Will age-and-length based modelling permit broader application of the next-generation fishery assessment model?

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Focus questions we address

- Does the general model need the capability to allow the distribution of length-at-age to change over time?

- How can size-structured models be included in the general model?

Clearly…

- Any next-gen model will include age as an independent variable of the population array.
- Age is critical in fisheries population assessment because age is homologous with time—a fish increasing one year of age is matched with one year of time elapsing in the model time step.
- So mortality, inferred from changes in numbers with age, can be applied to model-predicted changes in numbers with time of each cohort individually.

Why age and length?

- Mainly, because length selectivity strongly affects all crucial model-predicted quantities:
  - catch in weight landed
  - model-predicted proportions by age for the fitting to age composition samples, and
  - proportions by length if length samples are fitted also.
- All fishery models must do this conversion of population numbers by age to numbers by body size to predict these crucial size-dependent model fit quantities.

Why age and length?

- So to capture the impact of length selectivity on the catch, modelling length dependence is crucial.
- And happily, data on fish size (mainly landed fish size, but also survey samples by size) are the most abundant sample measurements.
- Nearly every fish that is aged, is also measured for size.
- SUMMARY: Dependence on fish size is critical for fishery model inference, and measurements by size are abundant and inexpensive.

How age-based fishery models handle variation in length-at-age

- There are two broad classes of age-based model:
  - Age & length based: account for dynamical change in the length-at-age distribution
  - Age-only: models (the majority in application) that do not.
- Age-only models follow fish numbers by age but assume a distribution (e.g. normal) of fish by length, for each cohort, that does not account for higher mortality of faster growing fish.
- Age&len models account for changes in numbers with age and with length within each cohort.

Age-only models: 3 subclasses

- Three basic ways that non-dynamic-length models account for changes in numbers with length:
  - VPA-style: Ignore variation in length within age, and use the mean weight of each age group.
  - Empirical: Conditioning directly on sampled lengths-at-age (i.e. age-len keys)
    - (Used for earlier age-dependent models.)
  - Integrating under (non-dynamic) length-at-age pdf.
    - (Used by standard SS currently.)

Age-only models: Integrating under the length-at-age pdf

- Take the example of Stock Synthesis as it is usually implemented currently.
- SS assumes a normal spread of lengths-at-age (or lognormal) as the underlying length-at-age pdf.
- The mean length of this normal for each model age is computed, say, using a von Bertalanffy growth curve.
- The standard deviation of lengths-at-age must also be specified for each age.
- This growth can also vary by cohort or over time if need be.

Age-only models: Integrating under the length-at-age pdf (cont.)

- Then to compute the crucial size-dependent model-predicted quantities:
    - Lengths are partitioned into fixed bins (e.g. 5 cm)
    - Data fish number proportions are computed for these 5 cm length bins for each age (or cohort).
    - To compute model-predicted number proportions by length, the normal (or lognormal) model length-at-age pdf is integrated across each 5-cm length bin range.
    - These are fitted by a multinomial likelihood (or other) proportion fitting method.

Are dynamic numbers by length-at-age worth incorporating in a next-gen model?

- Extra programming is needed to account for fish numbers by both age and length.
- An extra dimension, of number by length in each age group, is added to the population array.
- At one time computation time made age&len unfeasible (e.g. Flexibest). But not really anymore.
- If we do want to accurately account for length selectivity, then we should dynamically model population number by both age and length-at-age.
- The data needed are the same as non-dynamic methods: Samples by age and by length.

Integrating growth

- So the big difference between age&len based models and age-len keys, is that the breakdown of age cohorts by length in an age&len based model is that everything is fully integrated.
- Growth is fully integrated into the estimator.
- Also for projections or where no age-length samples are available, the lengths by age can be fully represented.

Predict lengths-at-age (II)

- Thus, with selectivity, growth, and fits to (especially partially recruited cohort) lengths-at-age fully integrated, in theory all three of these essential elements of most stock assessment estimators are more accurately modelled.
- This becomes most important at the most difficult ages to accurately model, as fish are recruiting to fishable sizes.

Can a model accounting for both age&len be applied to service both age- and length-based assessments?

- Building and supporting generalized fishery model estimation (and management projection, and diagnostics, etc.) software is a lot of work.
    - (Ask two of our co-authors about that.)
- If dynamic accounting for lengths (as occurs in any length-based assessment) could be combined with numbers by age, it is plausible that a single model software will be sufficient to cover both situations: otolith ageing, or animals only measured by size.
- Having to build and maintain only a single model code would make next-gen model development a lot more efficient, both initially and for all future years.

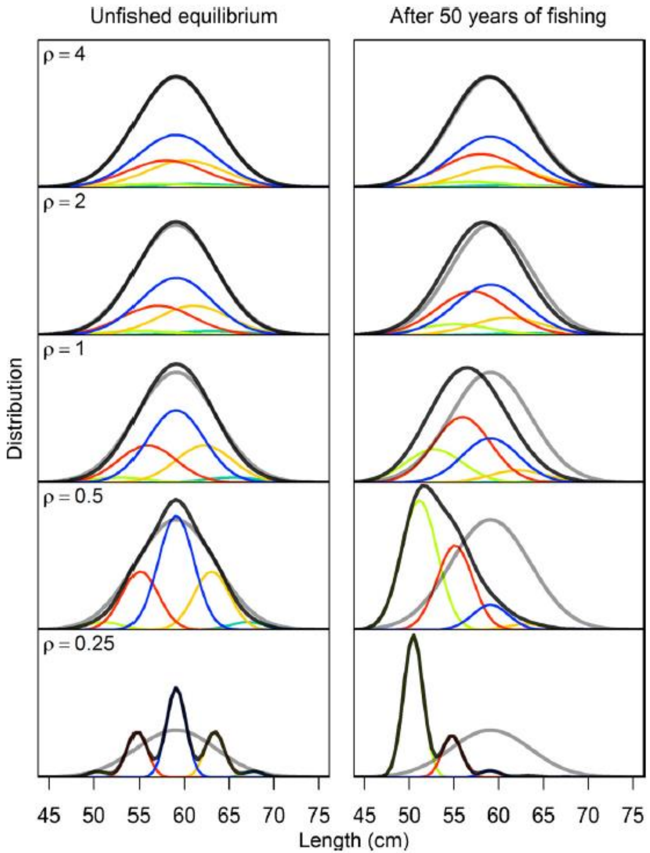
Some models do that currently

- Assessments models that account for population numbers by age and by length-within-age are not common currently.
- In South Australia we've been running them since about 2000 for our three main fish stocks.
    - King George whiting had been a fully spatial assessment, with dynamic age and length since about 2000.
- SS has incorporated dynamic length-within-age using 'platoons' an extension of Punt's 'growth groups'.
- Some other models have done this in earlier less general incarnations.

An early example: Deriso and Parma

- Deriso and Parma (1988; see also Parma and Deriso 1990) devised an analytic Bayesian-adapted method.
- To analytically compute the impact of logistic selectivity on a normal distribution of lengths at age, they let the logistic multiply the normal lengths at age by using the solution of logistic prior multiplying across a normal likelihood.
- Very clever, beautiful even.
- But not generalizable to all the other dynamics that a modern assessment model must typically incorporate.

Platoons for modeling age&len in an age-based assessment



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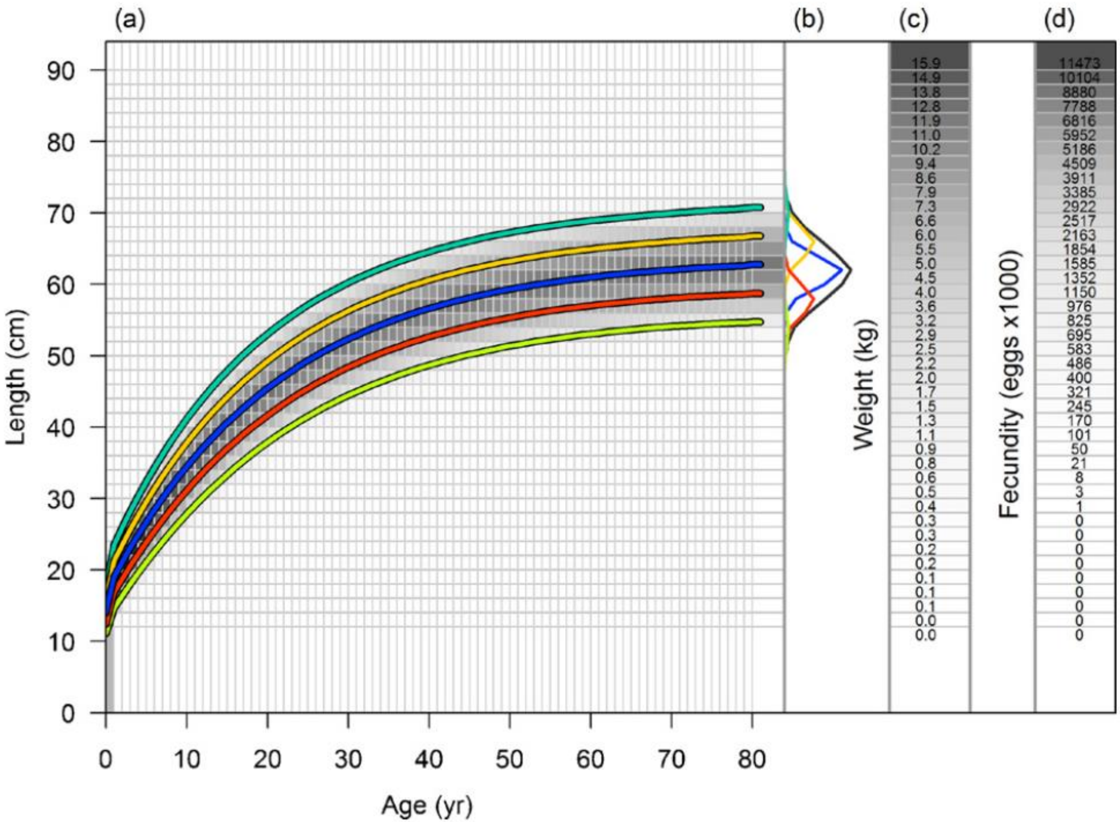
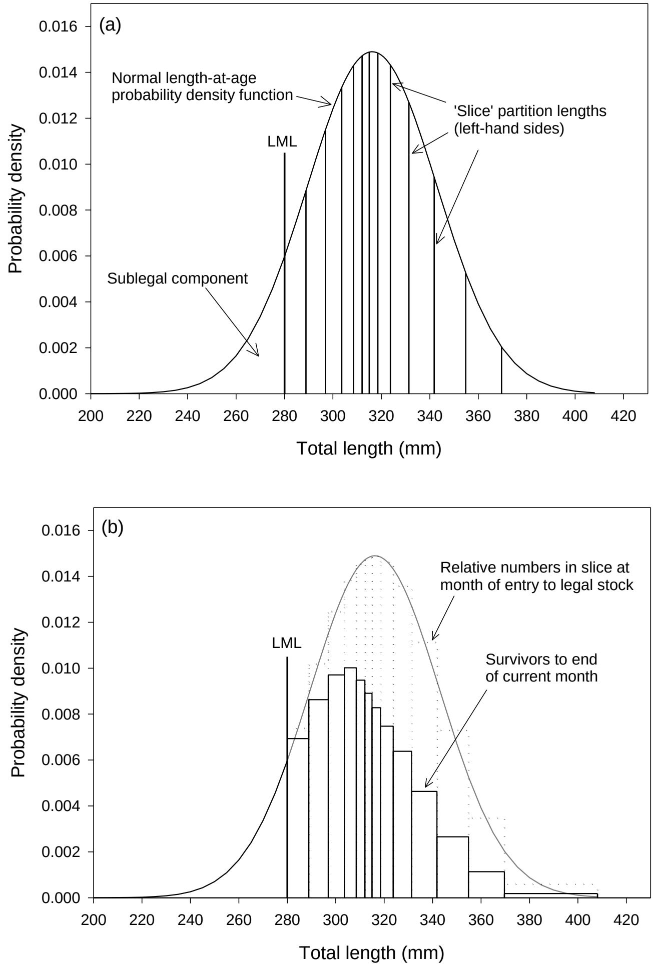


Slices for modeling age&len in an age-based assessment

Better growth estimates

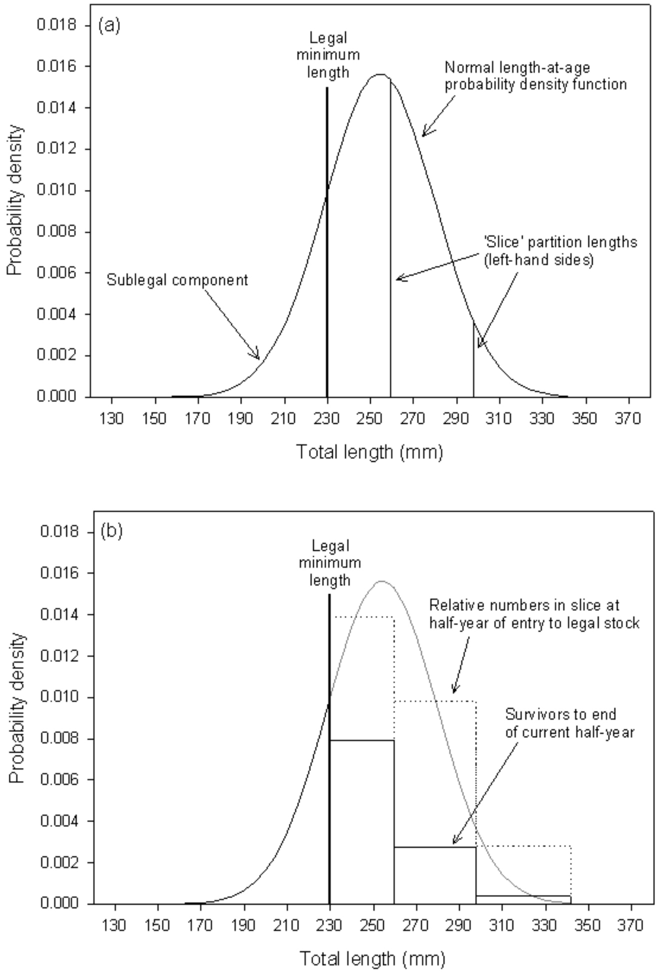
- Length-asymmetric mortality alters the shape of the cohort: the upper tail (first recruiting fish) is reduced faster.
- ‘True’ growth is the unaltered normal length-at-age pdf.
- Slice partition avoids (small) bias in growth by accounting for the faster removal of faster growing fish.
- Here King George whiting, partitioned by a monthly time step.



Slices for modeling age&len in an age-based assessment

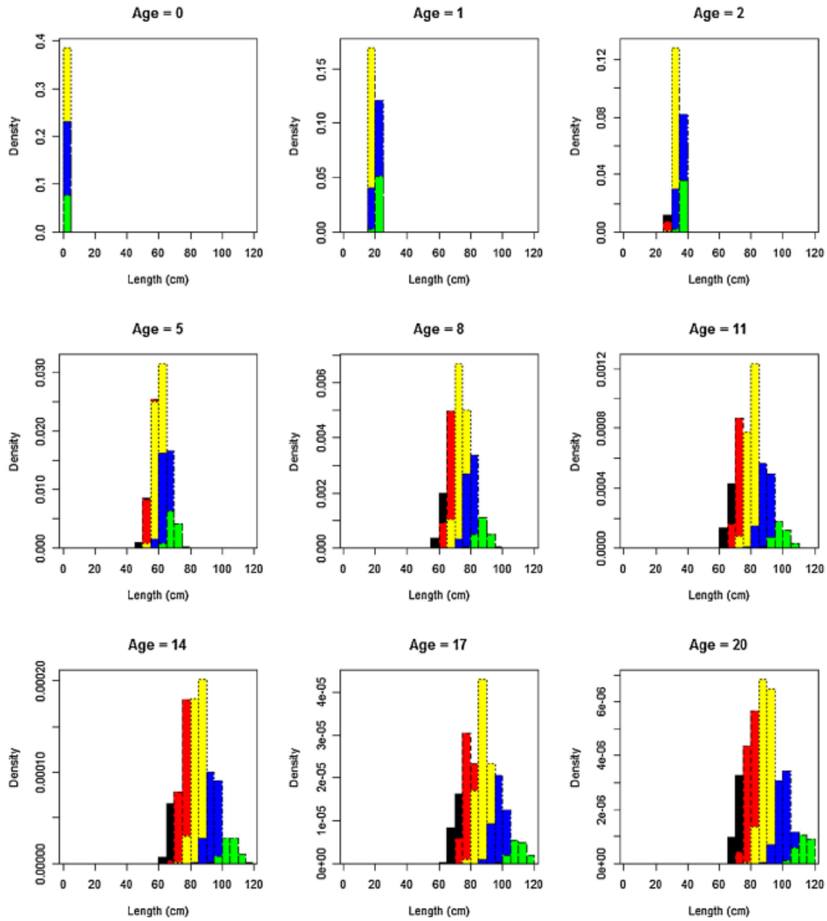
How 'slices' of fish length are created

- As each cohort grows across legal minimum length, with each model time step, the newly created 'slice' of legal-size fish is populated.
- The set of slice partition separation lengths marking each slice vary with cohort age.
- Computationally this is quite efficient, much more so than cohort-specific length-transition matrices..



Platoons in a length-based assessment

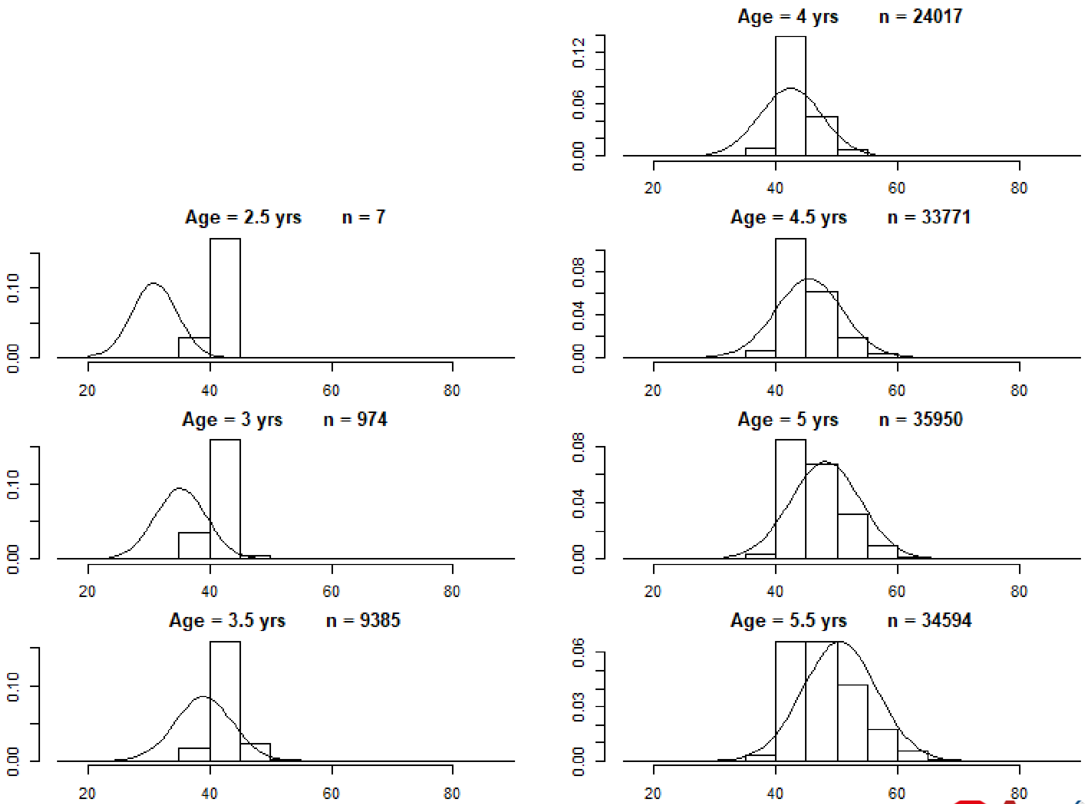
- By integrating a platoon's number distribution by length over the range of each length bin, length data are fitted.
- Since multiple platoons may cover each (here) 5 cm bin, model numbers by length bin are summed over both platoons within each age, and across ages, to give model-predicted proportions by length.



Simulated data comparisons of slices and platoons

- An individual-based age- and length-dependent fishery data simulator has been developed and data sets generated.
- Because this simulator is not based on either approach, it provides a more objective comparison of the two.
- We have focused on the scenario of steep logistic length selectivity to test the applicability of the two age&len based approaches for both legal minimum length and tight change in gear selectivity.
- Results are still being analysed….

Age-length data (binned) and slice-predicted growth for simulated (IBM) data



Recommendations for next-gen age-only model options

- First, Implement the two approaches for non-dynamic lengths at age:
  - Include empirical age-length keys as an option.
    - This gives users access to (basically) VPA.
  - Include the SS method, of integrating under a growth-modelled length-at-age pdf
    - (perhaps generalized to handle more pdf's or general length-at-age pdf shapes).

Recommendations for a next-gen age-based model: Yes on dynamic lengths

- If possible, we recommend implementing (at least) one generalizable method of dynamic lengths at age:
  - Platoons is quite general—any shape, not just a normal can be modelled.
  - Some options need to be chosen by users of platoons—they need assignment of parameters that specify the standard deviation and relative position of each platoon.
- Slices are not as generalizable, but require much less input from less experienced users: Only a standard length-at-age growth description is needed (which also specifies the sd at each age).

Million dollar question (literally?)

- Can a single model be used for both age-based and length-based assessments?
- Technically this should be possible, but the simulated data testing to date has not yet answered that question fully.
- Numbers by age will always be included in the population array.
- The inclusion of numbers by age should not prevent accurate prediction of numbers by length.
- The methods of Punt, Allen Akselrud and Cronin-Fine, (along with platoons and slices) offer a plausible pathway to applying age&len based models to length-only assessments.
- Further work is needed to answer this question.

Summary

- There is no chance of building a single model that can be used for both age- and length-based assessments, unless both age and length are dynamic in the model population array.
- One big advantage of platoons is that if a user simply chooses to employ just one platoon, which is then simply the ordinary normal length-at-age pdf, the general model reduces naturally to the standard single length-at-age pdf for the cohorts under study.
- That means the (now) conventional single always-normal length at age, and dynamic lengths-at-age can both be easily implemented under a single framework.
- Then fully dynamic lengths at age can be called upon when needed

References

- Taylor & Methot (2013) Fish. Res. (Platoons)
- McGarvey, Feenstra, & Ye (2007) Can. J. Fish. Aquat. Sci. (Slices)
- Punt, Allen Akselrud, & Cronin-Fine (2017) Fish. Res. (age-only, size-only, or both)

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How standard age-length keys work

- There are several variations of age-length keys.
- But basically, the sampled numbers by length in each age group are *conditioned on*.
- That is, the model uses those proportions of sampled numbers by length in each age group as a histogram (pmf) taken directly as sampled.
- These empirical age-length keys are applied to compute model catch numbers by length within age. These are
    - fitted to length (at-age) samples,
    - used to compute catch in weight, and
    - used to account for (and estimate) length selectivity.

Age&length based fishery model

- Empirical approaches use observed sampled number proportions by length bin in each age (or vice versa) for size-dependent model predicted quantities like:
    - Total catch in weight,
    - Length selectivity strongly affects both
        - Predicted proportions by age for the crucial fitting to age samples, and
        - Proportions by length if length samples are fitted also.

Why age and length?

- Model population numbers by length in each age are crucial for predicting size-dependent quantities like:
    - Total catch in weight,
    - Age number proportions,
    - (for some age-based models and all length-based models) Length dist properties or binned proportions by
    - Length selectivity strongly affects both
        - Predicted proportions by age for the crucial fitting to age samples, and
        - Proportions by length if length samples are fitted also.
- All fishery models must do this conversion of

Age-only models: Empirical approaches

- Empirical approaches directly read in length-at-age proportions (from fishery or survey).
- These provide information on the breakdown by size in each cohort for computing crucial size-dependent model-predicted quantities.
- A fully formed growth submodel is not needed under this approach.

Limitations of empirical age-length keys

- If age-length samples are missing in some areas or time steps, the model cannot predict crucial quantities like catch-in-weight.
- Likewise, if fishing mortality or selectivity varies, empirical length-at-age tables cannot predict changes in lengths-at-age in the population or the catch.
- For projection modelling, into the future, under different fishing mortality rates, empirical age-length keys are not available to accurately predict length-dependent quantities (like catch in weight)?
- Not able to account for ageing imprecision.

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How is length selectivity modelled?

- It is not easy to account for differences in fish removal rates that vary with fish size.
- The hard part is accounting for that change in the length-at-age distribution of the population.
- Generally faster growing fish reach fishable size faster and so are removed sooner.
- Whenever age data are available, they are the best source of information on mortality rate.
- But changes in the size distribution (by age) are useful to accurately account for the strong second-order effects of length selectivity.
- This growth correction is mainly significant for high-F fisheries.

Main benefit of modelling length-at-age?

- **But more important than the Rosa Lee correction for length-asymmetric mortality on growth estimates, is the crucial need to accurately quantity the truncation (knife-edge or logistic) that strongly alters the predicted proportions by age as the cohort is recruiting to legal size.**
- **Since much of the catch is often of these partially recruited fish, models fitting to ages benefit by the best submodel they can use to accurately predict what proportion is expected to be observed for each age group, when many (even the majority) of those fish are still too small to be captured.**