A framework for multi-year Leslie-Davis depletion modelling and its use as a stock assessment model feature

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A role for depletion methods

Globally many fish stocks require catch limits to be set using scientifically-based methods, but for which insufficient data is available for a demographically informed integrated stock assessment.

- Often these fisheries may only have catch totals per month or year, lacking effort data and composition data.
- But some also possess effort totals, and under such data "moderate" conditions, Delury or Leslie-Davis (1939) depletion modelling may be useful.

In 2017 we published a paper in Fisheries Research (Feenstra et al. 2017) on a method that extends the typical use of Leslie-Davis within single years, so that it estimates both recruitment and population simultaneously for multiple years. "EDM" = extended depletion model.

southern rock lobster (*Jasus edwardsii*).....→

← "pot" = fishing gear
(1 pot set & lifted =
1 unit of fishing effort =
1 "potlift")

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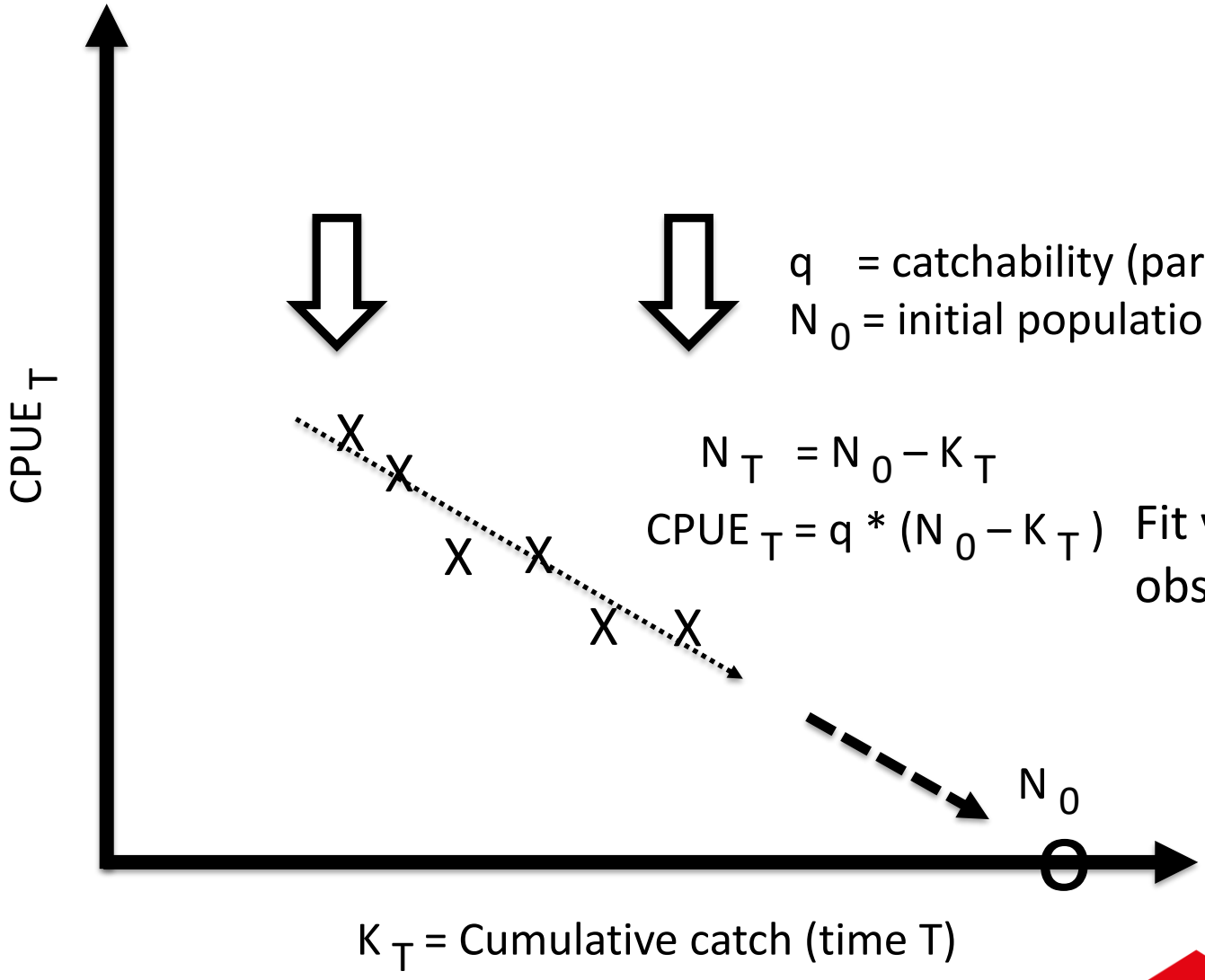
EDM: Leslie-Davis model of CPUE



q = catchability (parameter)

N_0 = initial population (parameter)

$$N_T = N_0 - K_T$$

$$CPUE_T = q * (N_0 - K_T)$$

Fit via log-normal observation errors.

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EDM: Feenstra et al. (2017)

Partition of 12 months into a fitted depletion period ("FDP"), and the rest of the year ("non-FDP").

Within year "t", during the FDP:
start-month ("m") exploitable population ("N") is modelled as

$$N_{t,m} = e^{-\sum_{j=0}^{m-1} M_j} \left(N_{t,0} - \sum_{i=0}^{m-1} e^{-0.5M_i - \sum_{j=i}^{m-1}(j-i)M_j} C_{t,i} \right)$$

For non-FDP (t): add recruitment and subtract catch

Non-FDP catch total

$$N_{t+1,0} = N_{t,m_{sa}} e^{-M_{am}} + R_t e^{-(1-Tr_t)M_{am}} - e^{-(1-Tc_t)M_{am}} \sum_{i=m_{sa}}^{11} C_{t,i}$$

EDM: pros and cons

Assumptions include those inherited from Leslie-Davis, that during the Fitted Depletion Period:

- Catch conditioning.
- Catchability is homogenous.
- Selectivity is homogeneous.
- There occurs sufficient stock depletion.
- There occurs no recruitment.

Benefits include:

- Estimates of both recruitment and exploitable population.
- During non-FDP, there are no requirements about catchability nor data on fishing effort.
- Provides a means for detecting changes in q over years.
- Allows addition of a recruitment index, without requiring a CSA-like constraint on catchabilities.

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EDM: more features

When catch and CPUE are available only by weight, EDM can estimate biomass (exploitable), but recruitment = positive "production".

- This was determined after the 2017 paper (not a focus).

The FDP can be quite a brief period, as long as sufficient depletion has taken place.

- In South Australia's rock lobster fishery, the fishing season is eight months (October-May), but a suitable FDP was determined for only January-March.

EDM is here compared with an integrated length-sex structured stock assessment model ("LenMod") that is catch(weight)-conditioned and fits to
a) commercial CPUE, b) catch numbers,
c) length-sex composition.

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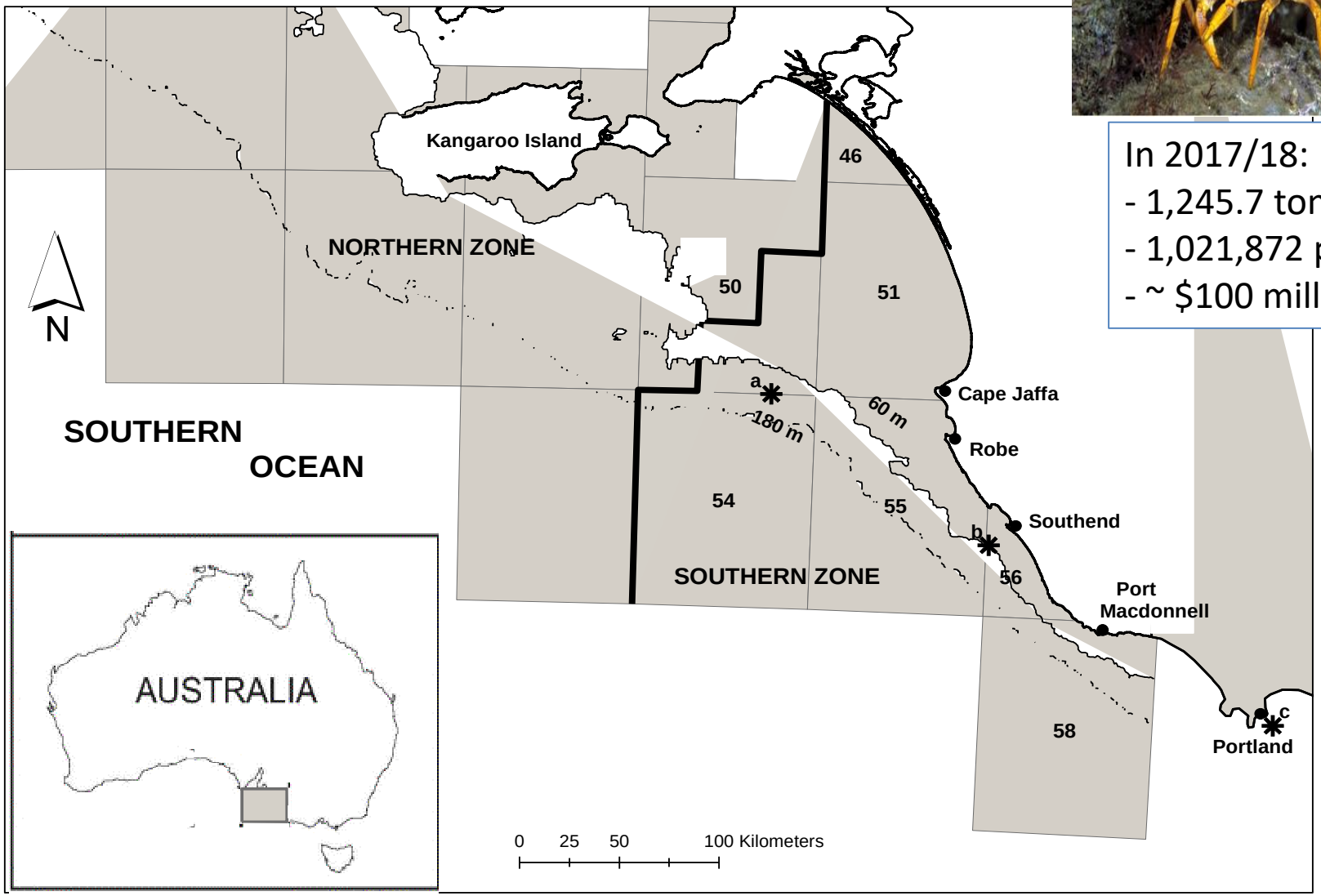
South Australia's Southern Zone southern rock lobster fishery

In 2017/18:
- 1,245.7 tonnes
- 1,021,872 potlifts
- ~ $100 million



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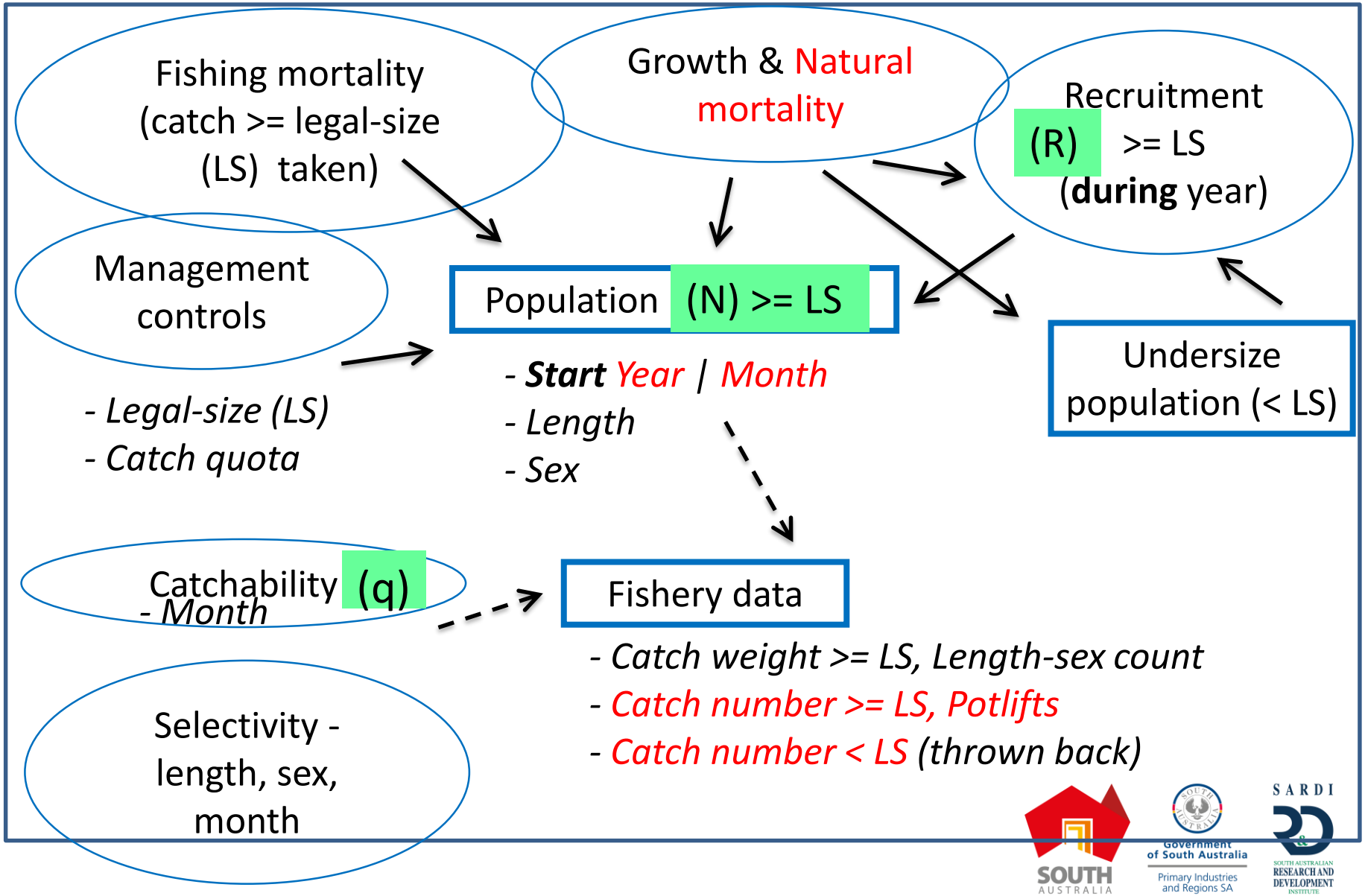
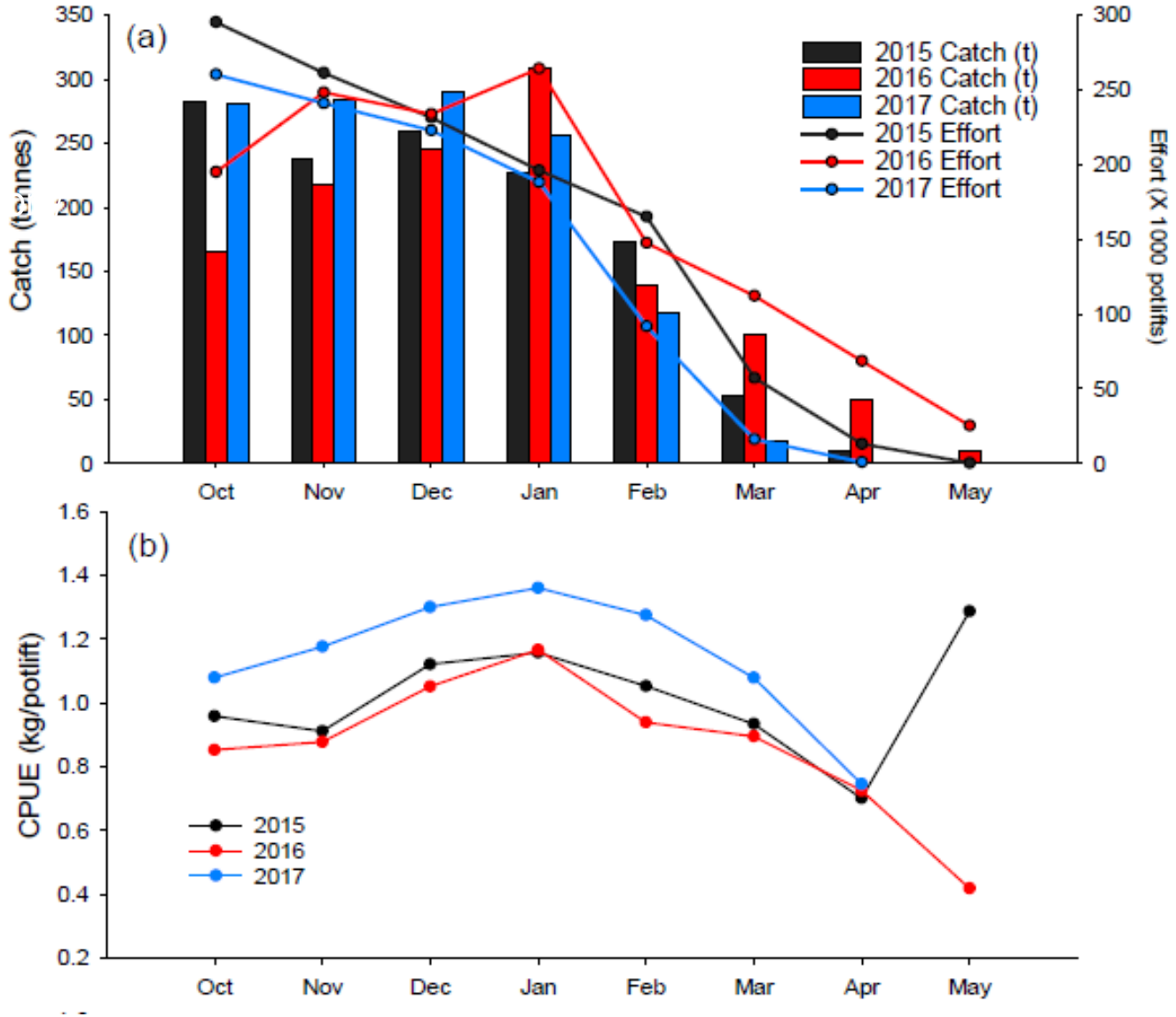
Fishery processes



Linnane, A. *et al.* (2019)

Fishery data

Southern Zone Rock Lobster



Selectivity changes to LenMod

Feenstra et al. (2017) used the LenMod version that was part of stock assessment current at the time, involving homogeneous length selectivity across all months.

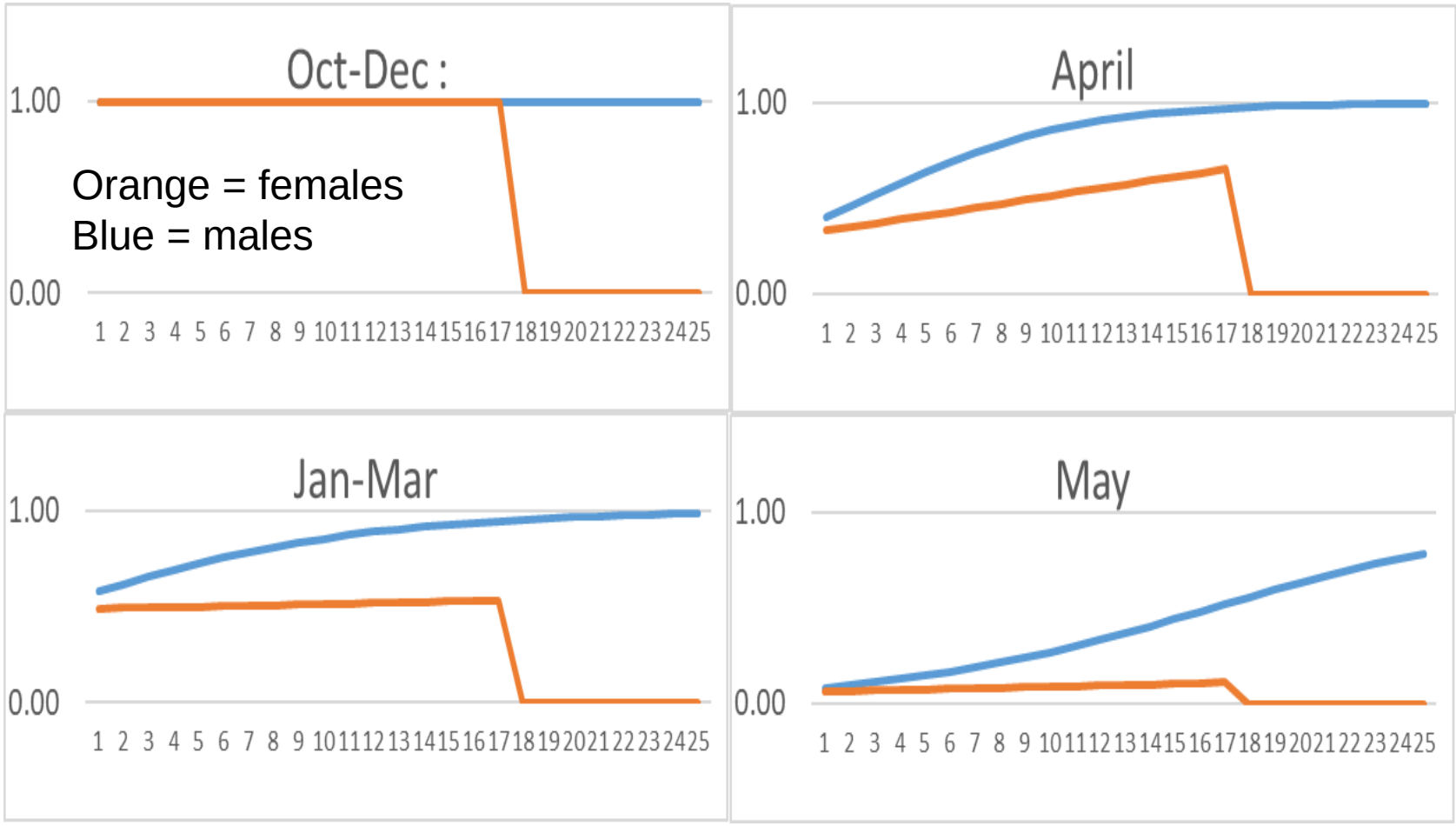
But a subsequent study has determined that a more parsimonious version of LenMod varies length selectivity by: Oct-Dec, Jan-March, and Apr+May.

- Oct-Dec: - 100% (for legal sizes).
- Jan-March: - ~ 50% - 75%
- Apr+May: - ~ 10% - 50%

Mean estimated catchability (q) by LenMod also varies substantially by period:

- LenMod: Jan-March / Oct-Dec = 1.60.

LenMod selectivity estimates > LS



LenMod and EDM

Both LenMod and EDM have now been fit to data up to calendar year 2018.

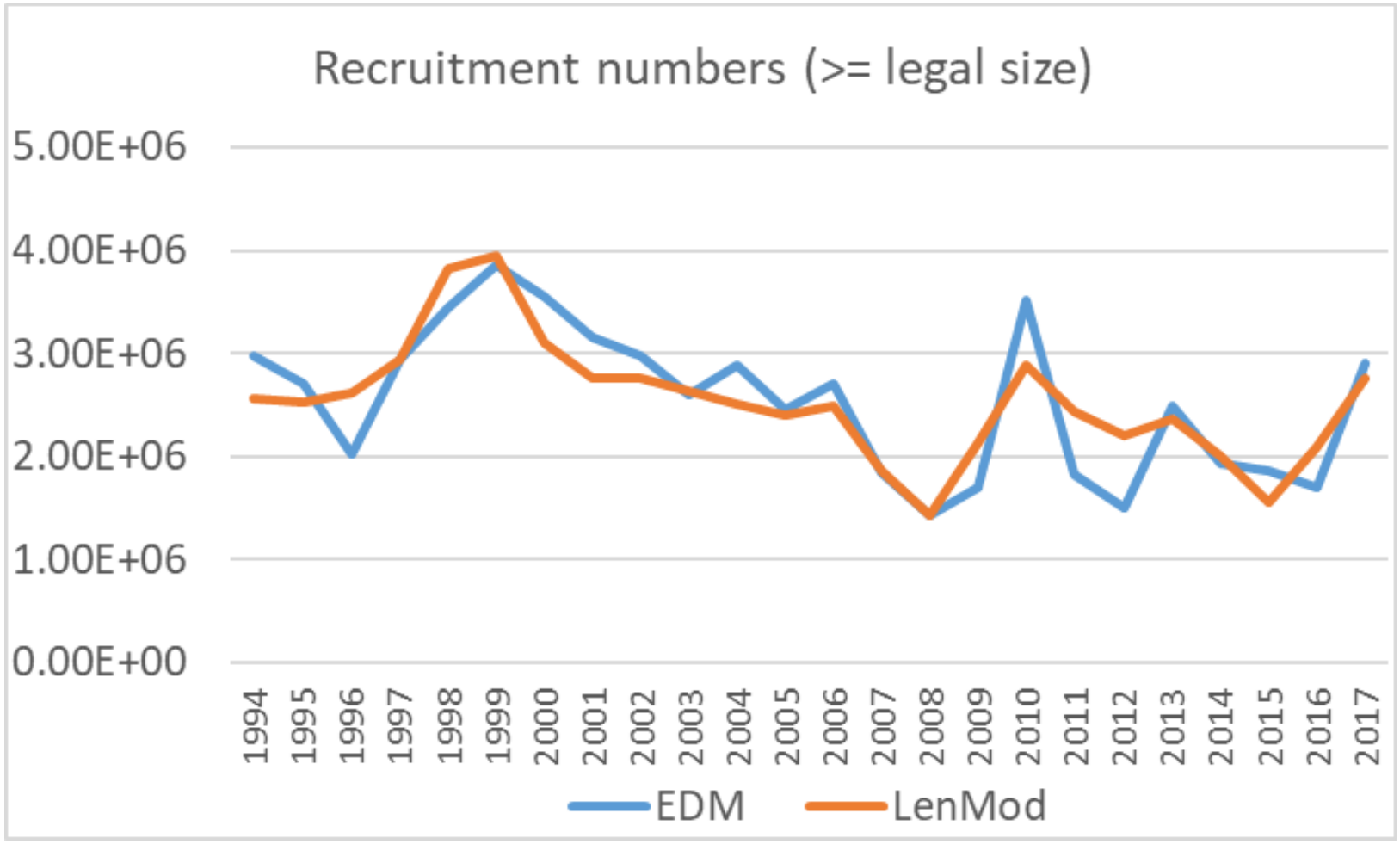
Catchability, ratio = EDM (FDP) / LenMod (monthly)

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1.39	1.25	1.06	0.74	0.78	0.77	0.80	0.25

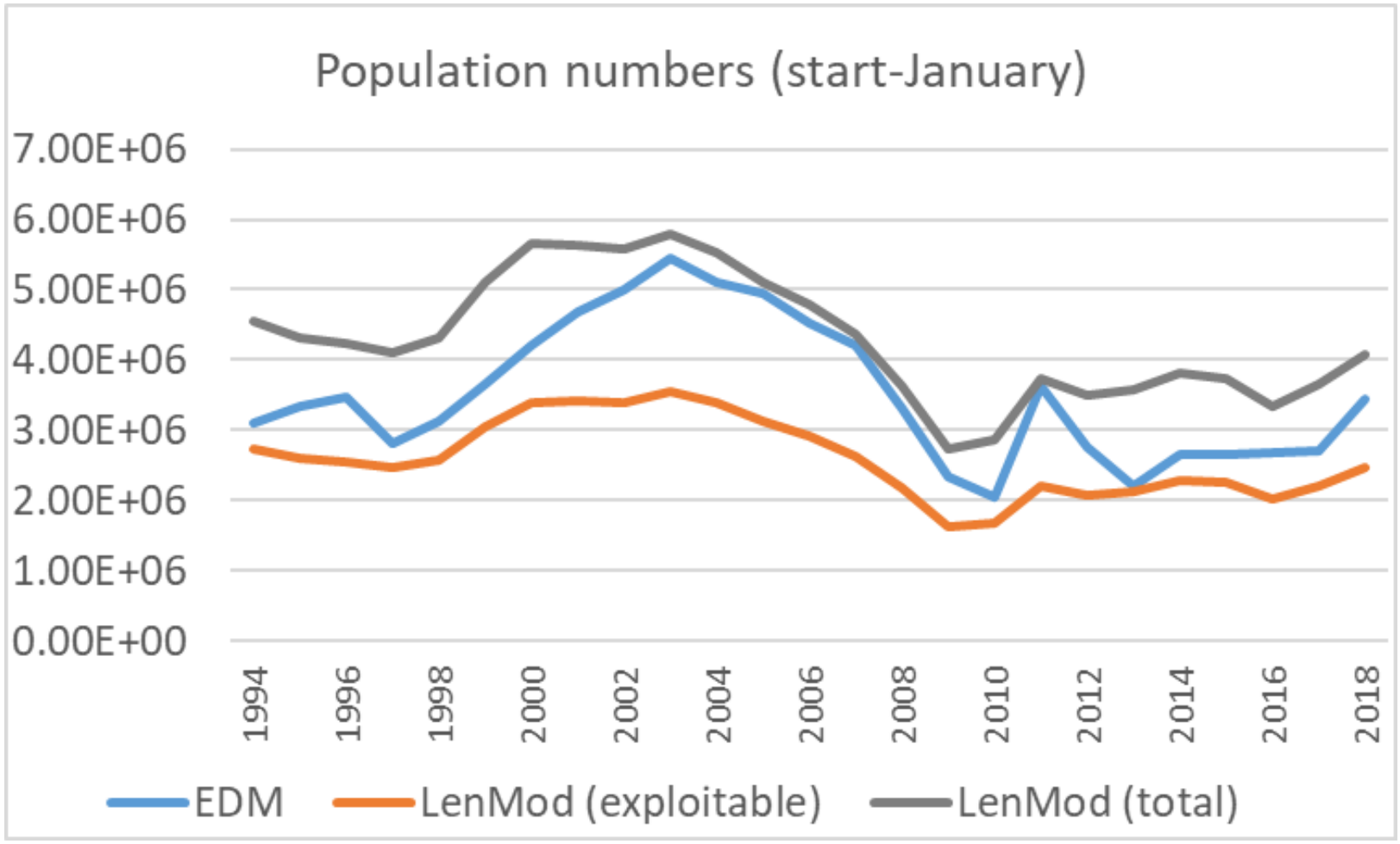
Abundance, ratios = EDM / LenMod (1994+)

- Yearly recruitment (to LS): 1.004 (= +0.4%)
  - 1.03 in Feenstra et al. (2017).
- Start-January population (exploitable): 1.34 (= +34%)
  - 0.88 in Feenstra et al. (2017)

Recruitment: LenMod v EDM



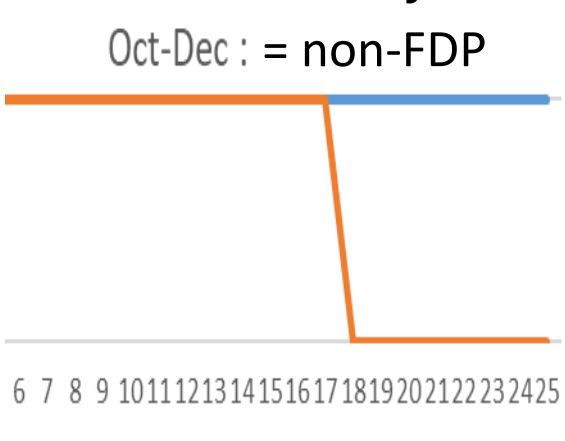
Population: LenMod v EDM

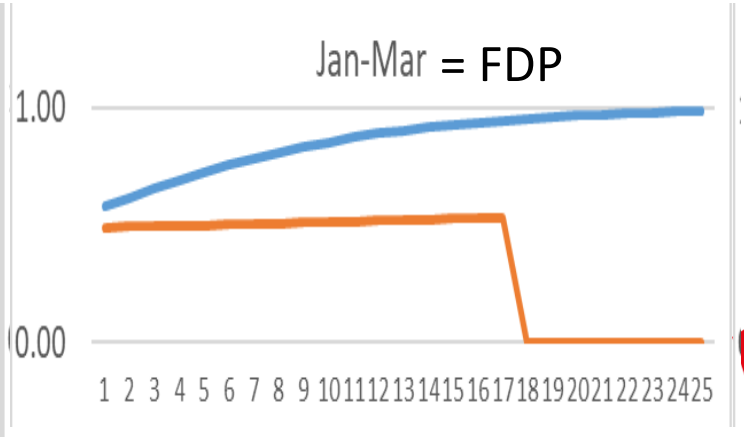


Selectivity: FDP v Non-FDP

Although EDM does not make an assumption about q outside the FDP, it can estimate positively biased population if selectivity is substantially less for FDP than non-FDP.

- Shape of FDP selectivity curve is such that fewer animals are available than during non-FDP.
- This means that non-FDP catch includes animals that are not available for capture during the FDP.
- But yearly recruitment is not impacted by this (at least in validation with LenMod) because total catch is accounted for each year.





EDM and the general model

Standalone option:

- Via a control switch, calling a separate exe/dll file.
- As “separate package” noted in Focus Questions.
  - Easier for model and estimation code.
  - Potentially harder for input and output code.

Alternatively, standalone EDM could be approximated (integrated) via a combination of input options.

- But the inputs may exist but be non-obvious.
- It may push the program to its limits (tests boundary of software).
- Will it retain ability to test between year changes in q?

EDM subsumed by LenMod

I endeavoured to replicate EDM's results on South Australia's lobster using LenMod via changing input files alone (no code changes) and such that no data-rich information was retained (e.g. growth, length weight).

- From Focus Questions: "delay difference models can be represented exactly using an age-structured model" + "it should be possible to represent a data-poor method with a standard stock assessment model".

This almost succeeded. It required two changes to the code:

- Re-dimensioning a temporary vector on time (not length).
- Commenting out the initial state routine, replacing it with code that simply assigns a single N0 parameter to t = 0.

But – having done the above – the results matched standalone EDM with < 3% discrepancy and identical trend.

LenMod input file changes

- Length dimension was reduced to one sublegal and one legal bin.
- Length-weight was set as a 2-element vector of 1 (not a function).
- Removed the growth process from the list of optional input processes.
- The fixed settlement recruitment spread vector was set to 0 for undersize and 1 for legal size.
- Maximum length and sex selectivity for all months.
- A single catchability parameter was set to be estimated only for the FDP (Jan-March).
- Likelihood weights were set to 0 for non-CPUE components (or equivalently, data removed).

Conclusion

EDM may be useful in data-limited (or –moderate) fisheries to estimate abundance/biomass.

In more data-rich fisheries EDM may afford a) the possibility of detecting yearly changes in catchability, or b) provision of an alternative set of abundance/biomass estimates.

EDM can be incorporated by a general model via an appropriate set of inputs.

- But this needs to be carefully validated with standalone EDM. (The initial state problem did not raise a runtime error, but caused LenMod to overestimate population.)
- User documentation concerning appropriate inputs.

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