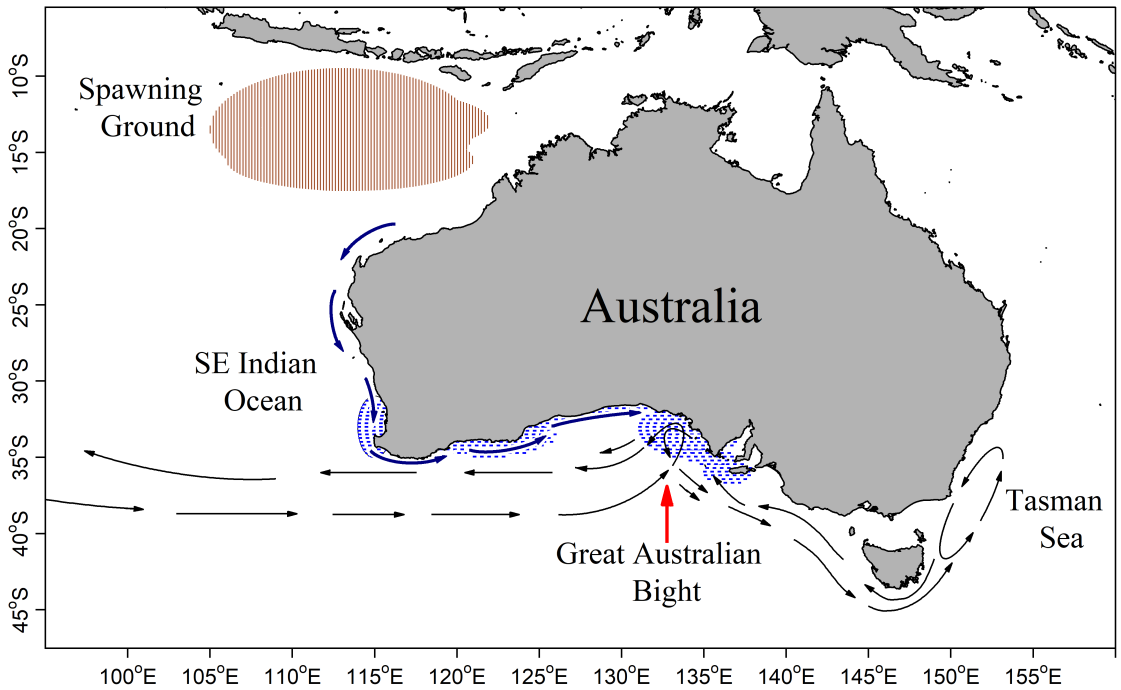

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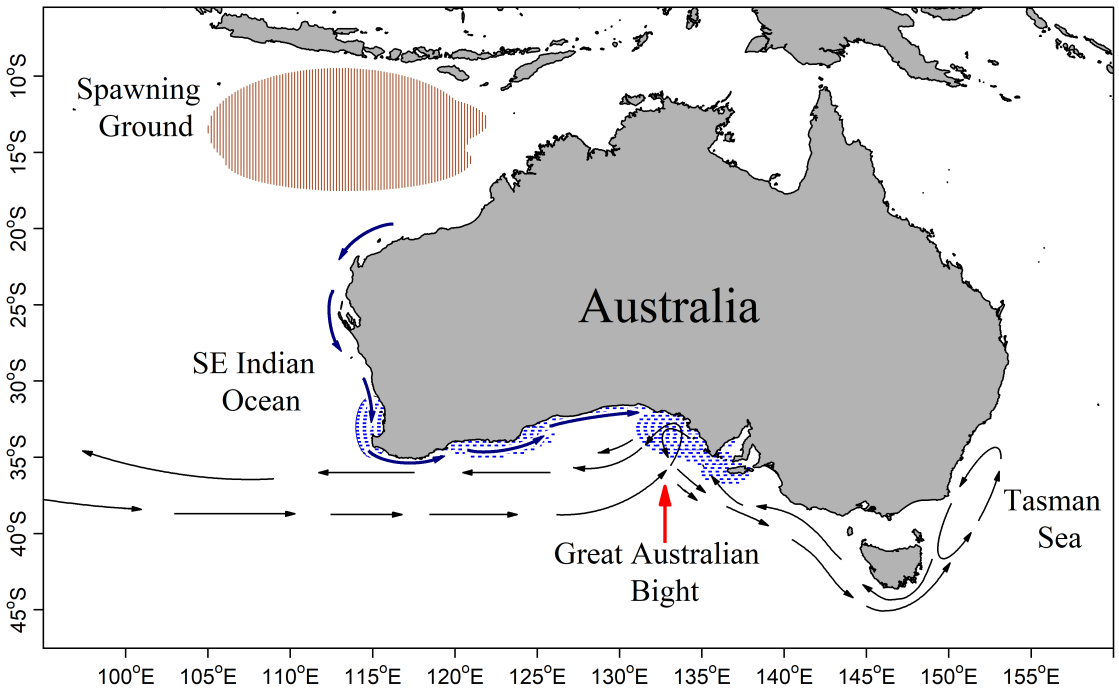

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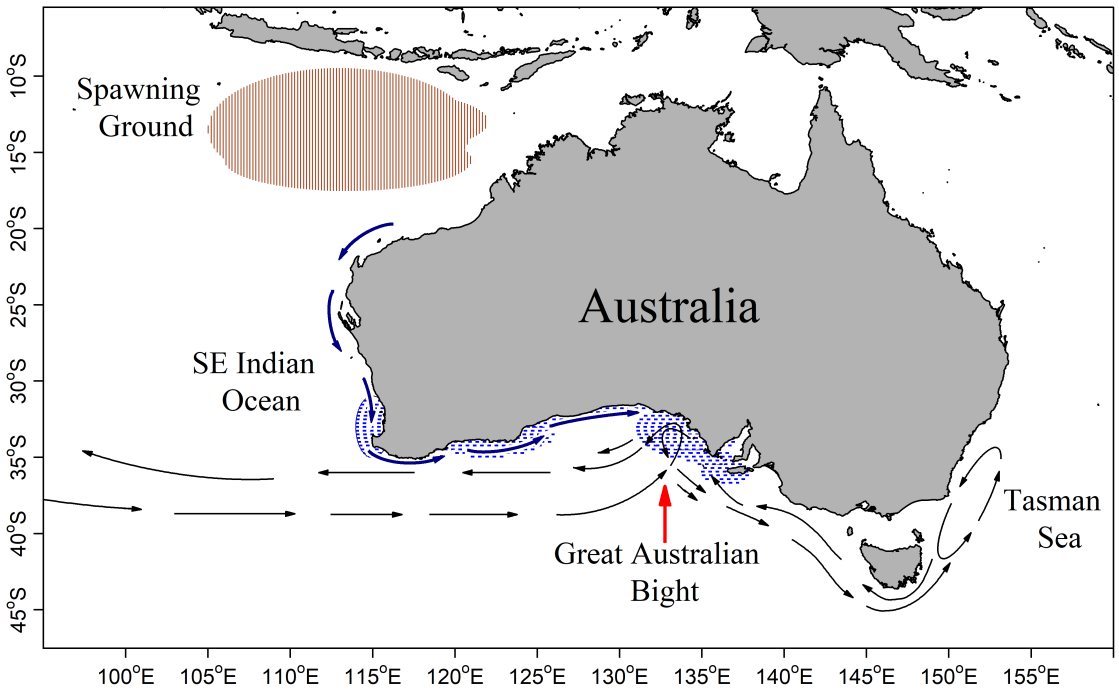

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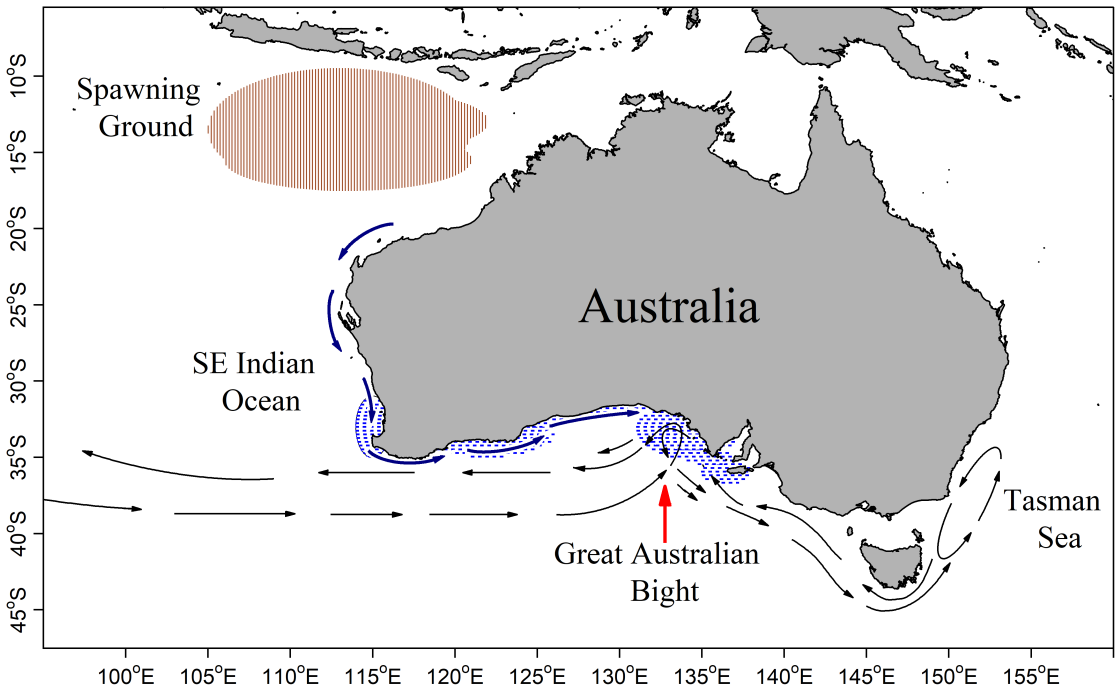

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Entrainment

McQuinn [1997] proposes the "adopted migrant" hypothesis.

- Sympatric distributions characteristic of spawning populations of Atlantic herring.
- Progeny intermingle and are not nominally aligned to their natal spawning migration.
- First-time spawners adopt a contingent through social interactions with experienced conspecifics.
- By repeating the same migration in subsequent years contribute to guiding future cohorts.

Also known as:

- *Entrainment* hypothesis [Petitgas et al. 2006].
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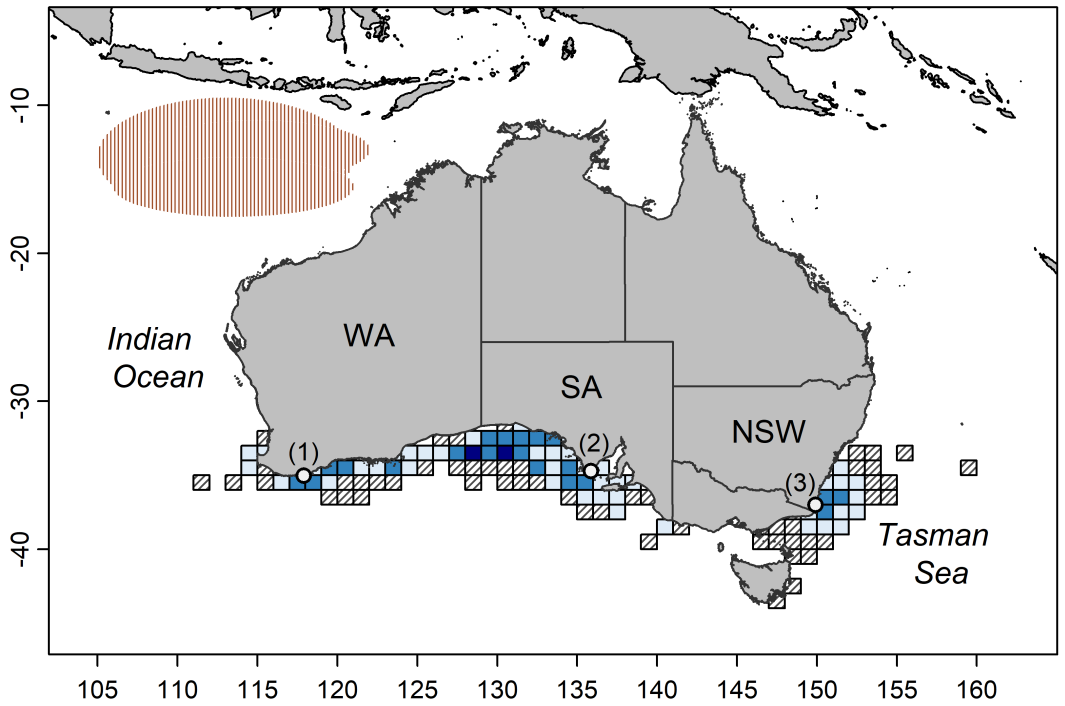

Australian catch

- Confidential
- <= 1000 t
- 1000 - 5000 t
- > 5000 t

Locations

(1) Albany (Nov. - Apr.)
(2) Pt Lincoln (Dec. - Apr)
(3) Eden (Oct. - Dec.)

- NSW fishery targeted close-packed schools on southward migration.
- $F_{NSW} \approx 0.8\,\mathrm{yr}^{-1}$ during 1960s [Hampton 1991].
- Pole boats cooperated with purse seiners from mid '70s.
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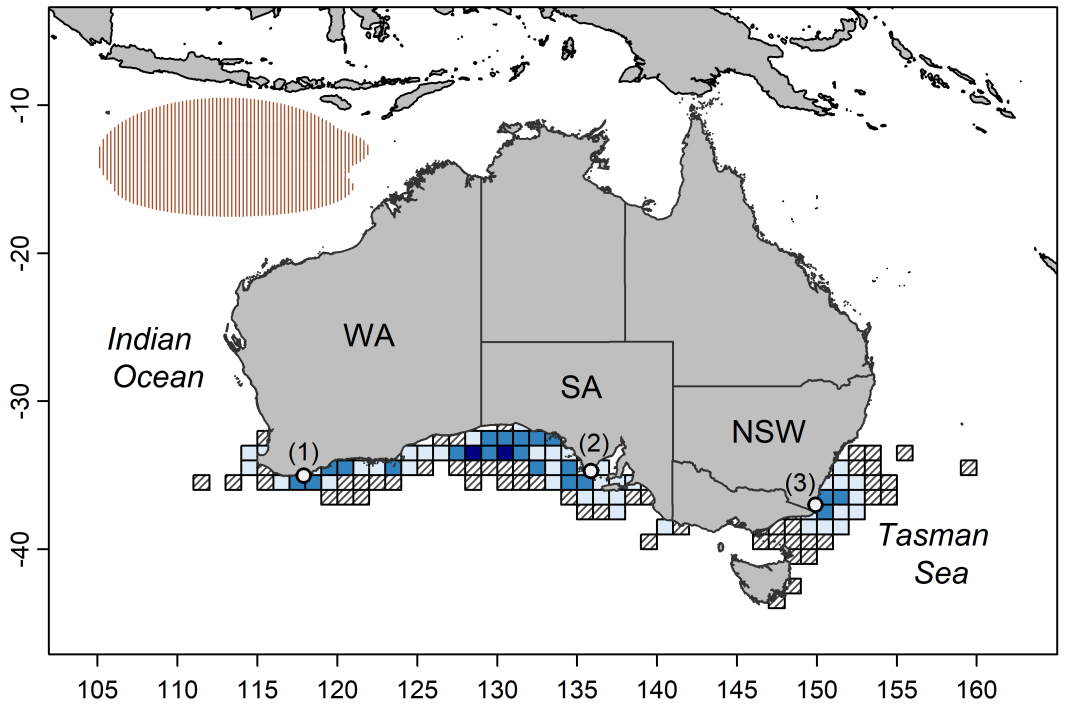

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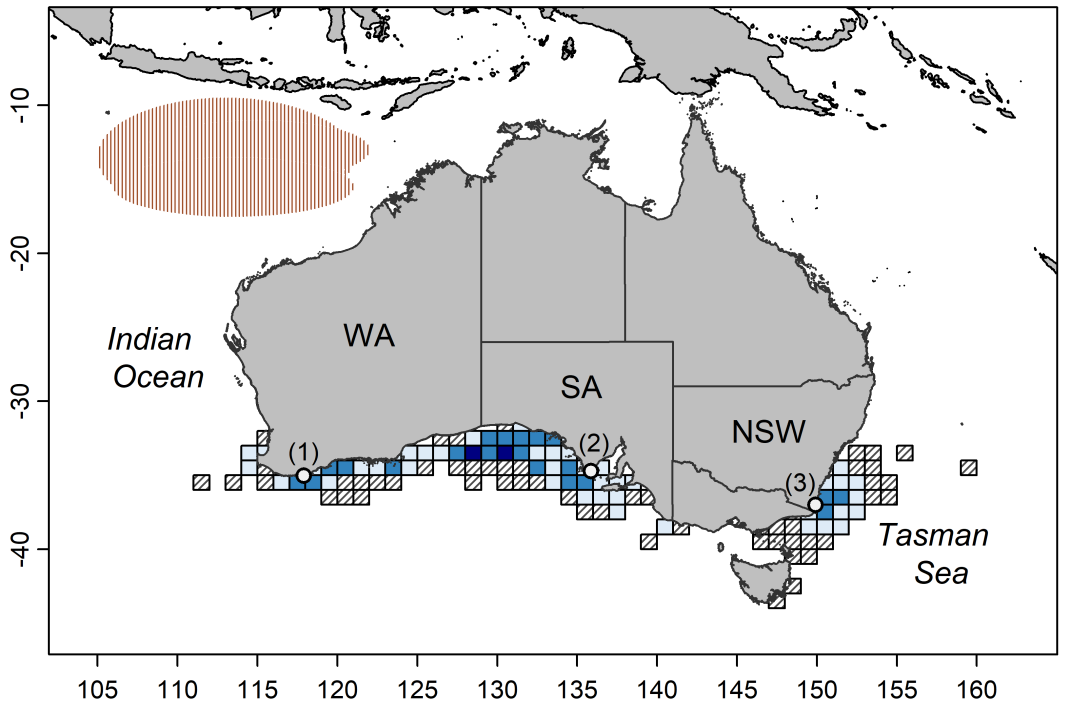

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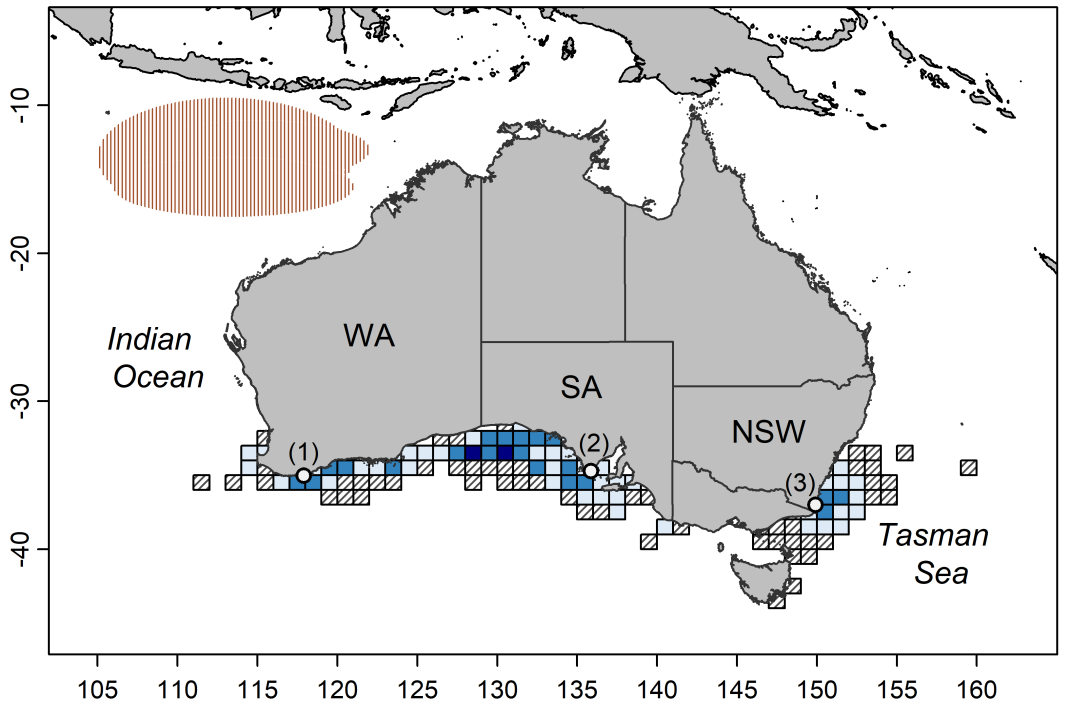

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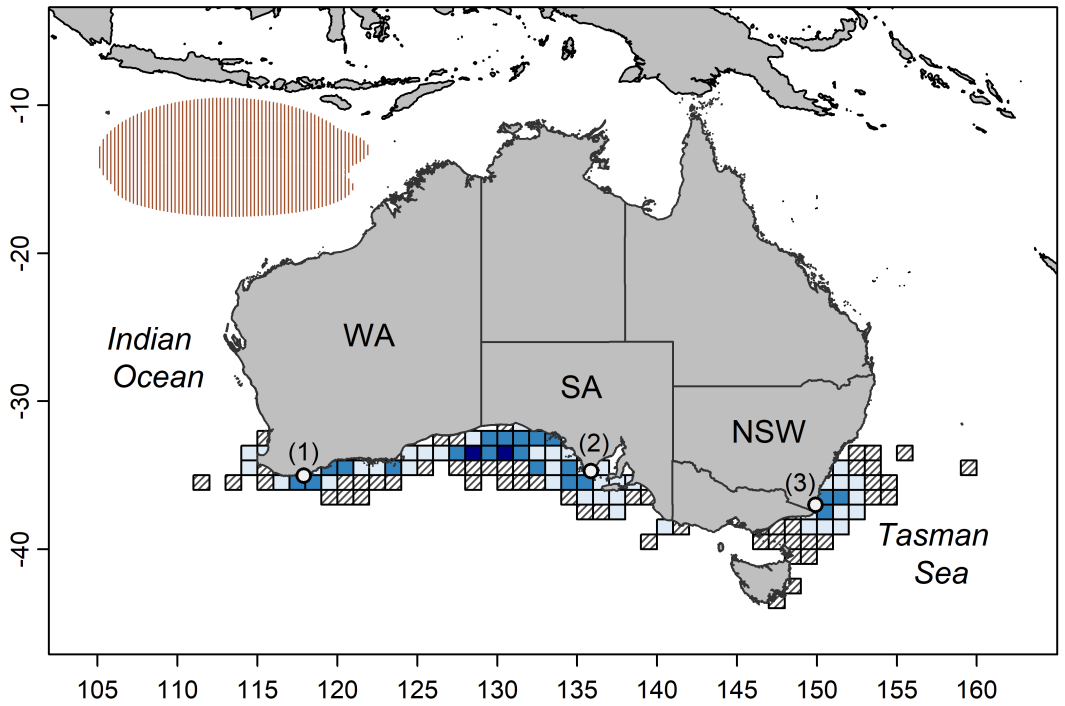

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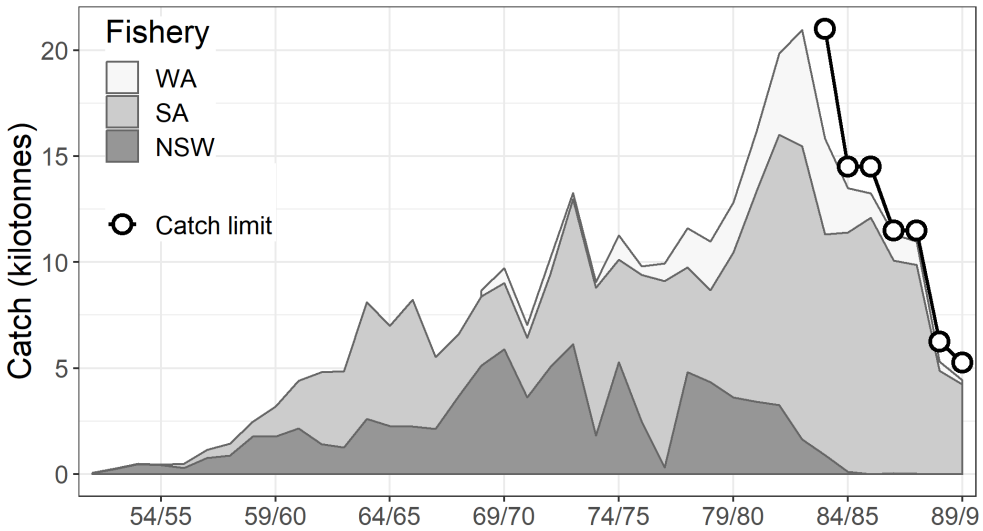

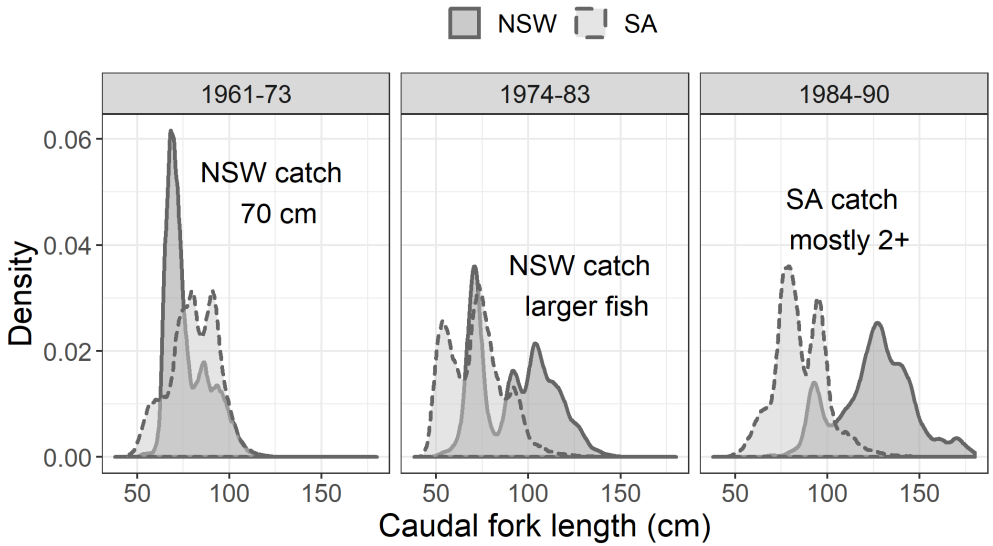

Suggested explanations:

- Low recruitment?
- Low escapement from WA/SA?

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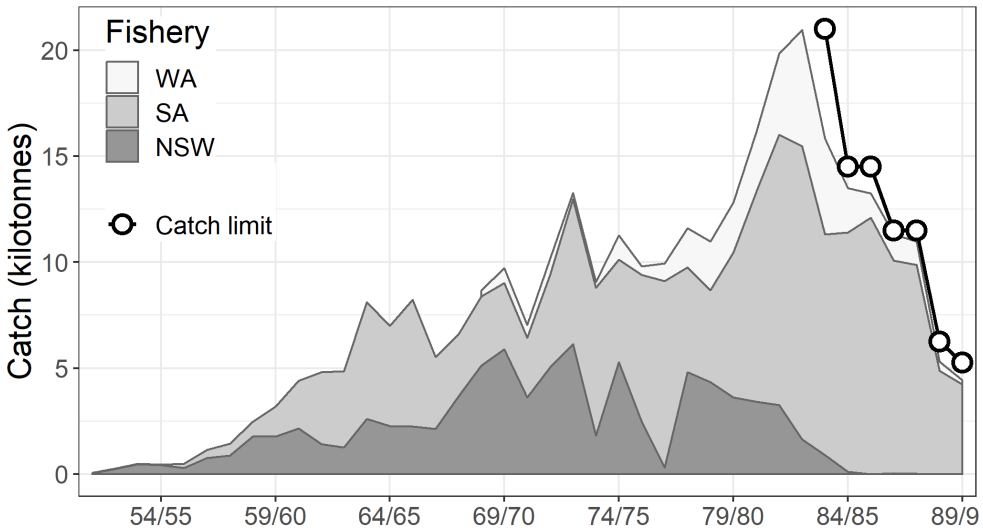

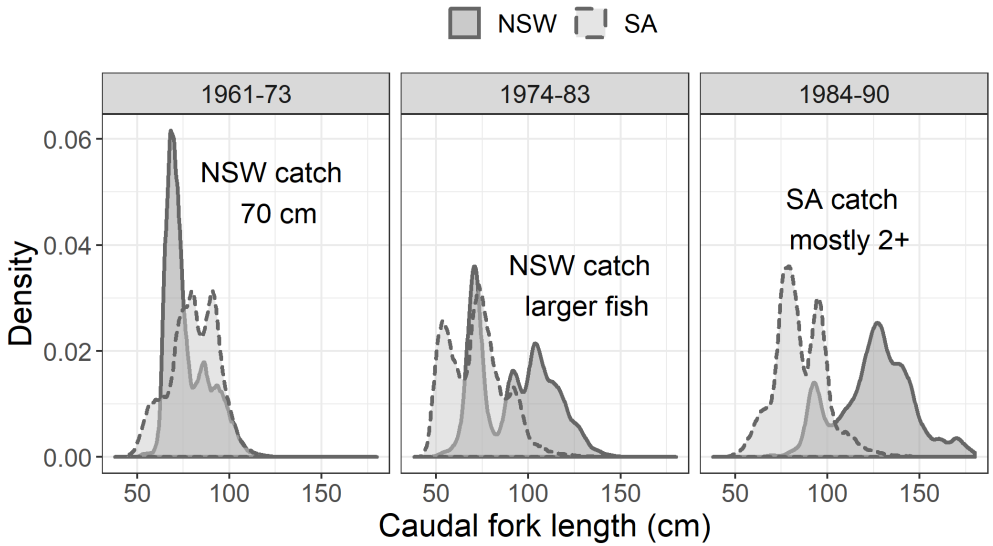

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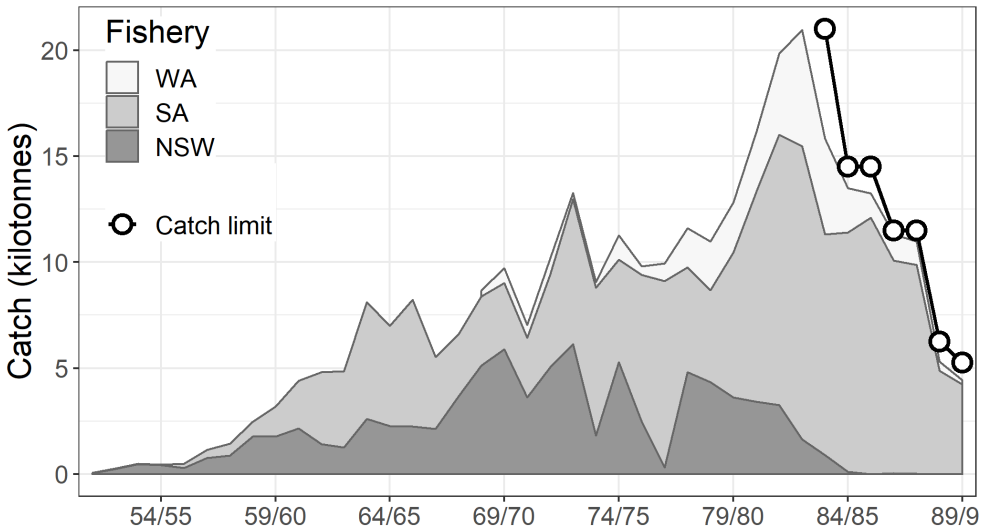

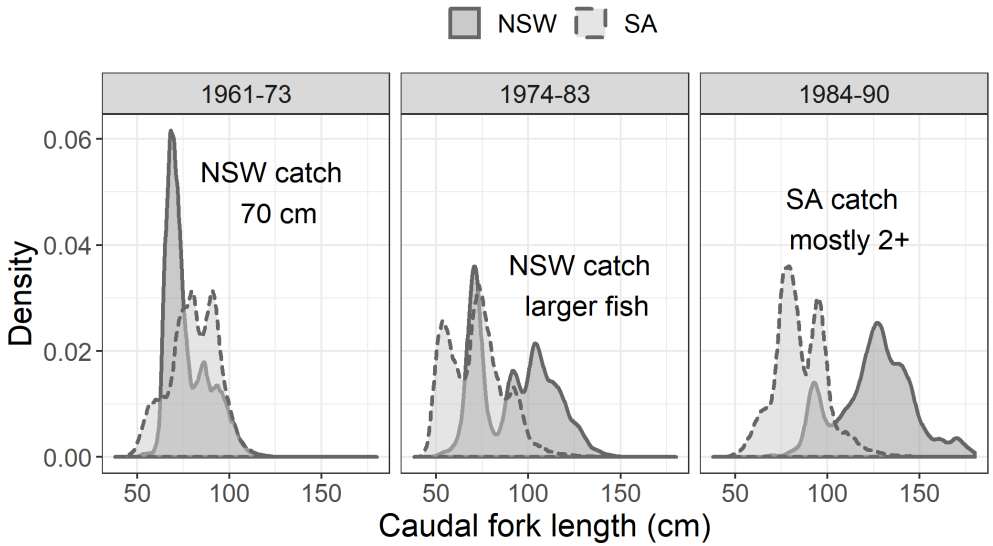

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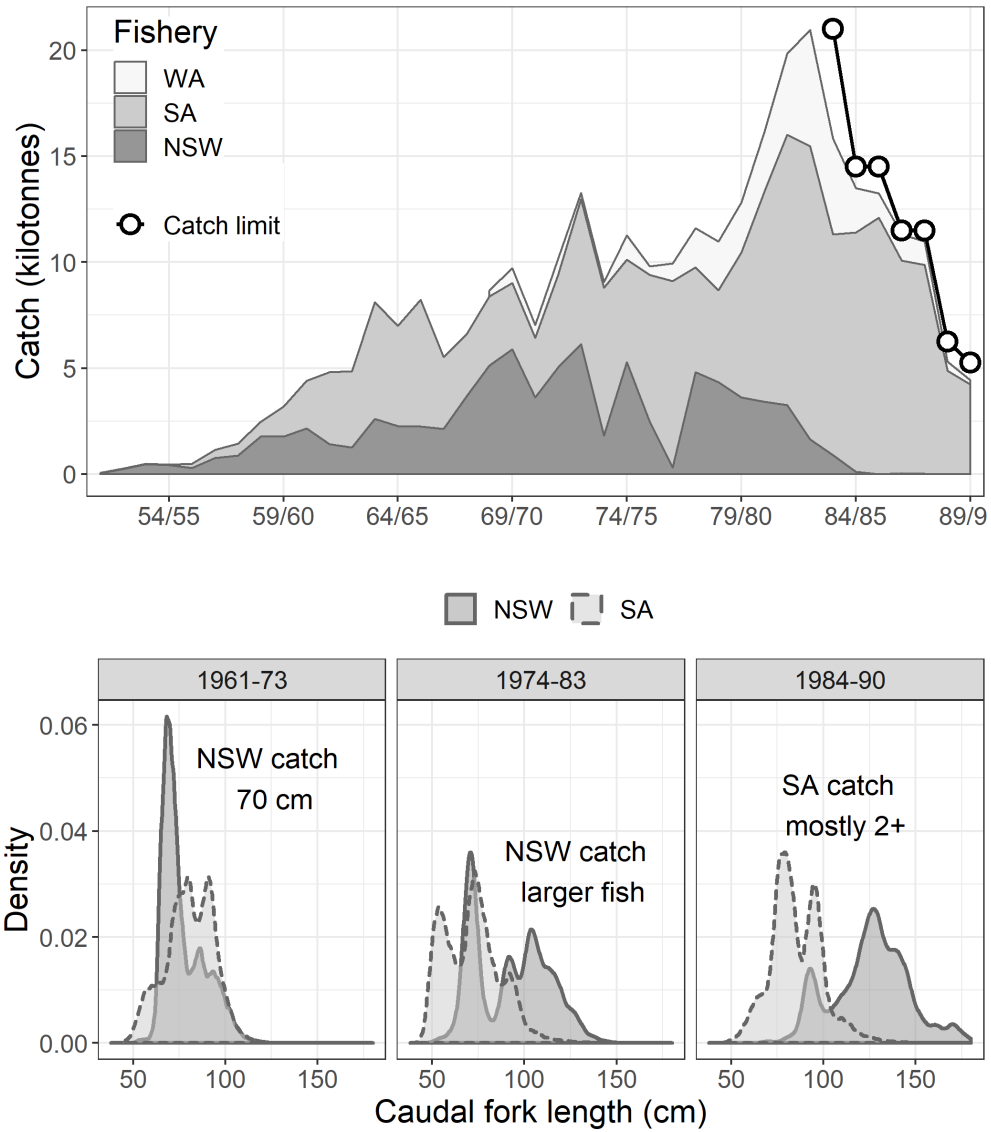

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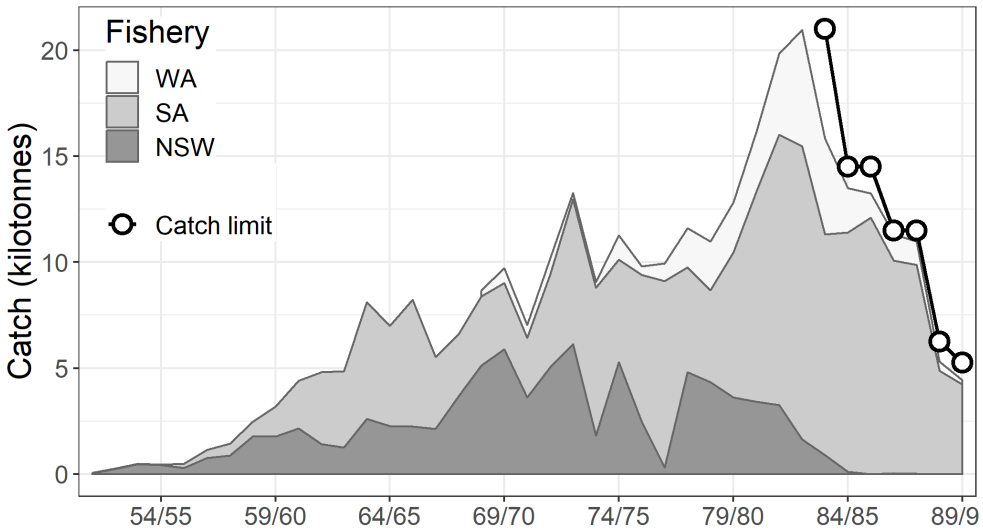

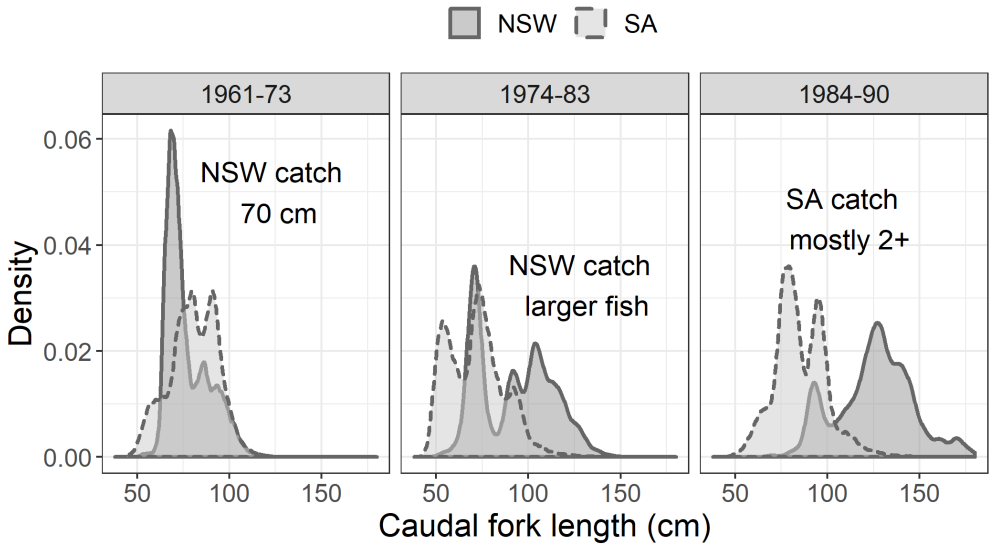

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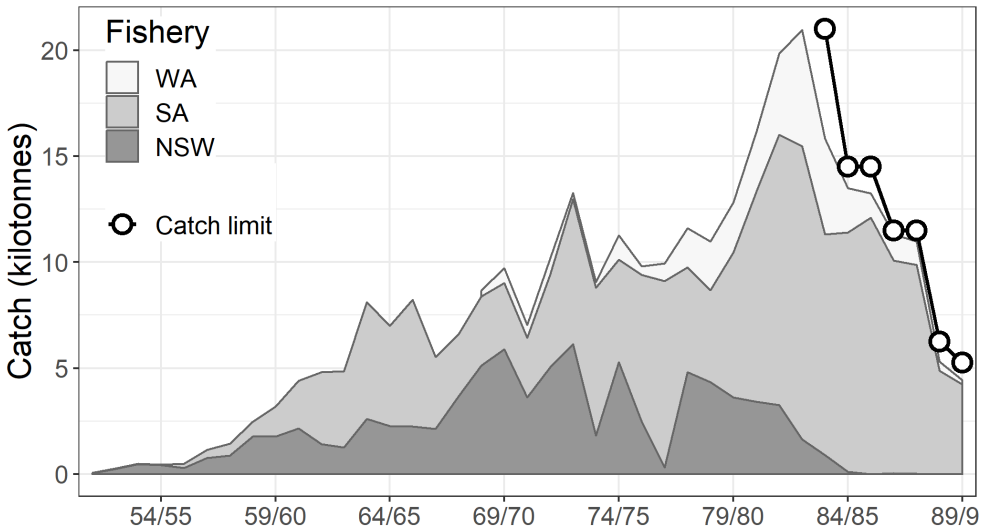

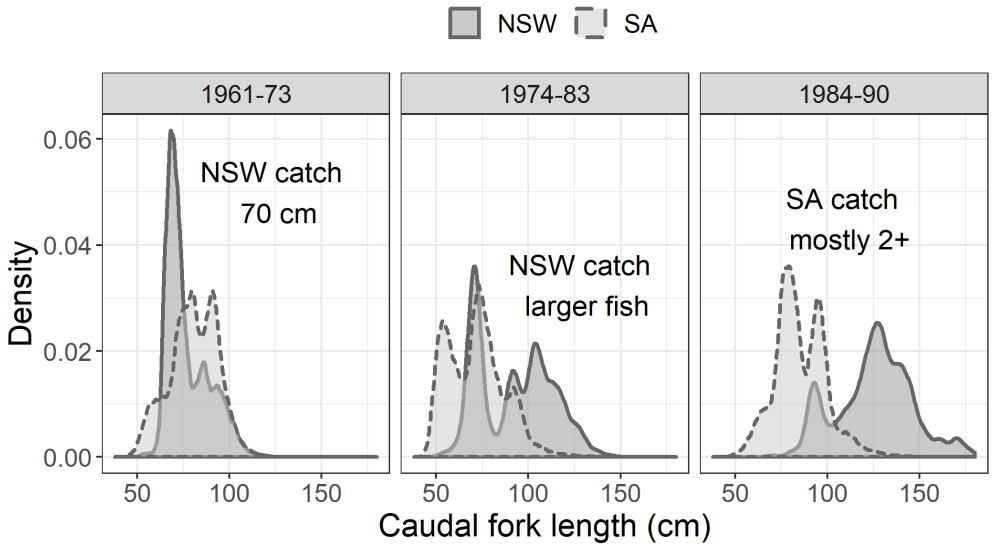

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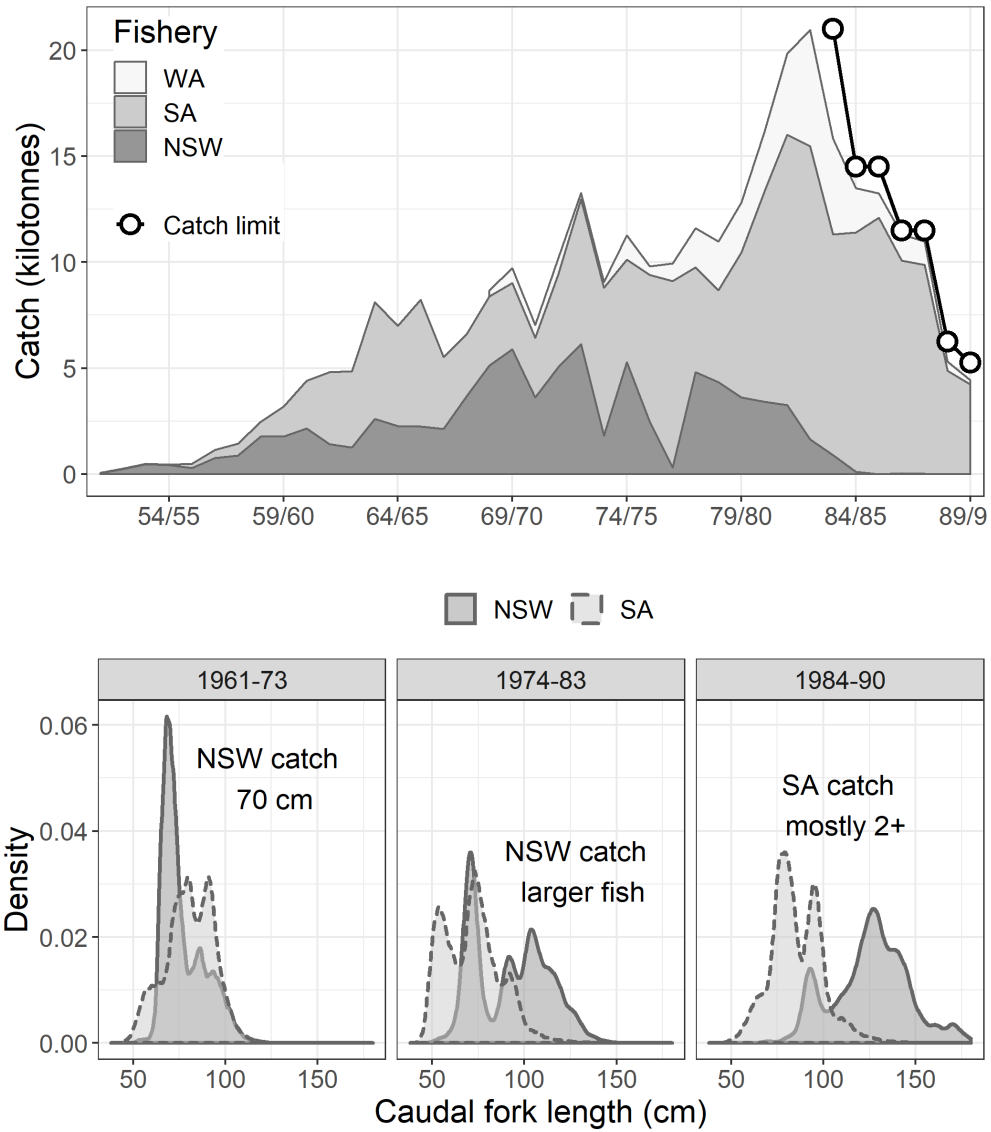

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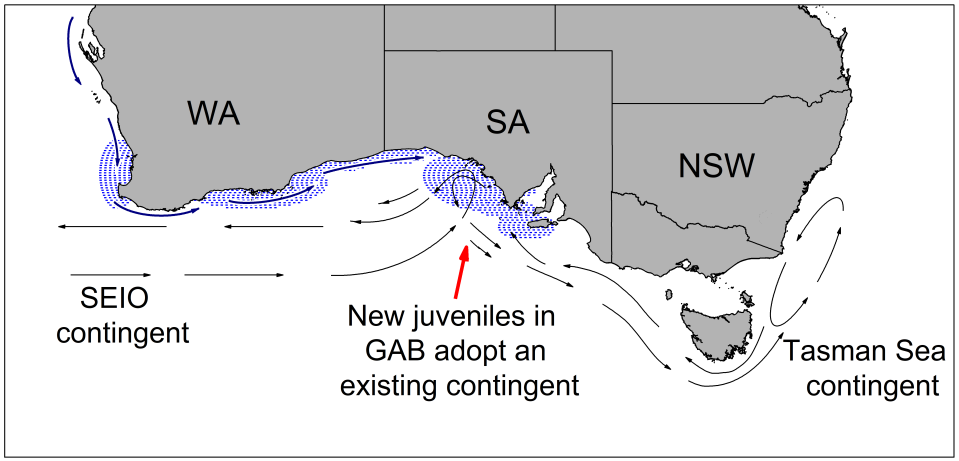

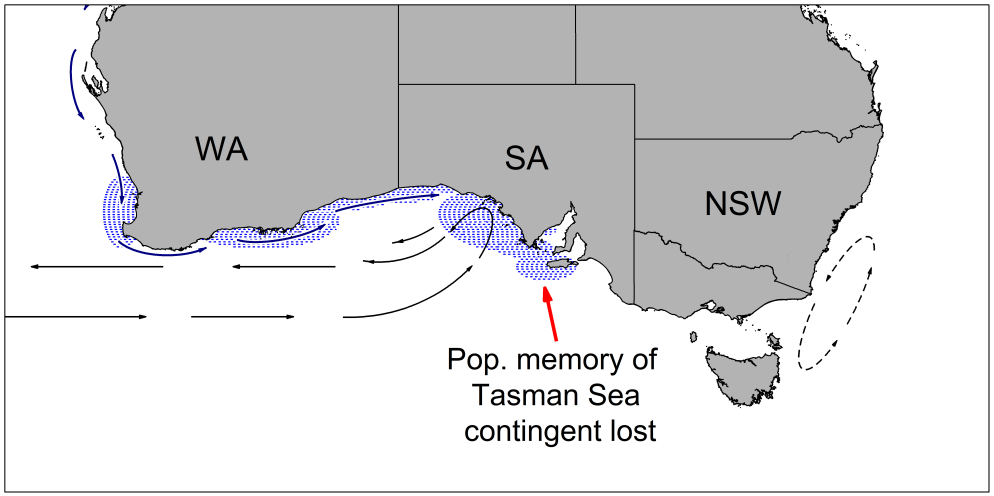

If migration was reliant upon social interactions in the GAB, collapse readily explained

Very high fishing mortality off NSW depleted the Tasman Sea contingent.

There were no migrants demonstrating the Tasman Sea contingent to juveniles in the GAB.

The NSW fishery collapsed because of high fishing mortality off NSW, not SA or WA.

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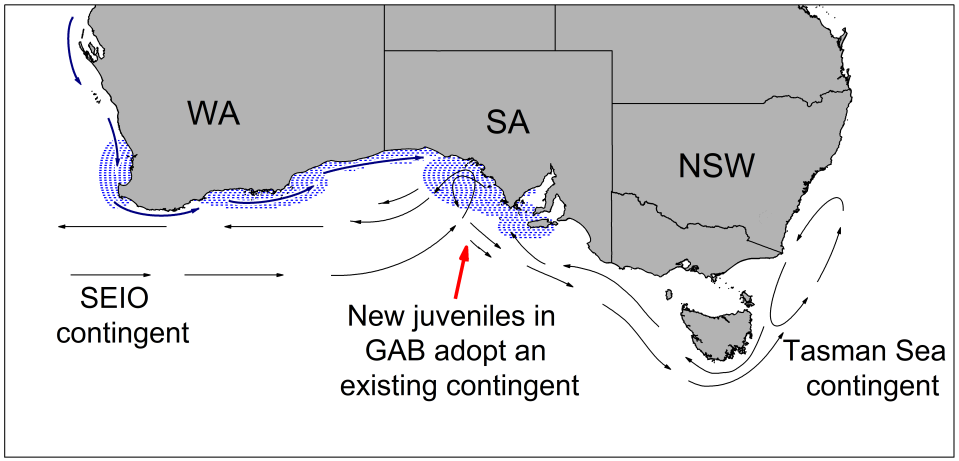

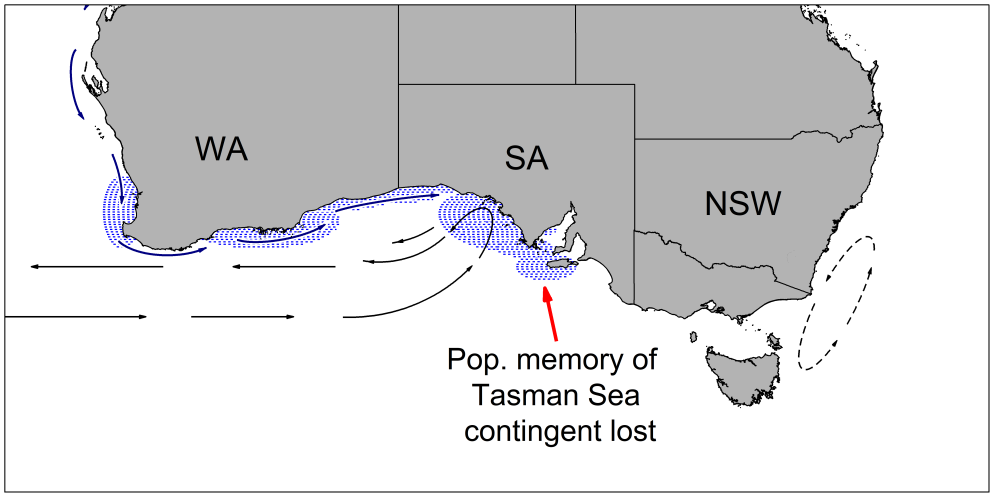

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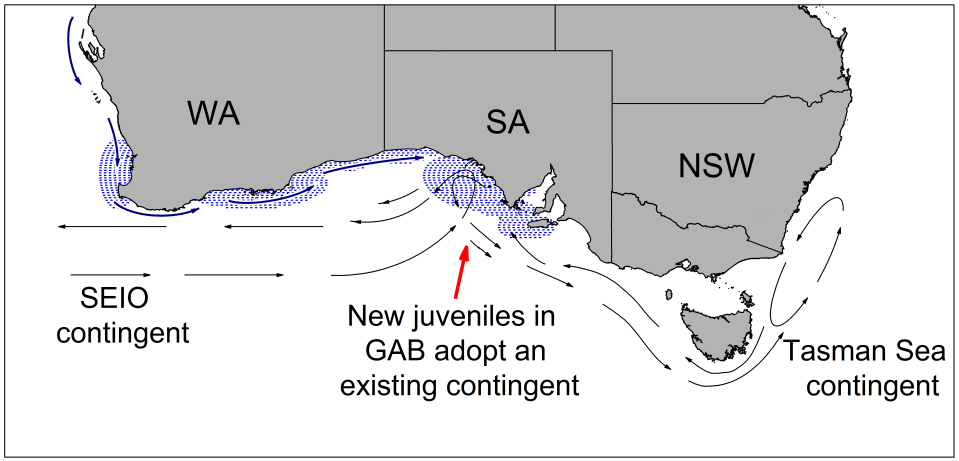

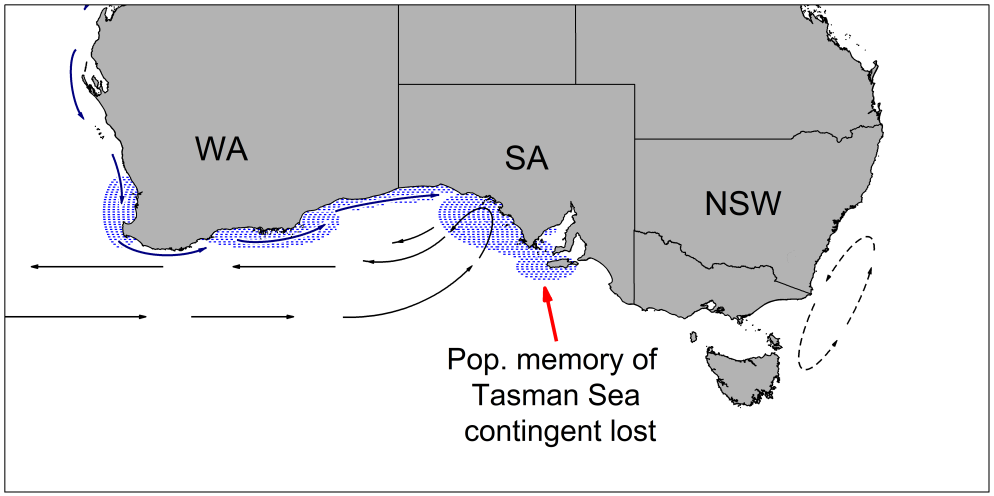

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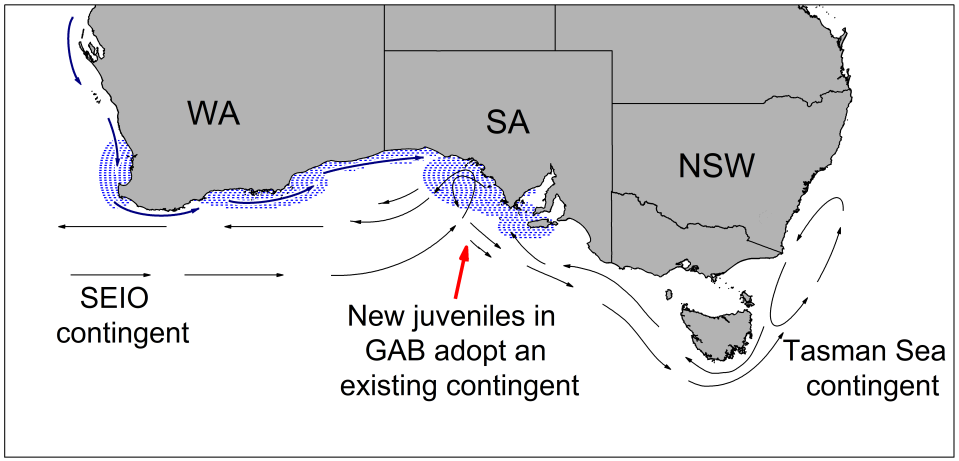

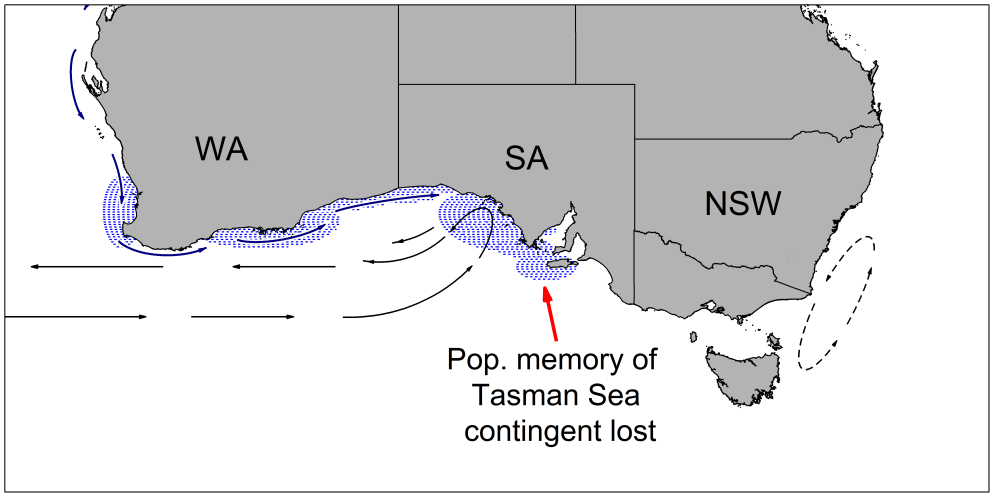

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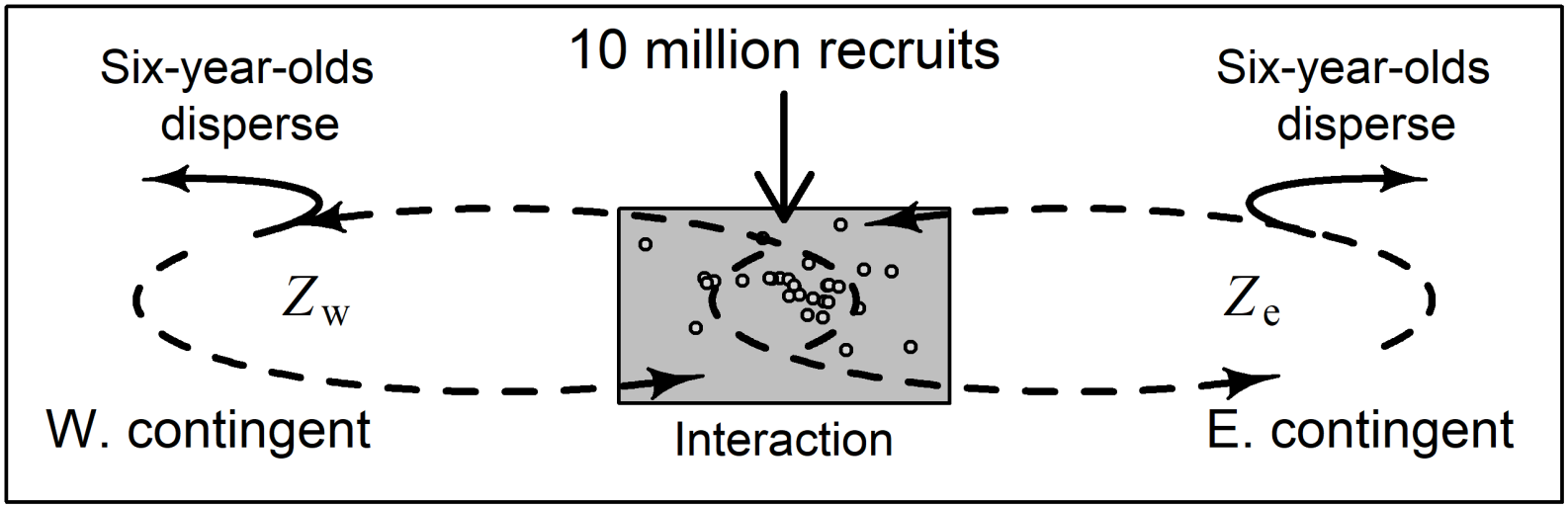
1. 10^7 recruits arrive in the interaction area each summer.
2. Proportions of recruits adopt each contingent depending on relative abundance.



3. Contingent-specific mortality, $\mathrm{Z_w} = 0.2\,\mathrm{yr}^{-1} \neq \mathrm{Z_e}(t)$.
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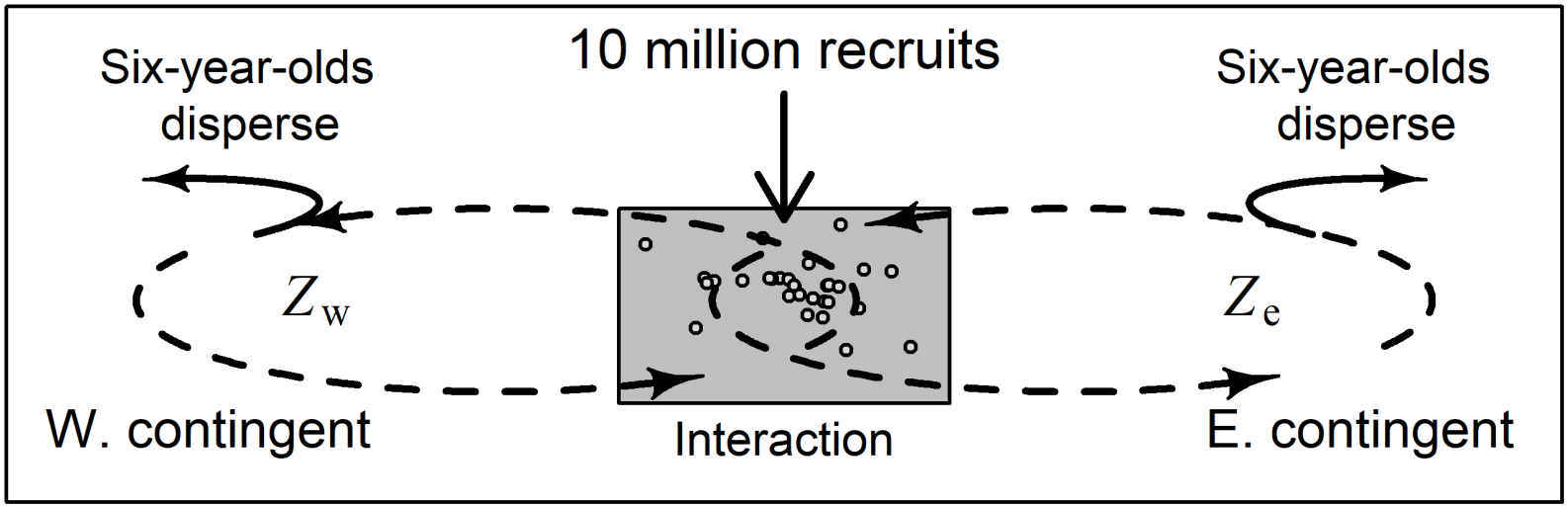

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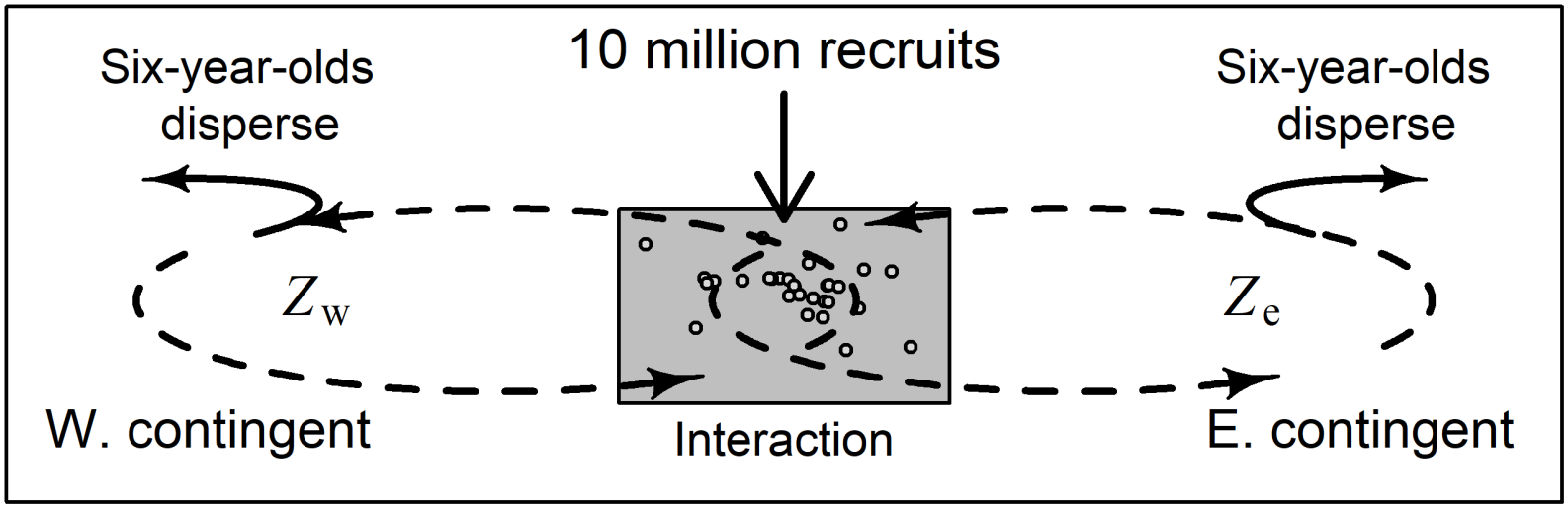

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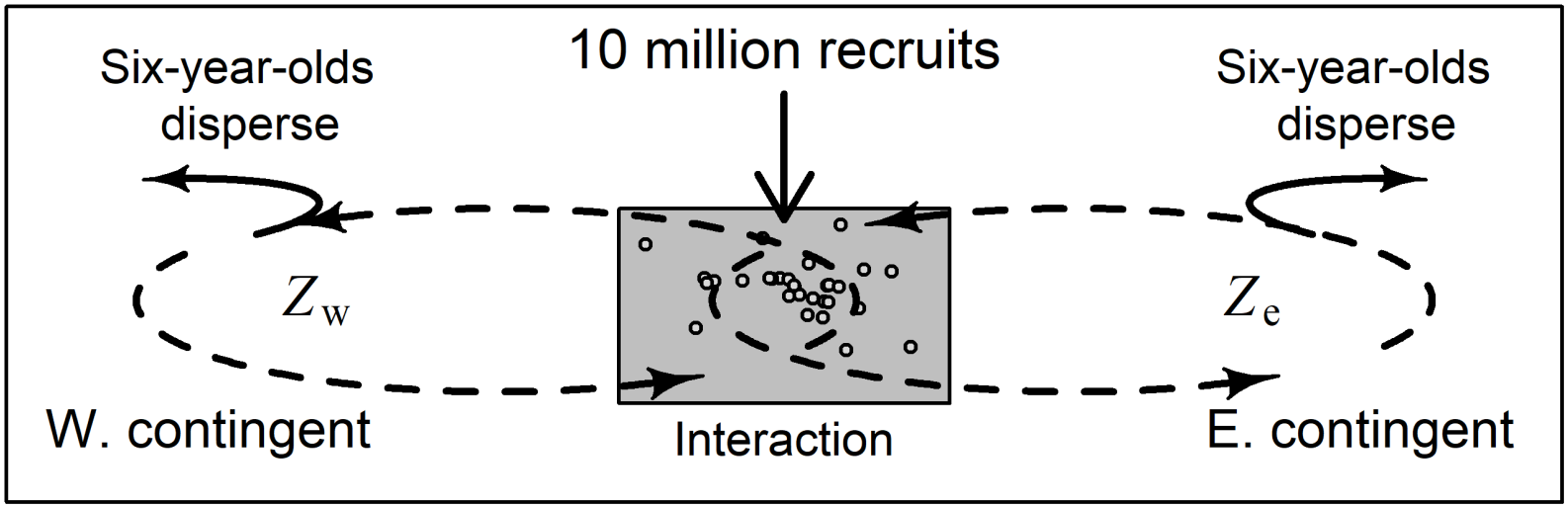

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4. Iterate age.
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An entrainment simulation algorithm

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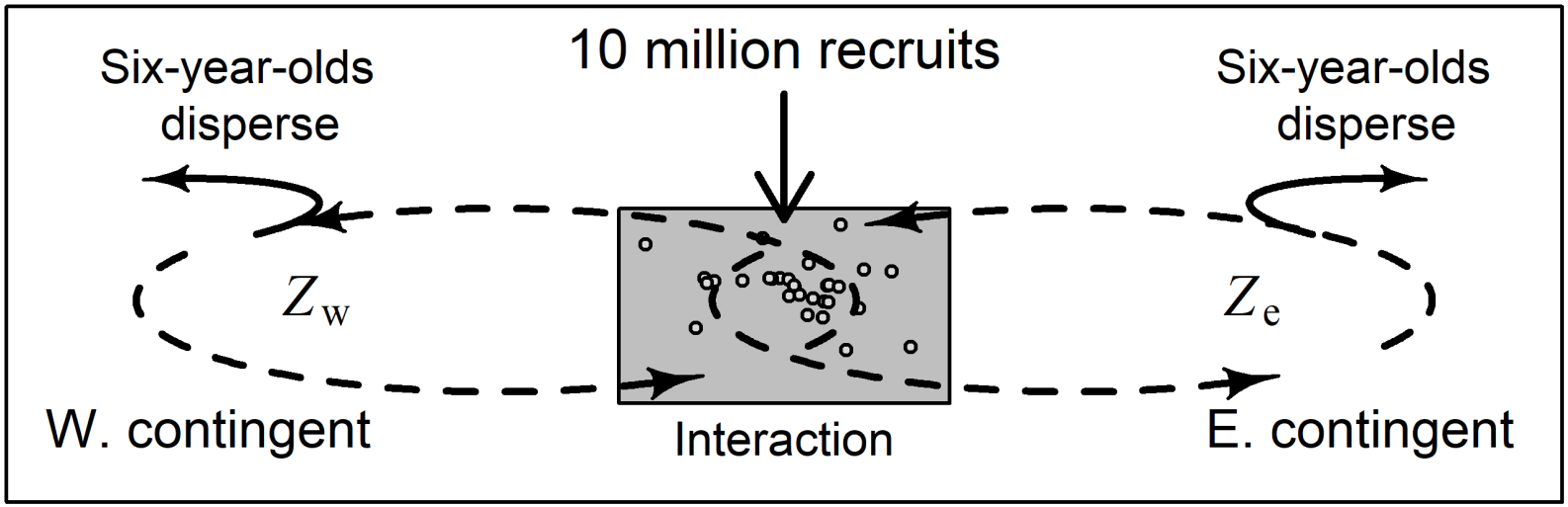

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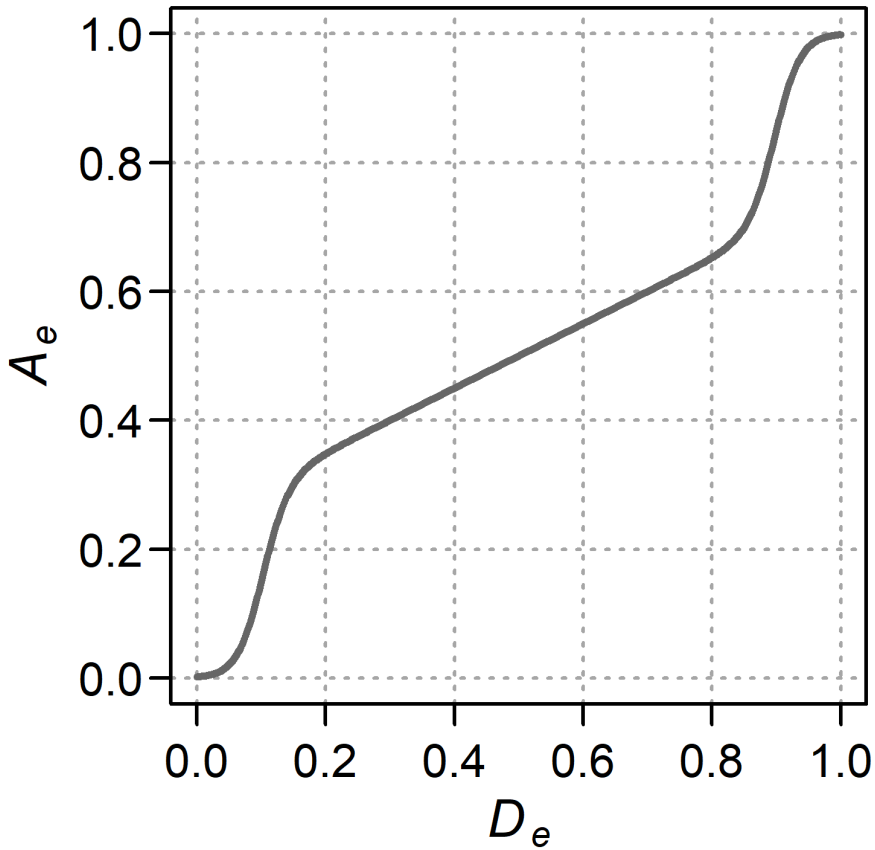
Contingent adoption rule



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- Incorporates *conformance*.
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D_e = proportion of demonstrators entrained in the east contingent.

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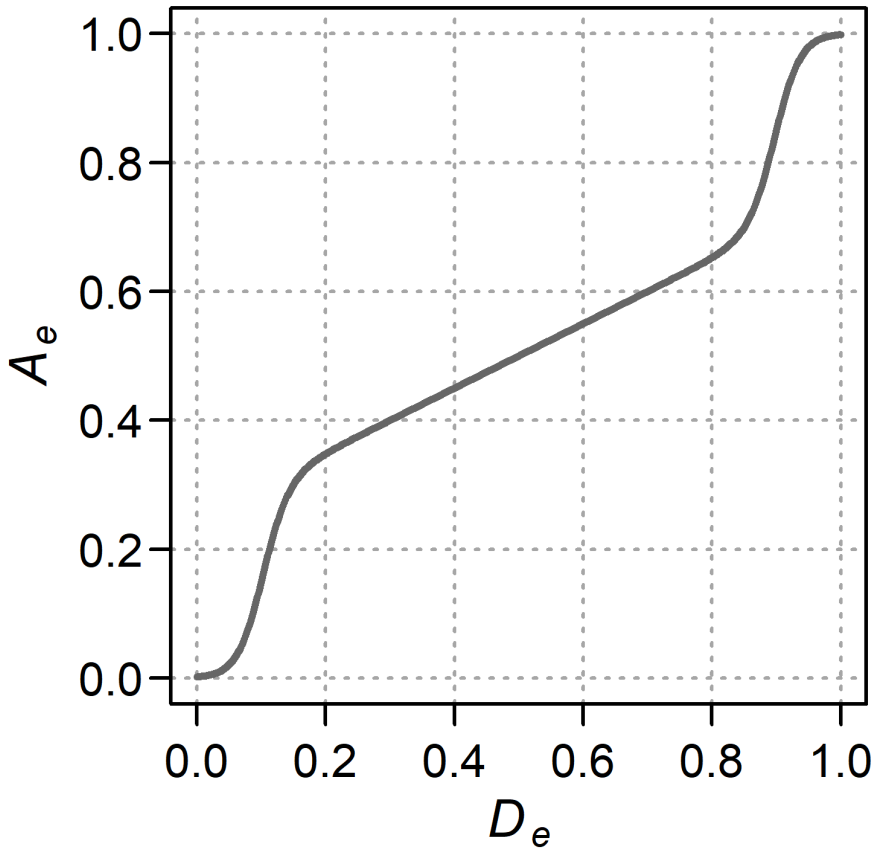

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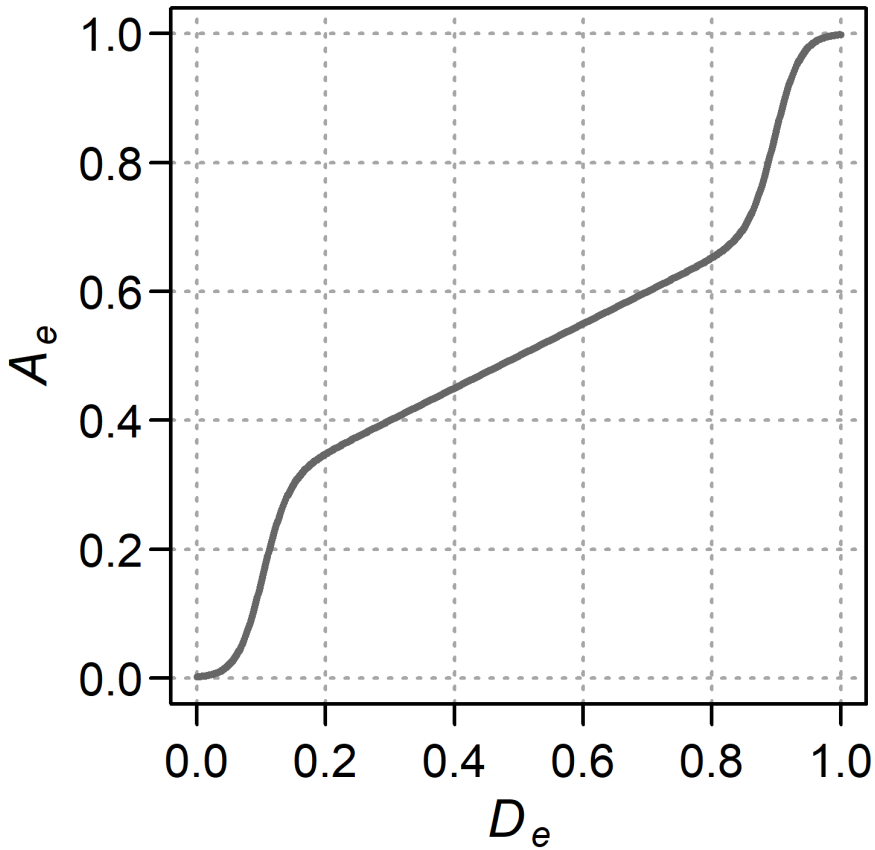

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- Differences among contingents in mortality (i.e. $Z_w \neq Z_e$) important.
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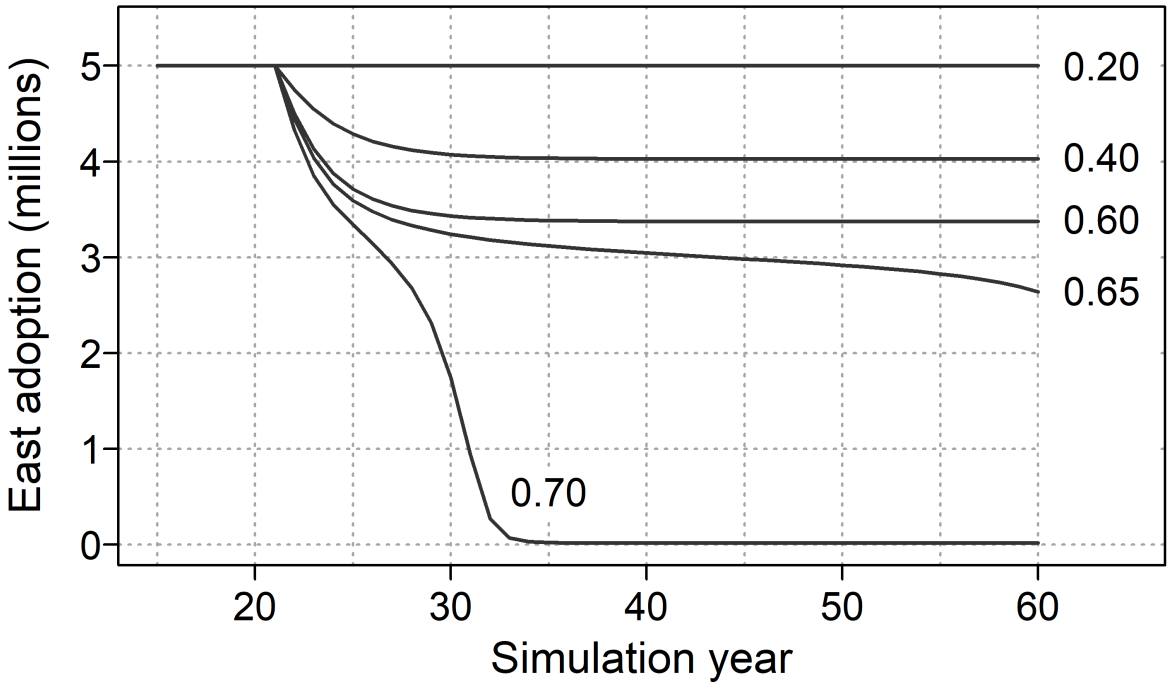

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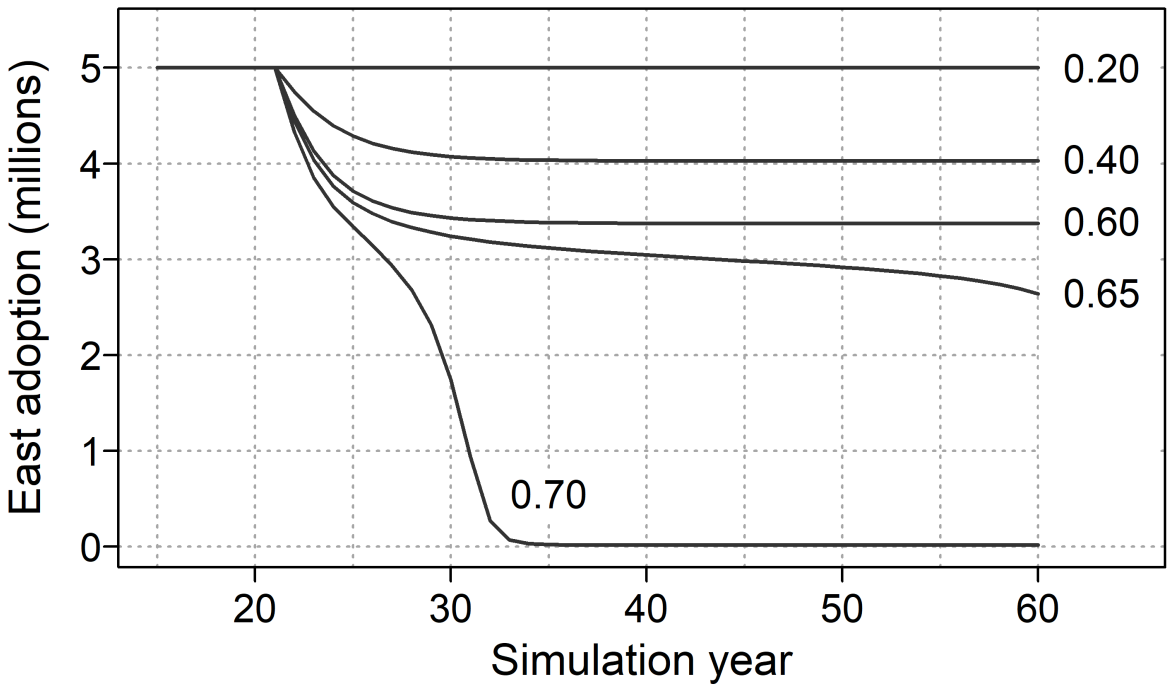

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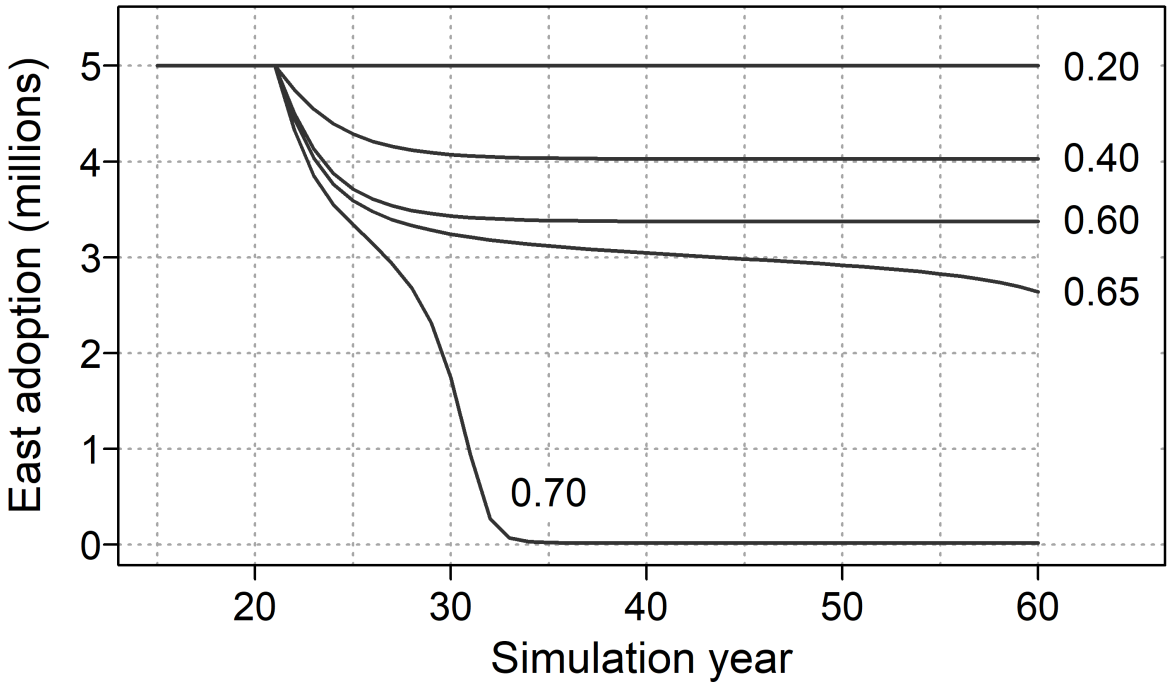

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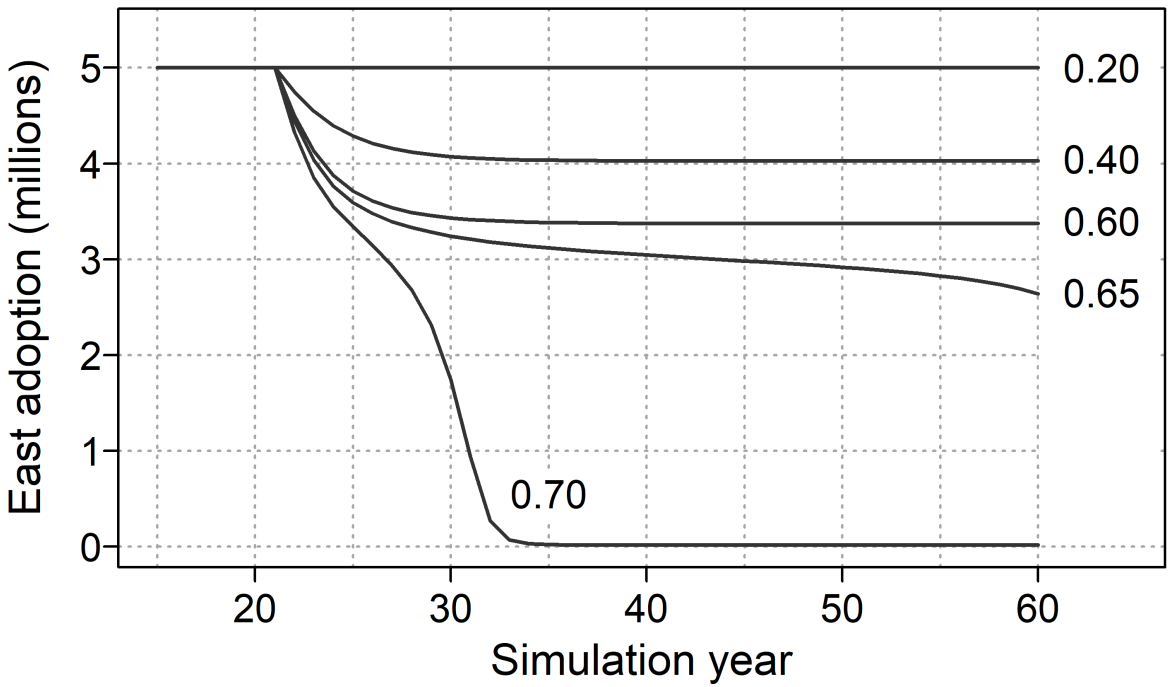

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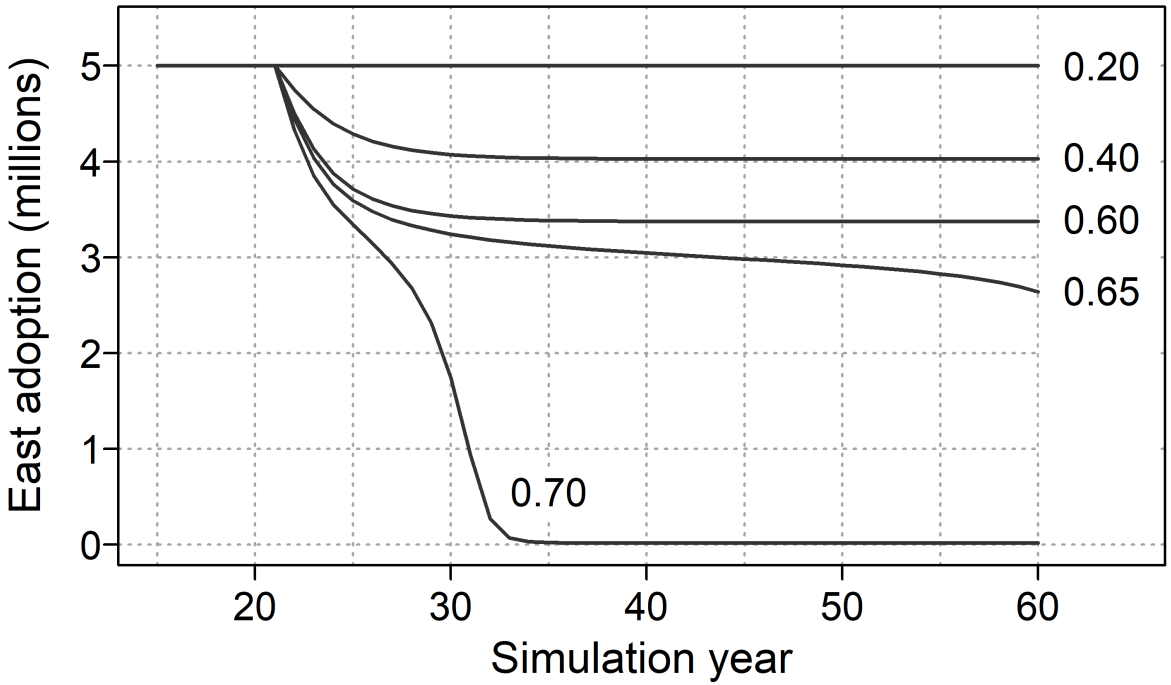

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A mortality scenario

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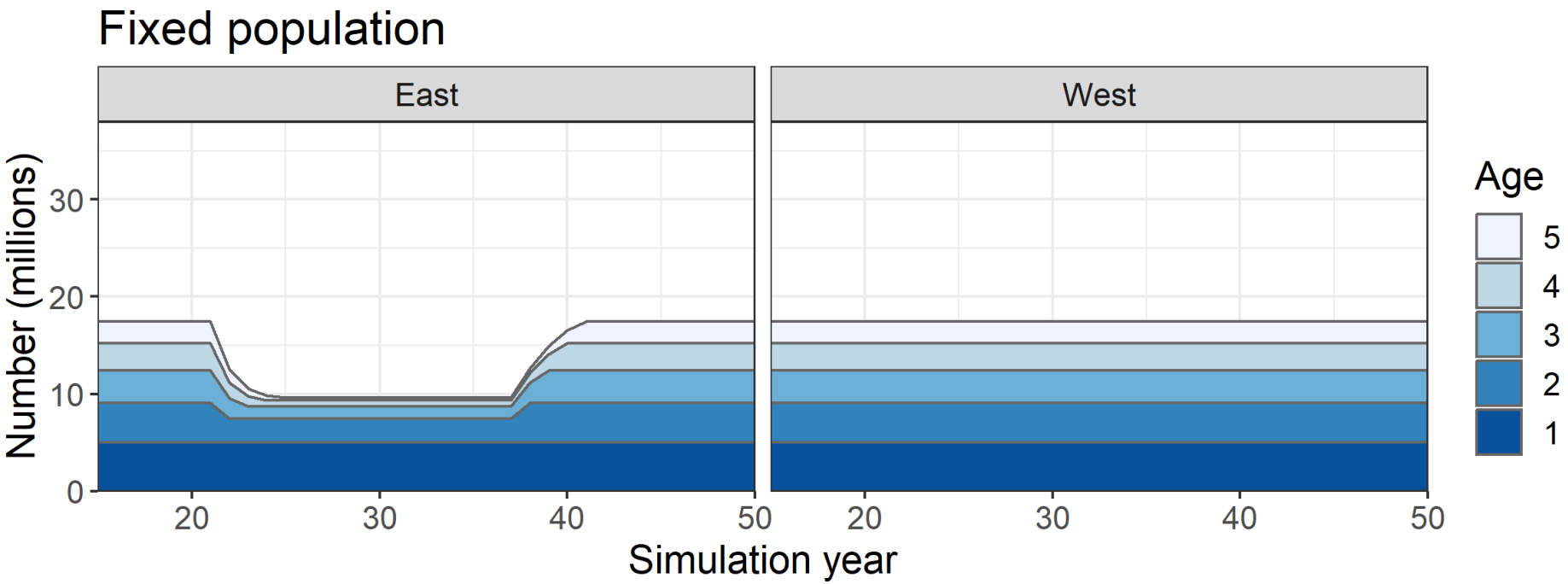
Age-structured migrating populations (yrs 15 – 50)



- Overall survival would be lower without fidelity to overwintering grounds.

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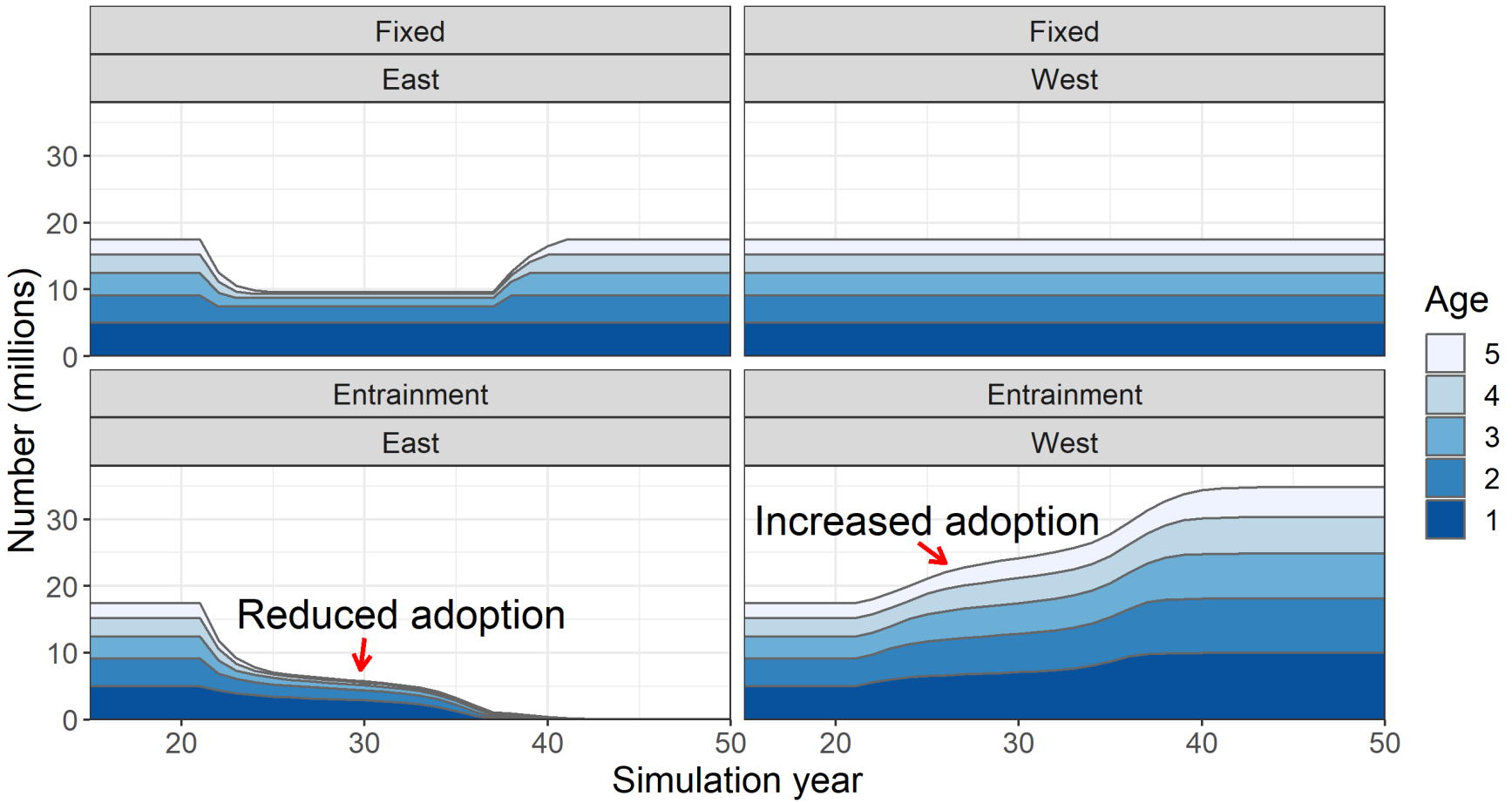

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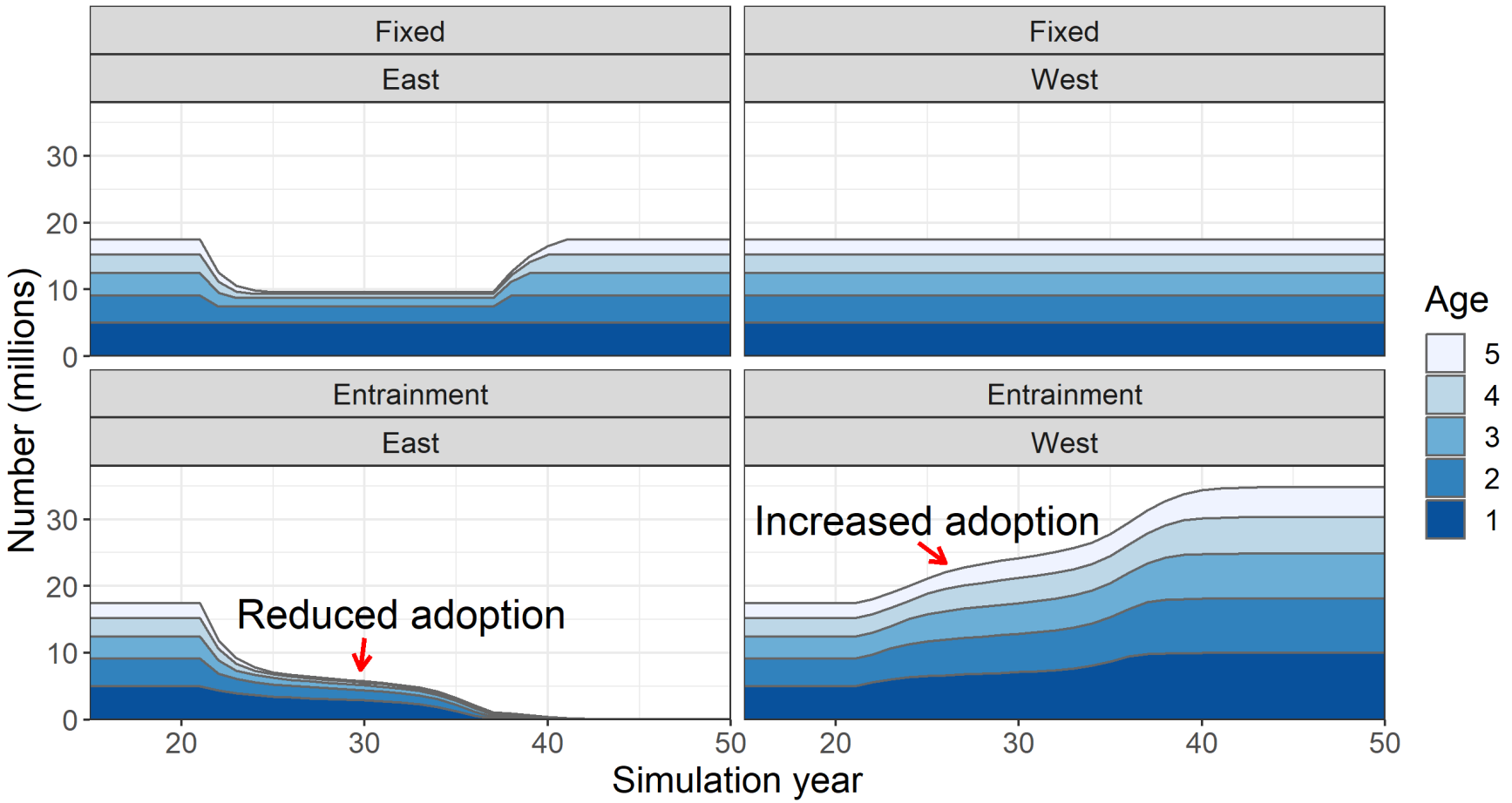

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Why entrainment matters

- Simplest, most plausible explanation for migratory behaviour of southern bluefin and other species.
- Social learning of migratory routes well accepted for other taxa.
- Populations can adapt to threats and opportunities.
- Produces dynamics not accommodated by stock assessment models.
- Petitgas et al. [2010] contend collapsed fisheries have suffered disruption to contingent structure.
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References


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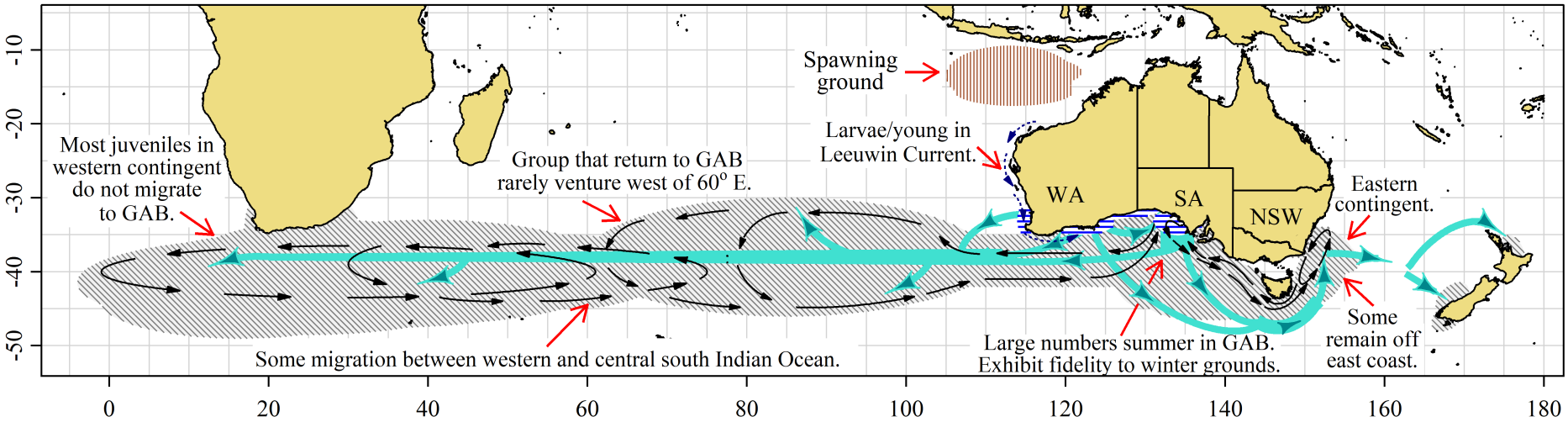
My presentation summarised in seven words

- Full map
- Fitness
- Longline tag releases
- Early surface fishery recoveries
- Comparison of lengths
- Archival tags
- Conspicuous questions
- Flickering
- Additional considerations
- Examples

Figure: Fargo. Series 1.

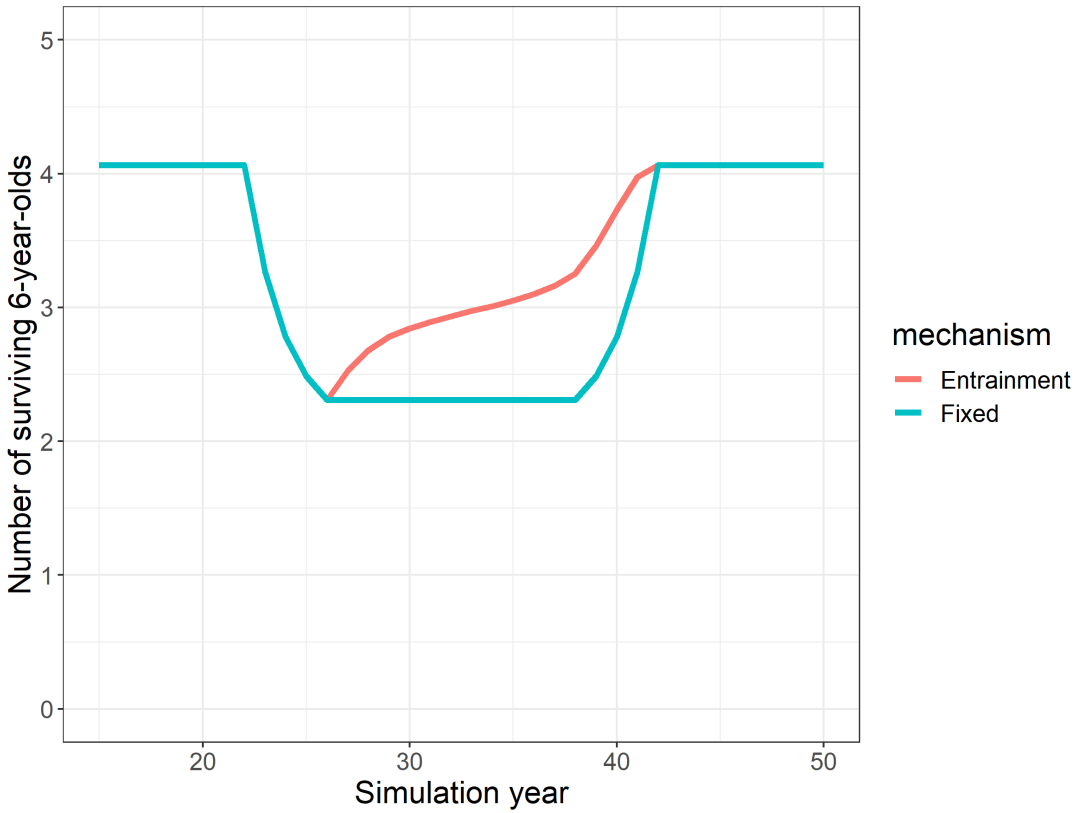
A map that includes NZ



◂ Appendix

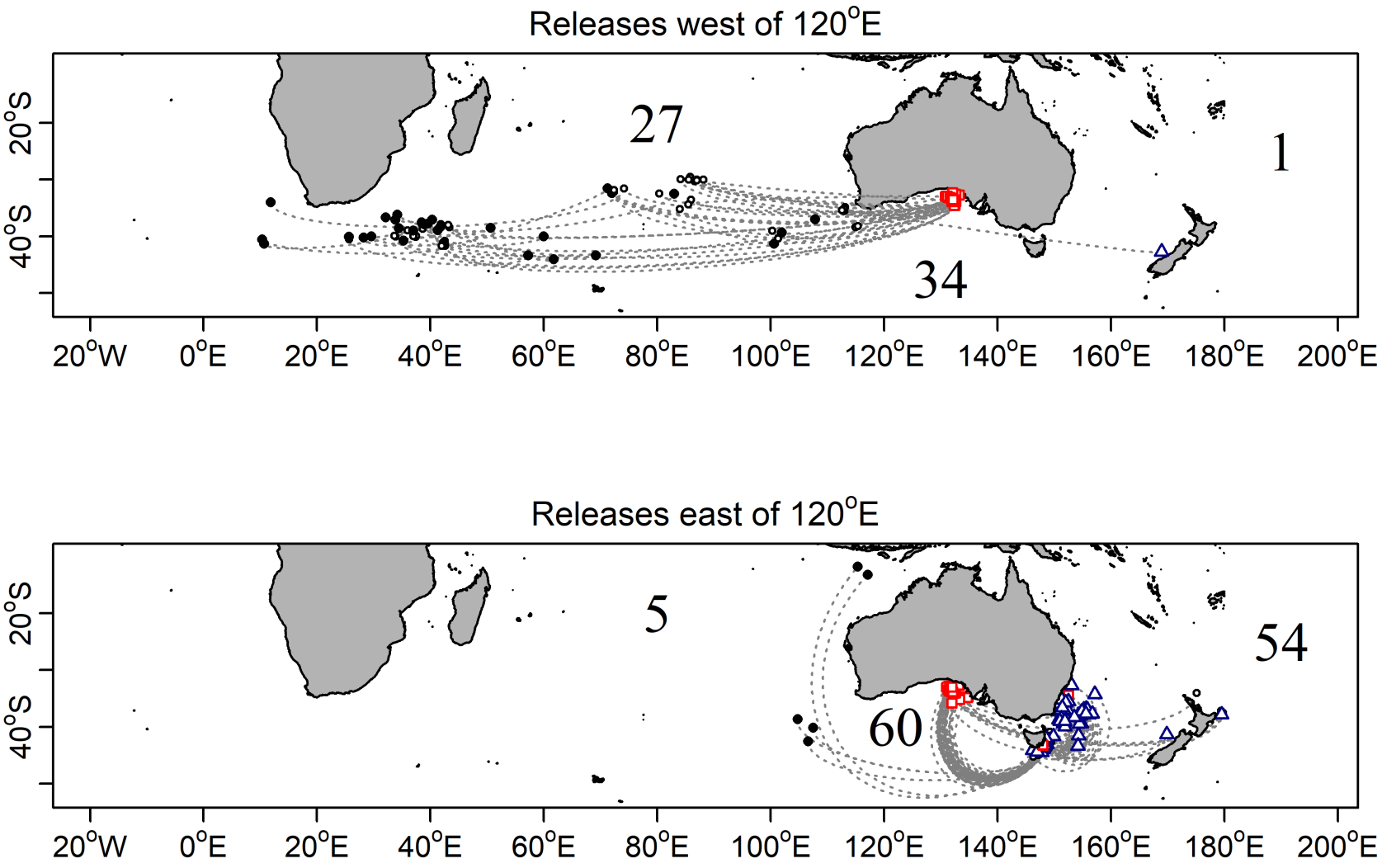
Fitness of cohorts from $0.7\mathrm{yr}^{-1}$ mortality scenario

Ratio of amounts of a type before and after selection can be used as a measure of fitness (Hansen, 2017, *Journal of Theoretical Biology*, **419**, 36 – 43).



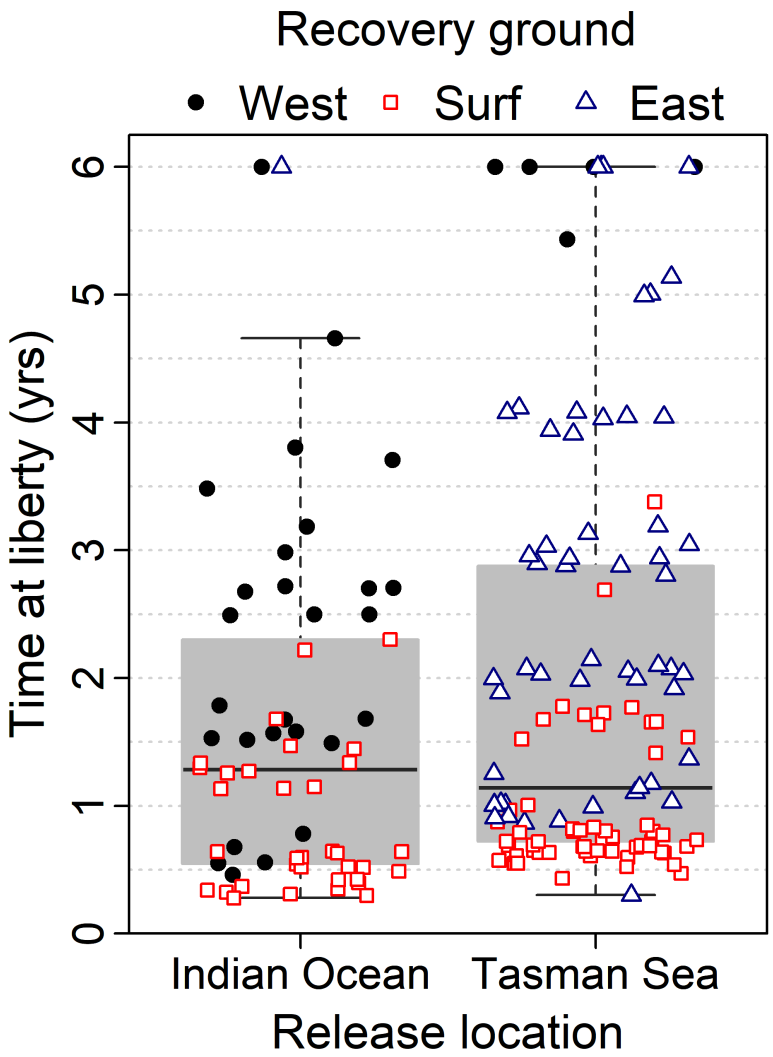
◂ Appendix

Recoveries ($>$ 90 days) of tags released from longliners



boxplots

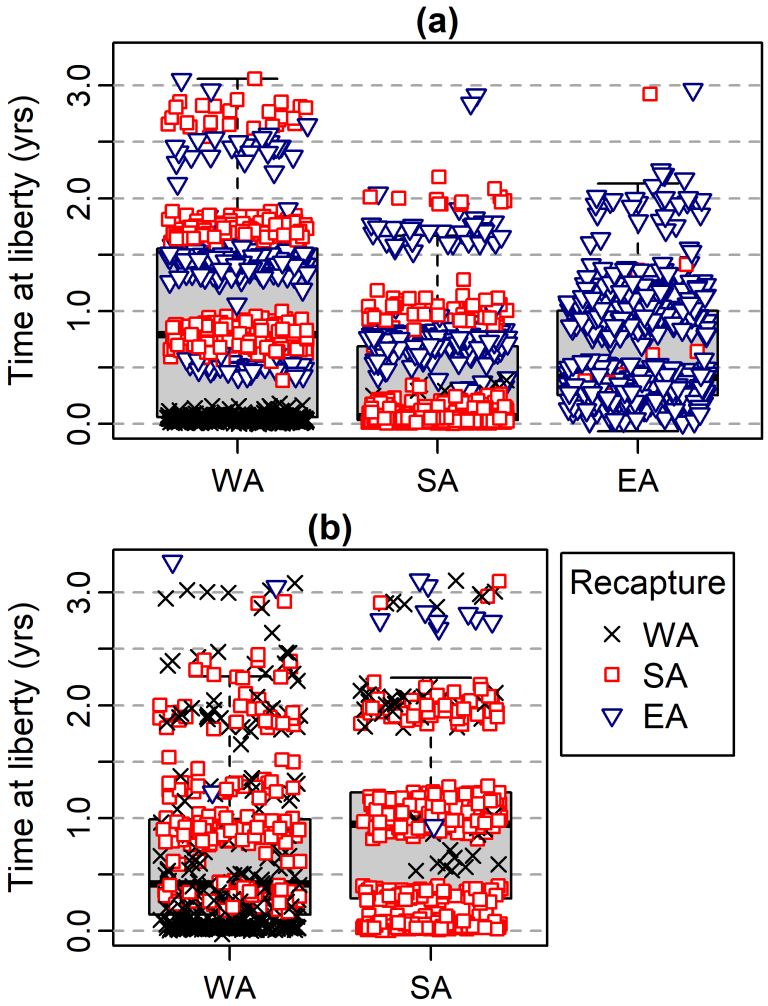
Evidence of homing to overwintering grounds



1. Individuals from each tagging group recaptured in GAB.
2. Longline recoveries only in same fishery up to five years later.
3. Juveniles that summer in the GAB home to overwintering grounds.

◂ Appendix

Tag recaptures by surface fisheries (releases before 1990)



Times-at-liberty of tags released (a) from WA, SA and EA (mostly NSW) and recovered by the surface fisheries during the 1960s.

Differences in distribution or recovery locations among tagging locations.

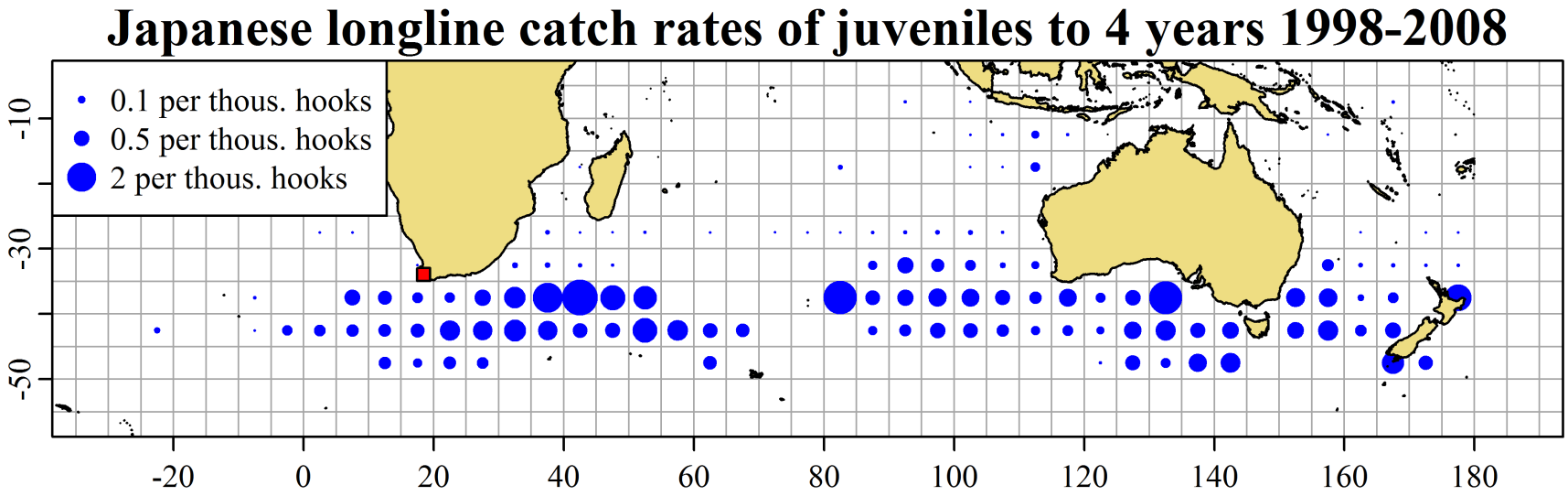
Recoveries of tags released (b) from SA and WA in 1983 and 1984.

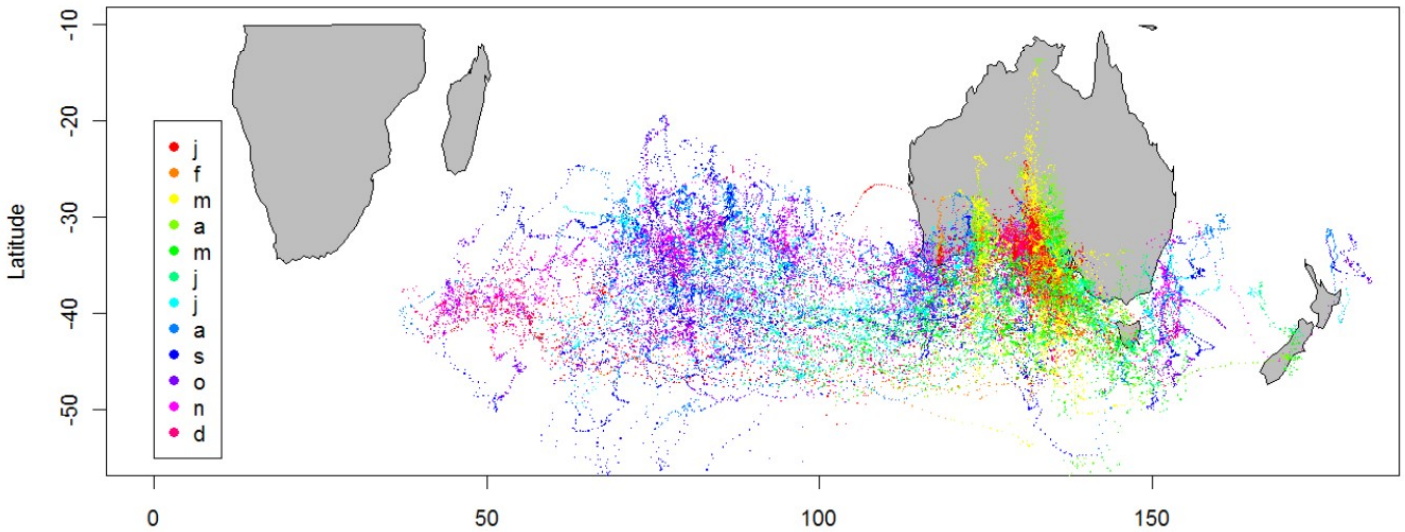
Almost no recoveries from NSW.

Fish recaptured with times-at-liberty of a year or more could have migrated to NSW.

◂ Appendix

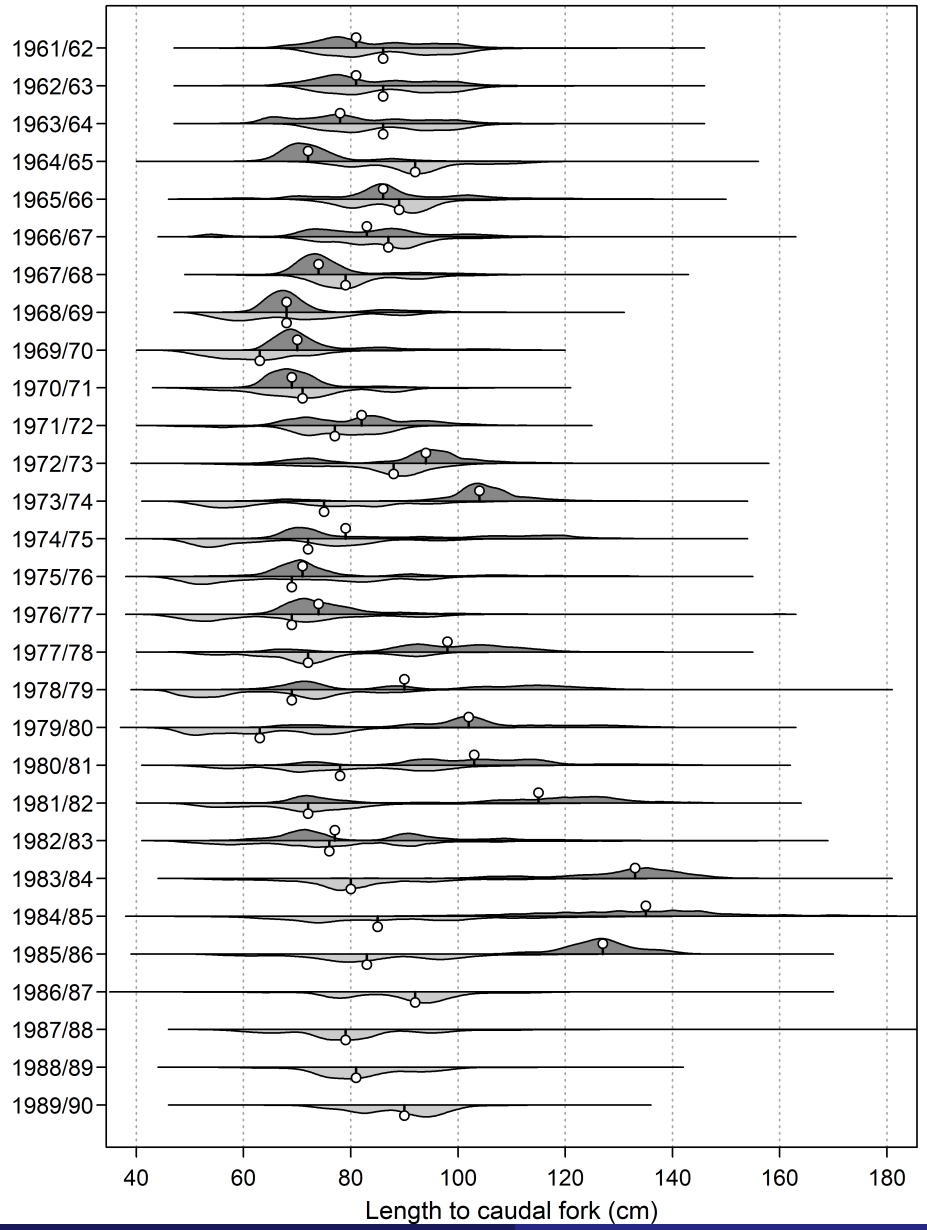
Juvenile catch and archival tags





◂ Appendix

Length-at-capture



Dark grey (top) densities are the annual length of NSW catch. The light grey (bottom) densities are lengths of the SA catch.

Up until the mid 1970s, NSW catch was dominated by a single age group around 70 cm in length.

◂ Appendix

Conspicuous questions of marine fish ecology (Bakun 2001)

1. Why "primitive" pelagic mode (thousands of offspring that nearly all die) has been so successful?
2. Why do extinctions of prey species not occur more often?
3. Why does it sometimes seem nearly impossible to recover a heavily exploited stock to its original productivity?
4. Why do fish species with more terrestrial-type reproductive modes seem to be so much less resilient to fishery exploitation?
5. Why do correlations between recruitment and environmental variables tend to hold for a period of a few years, but then break down?
6. Why do habitual spawning locations often seem quite consistent from year-to-year but drift radically from decade to decade unexplained by environmental properties?
7. Why do large mobile stocks tend to withdraw from the sites of major fisheries? How do they manage to do this?

◂ Appendix

Flickering

Davos, V., van Nes, EH. & Scheffer, M. (2013) 'Flickering as an early warning signal', *Theoretical Ecology* **6**, 309 – 317.

Mullon et al (2005) define three classifications of fisheries collapse, "plateau shaped", "smooth" and "erratic". Erratic collapses were the most common type among collapses examined.

Mullon, C., Fréon P. & Cury, P. (2005) 'The dynamics of collapse in world fisheries', *Fish and Fisheries* **6**, 111 – 120.

◂ Appendix

Additional considerations

- Stochastic recruitment.
- Variability in mortality.
- Rates of straying (roaming)?
- Carrying capacity of potential habitats.
- The spatial distribution of naive observers?
- Populations subject to entrainment likely to be prone to density-dependent catchability.
- Predators-prey interactions each subject to entrainment.
- Does spatial heterogeneity promote robustness to temporal heterogeneity?

◂ Appendix

Other examples

- Bohuslan periods of Atlantic herring.
- Brazilian episode of Atlantic bluefin tuna.
- Traditional knowledge of Pacific herring.
- South African sardines.
- Chesapeake Bay striped bass.
- Northern cod.
- Hoki?
- Gemfish off eastern Australia?
- Jackass morwong off eastern Australia?
- ... every population that has collapsed?

◂ Appendix

Implications

- Catch-based data poor methods.
- Hierarchical stock management?
- Climate change.
- Effects of MPAs.
- Episodic recruitment.
- Species distribution models.
- Archival tags.

"One of the most intriguing recent developments in fisheries science" MacCall (2012).

◂ Appendix