Using highest density intervals can reduce perceived uncertainty in stock assessments by billions of fish

Andrew Edwards and Marie Auger-Méthé

Using highest density intervals can reduce perceived uncertainty in stock assessments by billions of fish

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Short communication

Using highest density intervals can reduce perceived uncertainty in stock assessments

Andrew M. Edwards [a,b,*], Marie Auger-Méthé [c,d]

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Motivation

- Stock assessments need to communicate uncertainty of estimated quantities
- Often done through figures and tables depicting 95% credible or confidence intervals
- We show that computing such intervals with the usual equal-tailed approach has undesirable consequences

Motivation

Regarding recent assessment results, a fisherman remarked:

No offence to anyone, but my granddaughter could provide that amount of uncertainty.

Highlights the need to investigate ways to reduce uncertainty as much as possible.

Outline

Pacific Hake

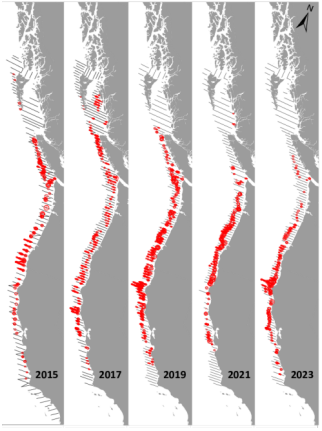
Pacific Herring

Petrale Sole

Pacific Cod

(not to scale)

Pacific Hake



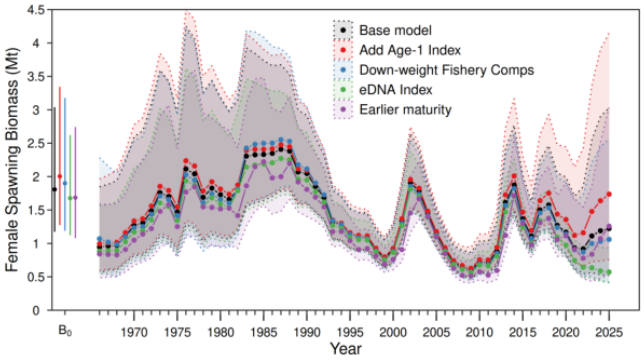
Pacific Hake stock assessment

- Ecological and economic importance in Canada and US
- Surveyed, assessed, reviewed, and managed jointly with US NOAA colleagues
- Statistical catch-at-age model conducted in a Bayesian setting

Pacific Hake stock assessment

- Ecological and economic importance in Canada and US
- Surveyed, assessed, reviewed, and managed jointly with US NOAA colleagues
- Statistical catch-at-age model conducted in a Bayesian setting
- Marginal posterior distributions for numerous quantities
- Need to summarise these – done using 95% credible intervals from 8000 Markov chain Monte Carlo samples

Example plot that contains 305 credible intervals

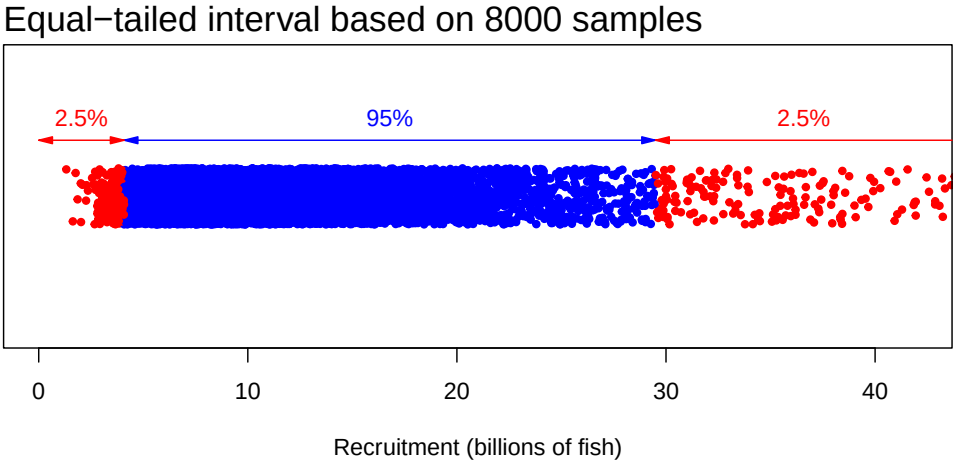


Using 2001 recruitment as example

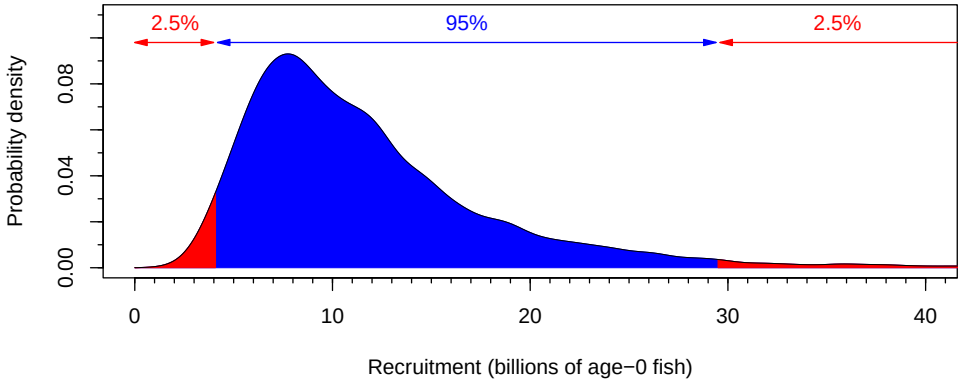
- estimate of number of age-0 fish in 2001
- based on the 8000 MCMC samples

```
length(rec_2021)
[1] 8000

summary(rec_2021)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  1.319   7.347  10.187  11.897  14.364 123.577

rec_2021[1:20]
 [1] 14.37140 14.83170  8.34762 10.98490 10.36430 11.61610 10.41970  7.91205
 [9]  6.79481 10.48440  6.56321  8.12976  5.04321 11.83990 22.46230  4.58049
[17]  9.38586 10.56900  5.76932  9.46697
```

Equal-tailed intervals for 2021 recruitment – usual approach

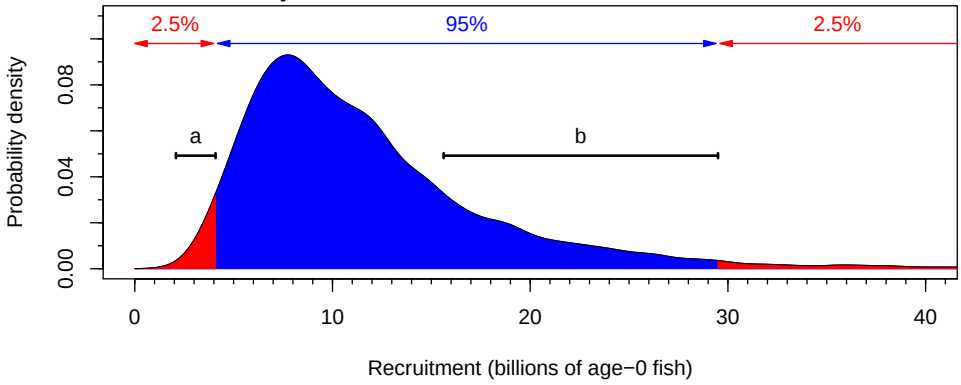


Equal-tailed intervals – usual approach



Equal-tailed intervals – usual approach

Values in range a are just as likely as values in range b.
But a is outside the ETI yet b is inside it.



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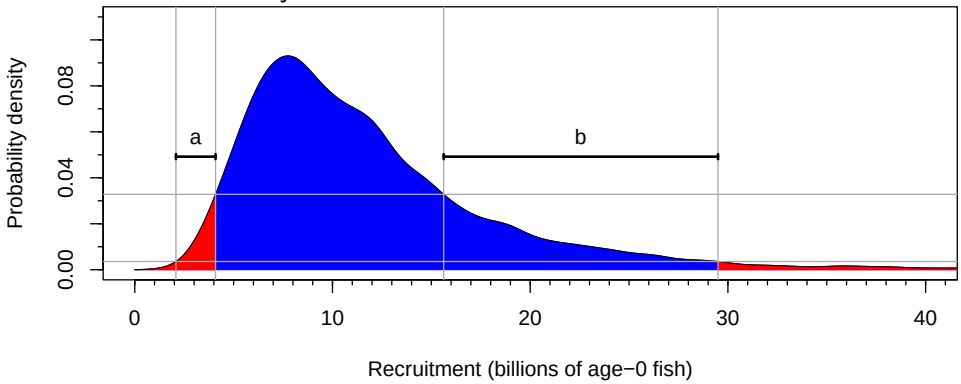
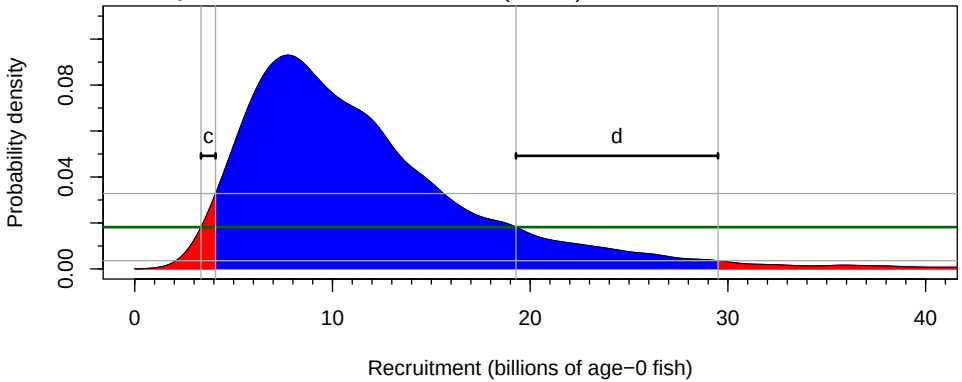


Equal-tailed intervals – usual approach

All values in range c are *more* likely than all in range d.

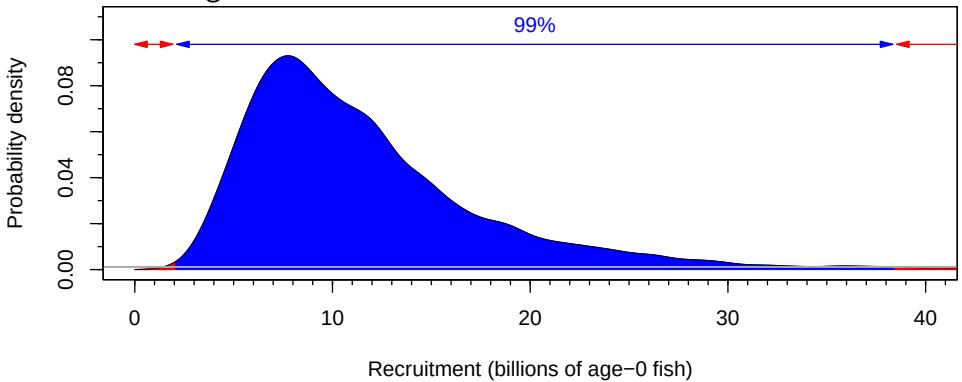
But c is outside the ETI yet d is inside.

This is "Intuitively undesirable" Kruschke (2015).



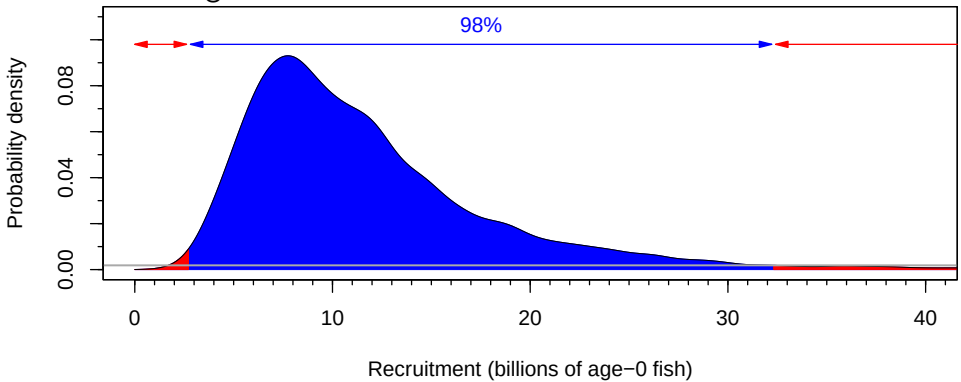
Highest density interval (HDI) – alternative approach

Horizontal line rising until area in blue is 95%. This is 99%:



Highest density interval (HDI) – alternative approach

Horizontal line rising until area in blue is 95%. This is 98%:



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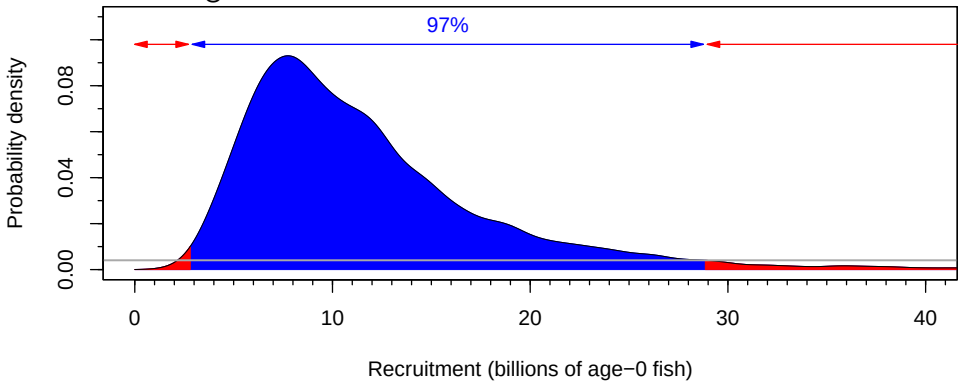

Highest density interval (HDI) – alternative approach

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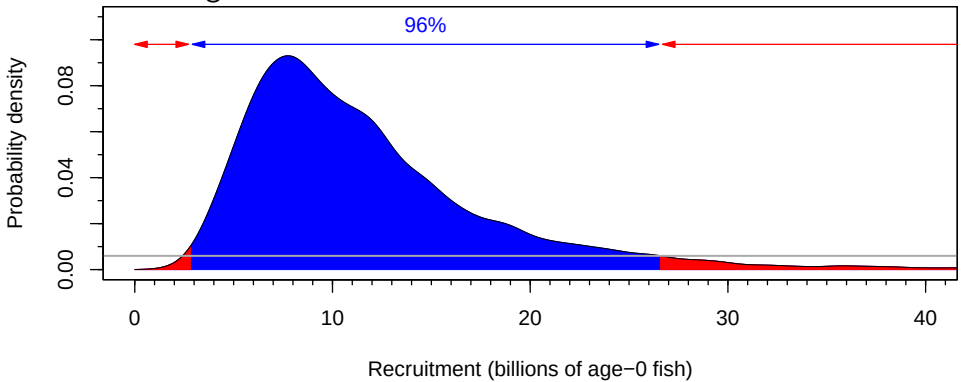

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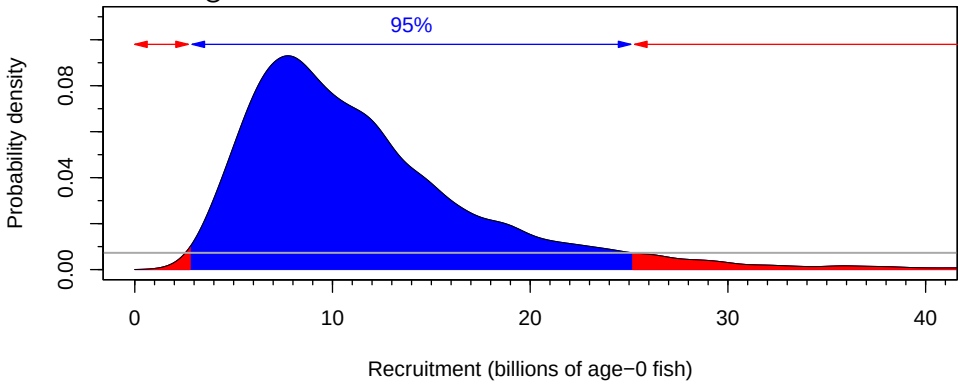
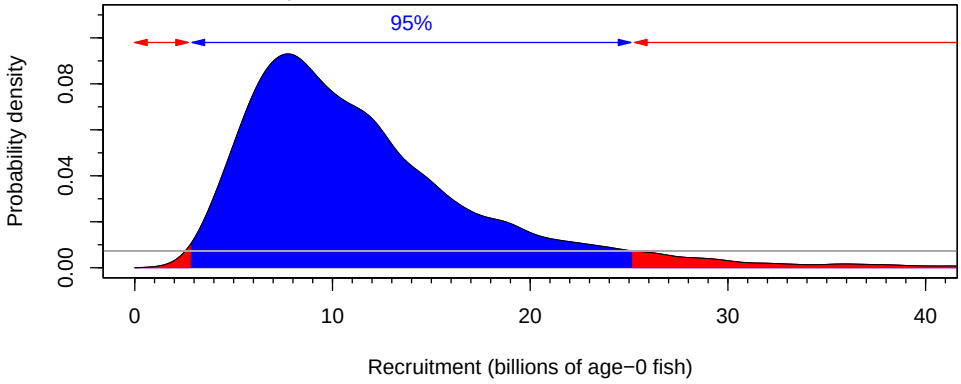
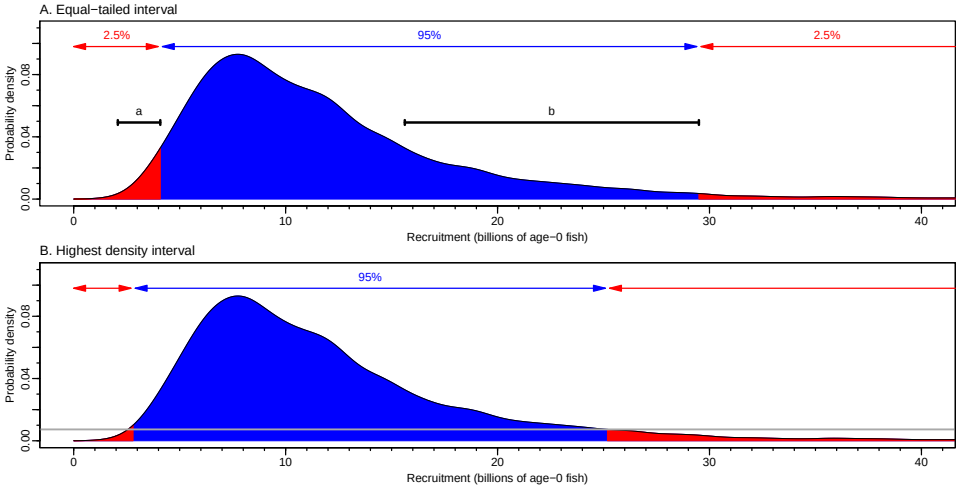


Highest density interval (HDI) – alternative approach

All values within HDI are more likely than all those outside it.
HDI is the shortest of all possible 95% credible intervals.



Comparing ETI and HDI



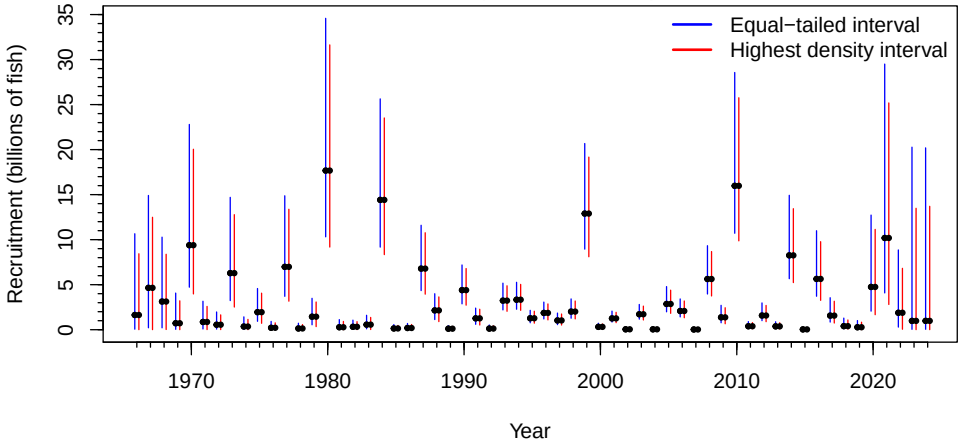
Comparing ETI and HDI

Type	Interval	Interval width
ETI	4.1 – 29.5	25.4
HDI	2.8 – 25.2	22.4

So the HDI reduces uncertainty by 3 billion fish.

Estimated recruitment through time

Just plotting the 95% credible intervals (and medians) for each year:

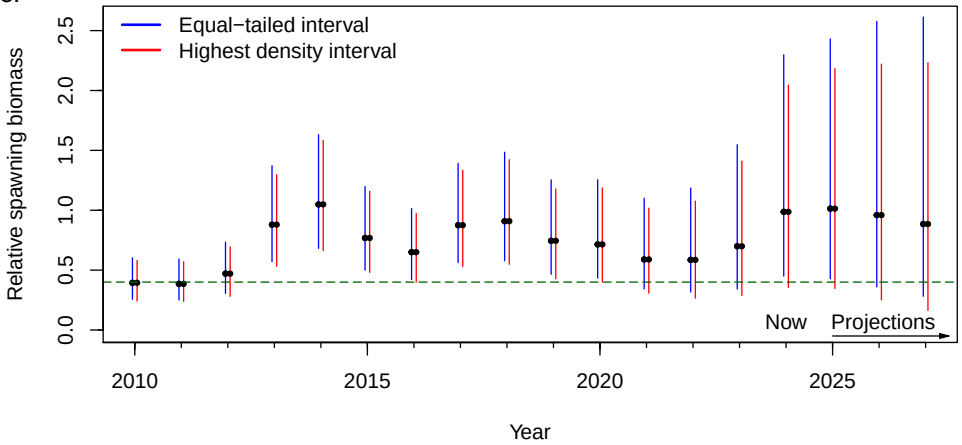


Estimated recruitment through time

Total reduction in perceived uncertainty across all years (except 2023 and 2024) is >30 billion fish.

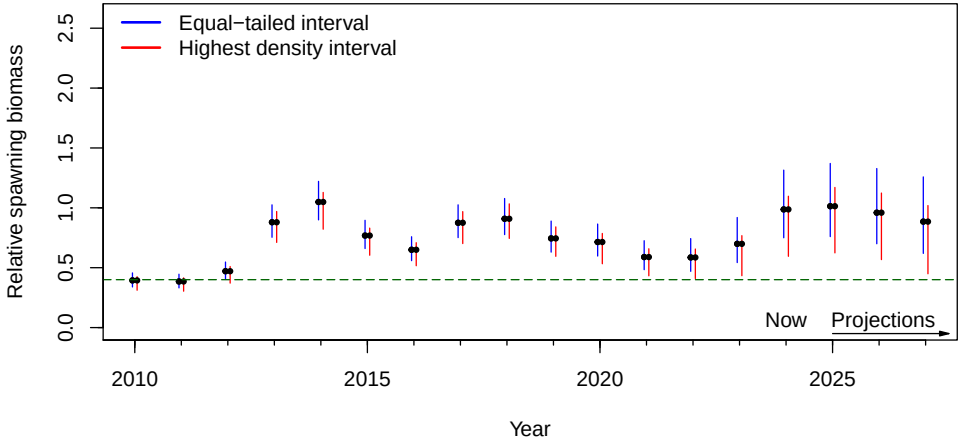
Estimated relative spawning biomass

Relative spawning biomass for each year, 95% credible intervals >0.4 is healthy zone:



Estimated relative spawning biomass

Relative spawning biomass for each year, 50% credible intervals:



Decision tables

Advice is also in the form of 'decision tables' that indicate probabilities of future events given different catches. Simplified example:

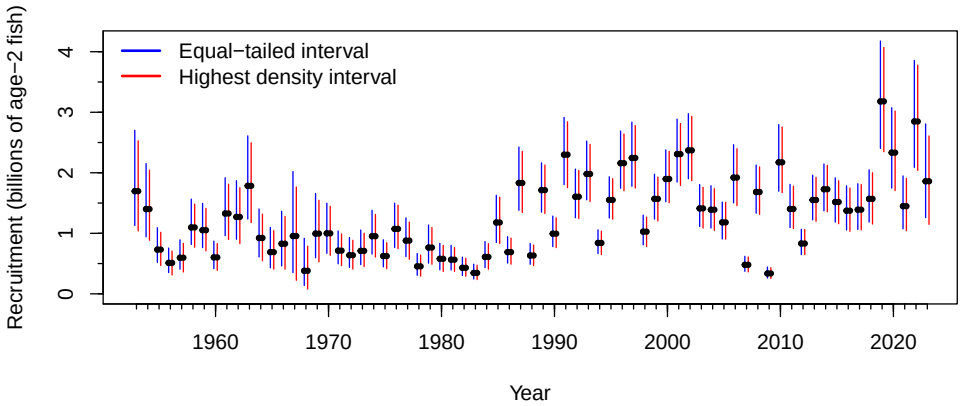
Catch (t) in 2024	Probability spawning biomass declines from 2023 to 2024	Probability spawning biomass in 2024 falls below 40% of unfished biomass
0	50%	2%
180,000	72%	3%
225,000	75%	3%
320,000	78%	3%
430,000	85%	5%

Unaffected by choice of interval, but we don't generally give probabilities for previous years

Pacific Herring Strait of Georgia stock

- Bayesian statistical catch-at-age model
- relative spawning biomass is B/B_0
- recruitment is for age-2 herring
- critical zone is relative spawning biomass < 0.3
- 90% credible intervals

Pacific Herring Strait of Georgia stock – recruitment

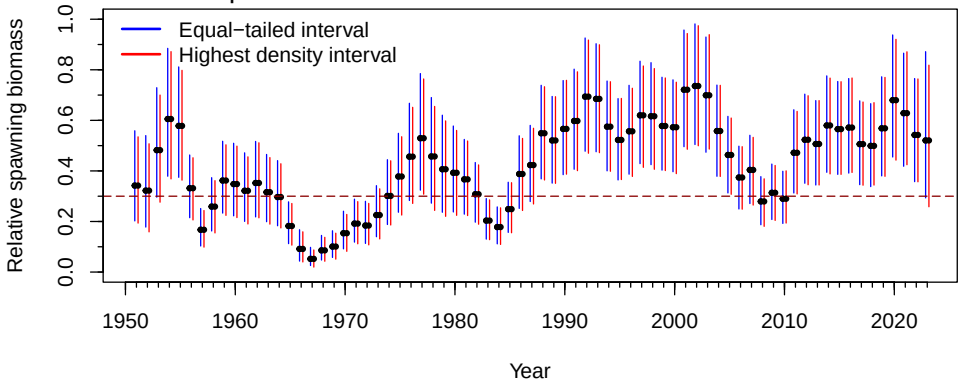


Pacific Herring Strait of Georgia stock – recruitment

- Slight lowering of the HDIs compared to the usual ETIs.
- Sum of the differences over all years between the width of the ETI and width of the HDI is 1.6 billion fish
- Across all five Pacific Herring major stocks, sum of differences is 4.6 billion fish

Pacific Herring – relative spawning biomass

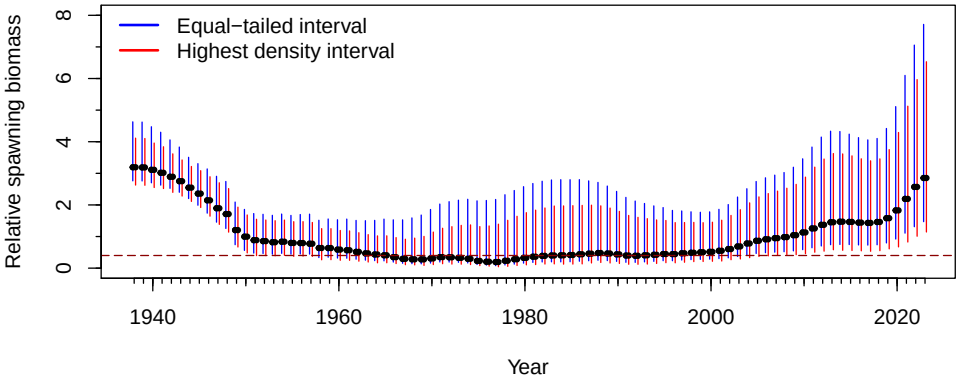
0.3 is limit reference point



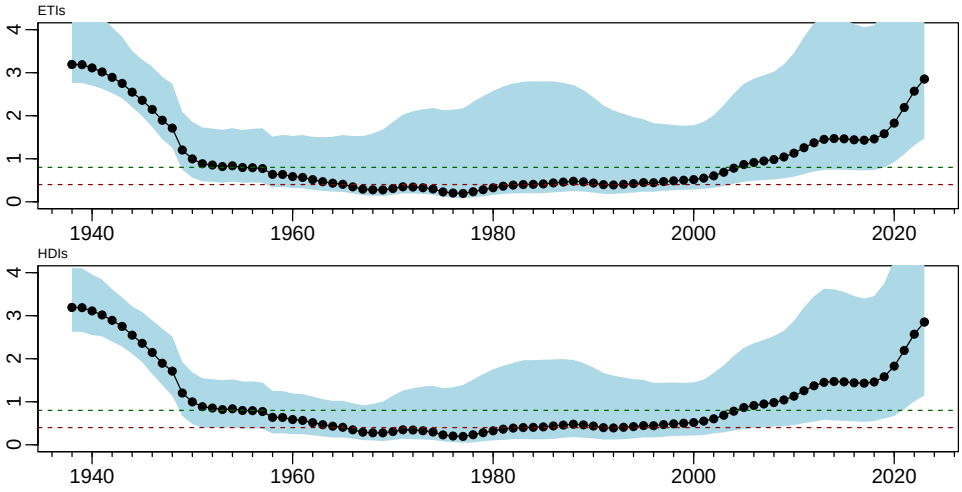
Petrale Sole

- Bayesian delay-difference model
- combines three different models that assumed different values of natural mortality (with 50% of total samples coming from one model and 25% from each of the other two)
- relative spawning biomass is B/B_{msy}
- critical zone is $B/B_{msy} < 0.4$
- 95% credible intervals

Petrale Sole – relative spawning biomass



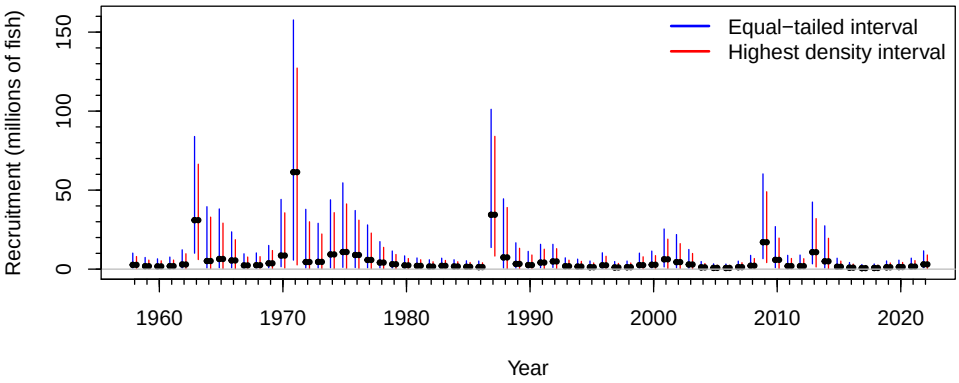
Petrale Sole – relative spawning biomass



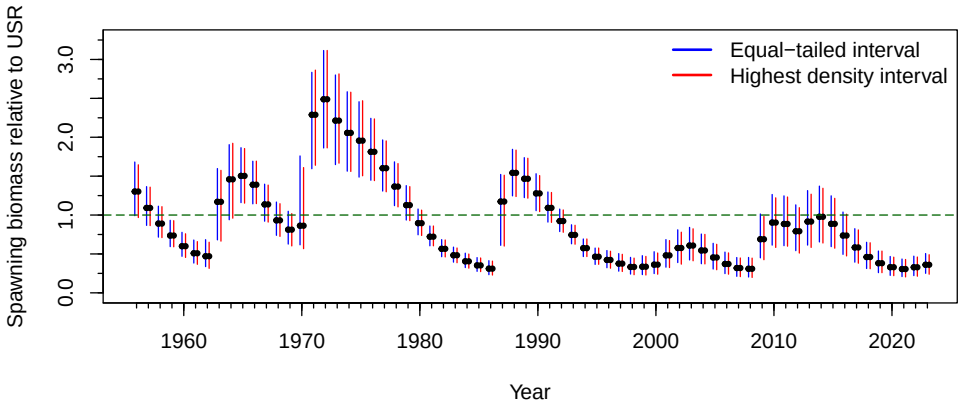
Pacific Cod (Area 3CD stock, west coast of Vancouver Island)

- Bayesian delay-difference model
- results from seven models (different parameter settings) were combined, 1,000 MCMC samples from each, yielding 7,000 MCMC samples
- upper stock reference point: the mean of the biomass estimates from 1956–2004
- lower reference point: lowest estimated biomass agreed upon as an undesirable state to be avoided, defined as estimated biomass in 1986
- 95% credible intervals

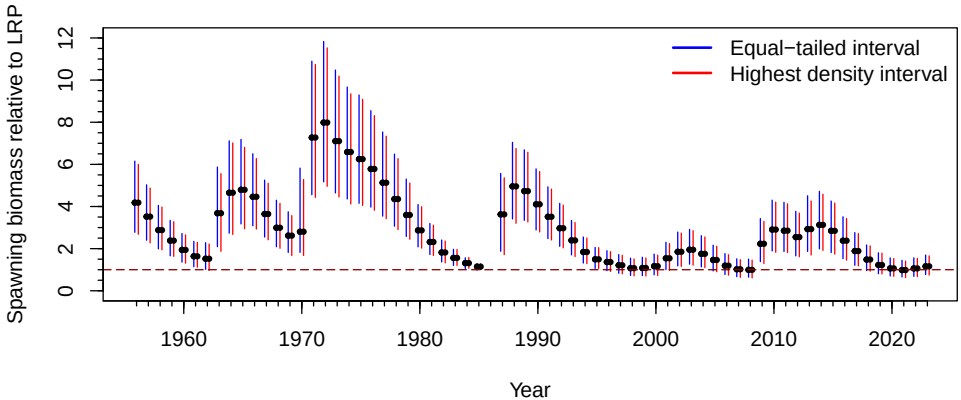
Pacific Cod - recruitment



Pacific Cod - spawning biomass relative to USR

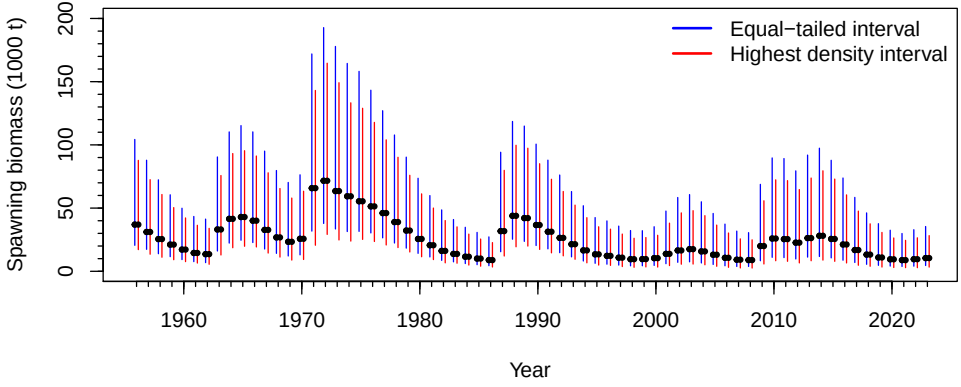


Pacific Cod - spawning biomass relative to LRP

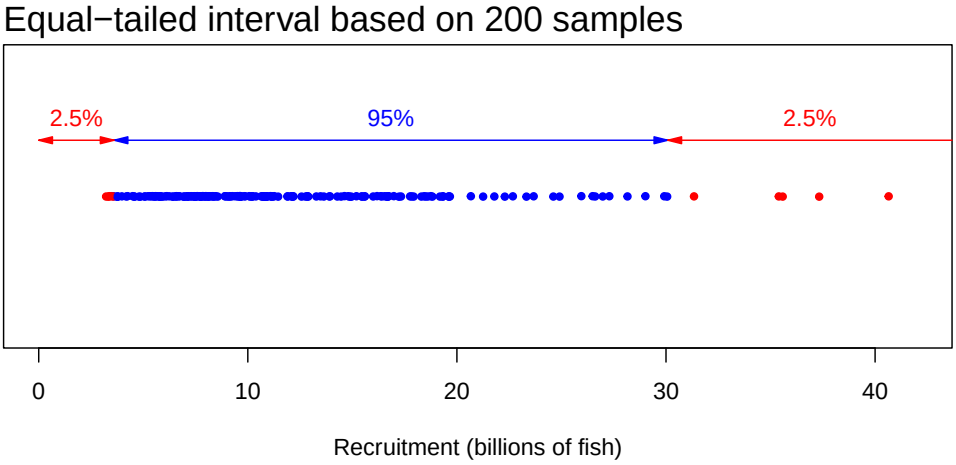


Pacific Cod - absolute spawning biomass

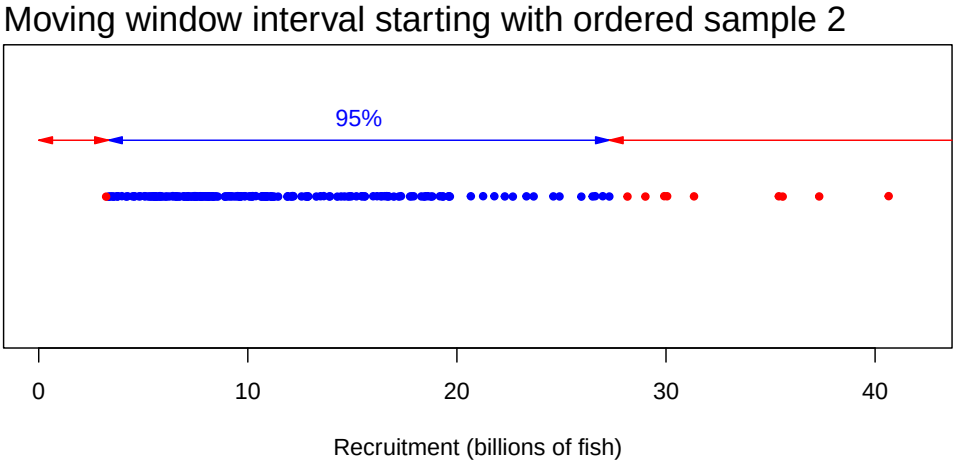
Given the symmetry for relative biomass, slightly surprising that the intervals do change when looking at absolute spawning biomass:



Equal-tailed intervals – calculation for usual approach



Highest density interval (HDI) – moving window approach



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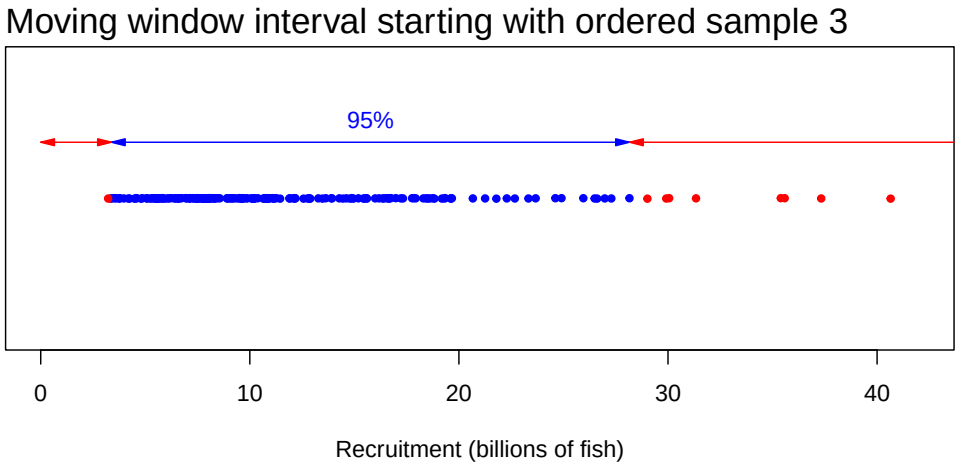

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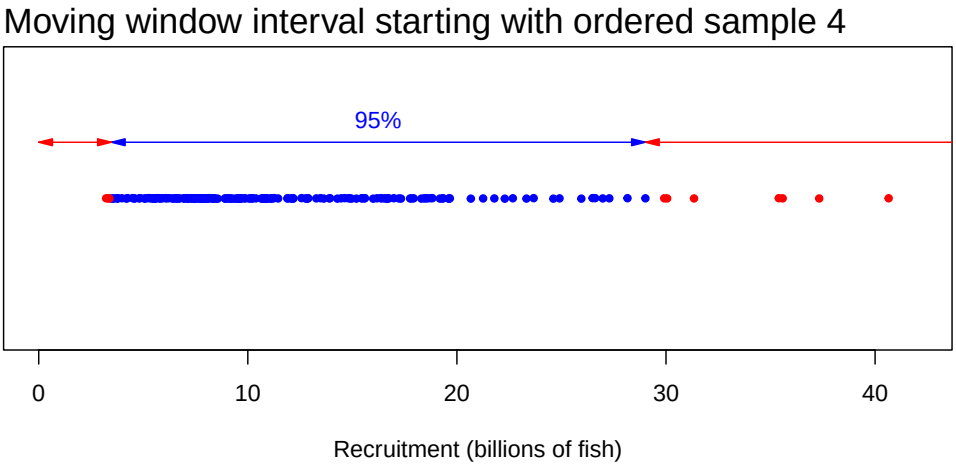

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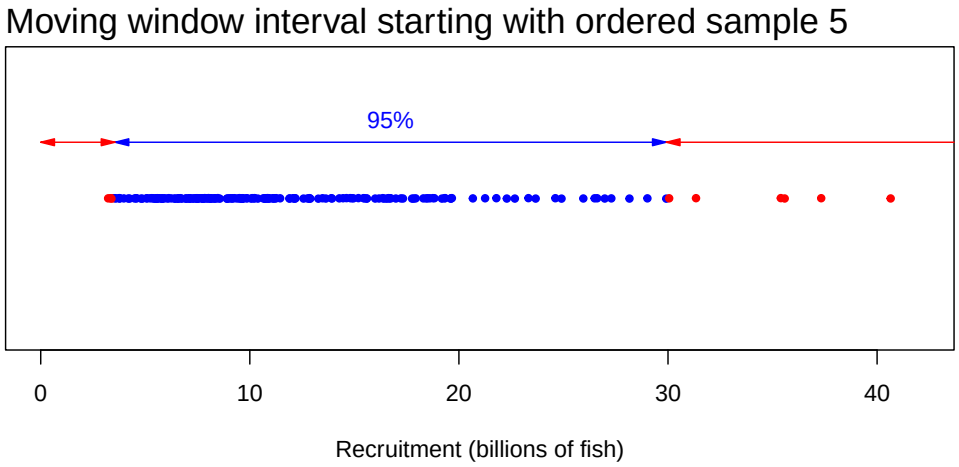

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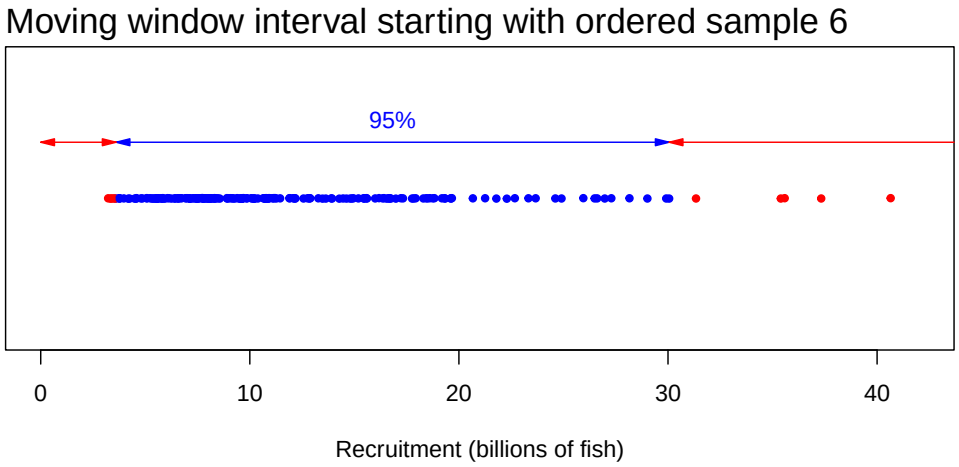

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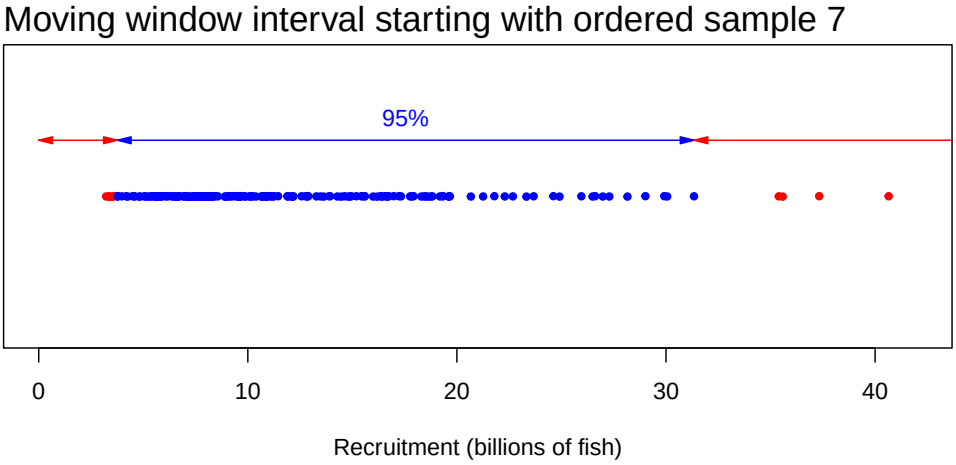

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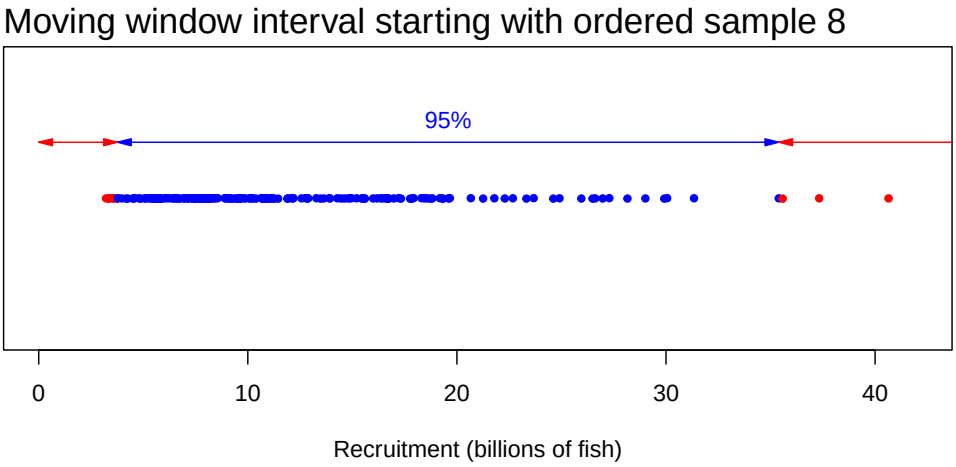

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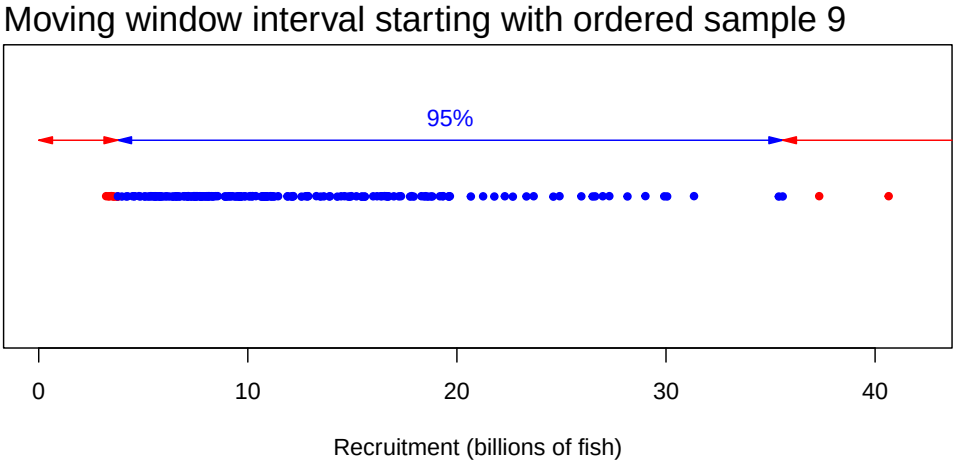

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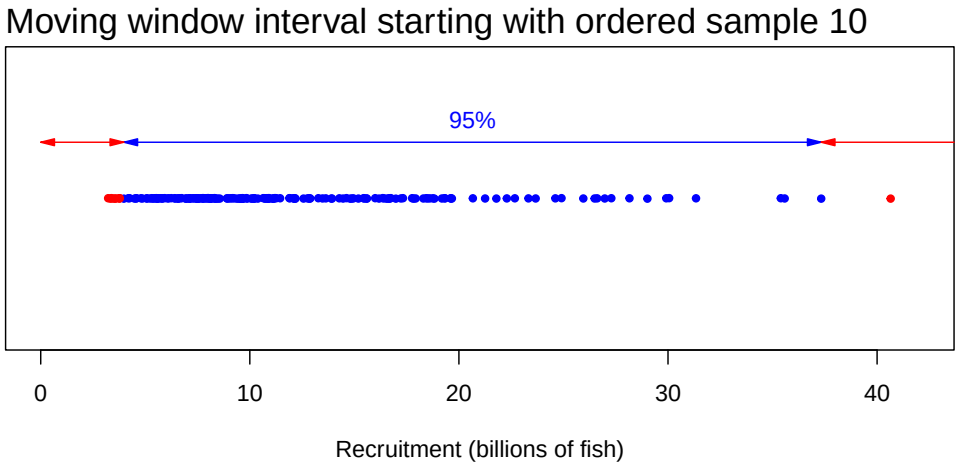

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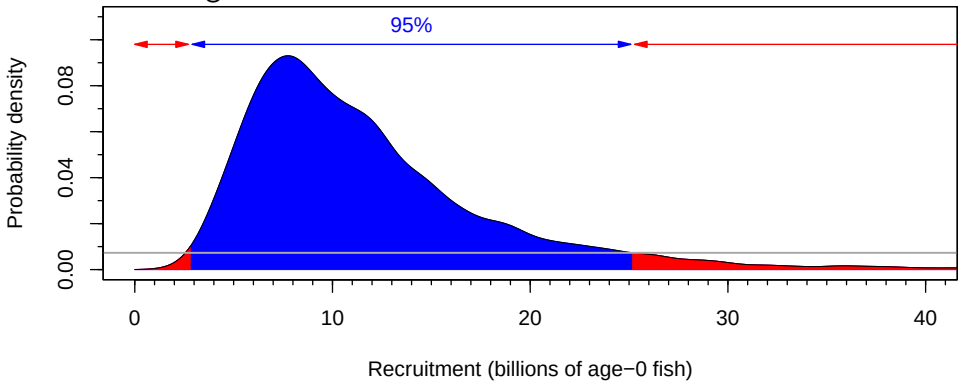

Discussion

Occasional uses of HDIs in marine ecology include:

- estimates of global fisheries
- analysis of salmon migration
- development of stock assessment methods
- summaries of biological and environmental data relating to Atlantic Cod
- estimating population sizes of sharks and whales
- one example in a fisheries stock assessment

Advantages of HDIs over ETIs not investigated or discussed.

Discussion

In general, ETI previously recommended because:

(i) it has a direct interpretation as the 2.5% and 97.5% percentiles.

(ii) it is invariant to nonlinear transformations of the data.

(iii) it is easier to compute.

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Yes, but simplicity has downsides as shown earlier

(ii) it is invariant to nonlinear transformations of the data.
Yes, but usually quantities are defined on the scale of interest

(iii) it is easier to compute.
Yes, but our new hdiAnalysis package helps, building upon HDInterval package

Thus, we recommend investigating the use of HDIs in stock assessments.

Summary

- results show expected narrower HDIs compared to ETIs
- consquences are stock-specific

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- results show expected narrower HDIs compared to ETIs
- consquences are stock-specific
- fundamentally, 95% HDI gives the 95% most likely values rather than middle 95% from ETI
- former seems intuitively desirable, as does reducing perceived uncertainty
- presenting HDIs or ETIs may come down to a case-specific choice
- can have potential management implications
- we encourage investigation of potential use of HDIs in stock assessments
- also applies to other fields where skewed distributions arise

R package: hdiAnalysis on GitHub, reproduces all results and provides code and vignettes for users.

Acknowledgments

- Jaclyn Cleary, Mackenzie Mazur, and Robyn Forrest for providing MCMC results
- Catarina Wor, Nick Fisch, Irene Andrushchenko, Paul van Dam-Bates, Matt Grinnell, Chris Grandin, and Kendra Holt for useful comments.
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