



Inshore fisheries for the northern shrimp *Pandalus borealis* in Iceland: do multispecies linkages and temperature improve management advice?

Within-fjord shrimp stocks



Important historically

- Almost 1 century of shrimp fishing in the west fjords.
- Peak landings were ~850 tonnes in Arnafjörður in 1994 and ~ 3000 tonnes in Ísafjörður in 1990.
- Surveys date back to the mid-1960s.

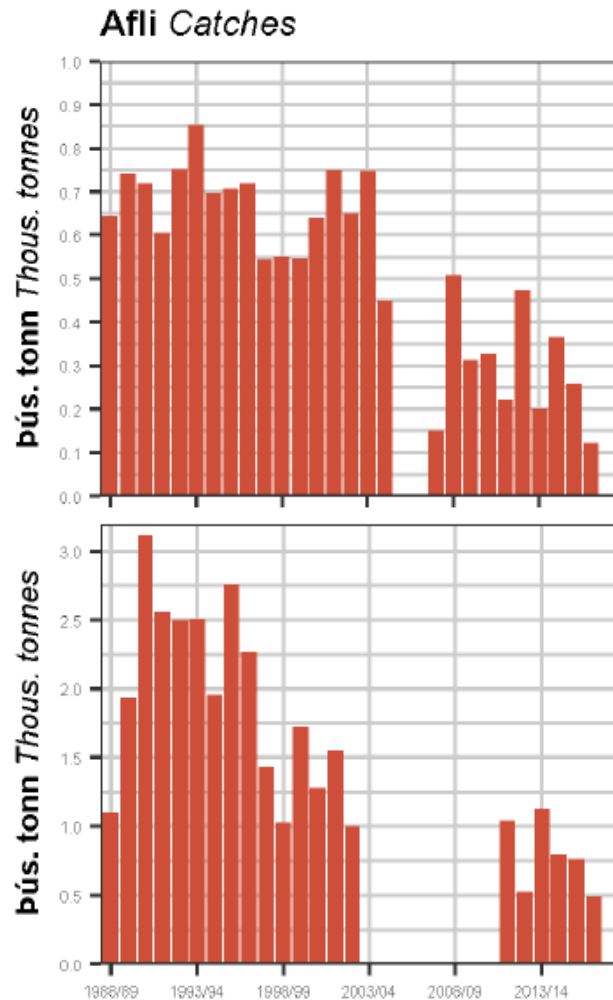


Still important locally

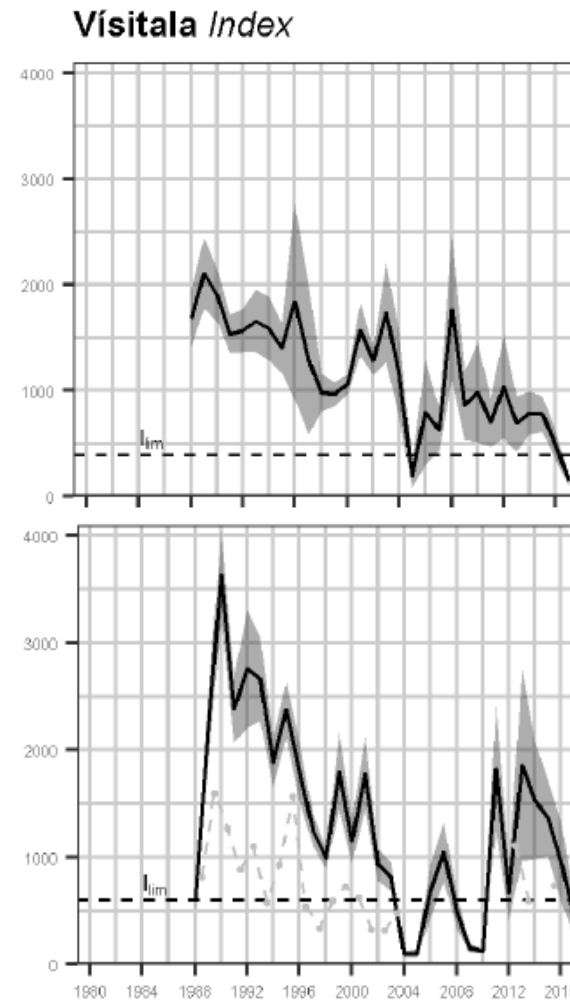
- Can use a small boat.
- But, recent decades marked by decreased biomass indices & fishery closures.
- This is despite consistent surveys and management.



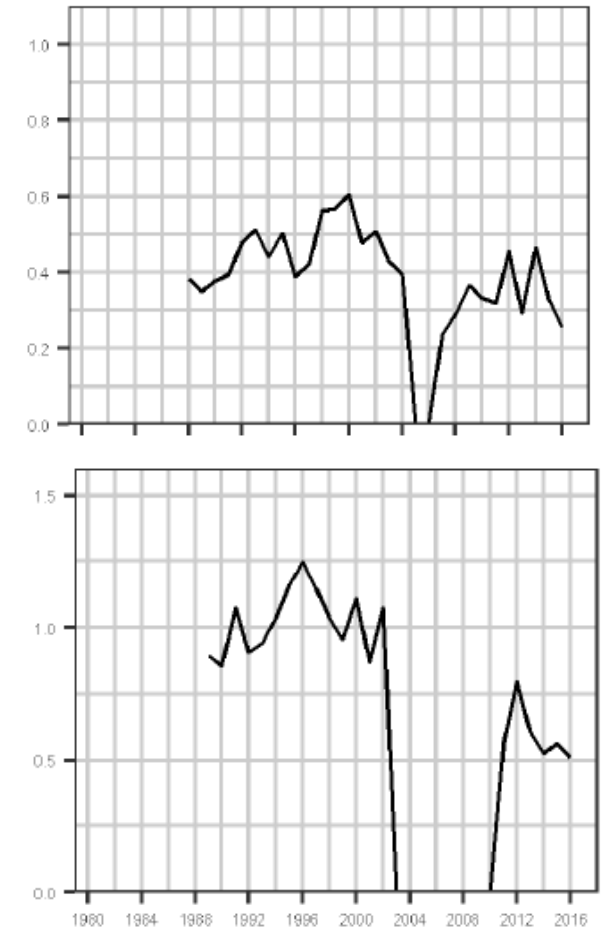
Arnarfjörður



Ísafjörður



Vísitala veiðihlutfalls *F*proxy



Within-fjord shrimp management

- Survey indices calculated from two annual surveys
- Generally, an advisory rule is applied to a reference biomass index to determine catch, but may be modified according to ICES guidelines.
 - Ísafjörður: $\text{Survey biomass}_{\text{year}} \times 0.5 = \text{TAC}_{\text{year} + 1}$
 - Arnarfjörður: $\text{Survey biomass}_{\text{year}} \times 0.346 = \text{TAC}_{\text{year} + 1}$
- No biomass estimates.
- Not popular.

This is a precautionary tale about the intertwining nature of

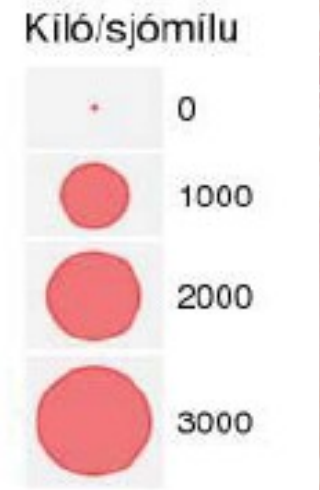
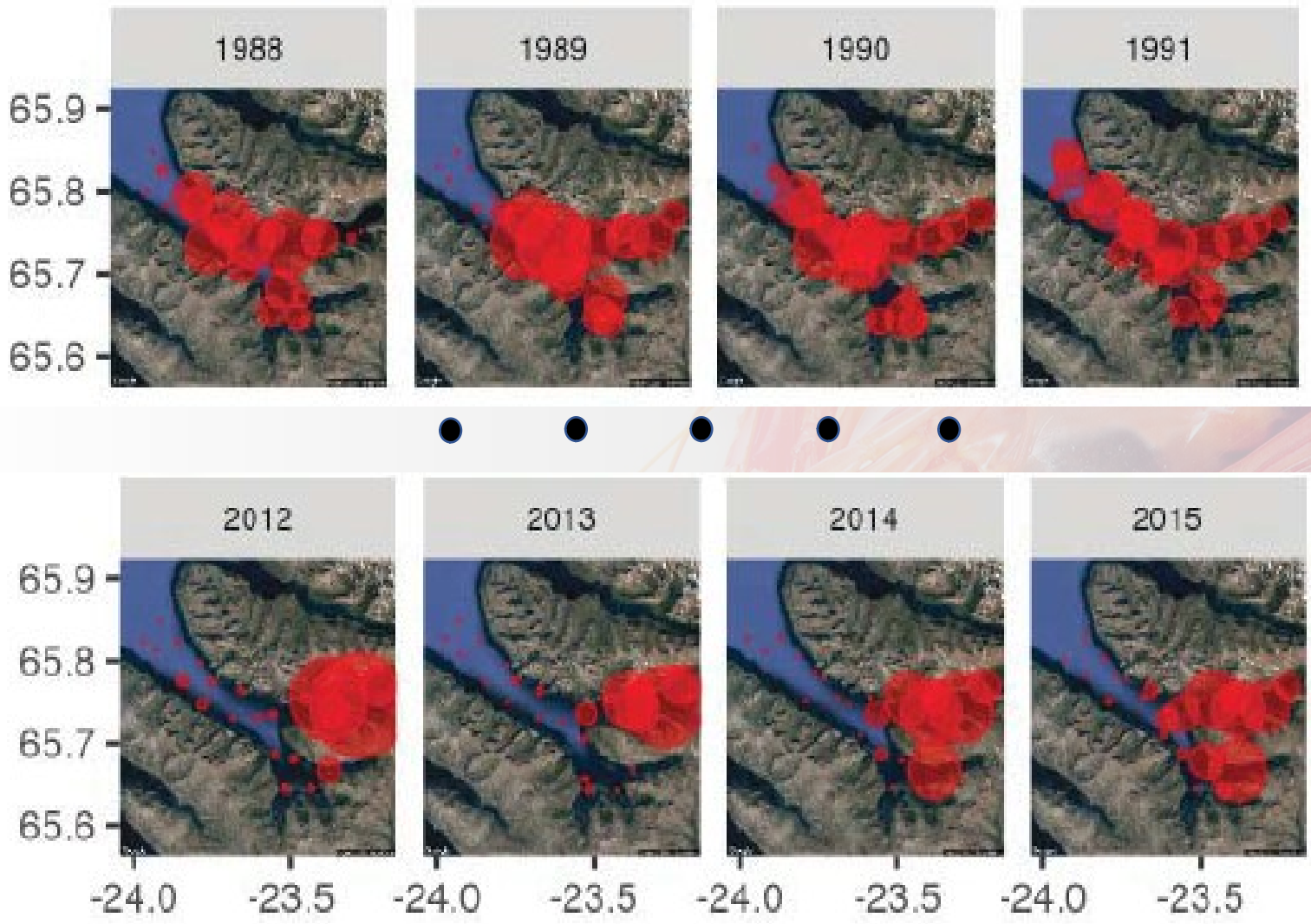
- Estimation of biomass & catchability
- Environmental effects on growth and mortality
- Optimization difficulties

Problems (a.k.a. #\$\$%! invertebrates...)

- No quantitative age data
- Growth by molting
- Growth sensitive to temperature
- Connectedness to offshore populations unclear
- Aggregate
- Food for everything

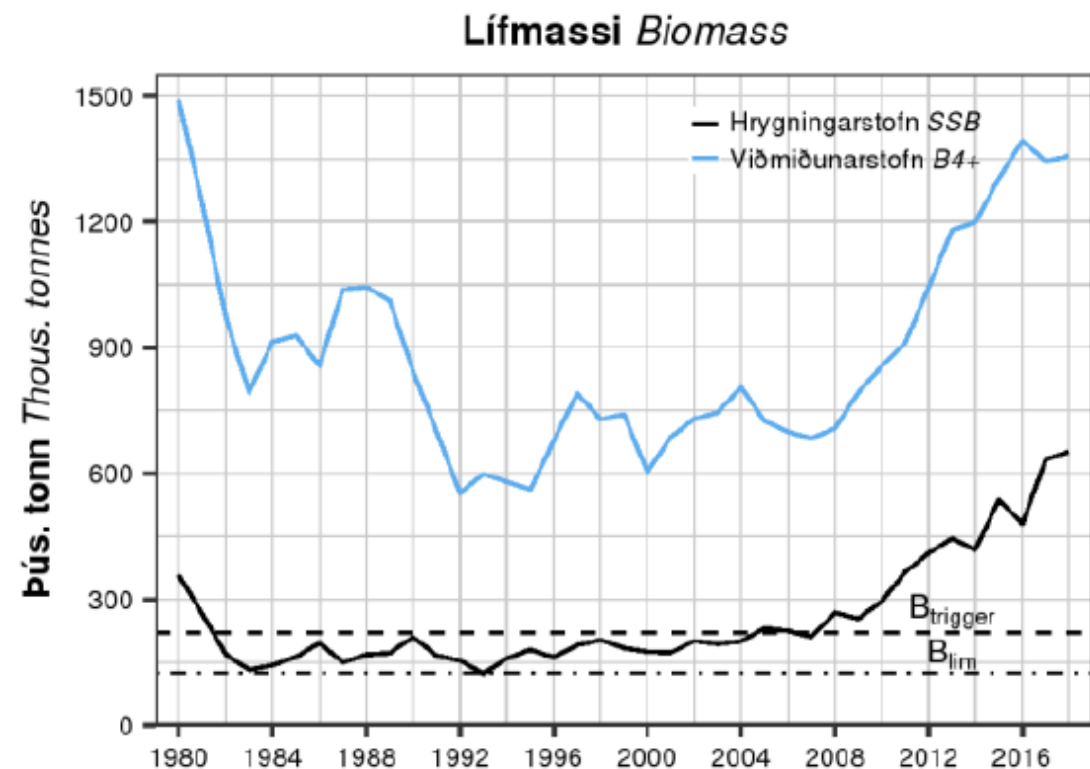
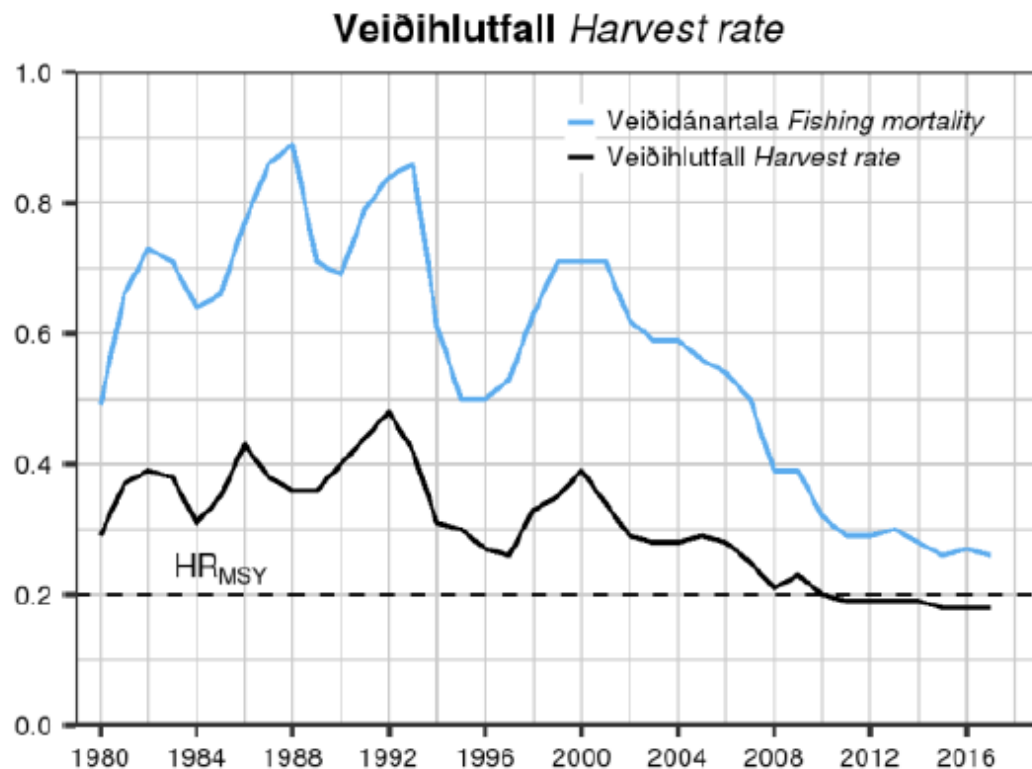
Aggregation prevents CPUE from dropping

Photo: www.captainatlantic.ca



Jónsdóttir et al. 2017

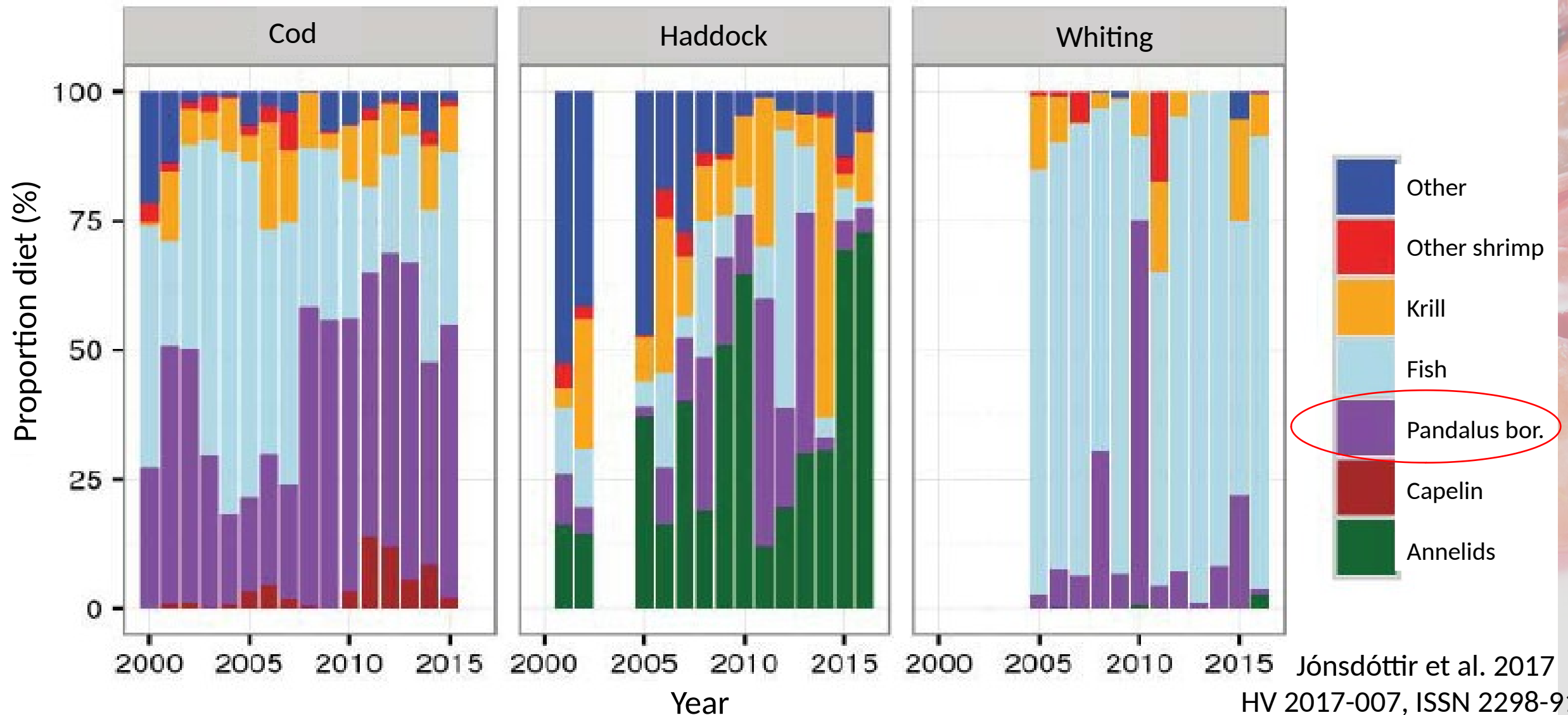
Cod stocks are doing great...



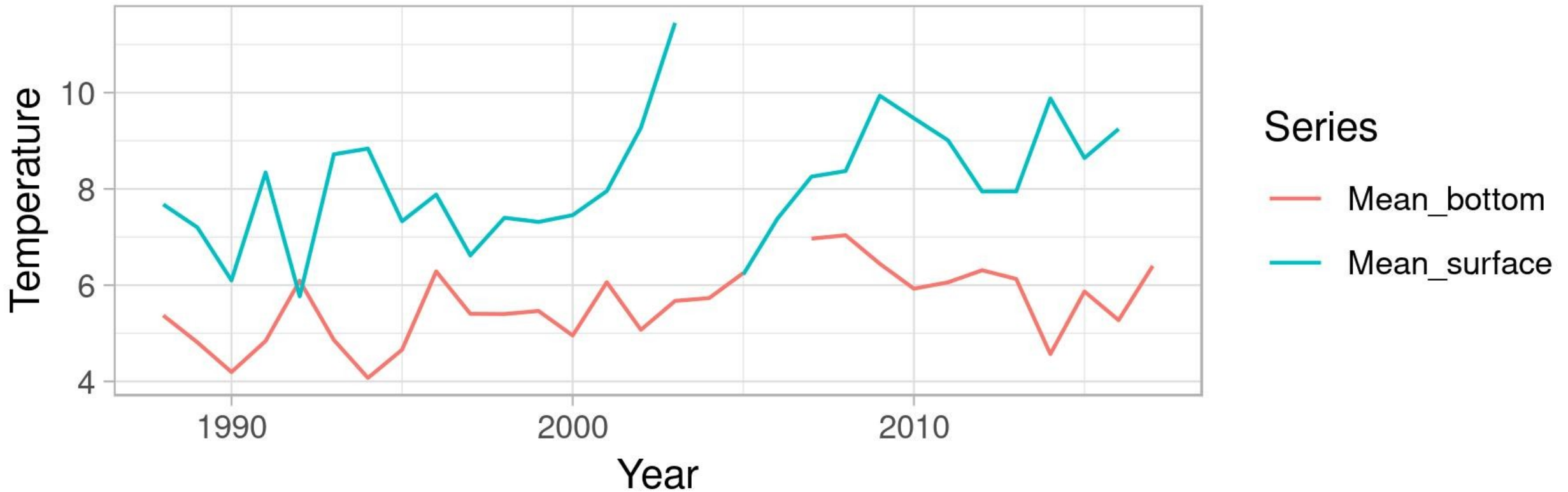
Dorskur. Afli eftir veiðarfærum, nýliðun 3 ára, veiðihlutfall og veiðidánartala, stærð viðmiðunarstofns (4 ára og eldri) og hrygningarstofns.

Cod. Catch by gear type, recruitment at age 3, fishing mortality and harvest rate, reference stock biomass (B_{4+}) and spawning stock biomass (SSB).

... and they love eating shrimp.



Temperature changes may affect growth



Motivation.

- What is causing shrimp declines?
- Is the advisory rule sufficient and not overly conservative?

Motivation.

- What is causing shrimp declines?
- Is the advisory rule sufficient and not overly conservative or lax?
- Can biomass be estimated?
- What effect do environmental variables have?
- [How do the advisory rules perform under uncertain biomass levels?]

Overview

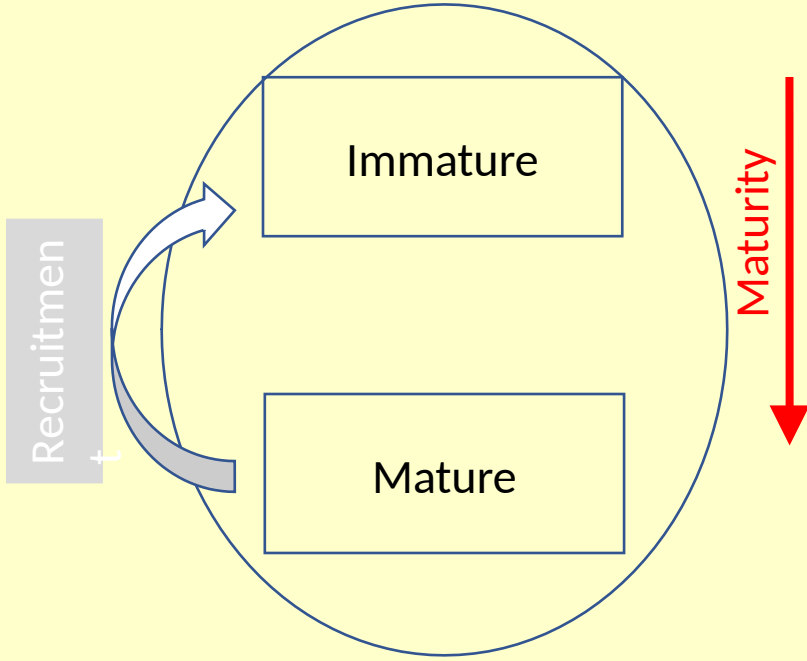
1. Operational model & data
2. Find 'best' model from an overparameterized state. Likelihood profiles:
 1. M / predation effort
 2. Recruitment upper bounds / catchability
 3. Stock-recruitment relationships
3. Describe the upcoming management strategy evaluation

I. Operational model

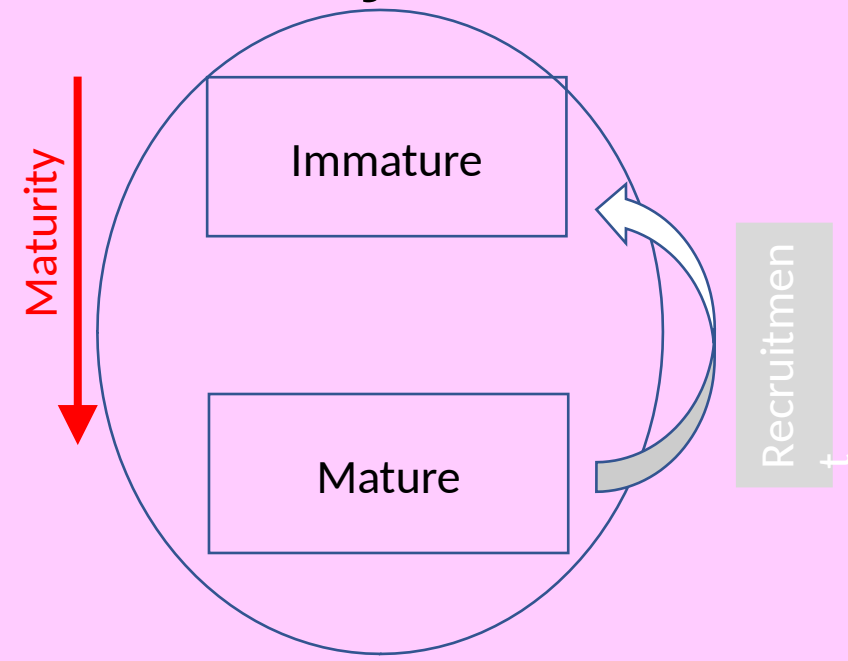
Size- and age-structured model Gadget

- Lengths 0.3-2.50 cm in 0.05 cm bins
- Ages 0-8
- No stock-recruitment relationship – recruitment estimated each year
- Predator fleets:
 - Cod (0 – 44 cm, 45 – 74 cm, > 75 cm)
 - Haddock (0 – 44 cm, 45 – 74 cm, > 75 cm)
 - Whiting Haddock (0 – 44 cm, 45 – 75 cm)
- Positive linear effect of temperature on k
 - in length-based Von Bertalanffy growth
 - 2 measures of temperature: surface and bottom from shrimp survey

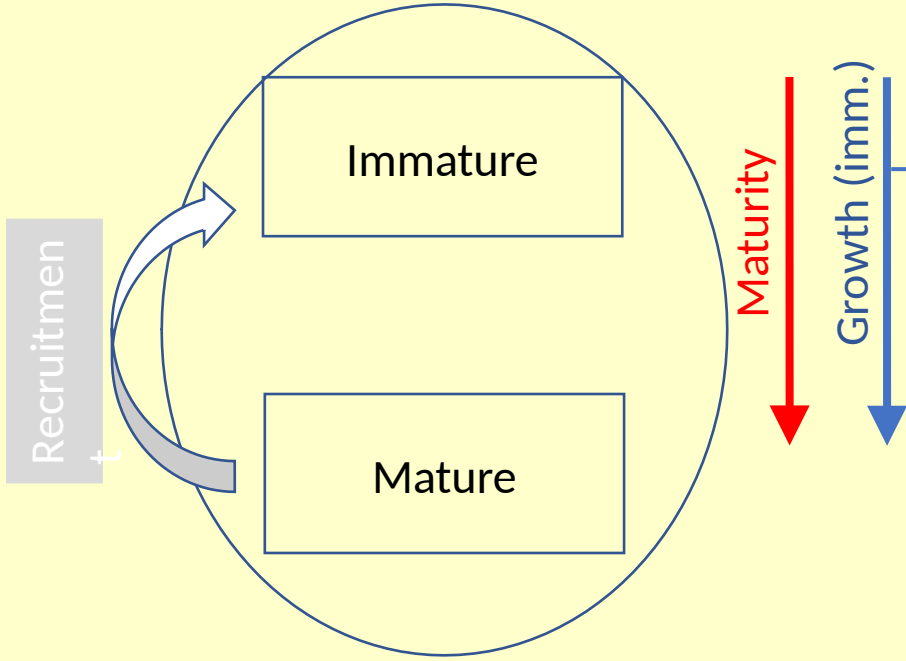
Arnafjörður



Ísafjörður

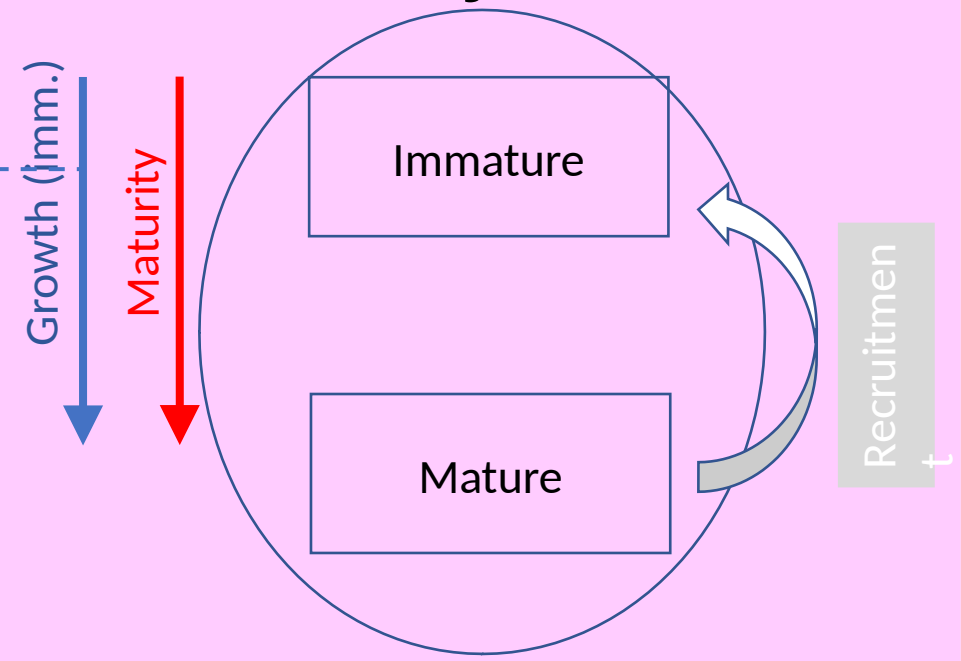


Arnafjörður

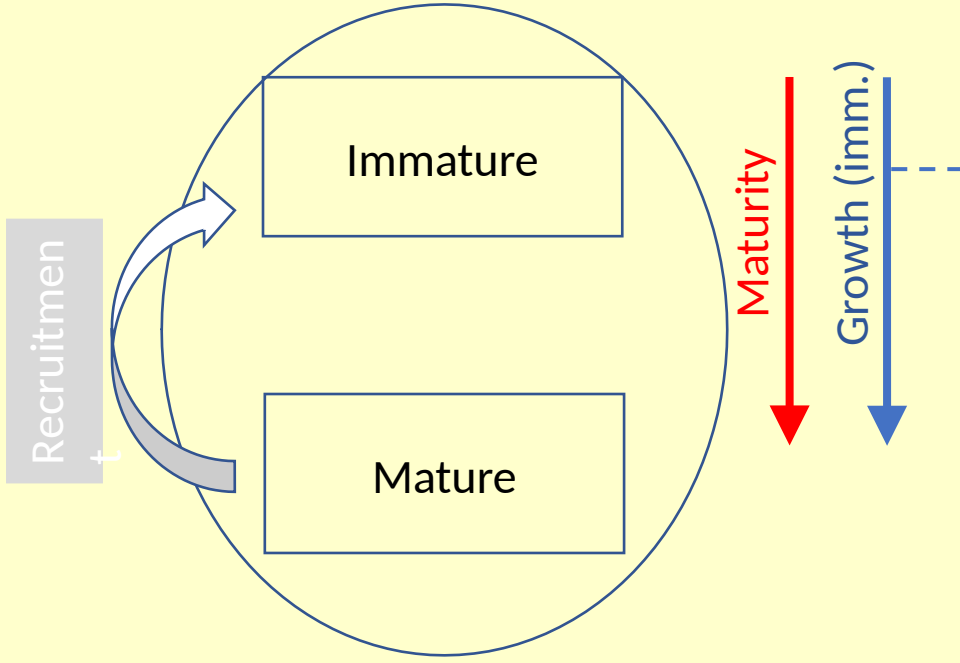


Same temperature effects, Linf

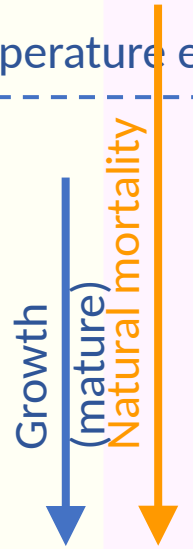
Ísafjörður



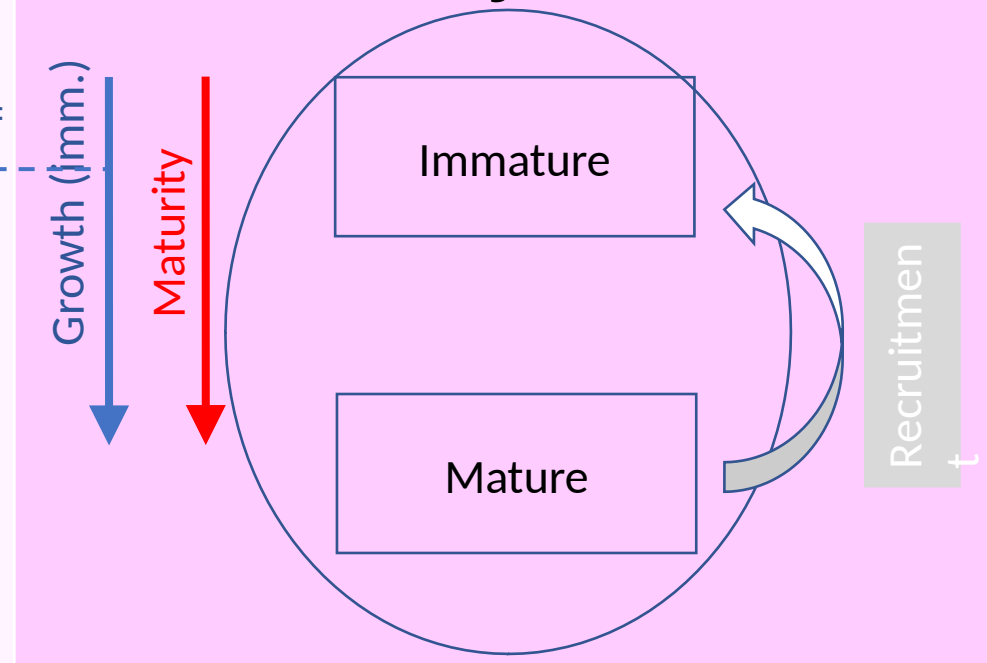
Arnafjörður



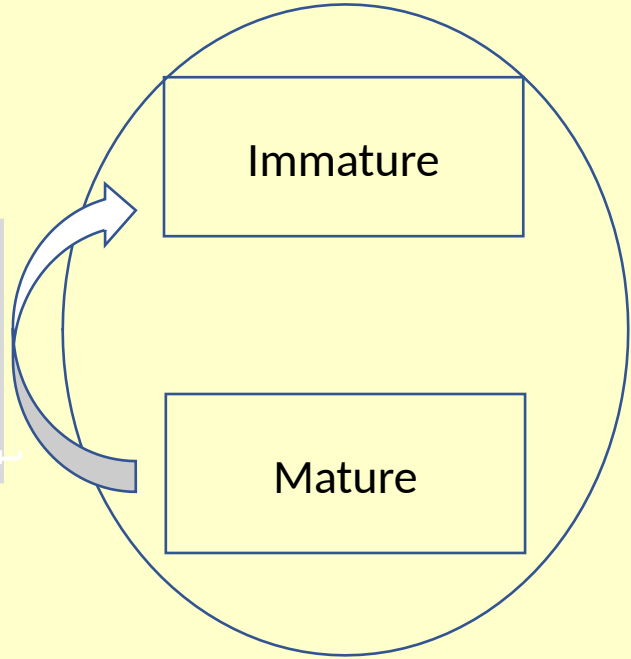
Same temperature effects, Linf



Ísafjörður



Arnafjörður

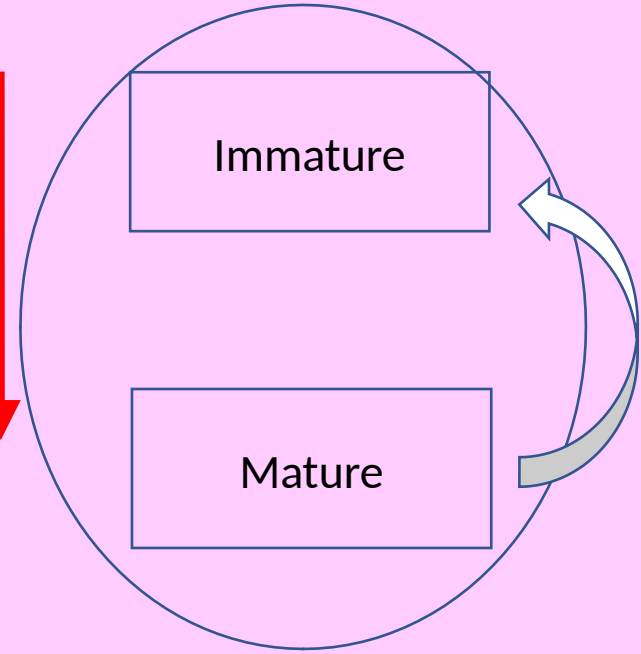


Maturity
Growth (imm.)

Same temperature effects, Linf

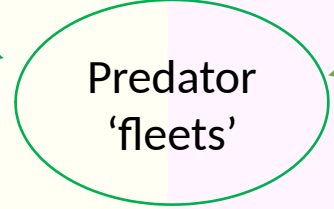
Growth (mature)
Natural mortality

Ísafjörður



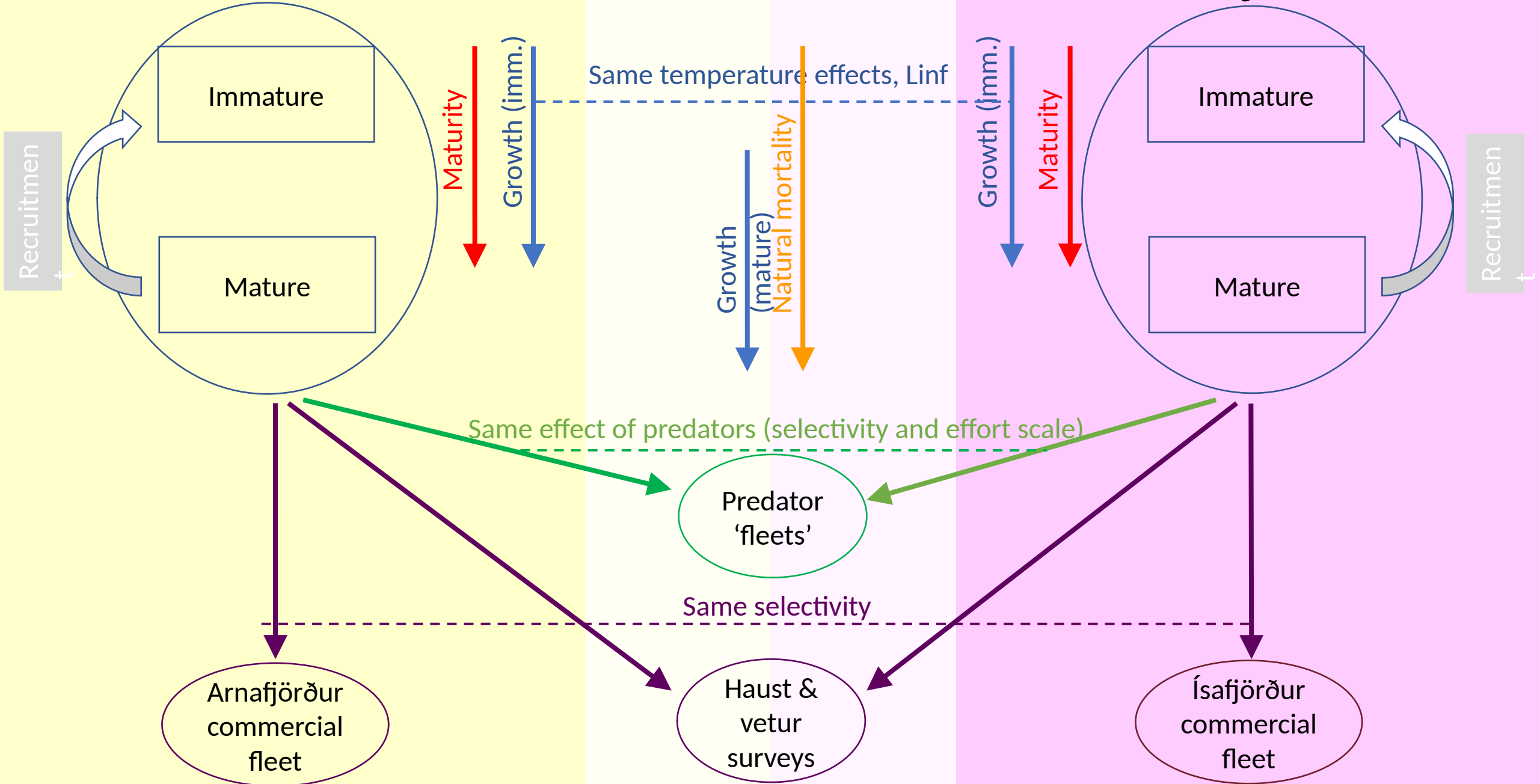
Growth (imm.)
Maturity

Same effect of predators (selectivity and effort scale)



Arnafjörður

Ísafjörður



I. Data

- Survey data from 2 surveys 1990 - 2017
 - Survey indices (6 slices)
 - Proportion at length
 - Proportion mature at length (single survey)
 - Mean temperature across survey readings for a given year, both bottom & surface
- Commercial/other samples: proportion at length
- Relative predation effort represented by predator biomass
 - composed of cod, haddock, whiting in 3 size categories each
 - Scaled by a single estimated scalar
- Landings incorporated directly
- Fit using:
 - Sum of squares (resulting in 'likelihood score')
 - Iterative reweighting to scale likelihood components
 - Mainly simulated annealing, followed by Hooke & Jeeves

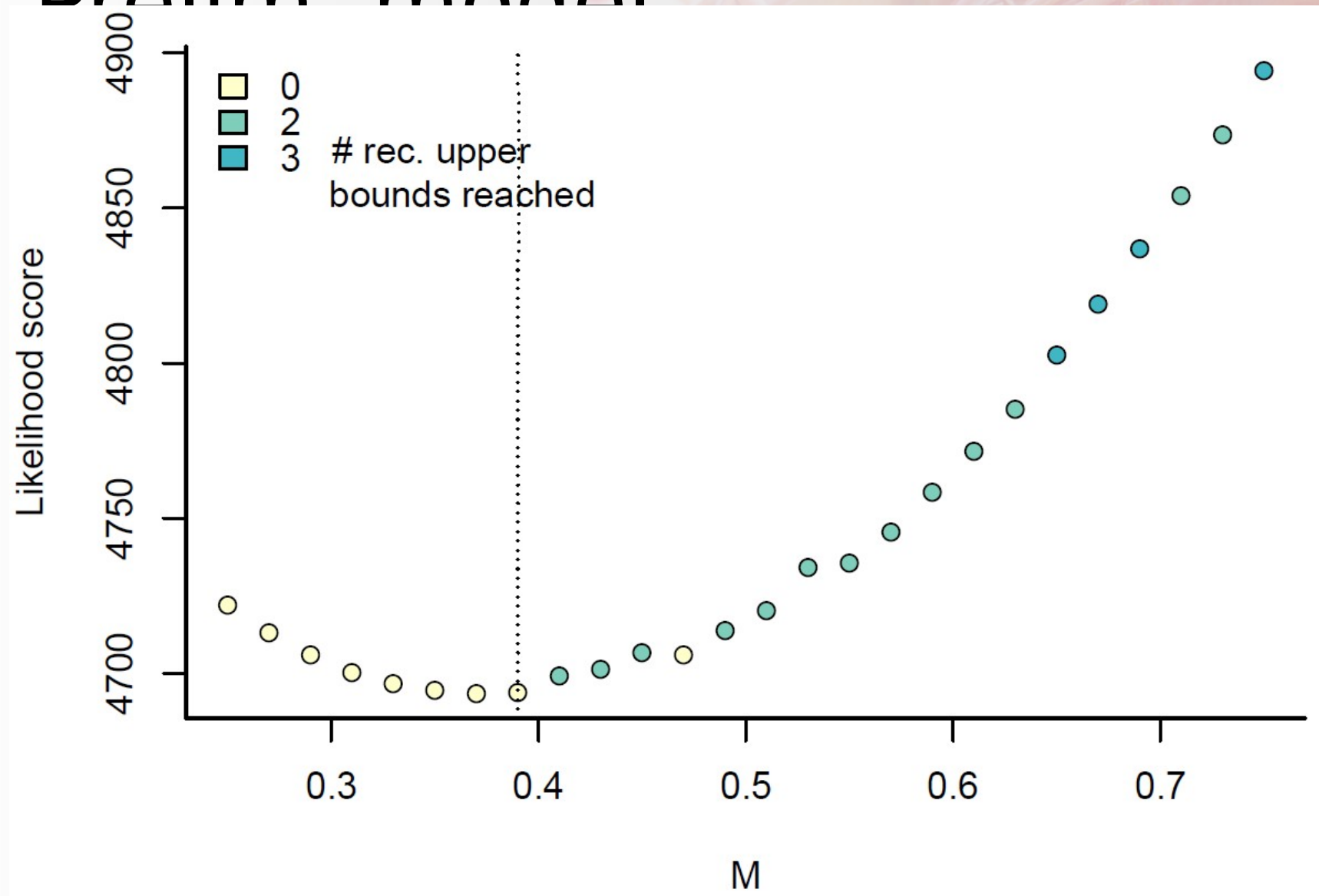
II. Best model?

1. Preliminary model based on only Arnafjörður
2. Developed model with both Arnafjörður and Ísafjörður

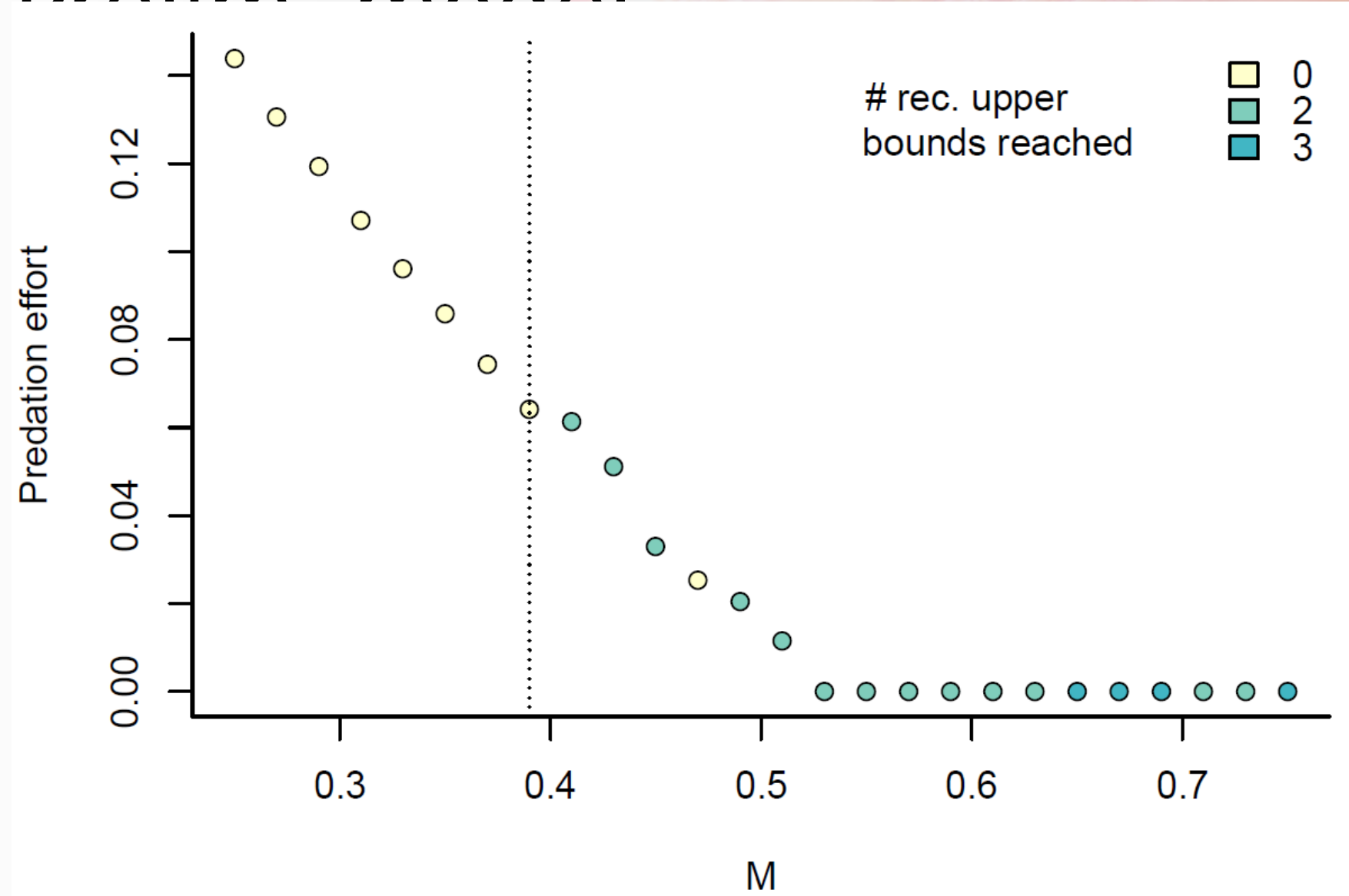
II. Best model? Properties of the Prelim. model



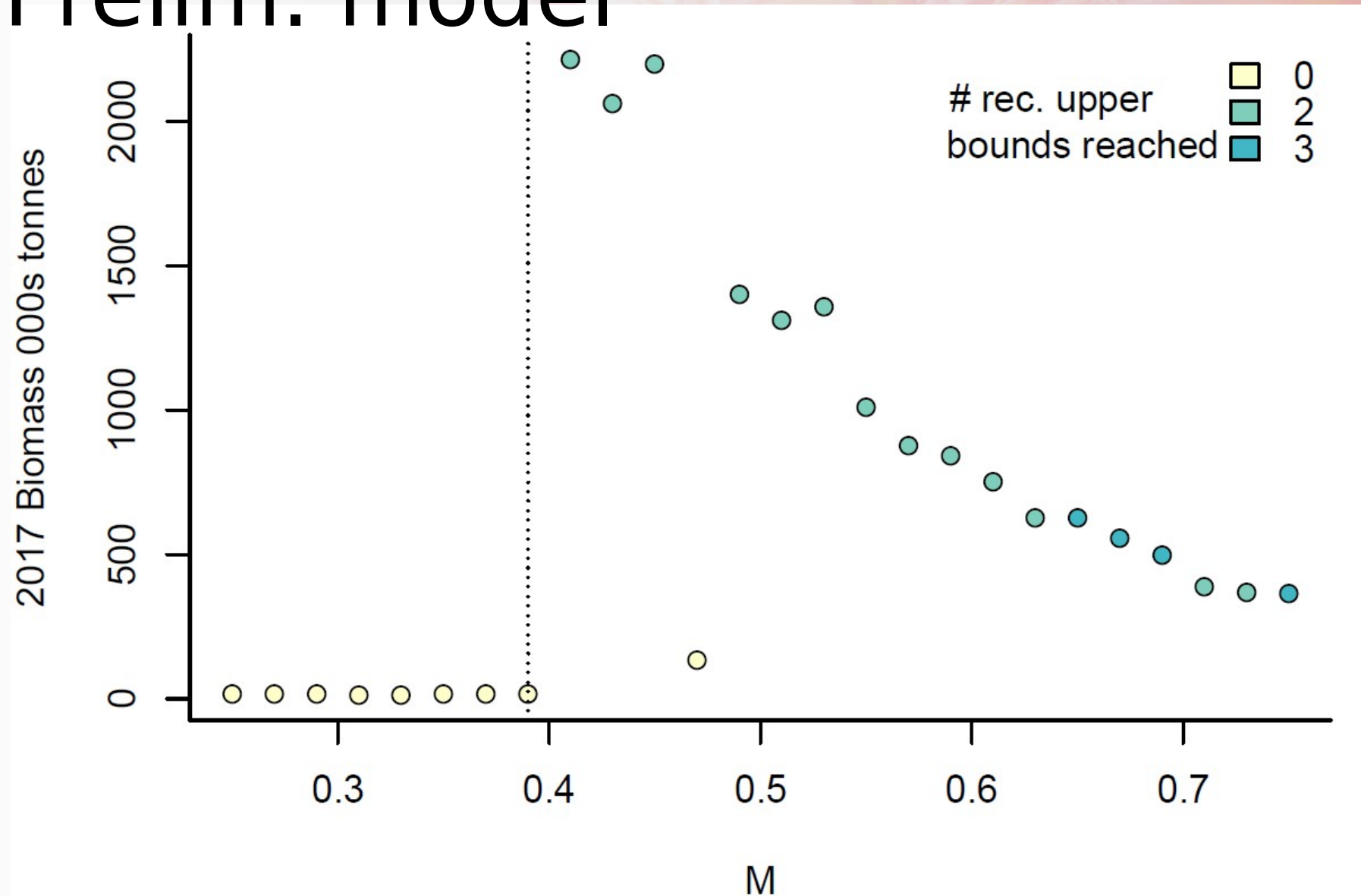
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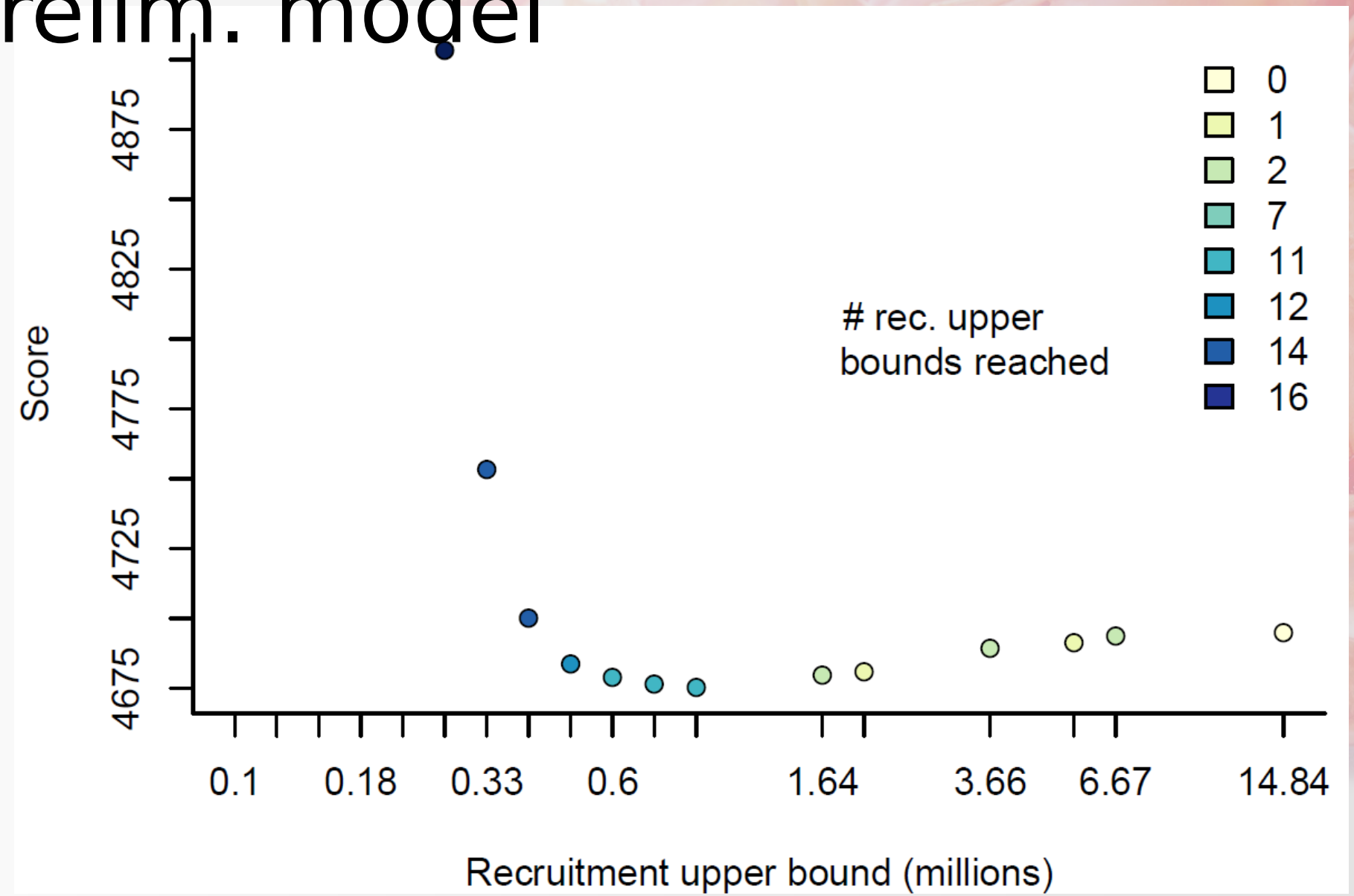
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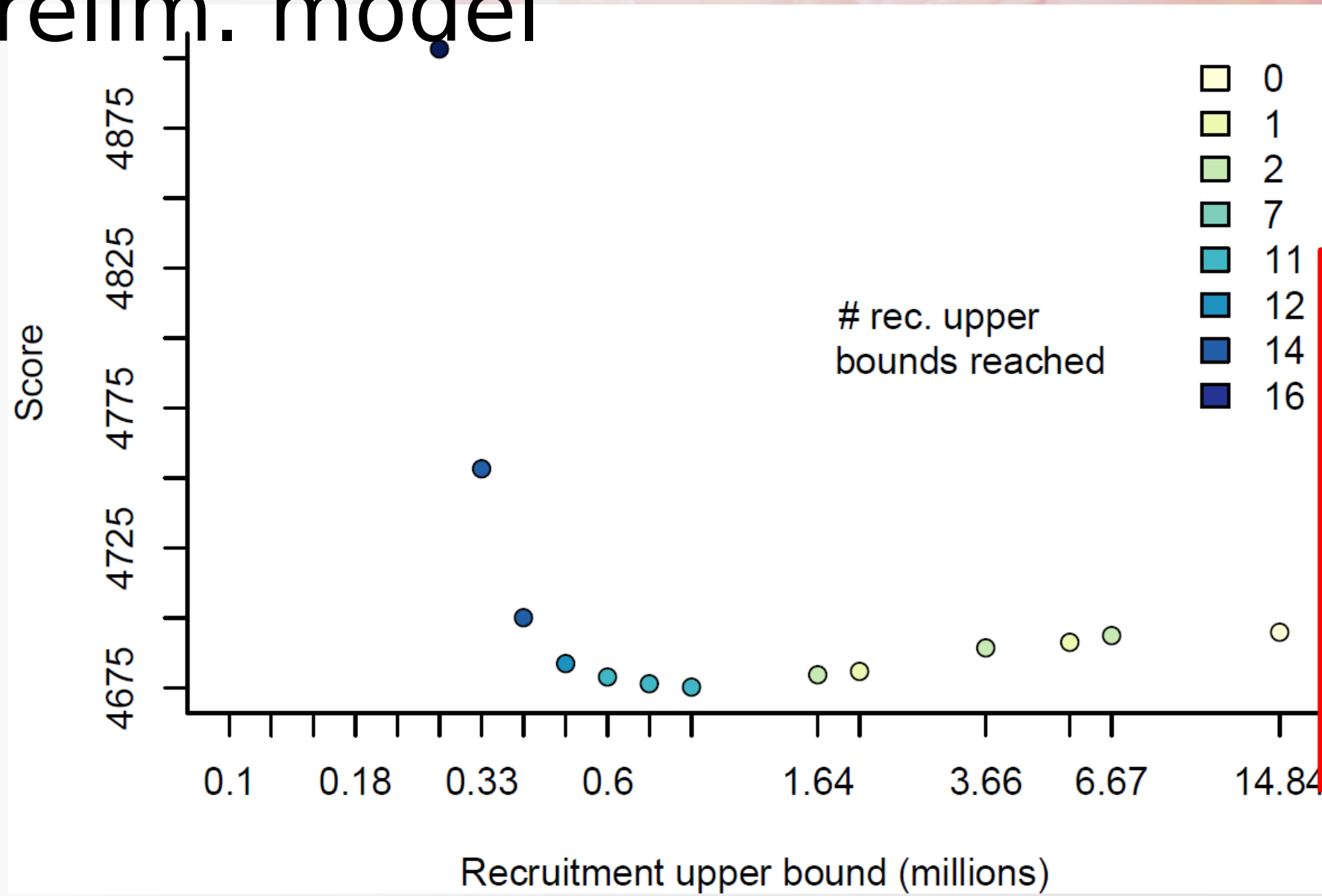
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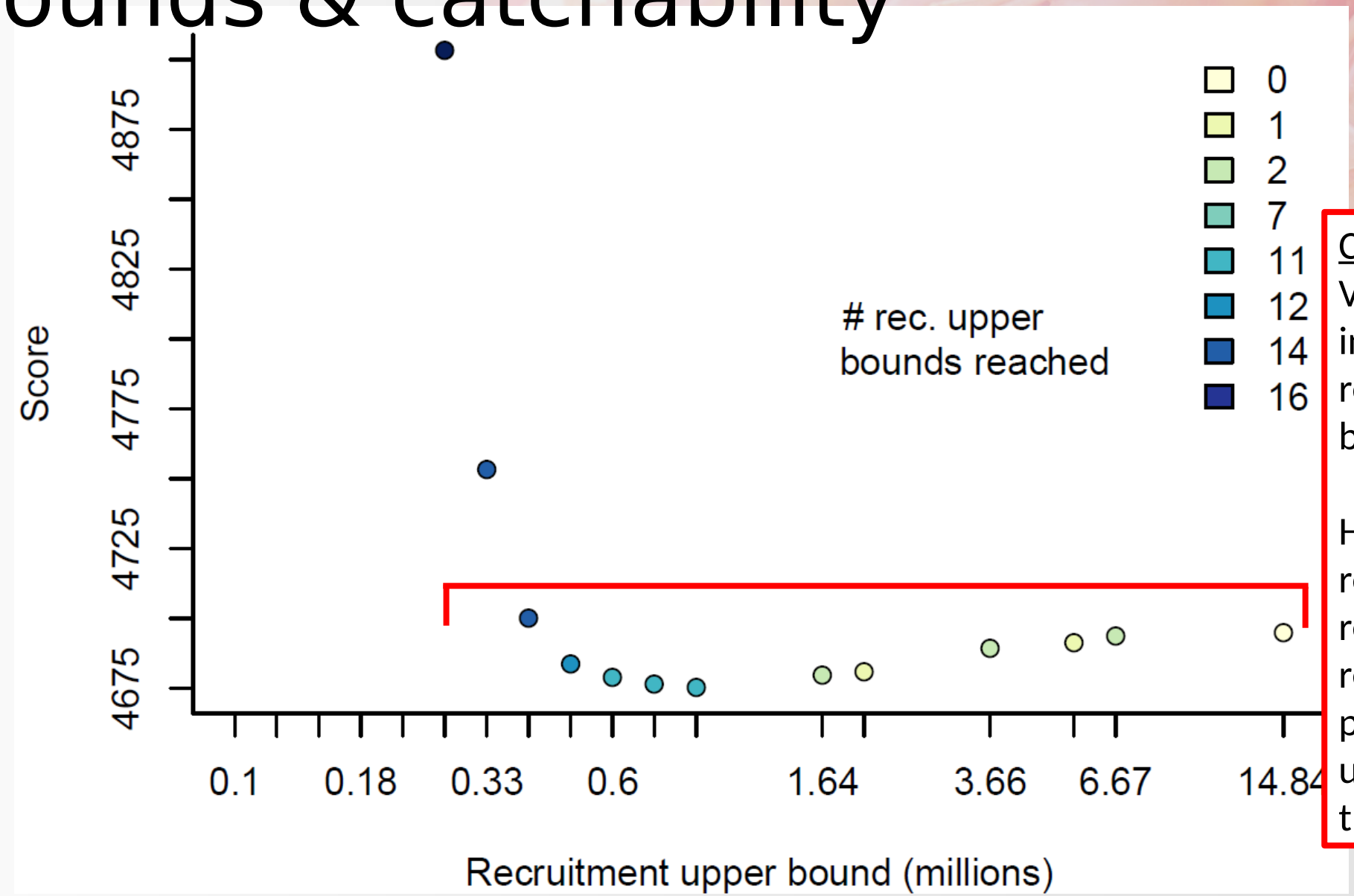


II. Best model? Properties of the Prelim. model



Conclusion:
Very little information regarding absolute biomass.

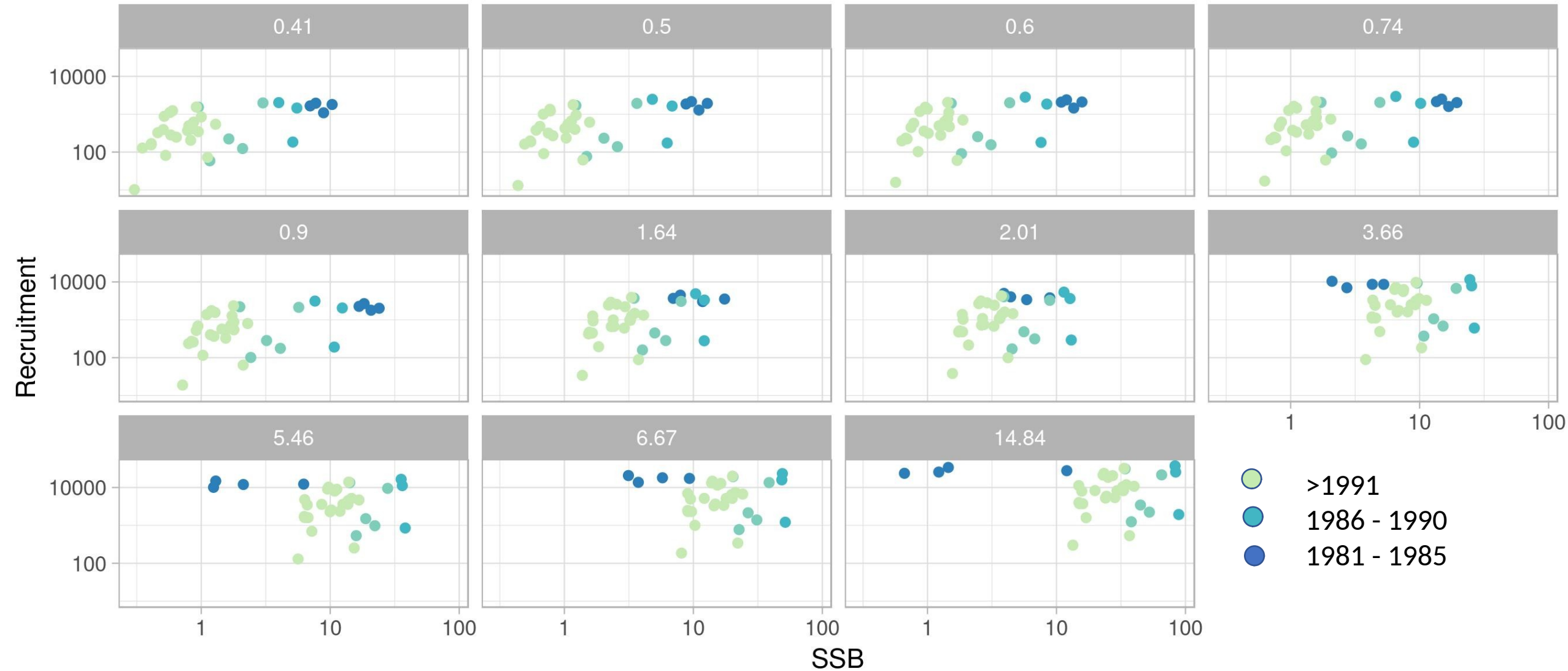
II. Best model? Recruitment upper bounds & catchability



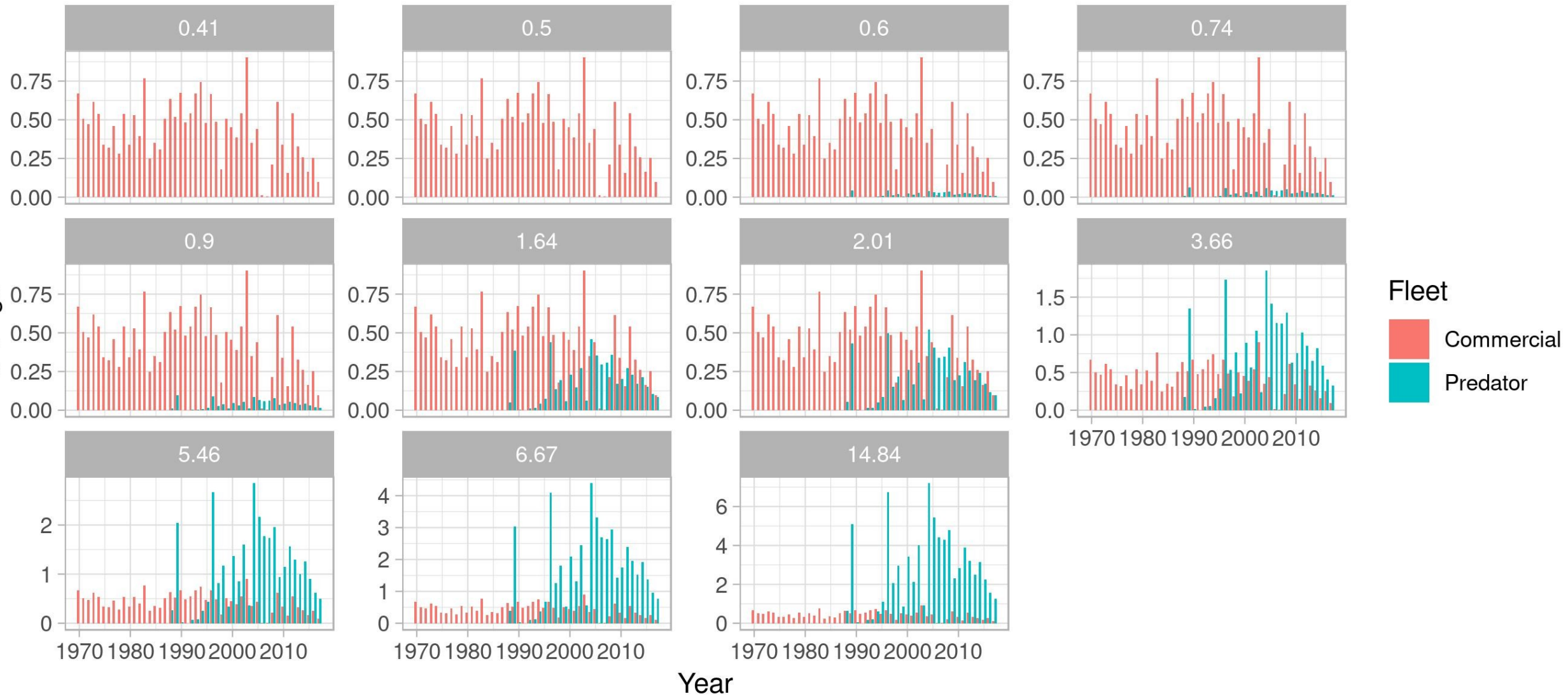
Conclusion:
Very little information regarding absolute biomass.

However, can resulting stock-recruitment relationships and predation levels be used to narrow down the 'right' answer?

II. Best model? SR relationships



II. Best model? SR relationships



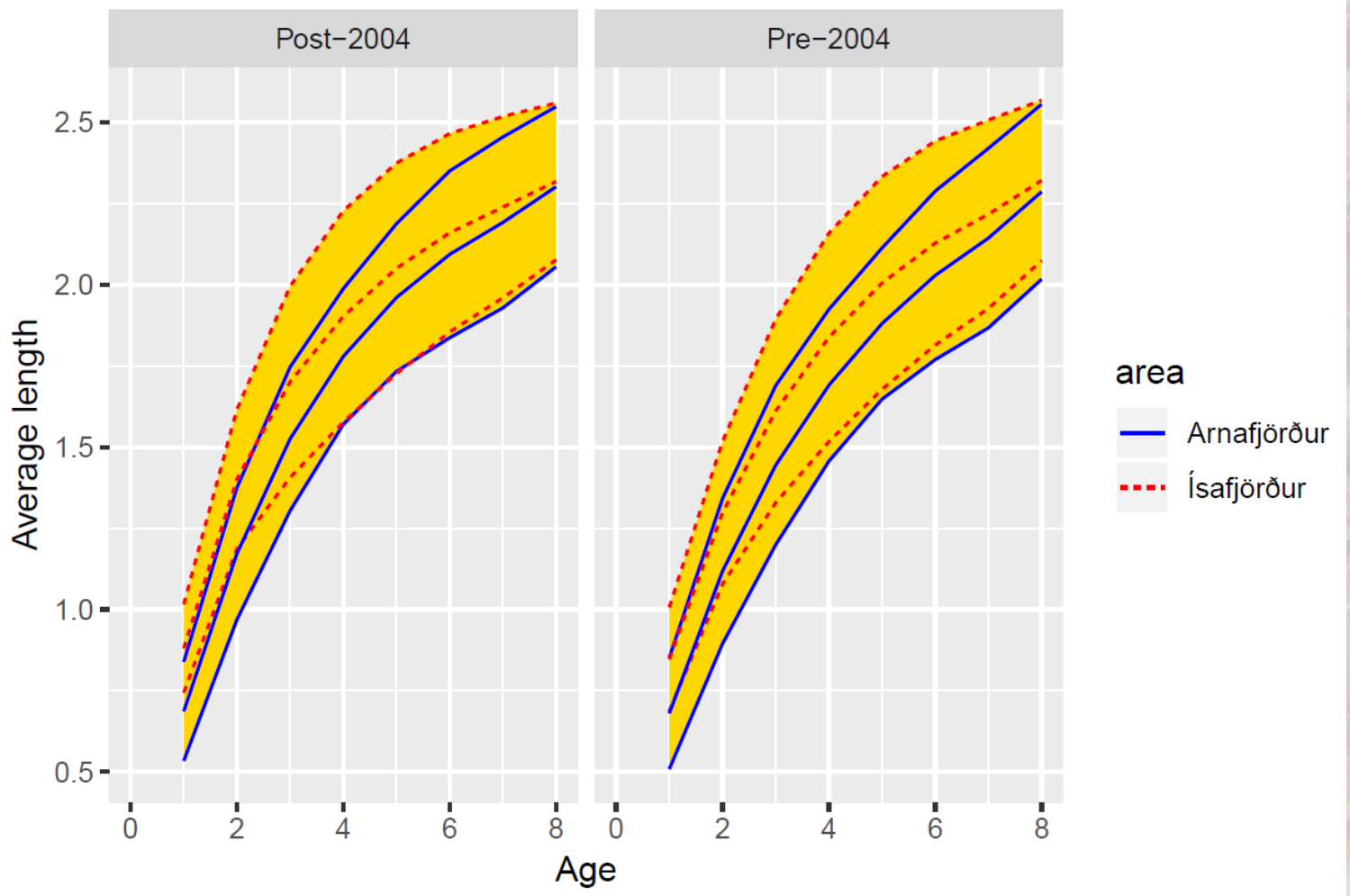
II. Best Developed model so far (not final)



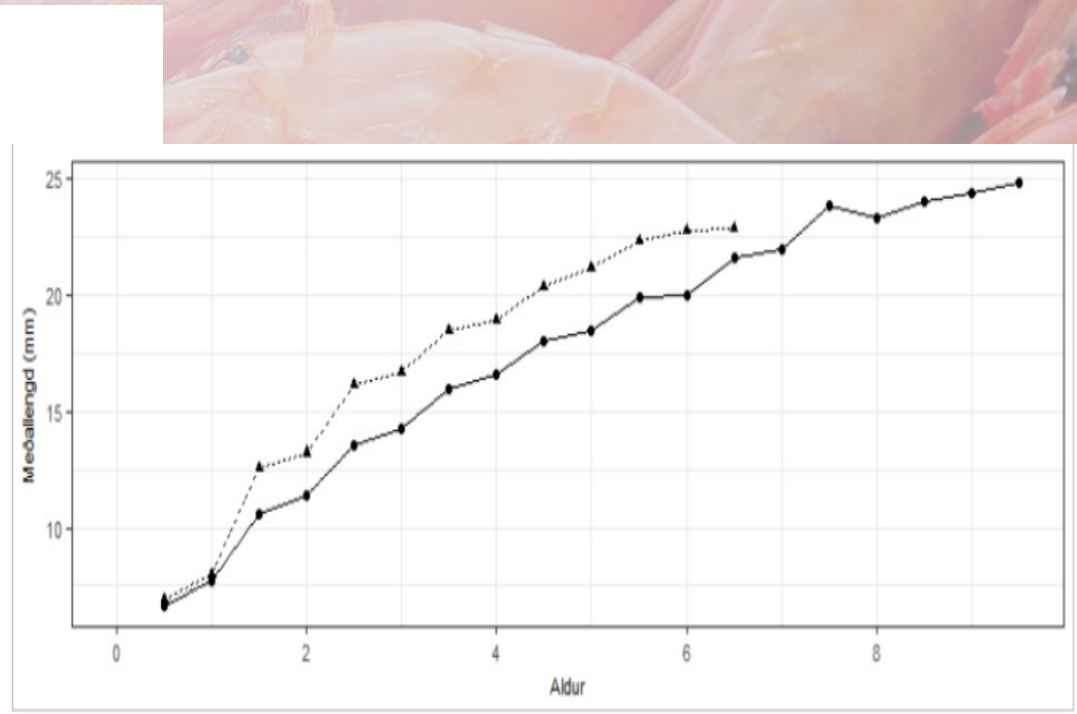
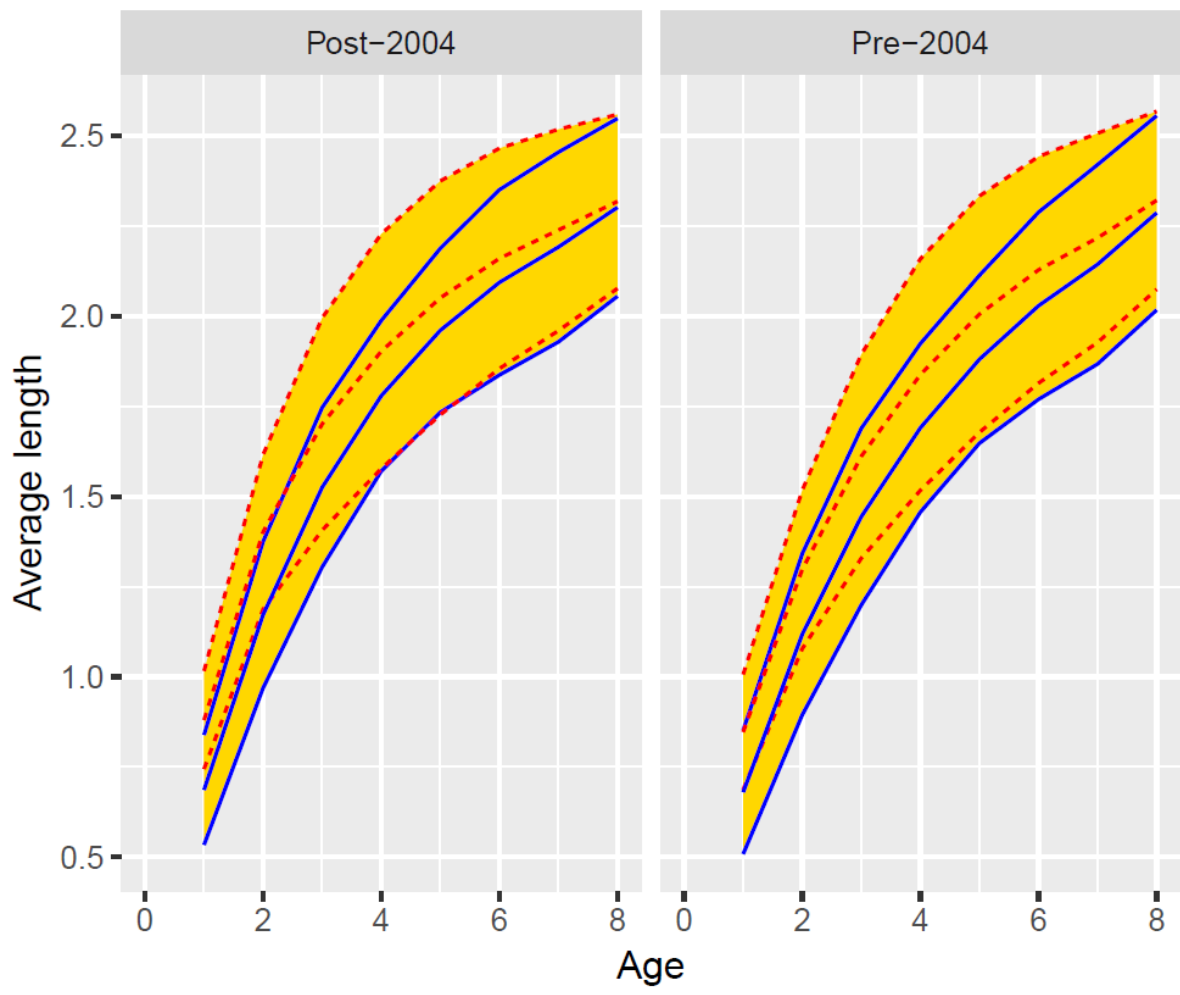
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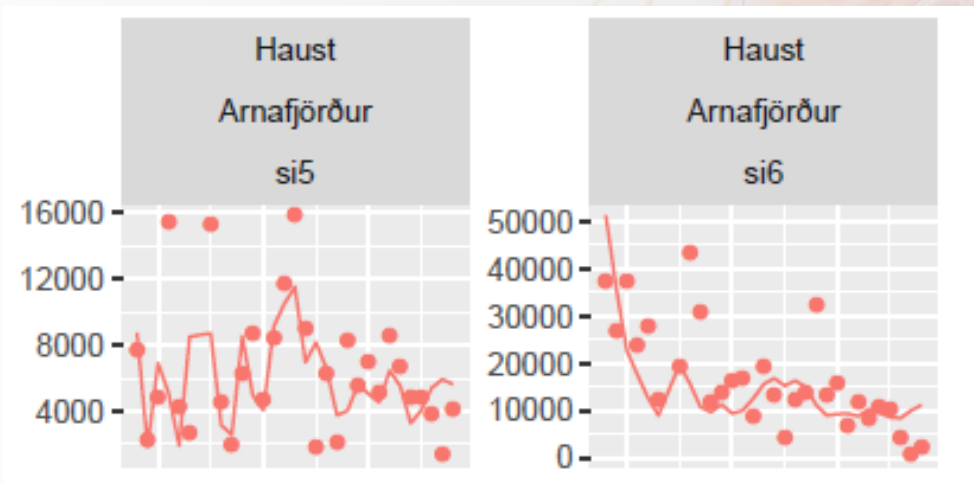
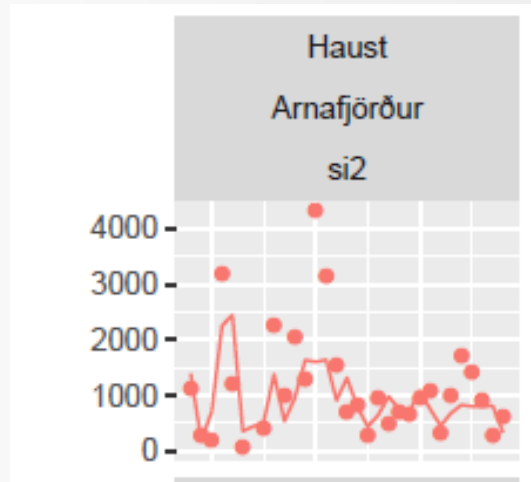


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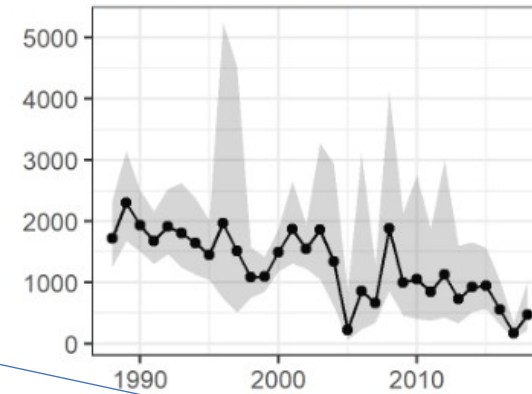


3.mynd. Meðallengd rækju (mm) eftir aldri og árgöngum í Arnarfirði og Ísafjarðardjúpi. Neðri myndin sýnir meðallengd allra árganga eftir aldri í Arnarfirði (heil lína) og Ísafjarðardjúpi (brotin lína).
 Figure 3. Mean length (mm) of shrimp by age and year classes in Arnarfjörður and Ísafjarðardjúp. The lower graph shows the mean length of all year classes by age in Arnarfjörður (solid line) and Ísafjarðardjúp (broken line).

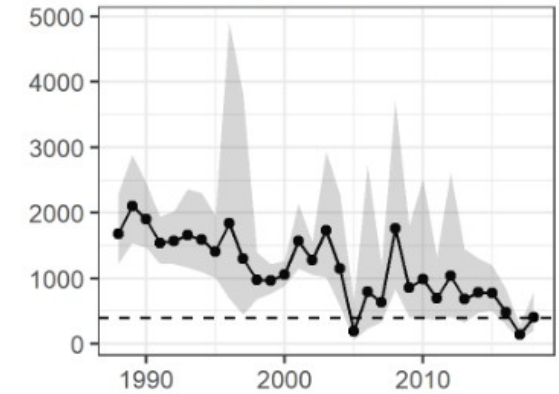
II. Best model? M & predation effort



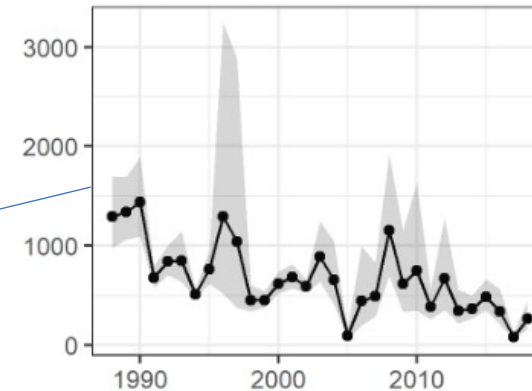
Total stock index



Fishable index



Female index



Juvenile index

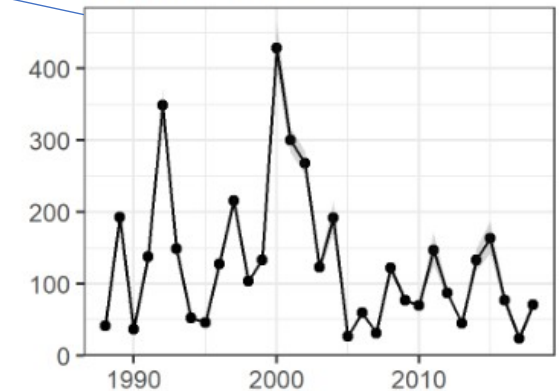


Figure 4. Shrimp in Arnarfjörður. Stock biomass index, fishable biomass index, female biomass index and juvenile biomass index of shrimp. The horizontal line indicates a value where the state of the stock is considered to be critical (20% of the mean of the three highest indices).

Mynd 4. Rækja í Arnarfirði. Heildarstofnsvisitala, veiðistofnsvisitala, kvendýravisitala og visitala ungrækju. Lárétt lína sýnir viðmiðunargildi fyrir ástand stofnsins (20% af meðaltali þriggja hæstu visitalna).

II. Best model? M & predation effort

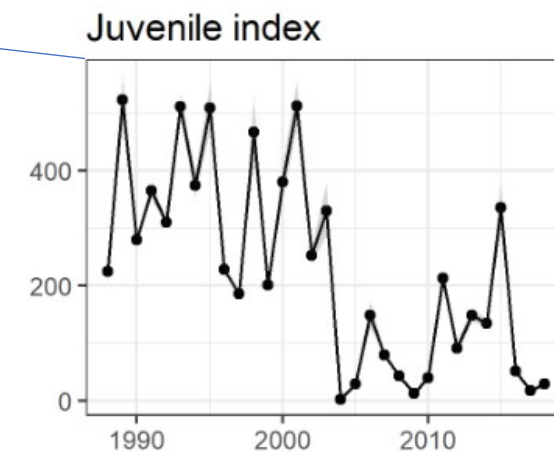
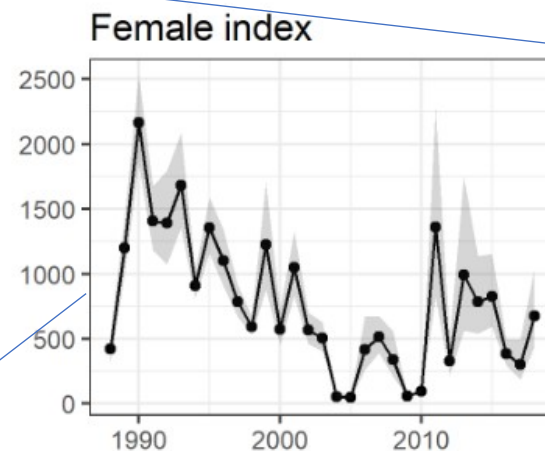
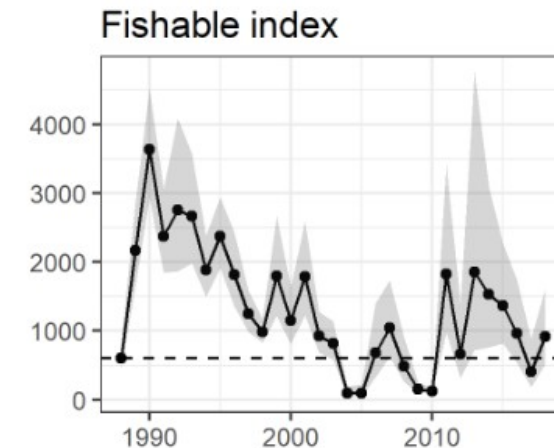
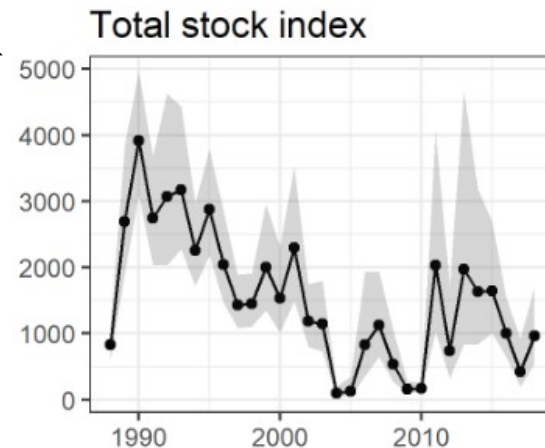
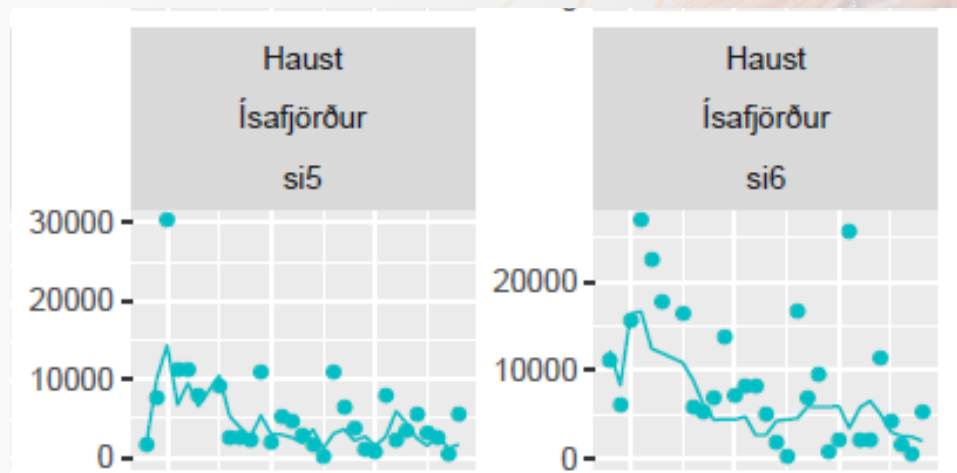
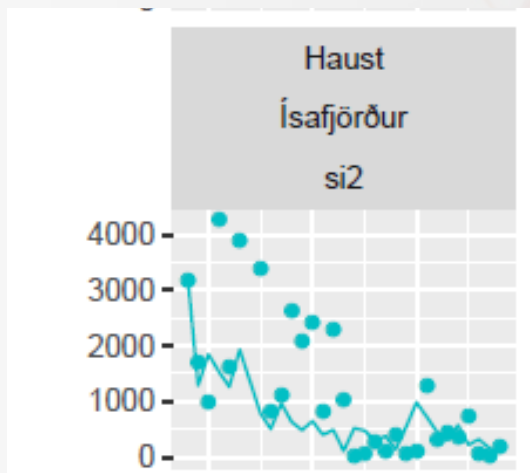
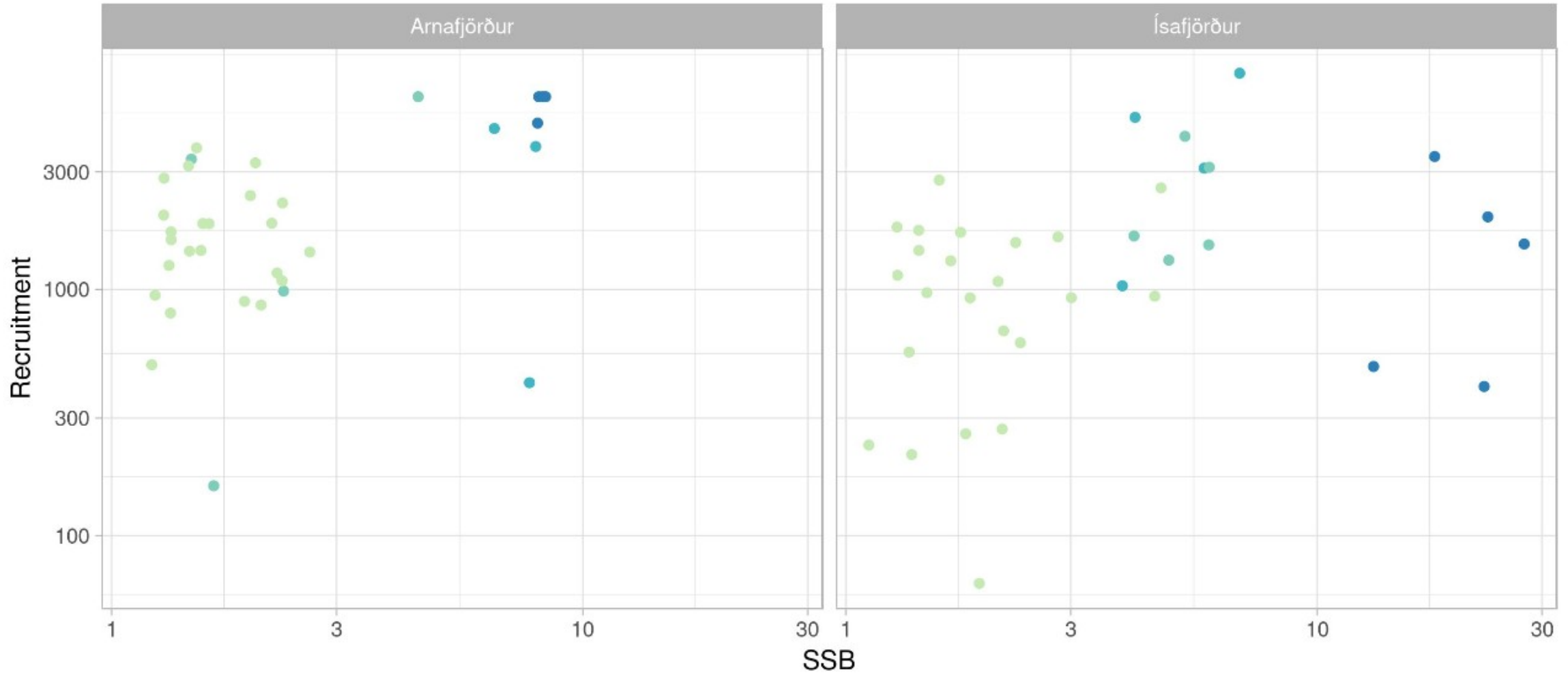


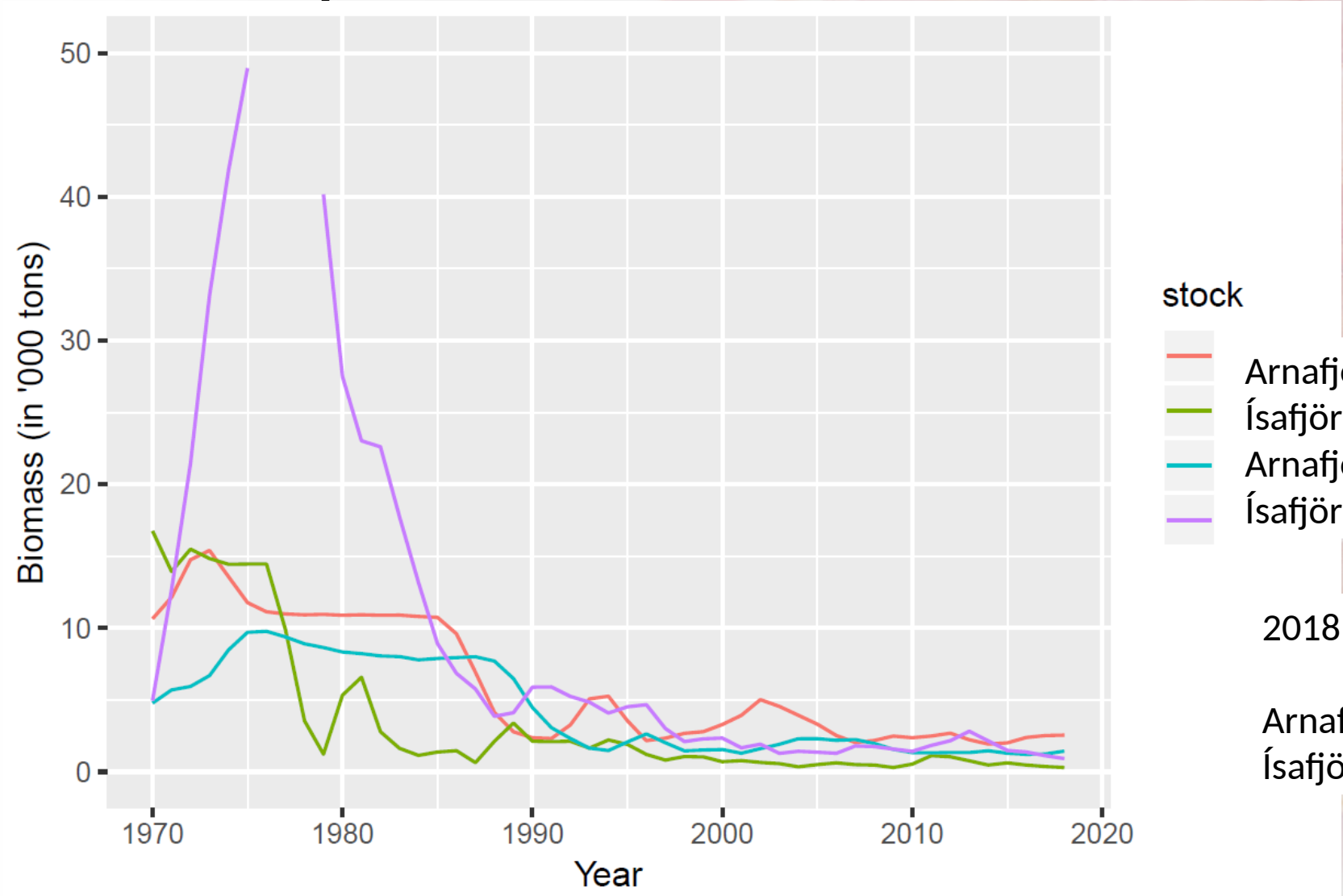
Figure 4. Shrimp in Ísafjarðardjúp. Stock biomass index, fishable biomass index, female biomass index and juvenile biomass index of shrimp. The horizontal line indicates a value where the state of the stock is considered to be critical (20% of the mean of the three highest indices).

Mynd 4. Rækja í Ísafjarðardjúpi. Heildarstofnsvísitala, veiðistofnsvísitala, kvendýravisitala og vísitala ungrækju. Lárétt lína sýnir viðmiðunargildi fyrir ástand stofnsins (20% af meðaltali þriggja hæstu vísitalna).

II. Best model? M & predation effort



II. Best Developed model so far (not final)

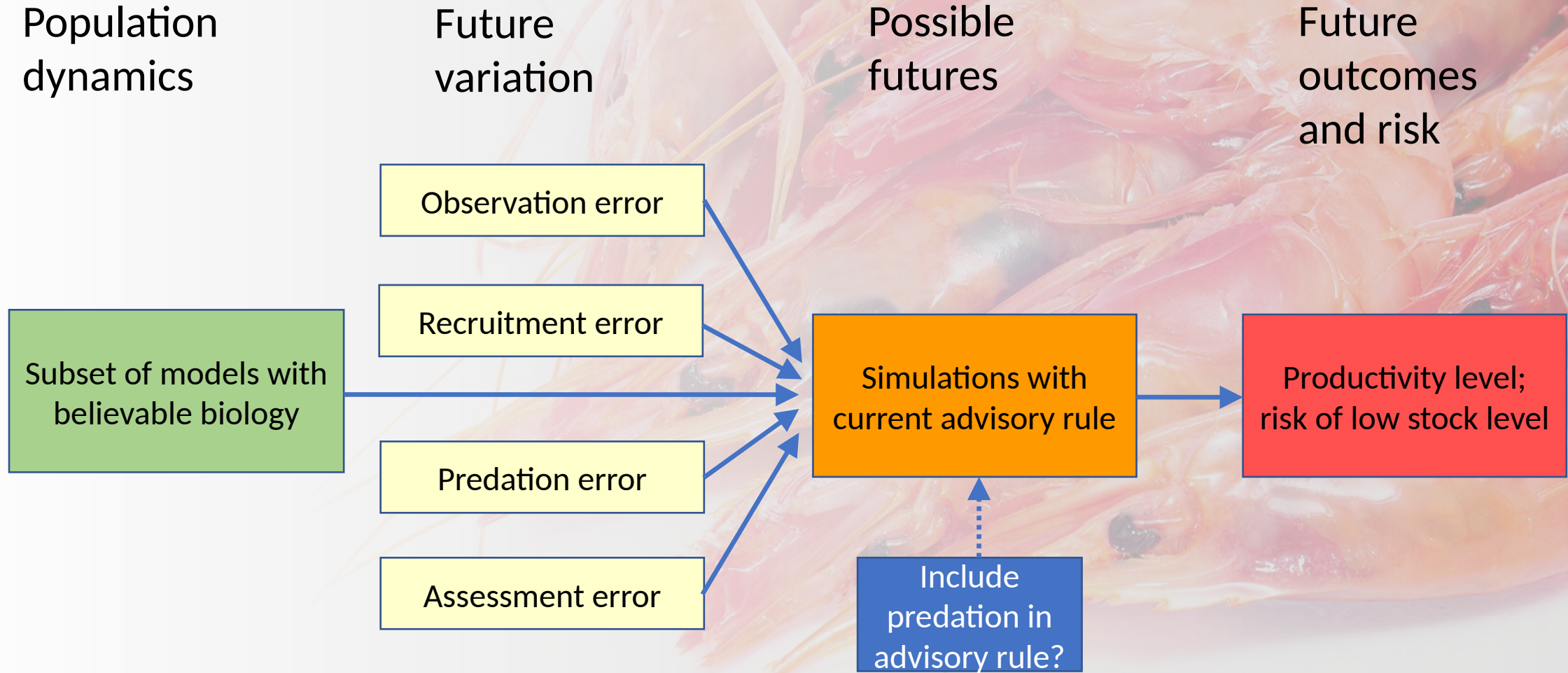


stock

—	Arnafjörður	Immature
—	Ísafjörður	Immature
—	Arnafjörður	Mature
—	Ísafjörður	Mature

2018	Mat. Biomass	Index	'q'
Arnafjörður	1441 t	402	0.3
Ísafjörður	920 t	912	1

III. Management Strategy Evaluation



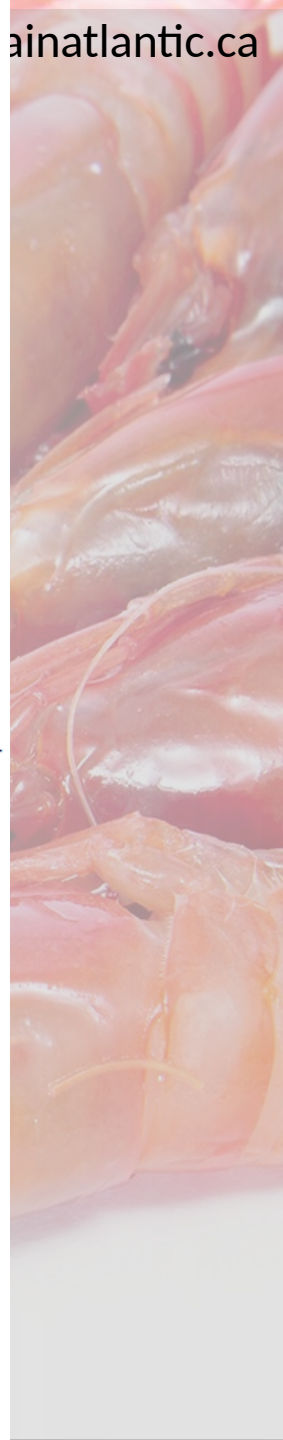
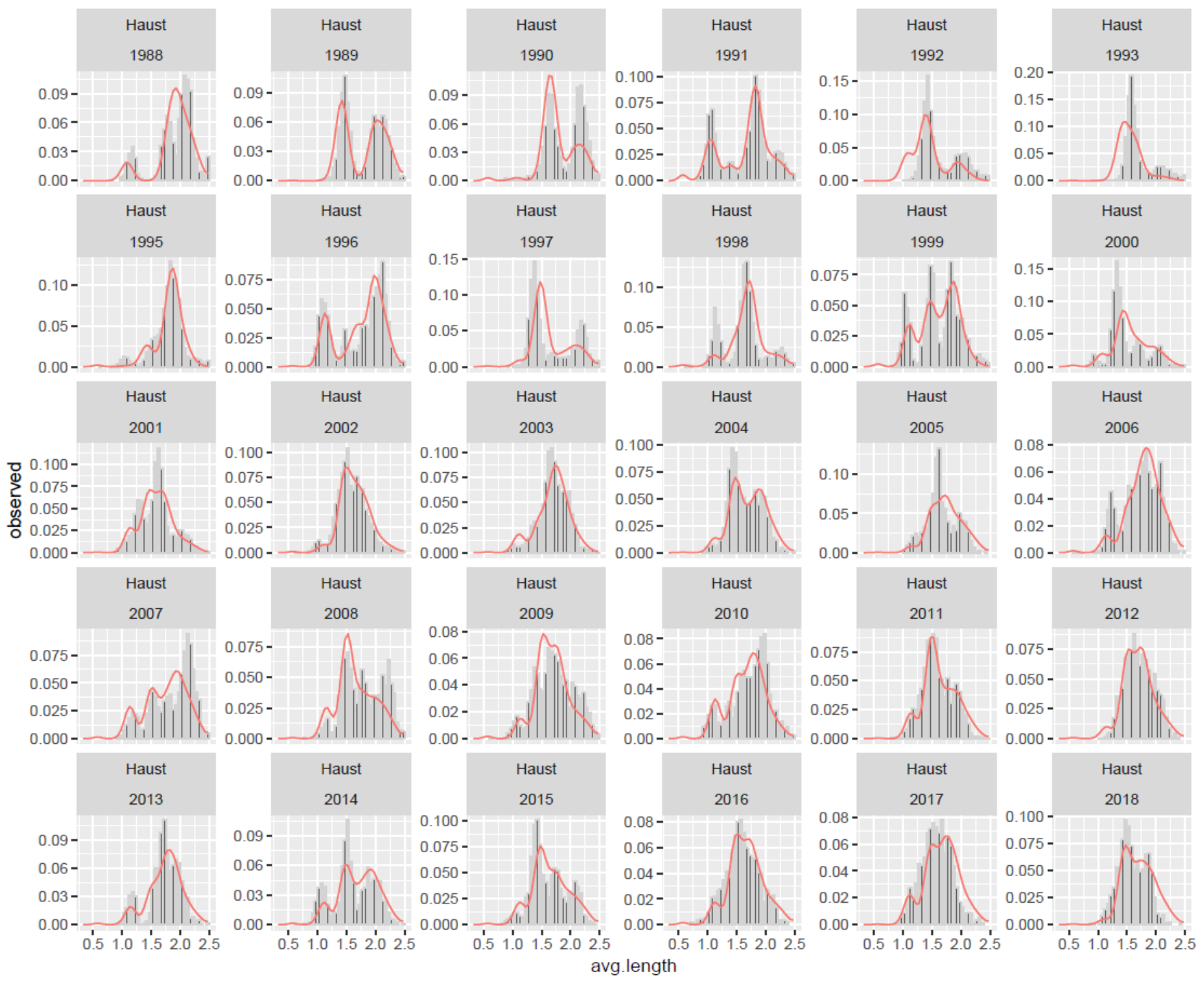
A large fishing net filled with salmon, with a fisherman visible in the background. The net is made of blue mesh and is overflowing with bright orange salmon. A fisherman wearing a red hat and a green jacket is visible on the right side, holding a long wooden pole. The background is a bright, overcast sky.

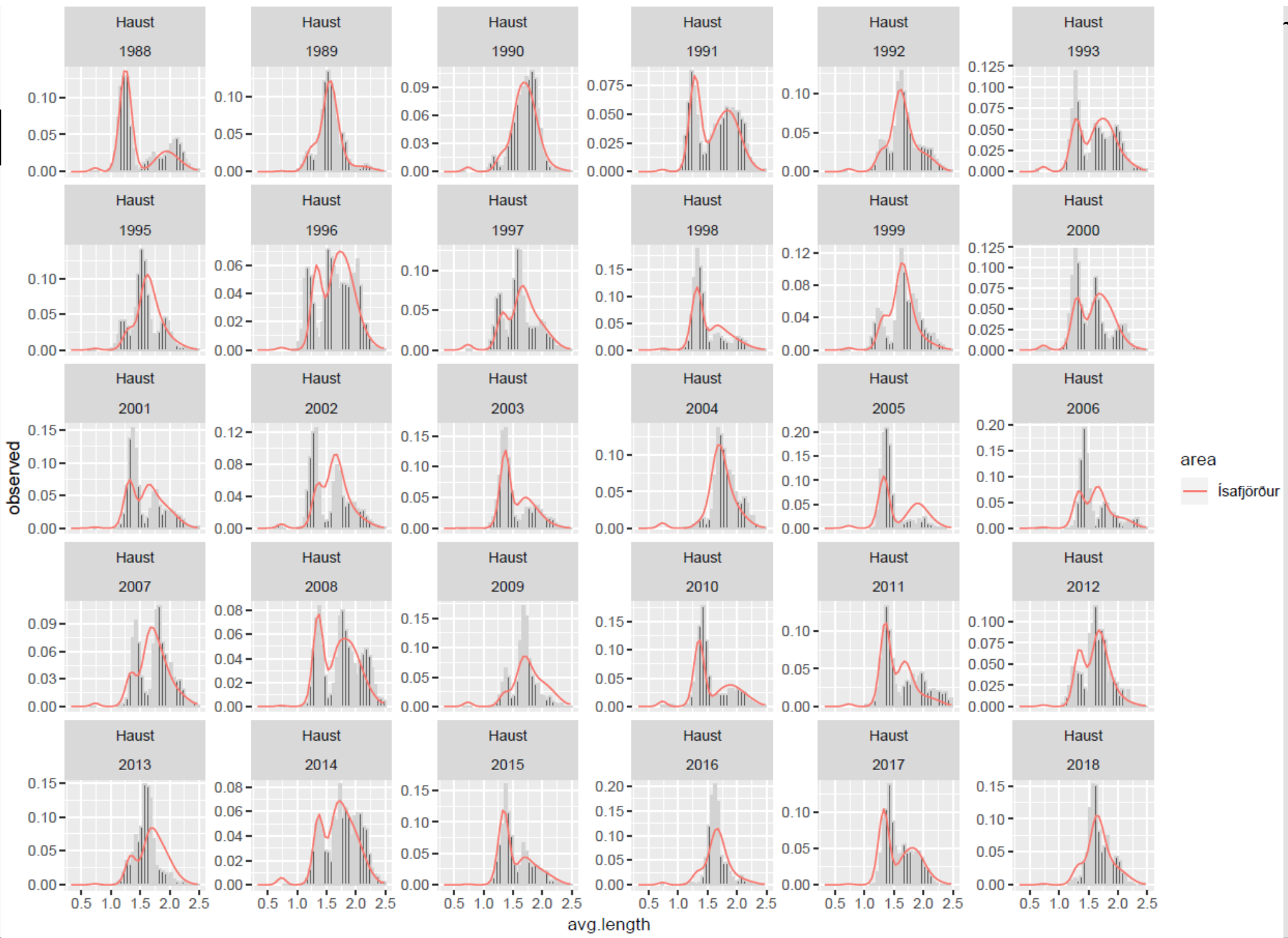
Conclusions

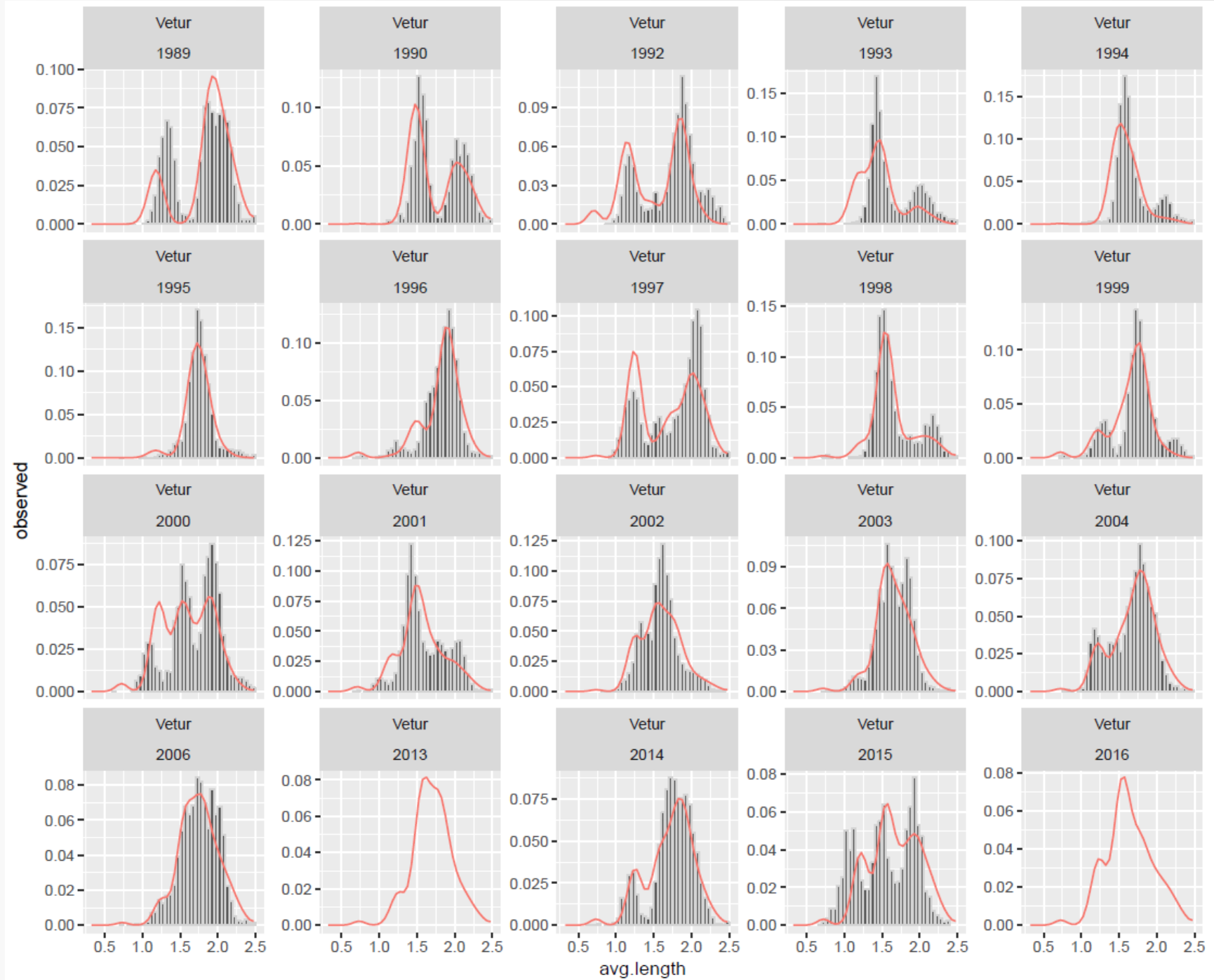
- True ecology = overparameterization
- Care should be taken in how model choices can constrain belief in ecological states
- Useful exercise despite difficulties in estimating catchability

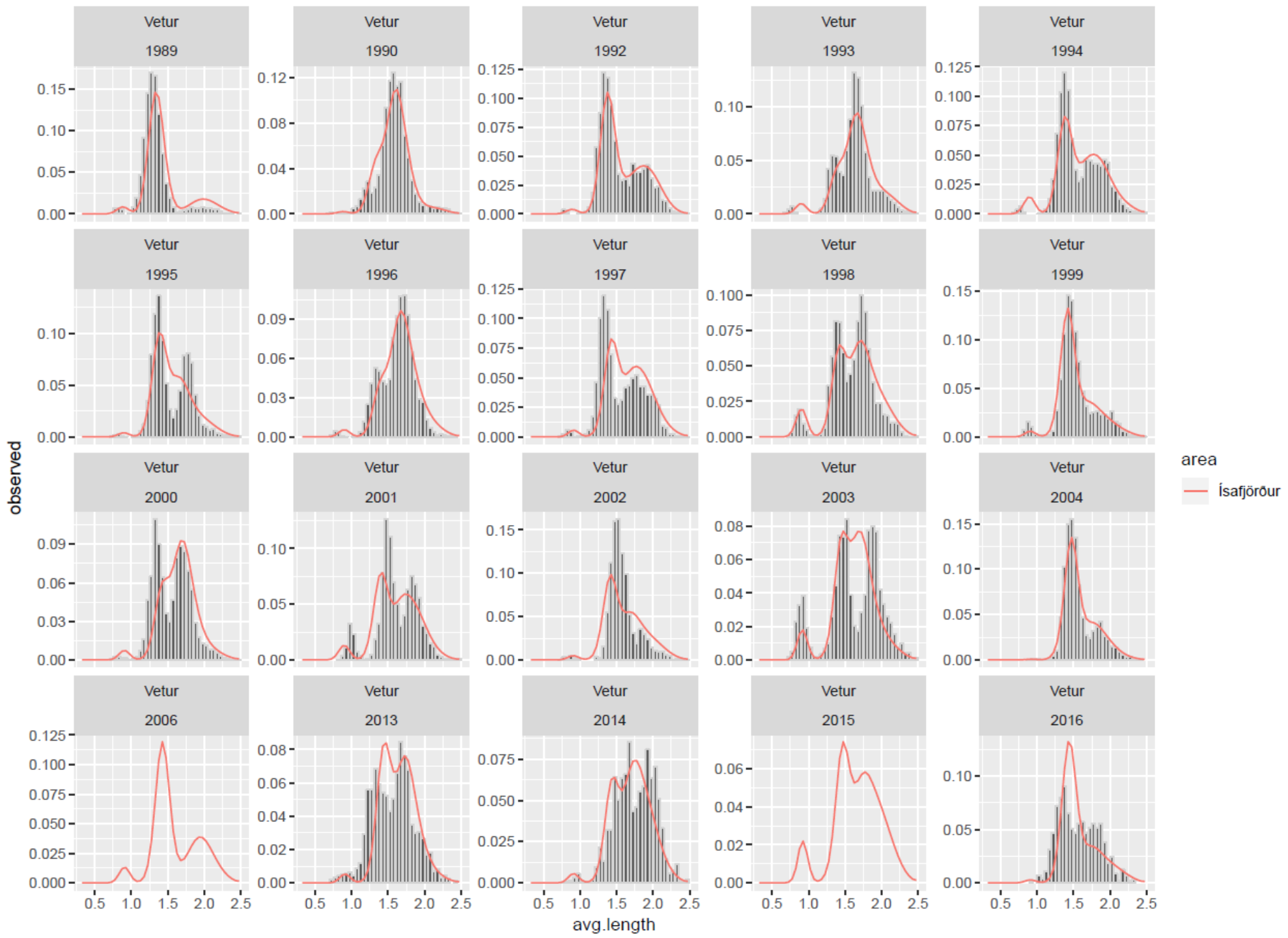
Thanks!



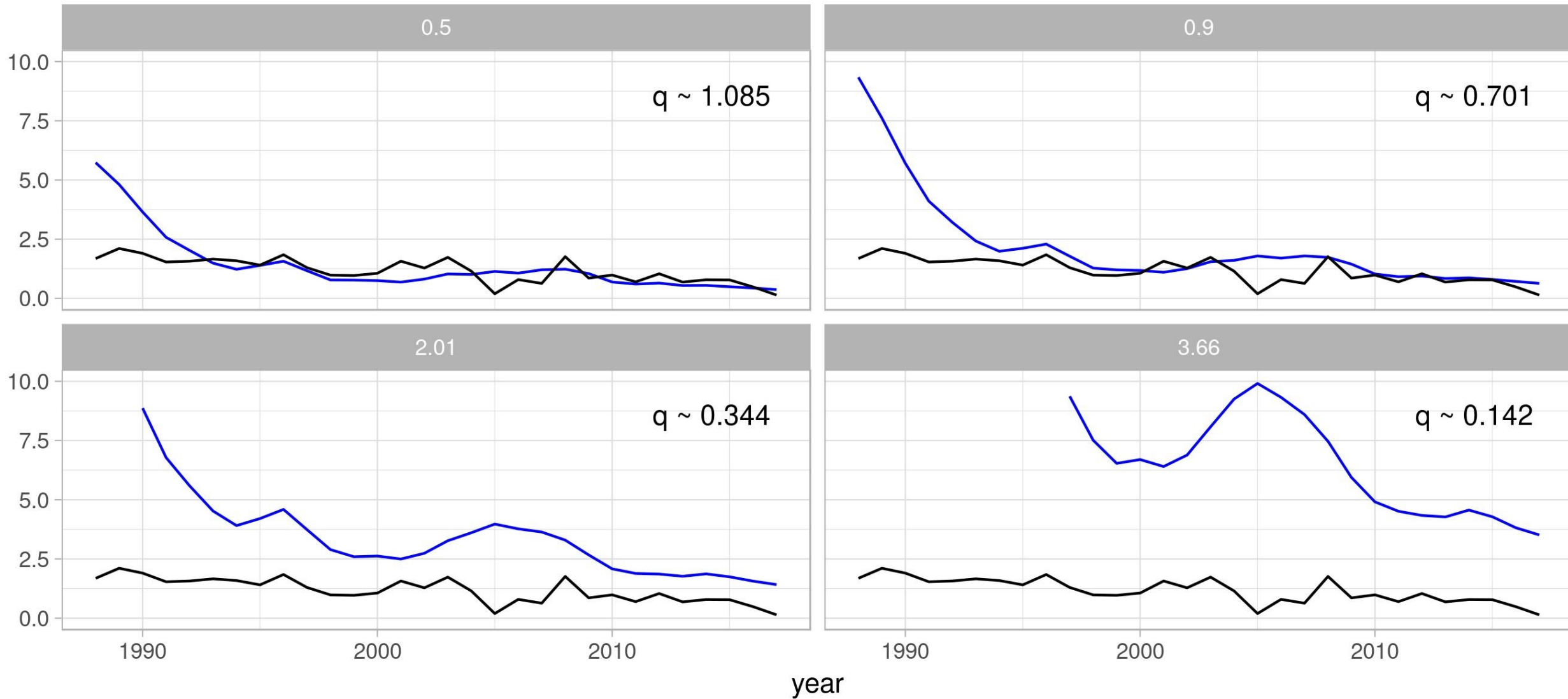






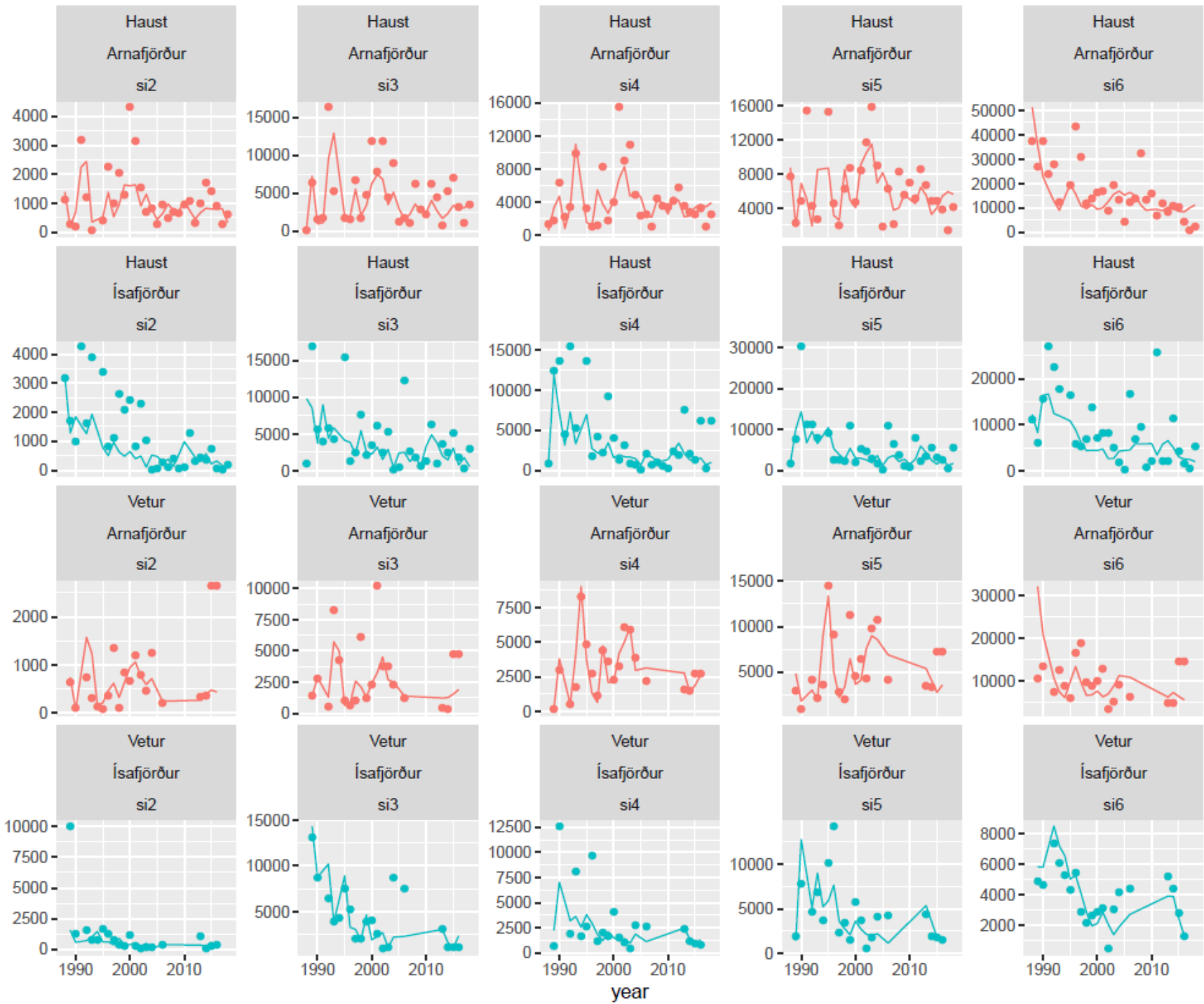


II. Best model? SR relationships





predict



area

- Arnafjörður
- Ísafjörður

