Universität Hamburg
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CENTER
FOR EARTH SYSTEM RESEARCH
AND SUSTAINABILITY (CEN)

# Probabilistic Time to Collapse as a Risk Communication Tool

or

# Adding the risk of stock collapse over time to stock assessments and harvest allocation decisions


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SeaUseTip

Fisheries and Oceans Canada


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# Stock Collapses



- Many fisheries continue to experience the collapse of their fish stocks and the loss of their fisheries

- Even though,
  - Many fisheries are managed based on scientific principles
  - Stock assessments and harvesting advice is provided with the precautionary principle in mind
  - Uncertainty is explicitly included in the development of the advice

(Bailey, 2011; Froese etal., 2021)

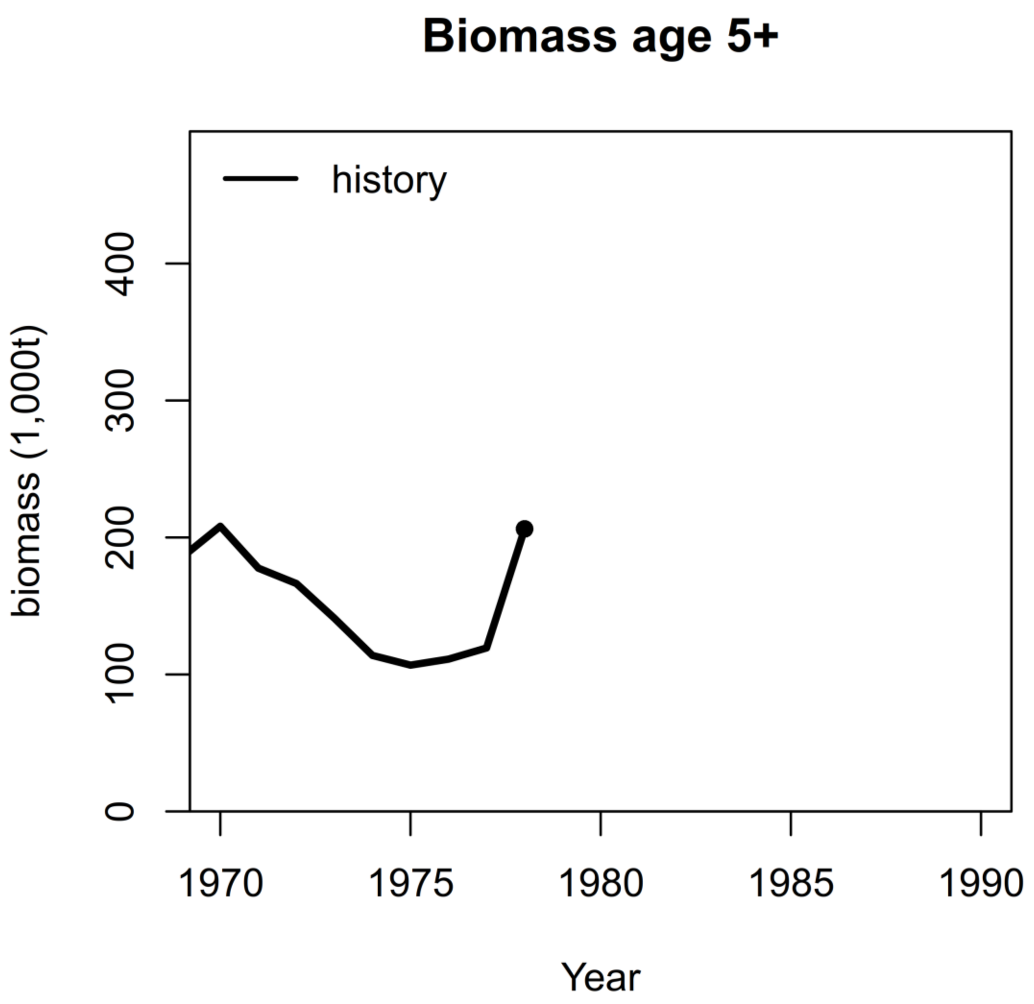
- Partly this can be explained as a failure to communicate
  - Providing information is not communicating
  - The message must be in a format useful to the receiver

- However, due to the inherent variability there is always a risk that a fish stock will collapse over a given amount of time.

# Stock Management



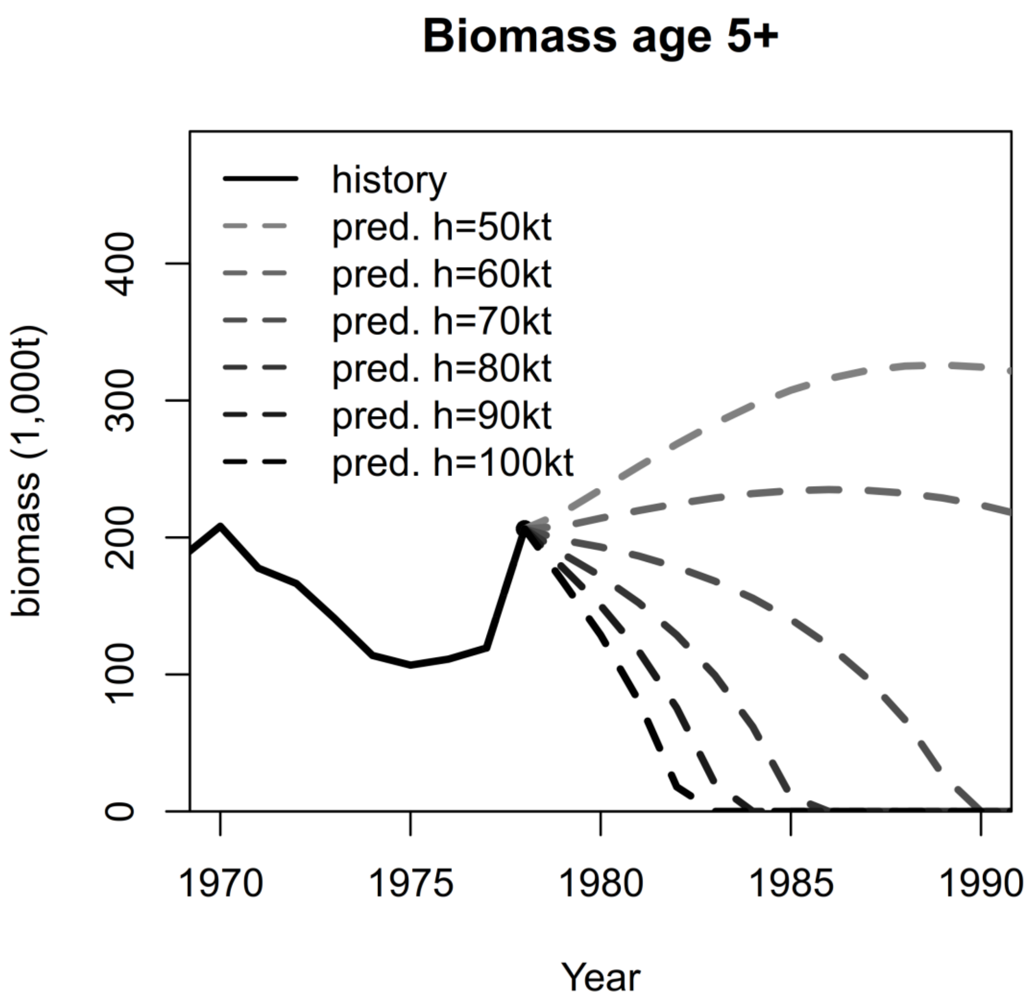
- (Assuming) We know the current state of the stock, how much should we harvest?



# Stock Management



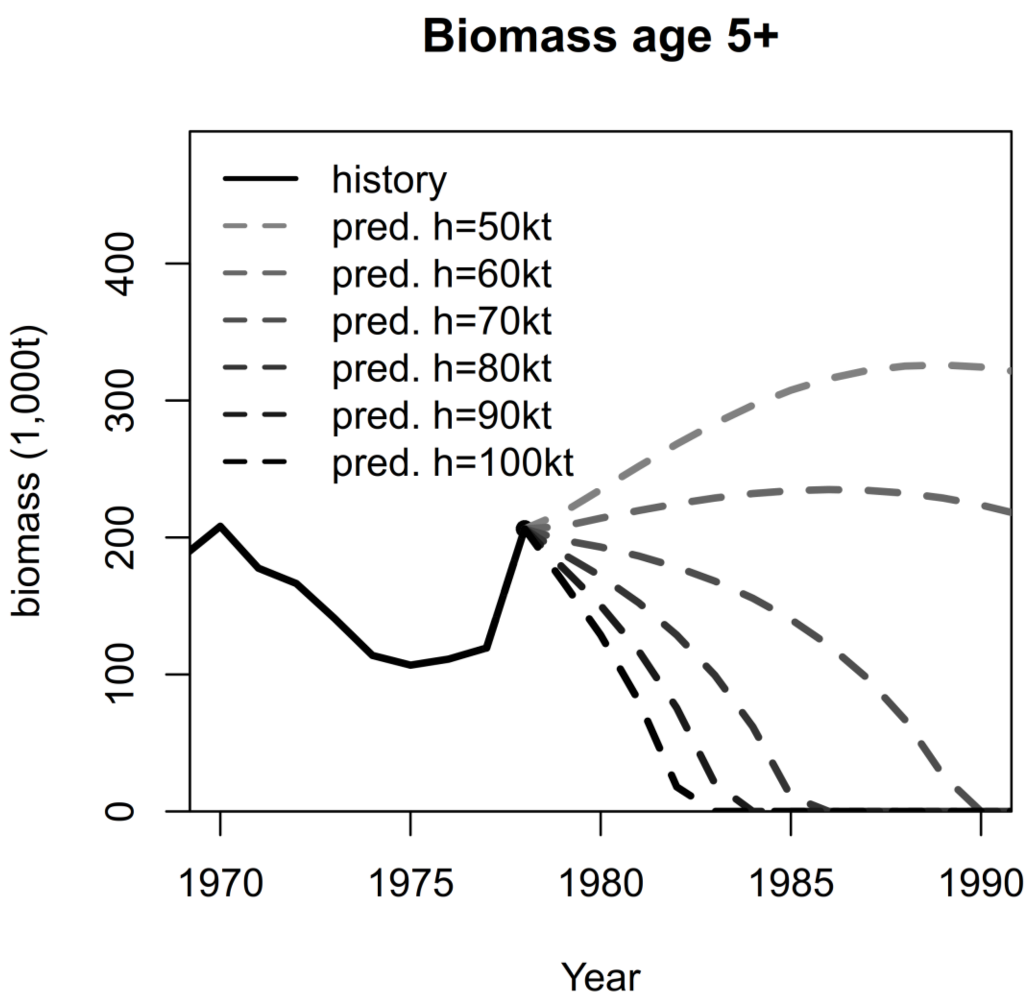
- How much to harvest to avoid stock collapse (and ensure strong future growth)?



# Stock Management



- How much to harvest to avoid stock collapse (and ensure strong future growth)?
- So far so simple:
  - Choose harvest level with collapse in the future.

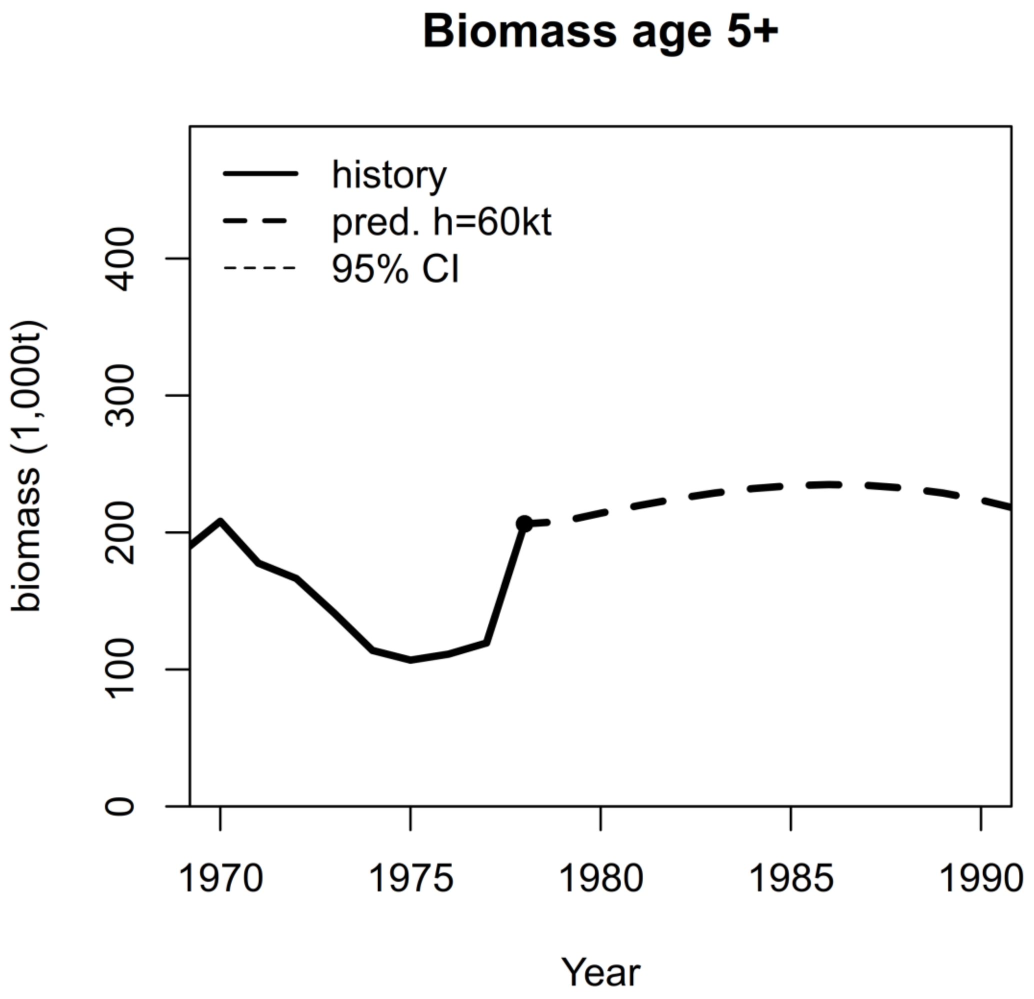


# Probabilistic Time To Collapse



- How much to harvest to avoid stock collapse (and ensure strong future growth)?

- So far so simple:
  - Choose harvest level with collapse in the future.
  - 60kt: Collapse is expected far in the future, no worries

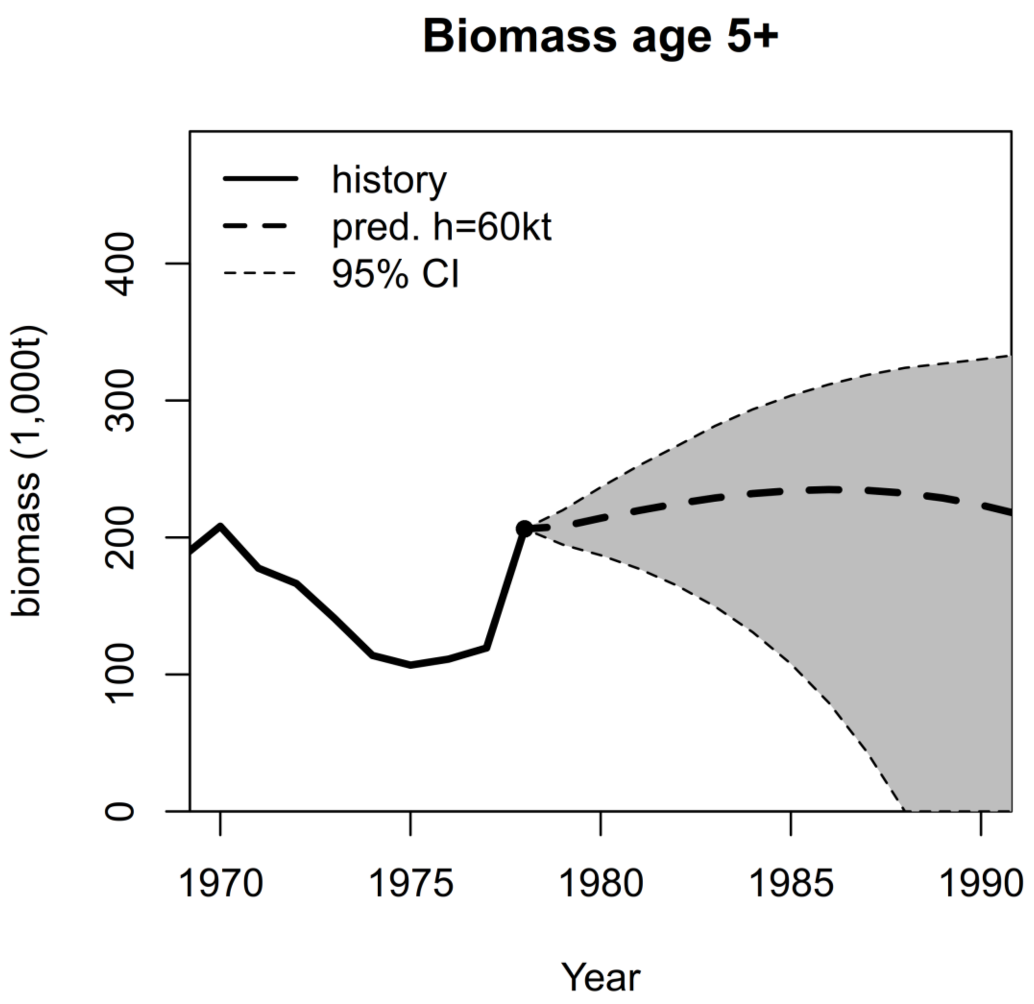


# Probabilistic Time To Collapse



- How much to harvest to avoid stock collapse (and ensure strong future growth)?
  - 60kt seem safe?

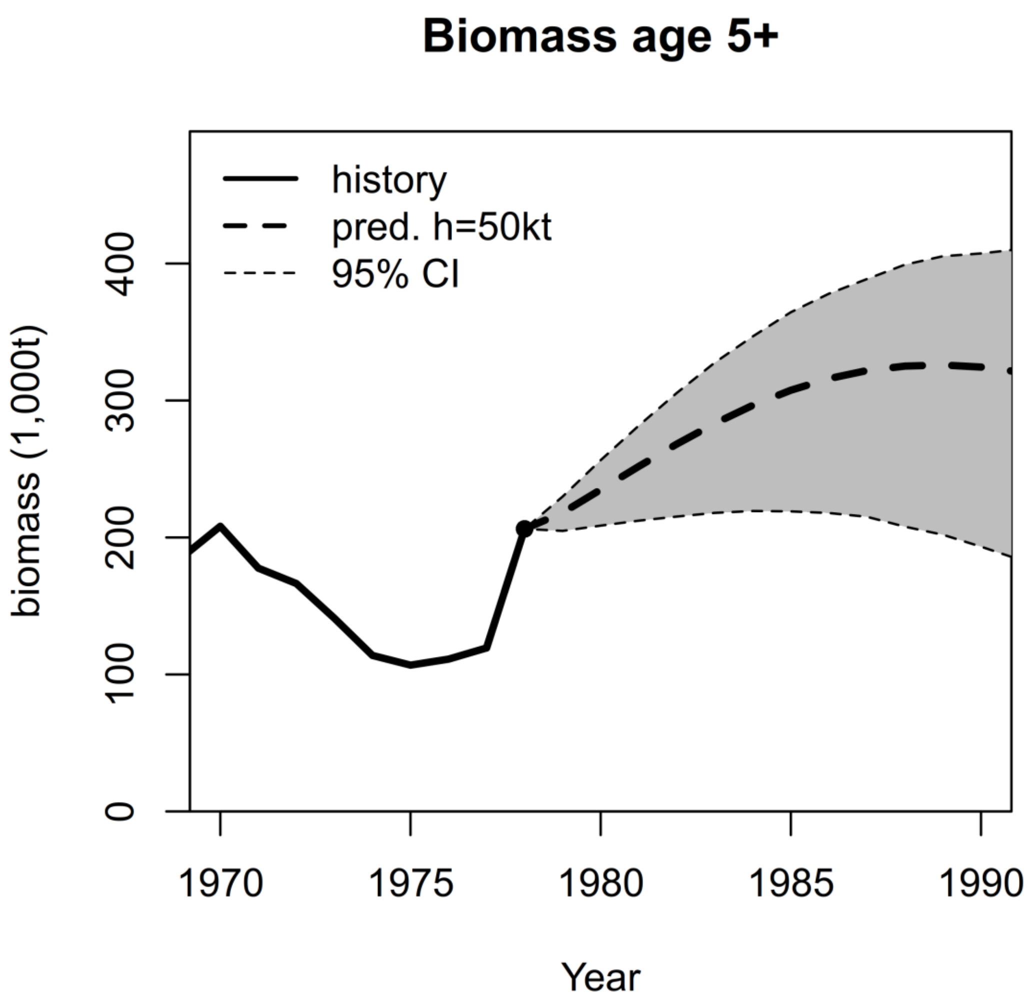
- However, there is uncertainty about the dynamics!
  - There is a chance the stock will collapse far sooner!



# Probabilistic Time To Collapse



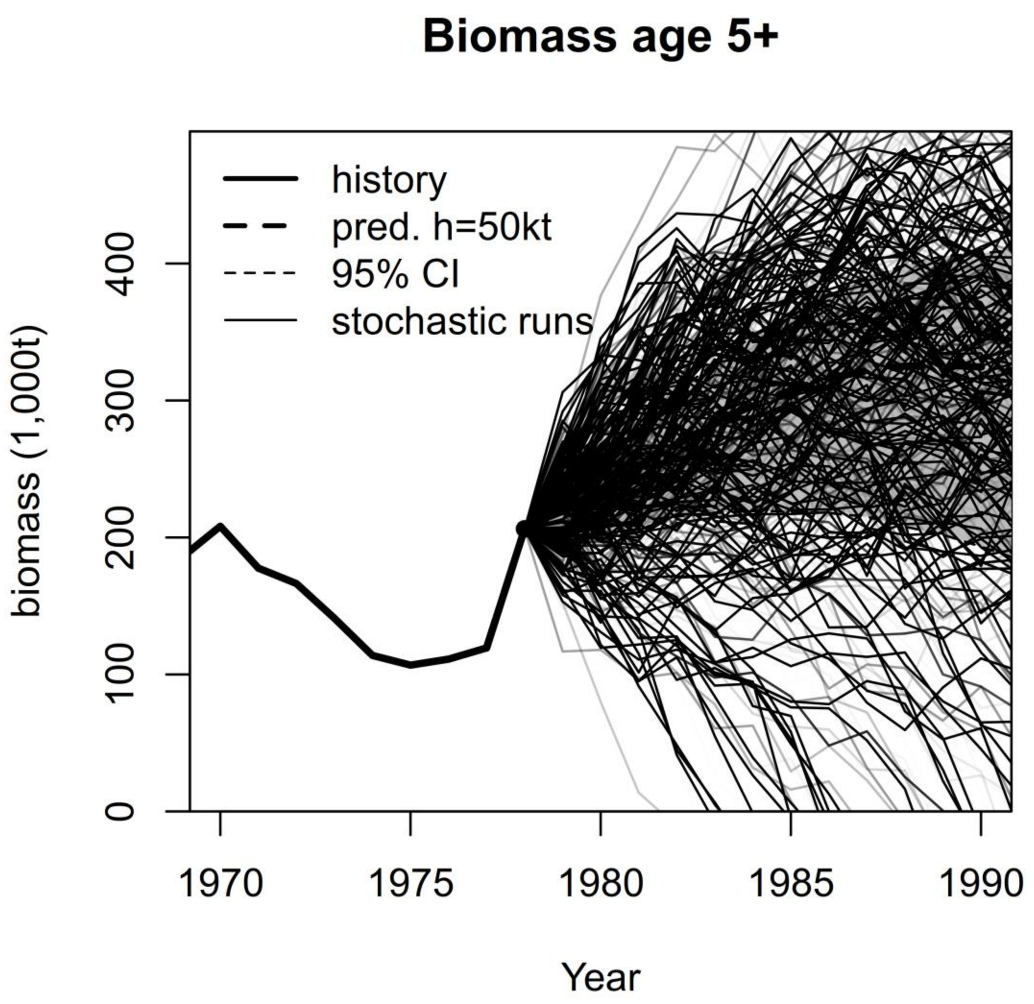
- How much to harvest to avoid stock collapse (and ensure strong future growth)?
  - 60kt seem safe?
- However, there is uncertainty about the dynamics!
  - There is a chance the stock will collapse far sooner!
  - Reduce the harvest level to eliminate the risk: 50kt



# Probabilistic Time To Collapse



- How much to harvest to avoid stock collapse (and ensure strong future growth)?
  - 50kt seem safe?
- Fish recruitment and mortality is subject to random shocks!

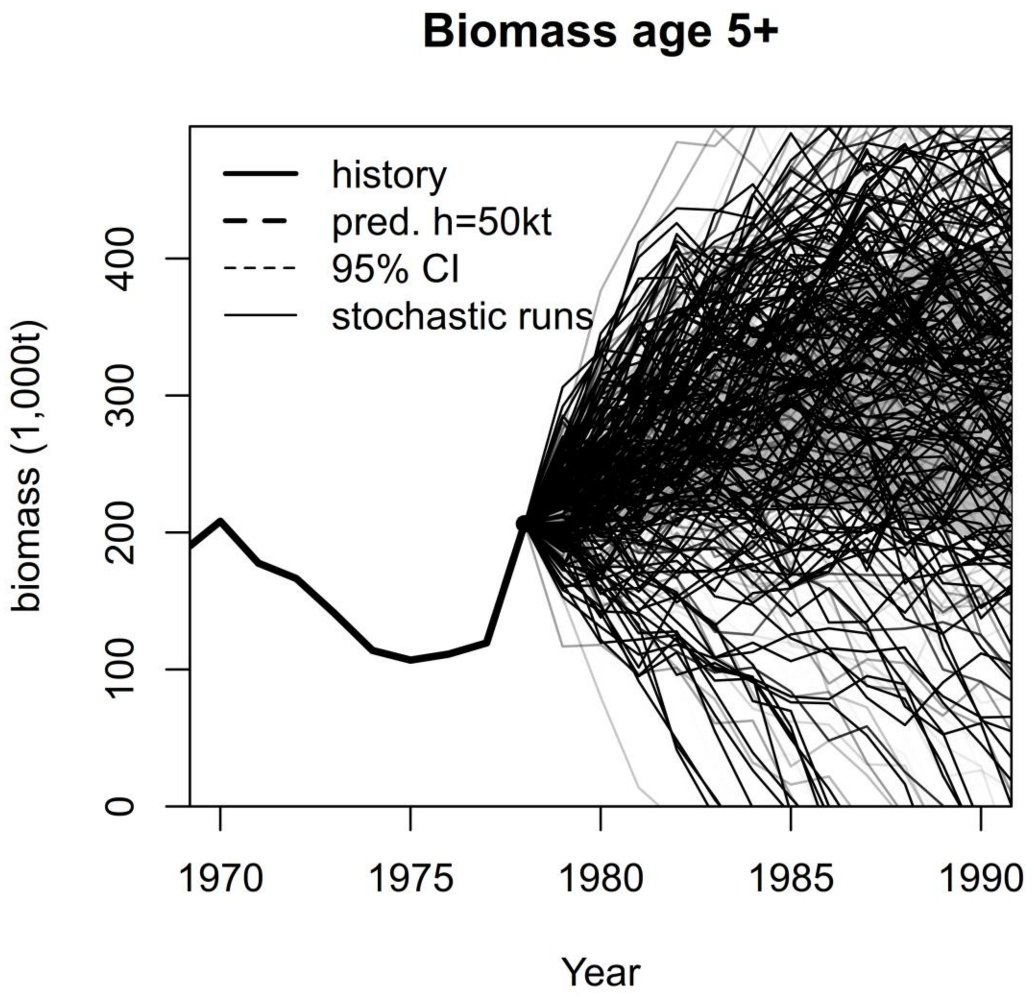



Non exhaustive set of 1000 stochastic runs

# Probabilistic Time To Collapse



- How much to harvest to avoid stock collapse (and ensure strong future growth)?
- Fish recruitment and mortality is subject to random shocks!
- Risk can not be eliminated, only reduced!

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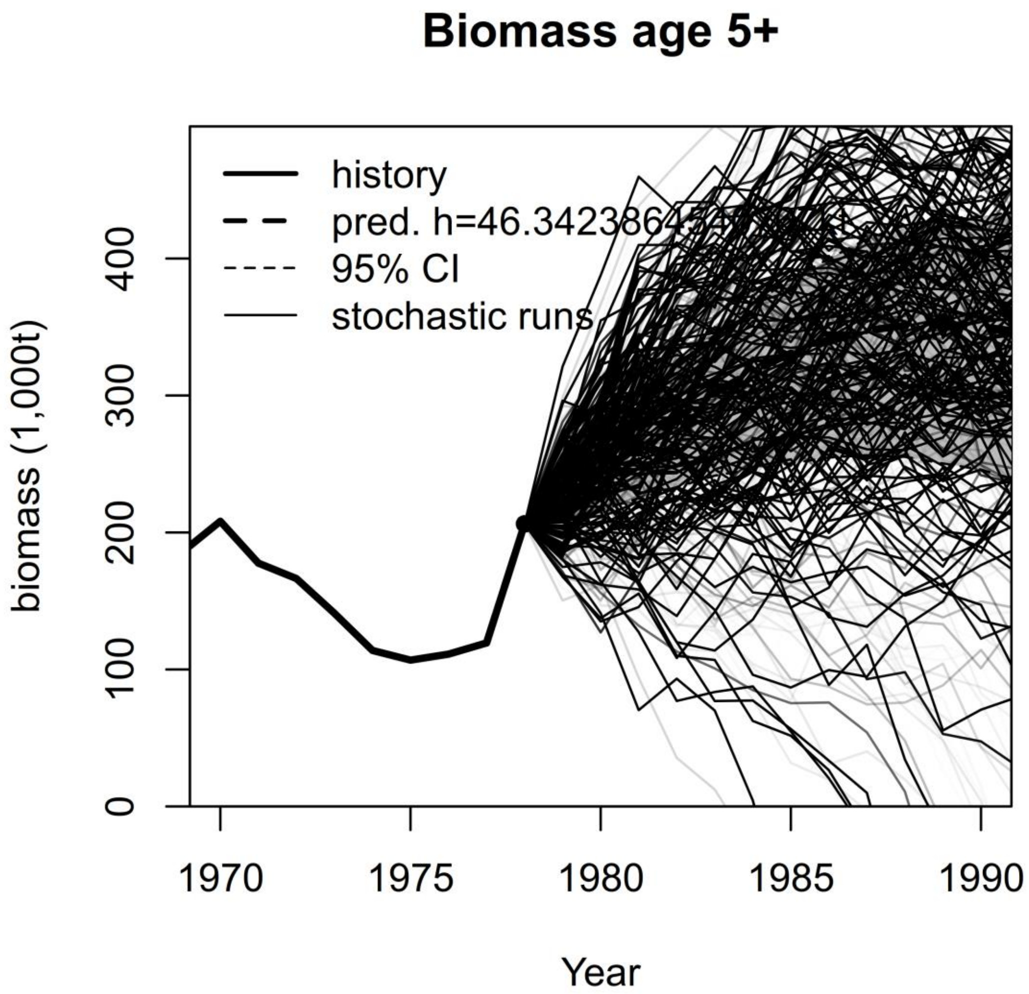


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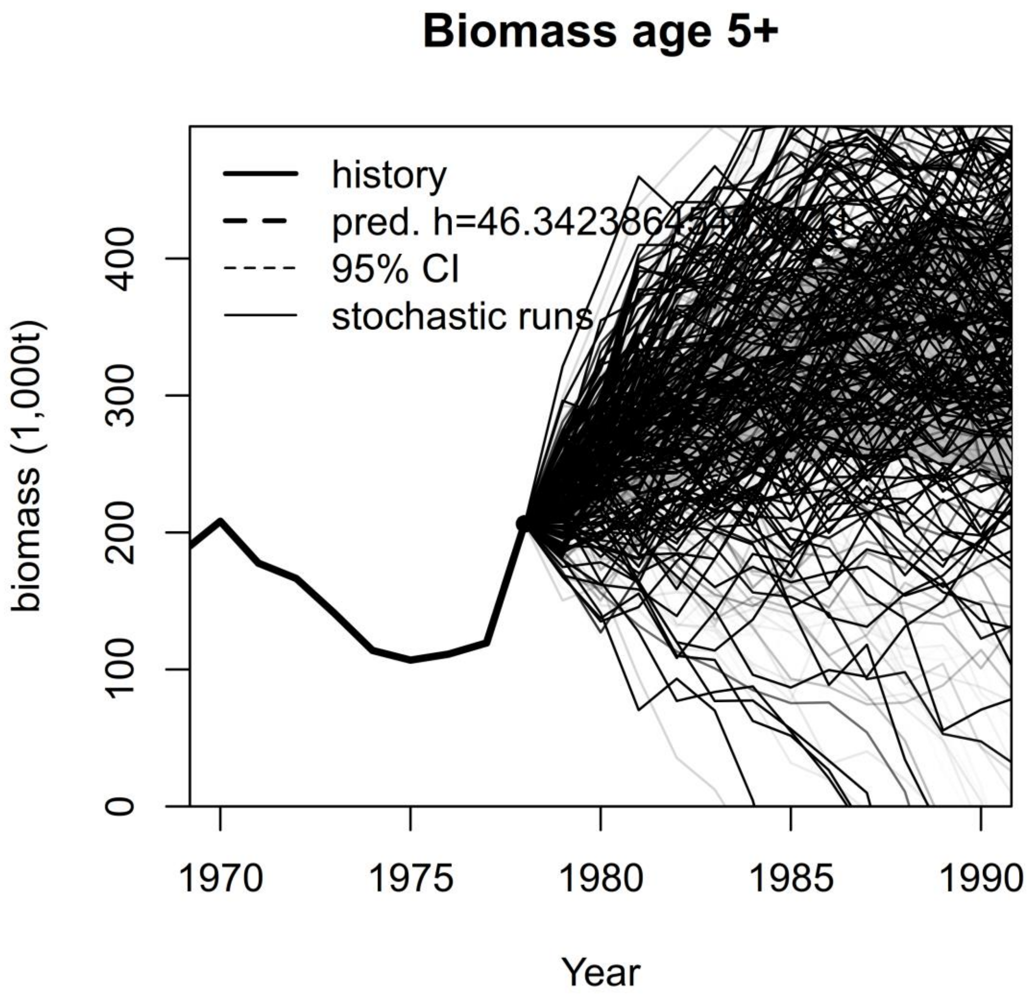
# Probabilistic Time To Collapse

- How much to harvest to avoid stock collapse (and ensure strong future growth)?
- Fish recruitment and mortality is subject to random shocks!
- Risk can not be eliminated, only reduced!
- ~~How high a probability of collapse within a timeframe do we tolerate?~~
    - Policy question, not a science question!

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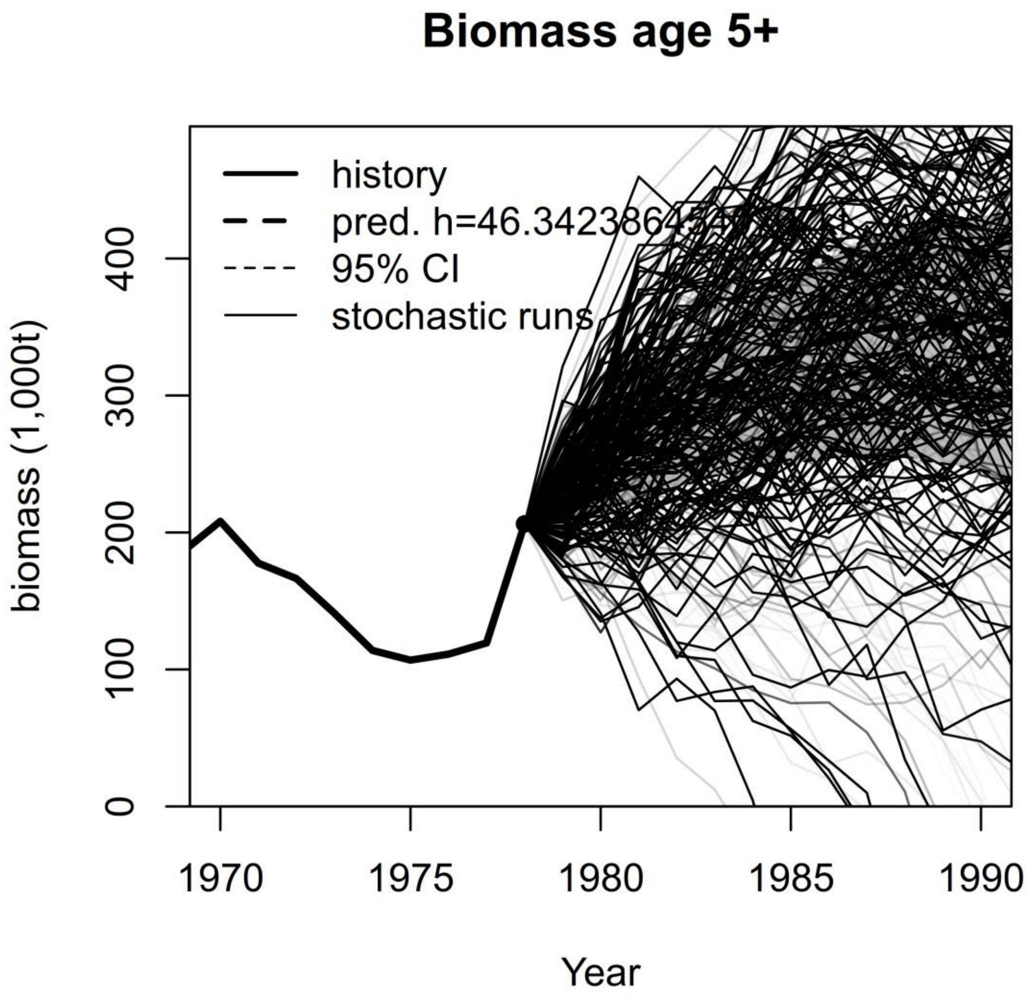
# Probabilistic Time To Collapse



- How much to harvest to avoid stock collapse (and ensure strong future growth)?
- Fish recruitment and mortality is subject to random shocks!
- Risk can not be eliminated, only reduced!
- How can the risk of collapse be communicated to decision makers?
  - These uncertainties are known, but their consequences for decisions are not communicated effectively.



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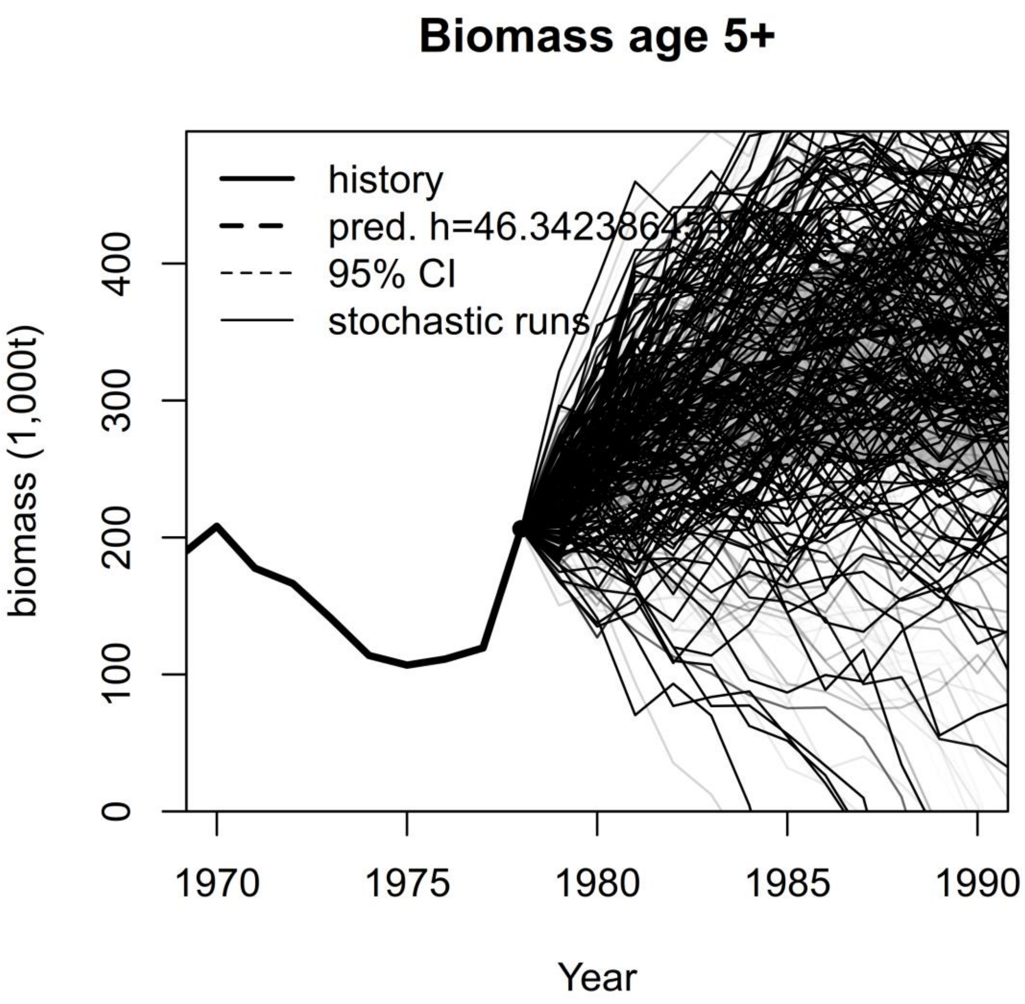
# Reframing the Problem



- The biggest risk is that the stock collapses / that the fishery becomes unviable
- The risk can not be eliminated
- There is path dependence
  - Choices today restrict future choices
- The **risk over time depending on choices** needs to be communicated
  - **Cumulative probability of collapse over time depending on harvests**

# Probabilistic Time To Collapse



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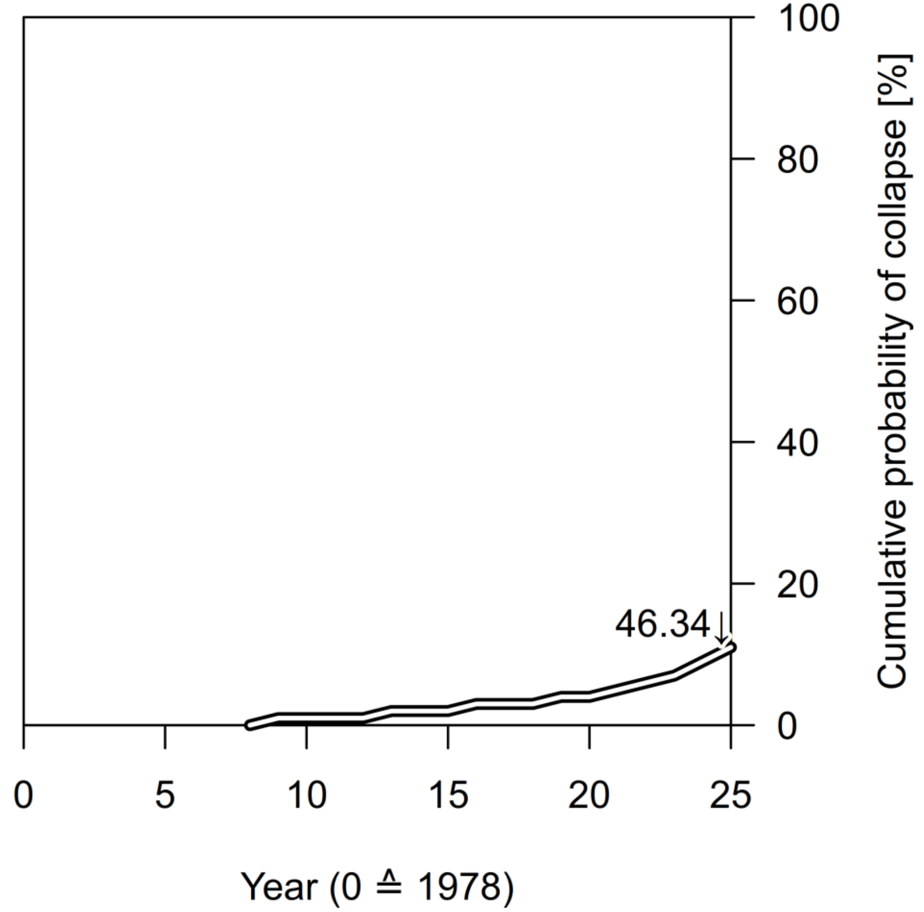
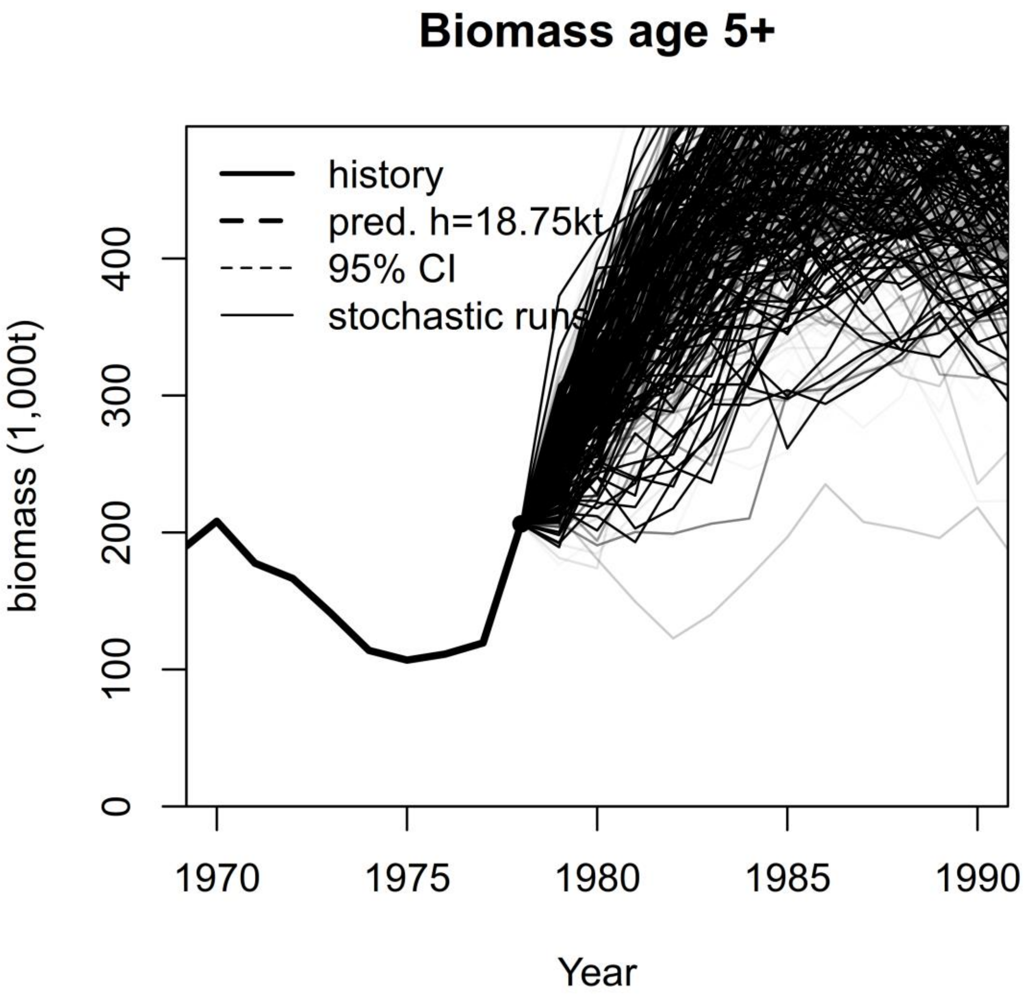



Cumulative time to collapse over 20k runs per 3125 SOW for each harvest level. Floating labels indicate harvests in 1,000t.

# Probabilistic Time To Collapse



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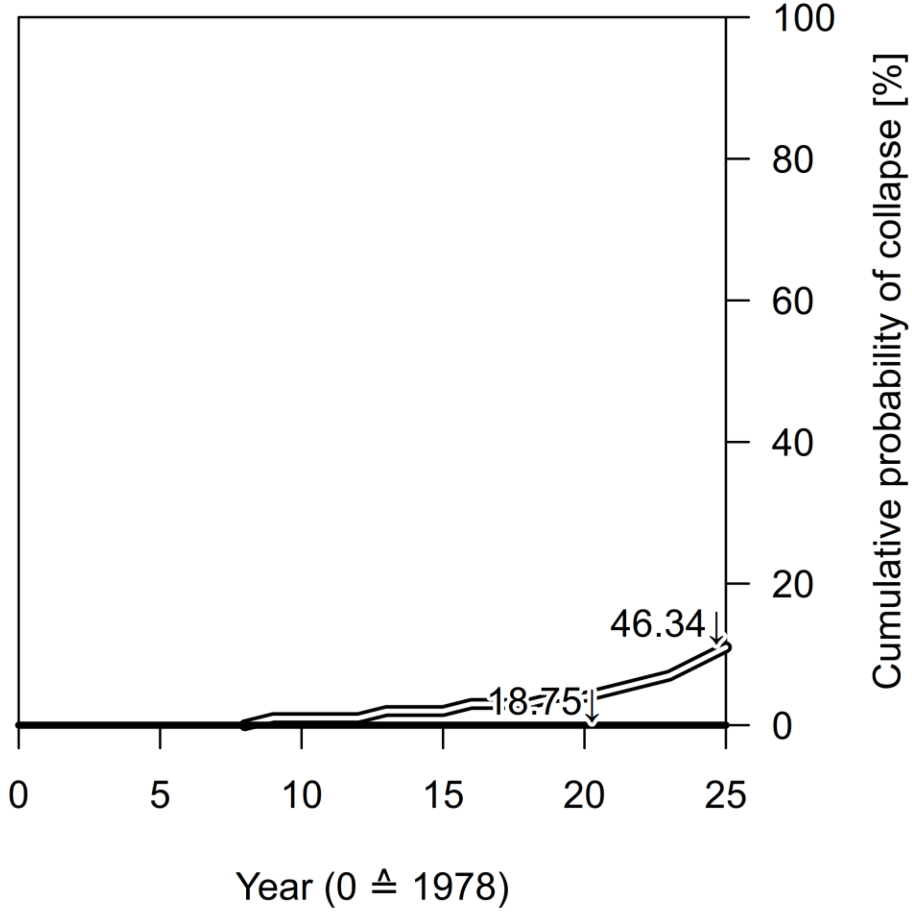


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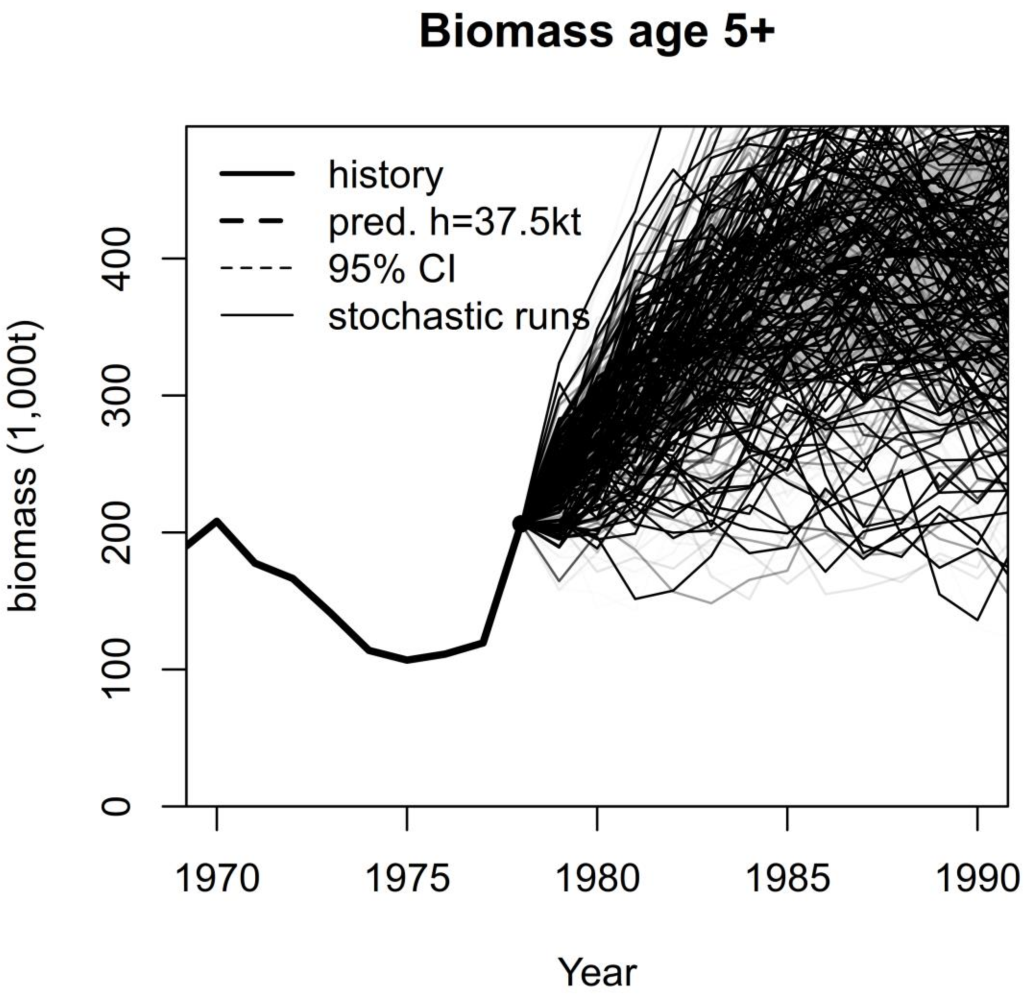


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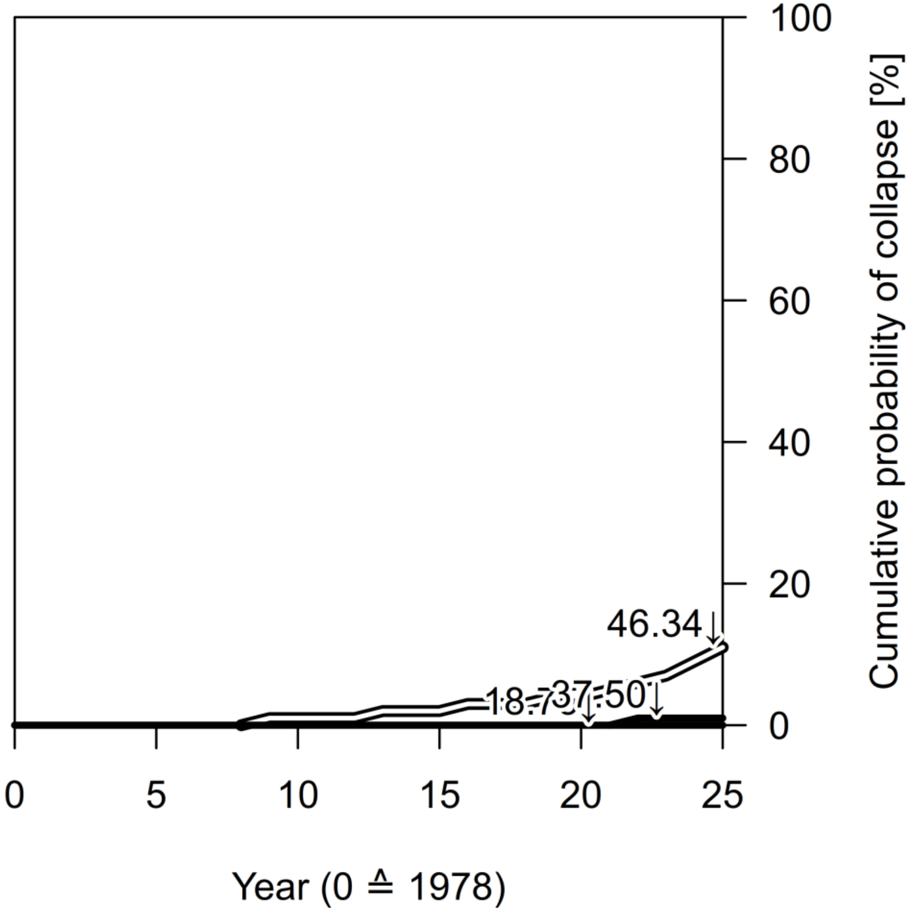


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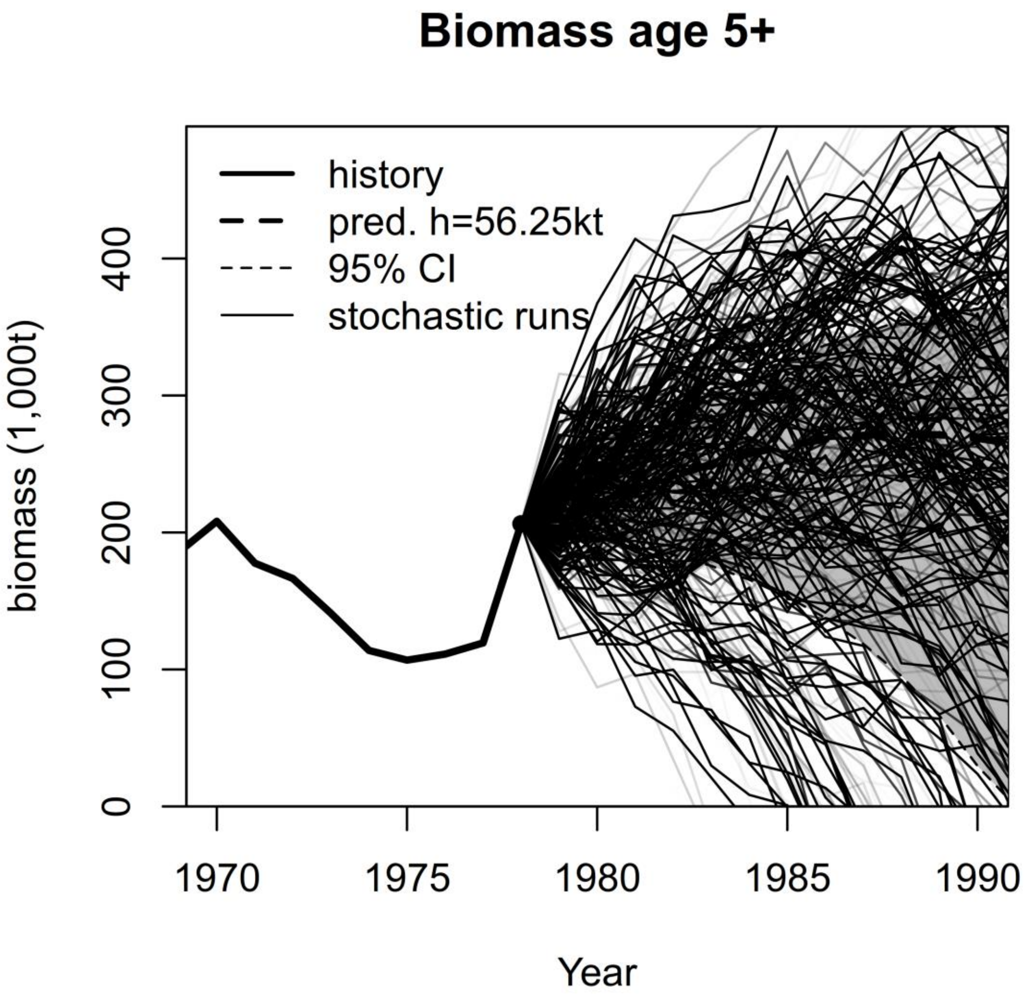


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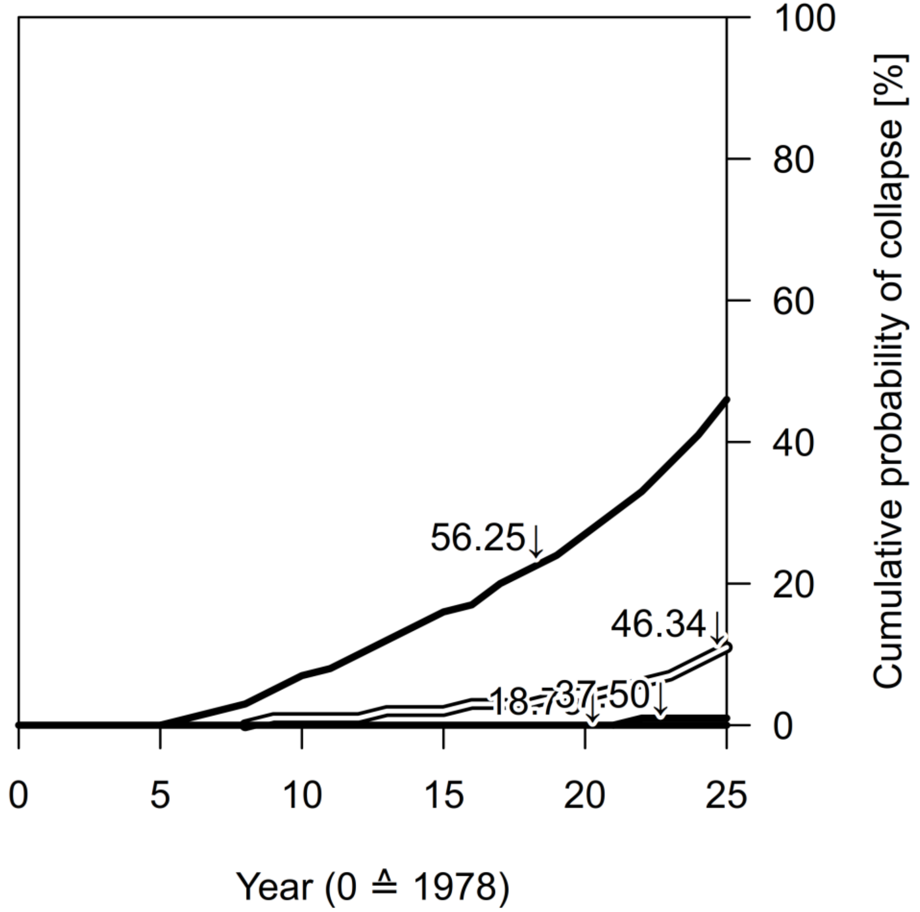


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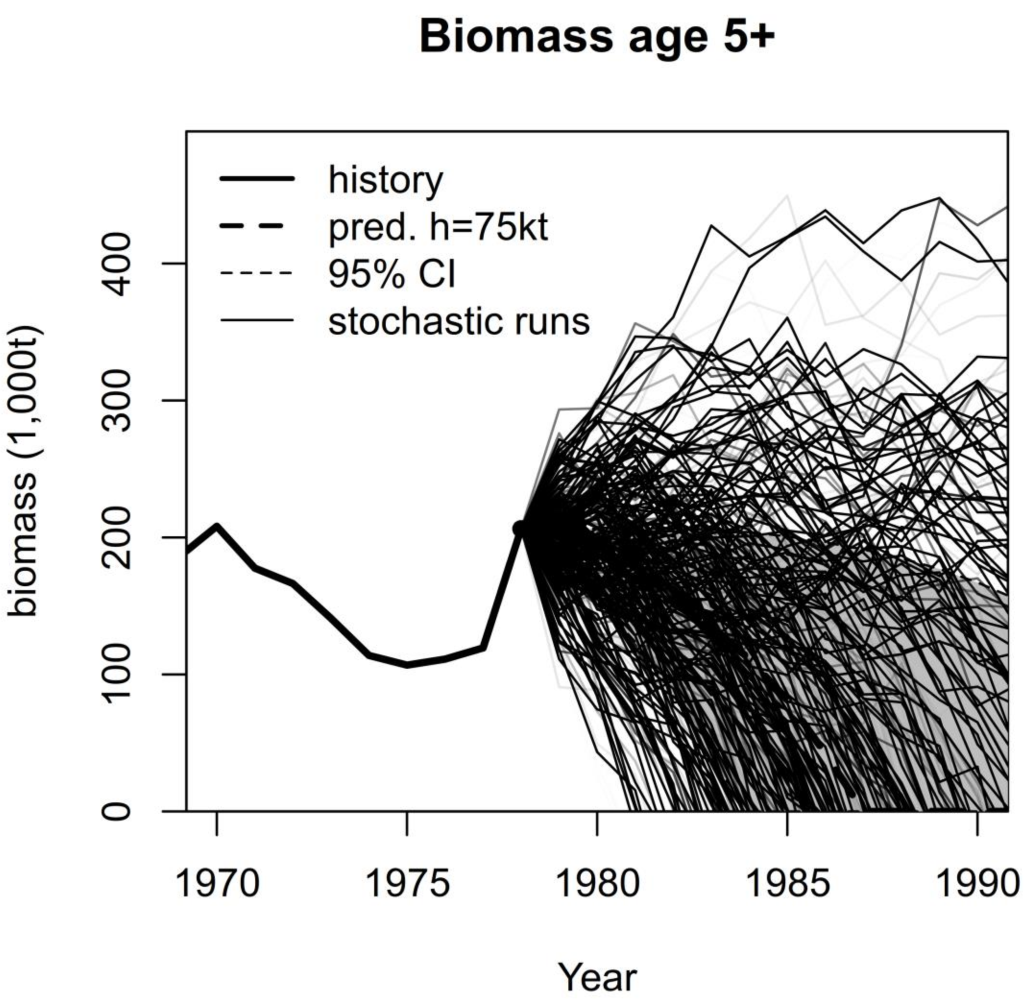


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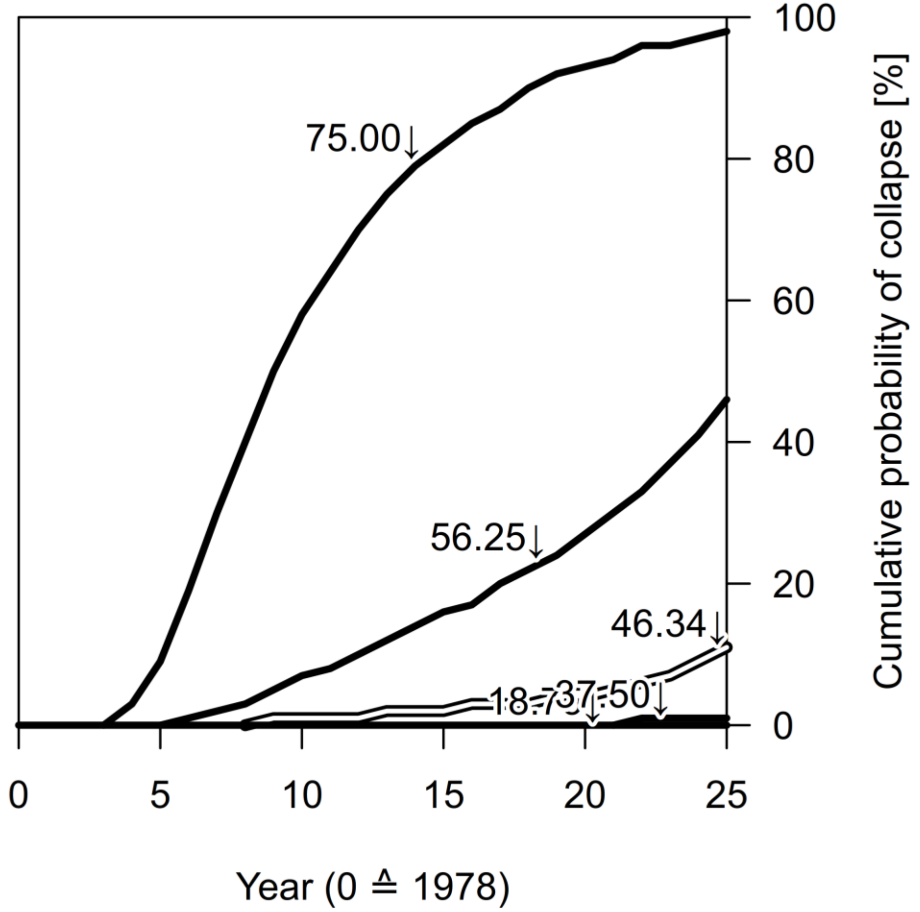


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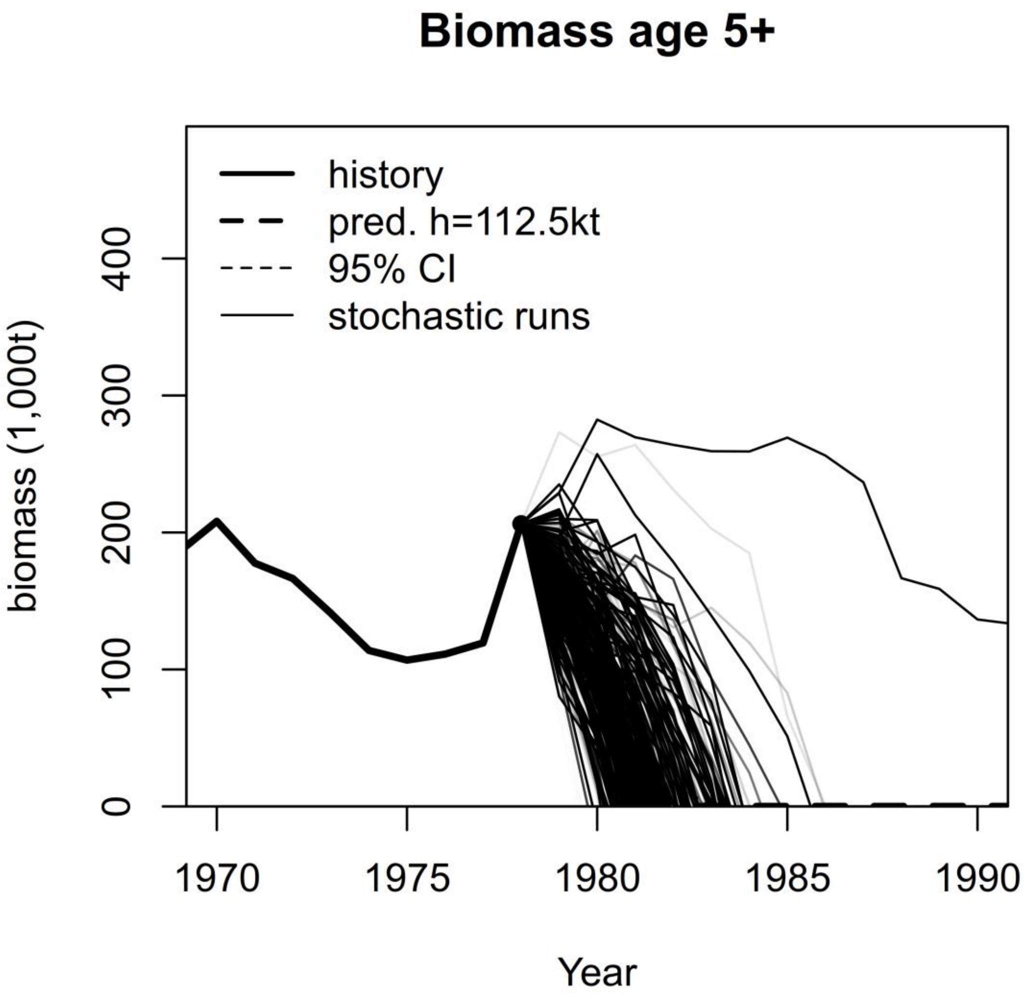


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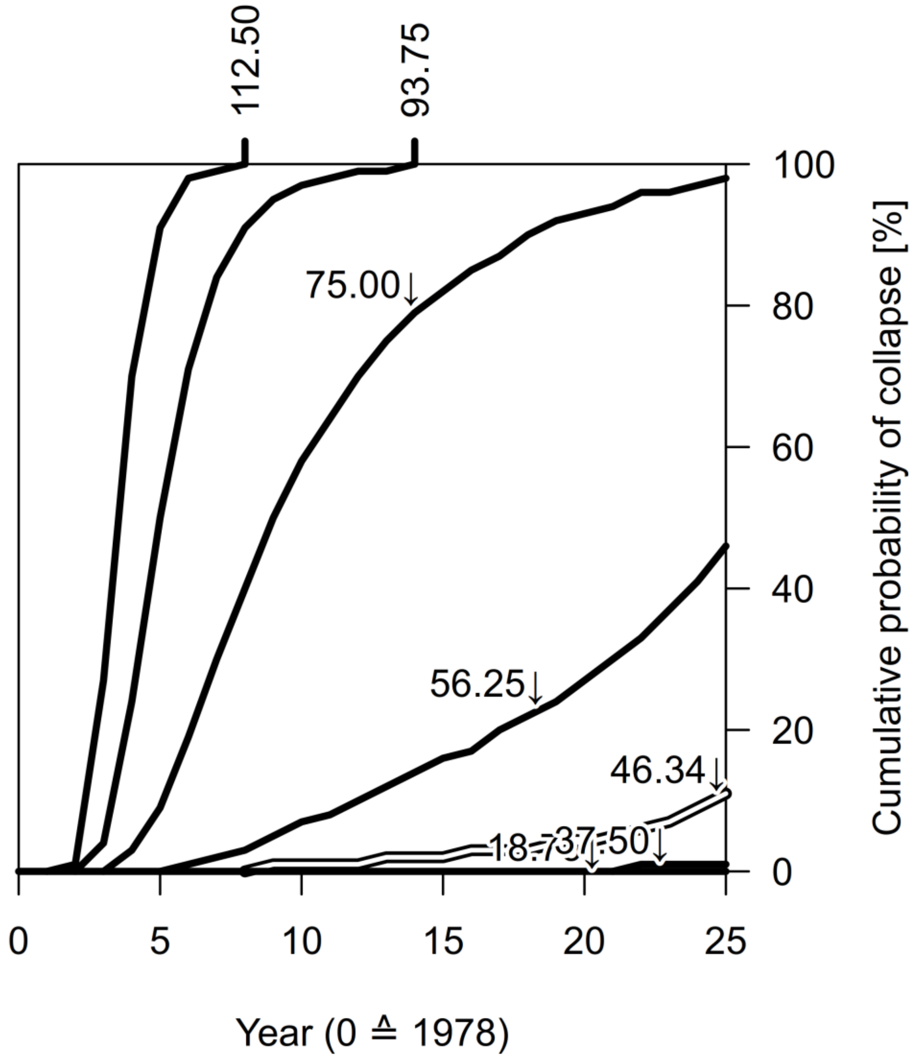


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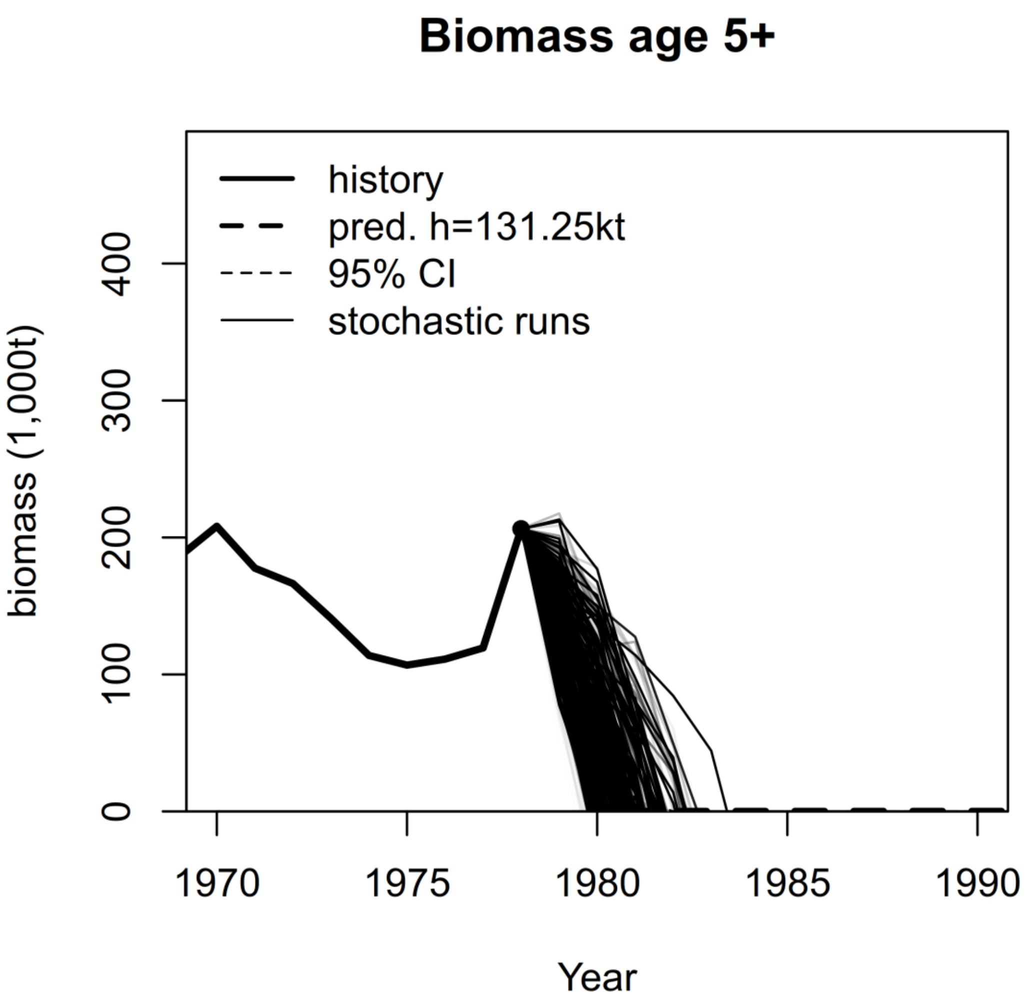


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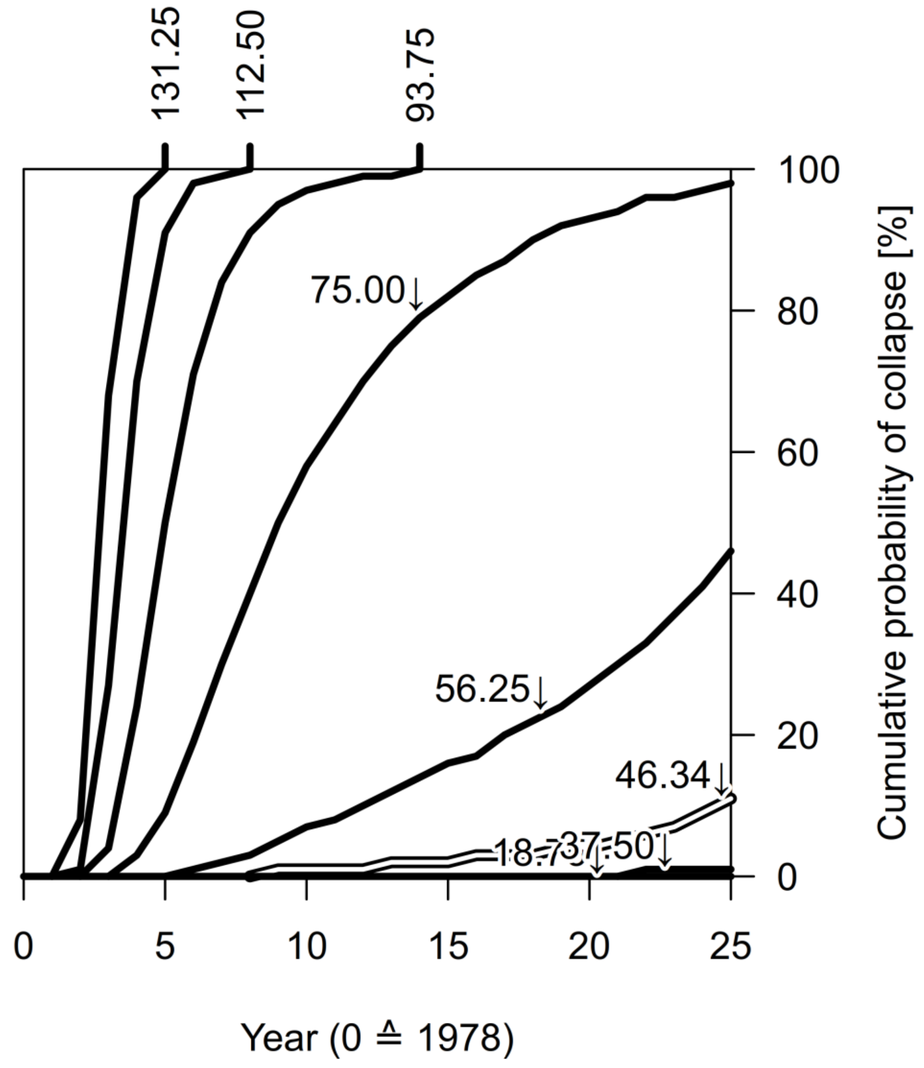


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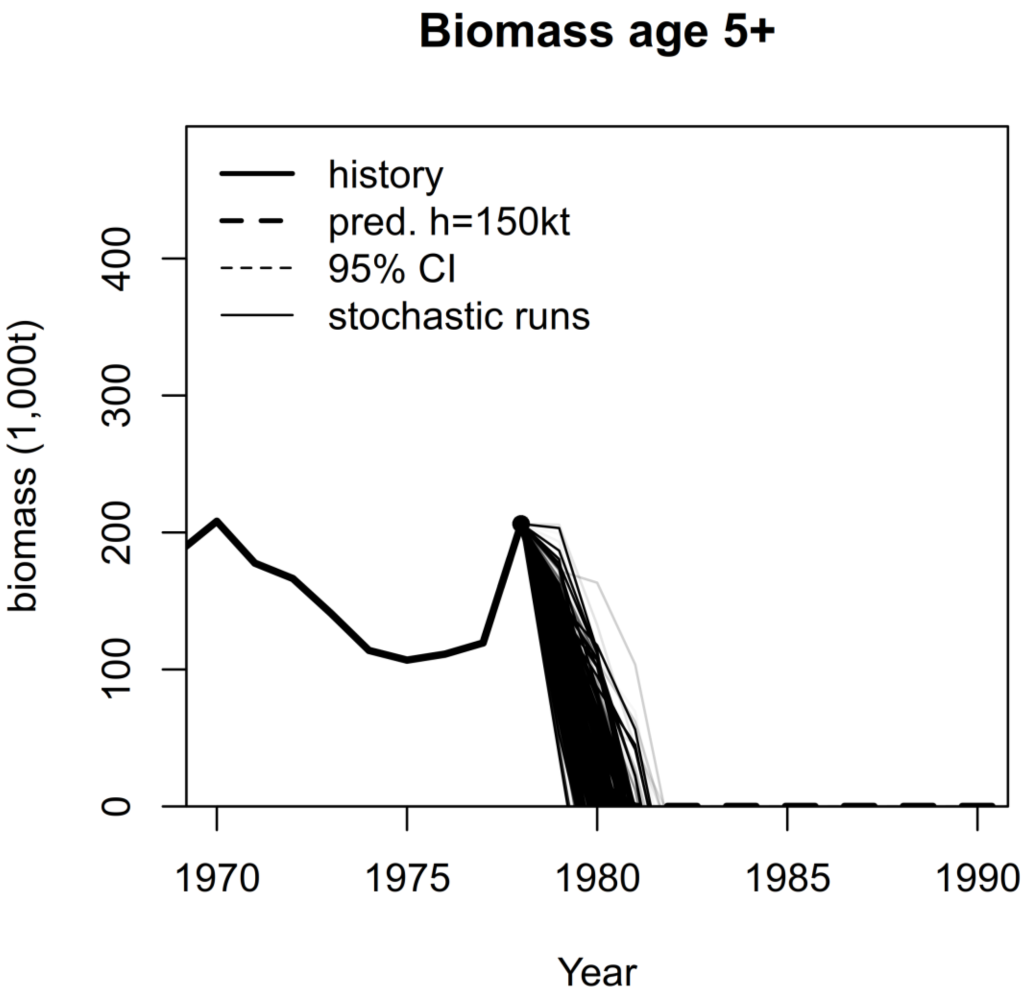


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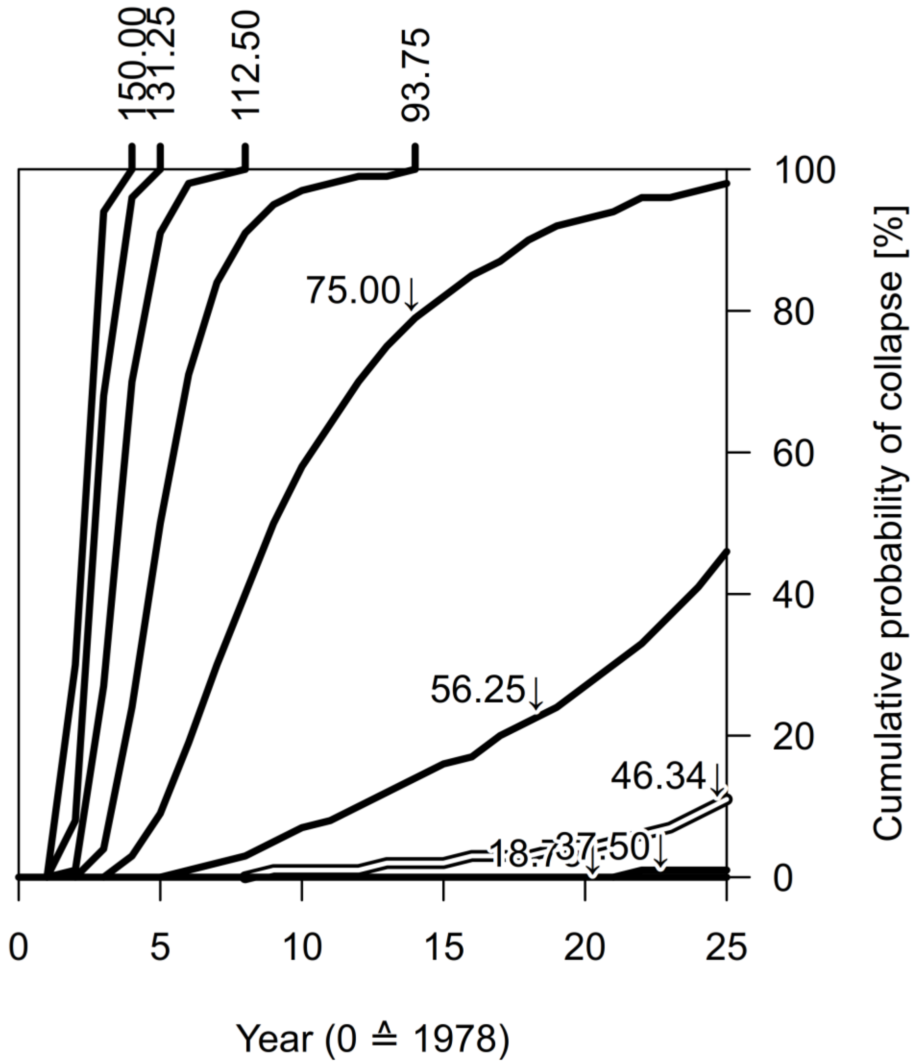


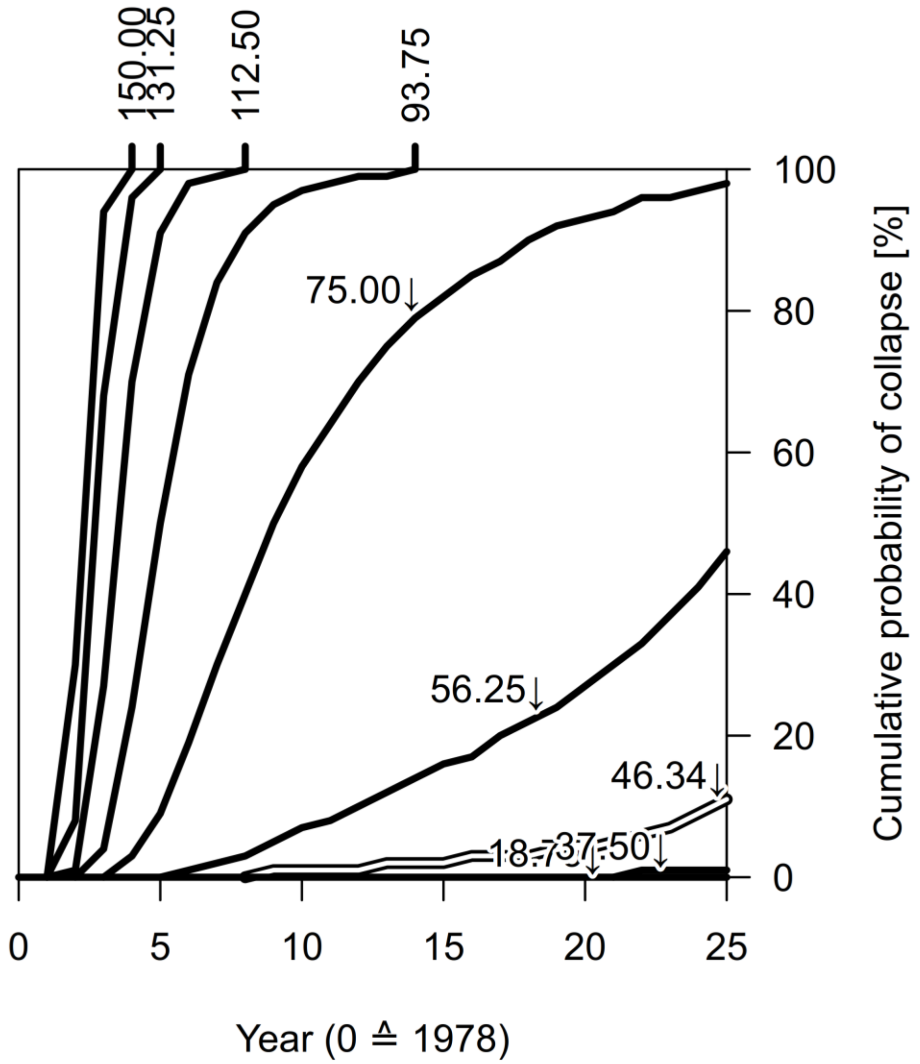

Cumulative time to collapse over 20k runs per 3125 SOW for each harvest level. Floating labels indicate harvests in 1,000t.

# Probabilistic Time To Collapse



- The Cumulative Distribution Function (CDF) of the time to collapse *collapses* the difficult abstract uncertainties into a single line.

- This allows an easy comparison of the future consequences of harvesting choices.



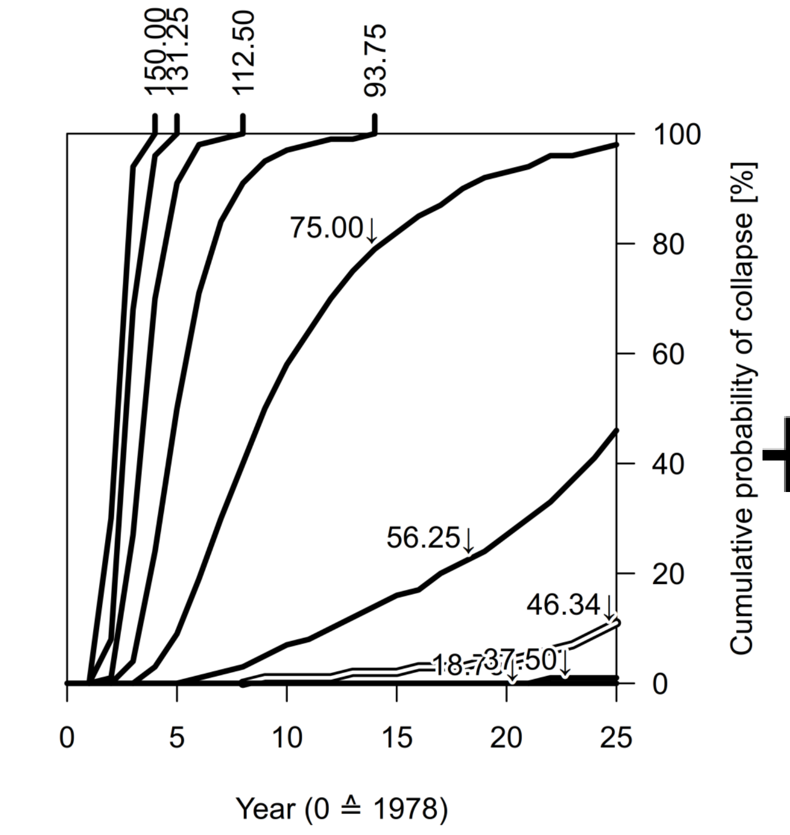

Cumulative time to collapse over 20k runs per 3125 SOW for each harvest level. Floating labels indicate harvests in 1,000t.

# Risk Management



- We can go one step further to communicate in the language of risk managers.

Cumulative Probability of Stock Collapse over Time

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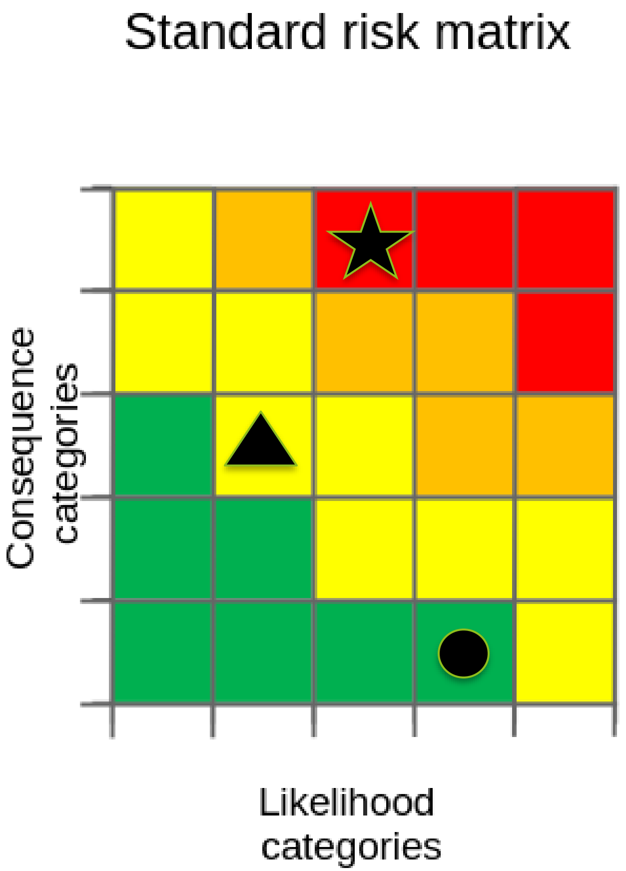


- The risk matrix is a product of the risk management literature.
- Part of the ISO 31000 risk management process
- Choices presented as combinations of outcome probability and severity
- Colours denote the range from tolerable to catastrophic

# Risk Management

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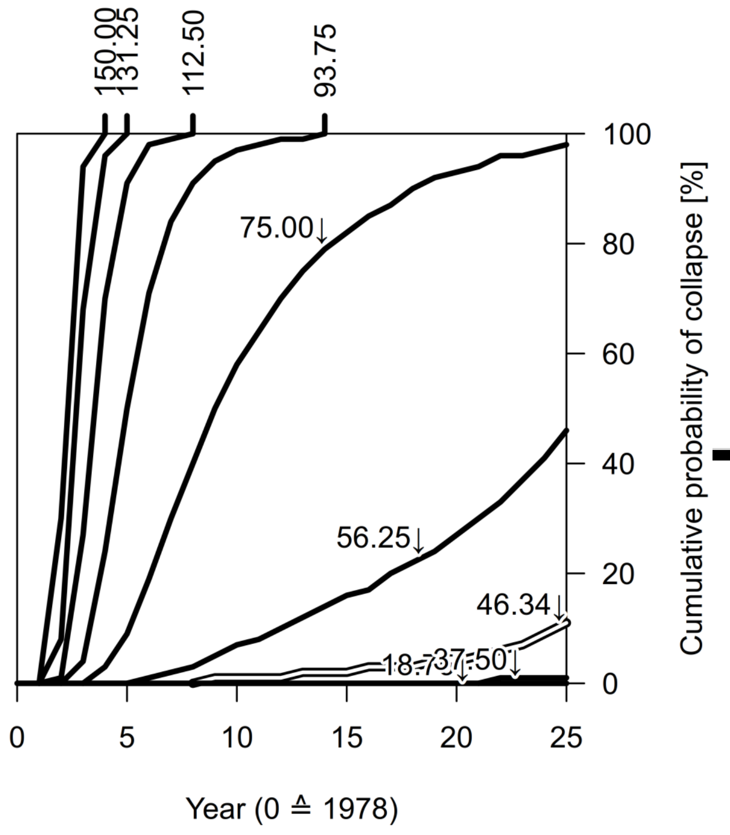
Cumulative Probability of Stock Collapse over Time

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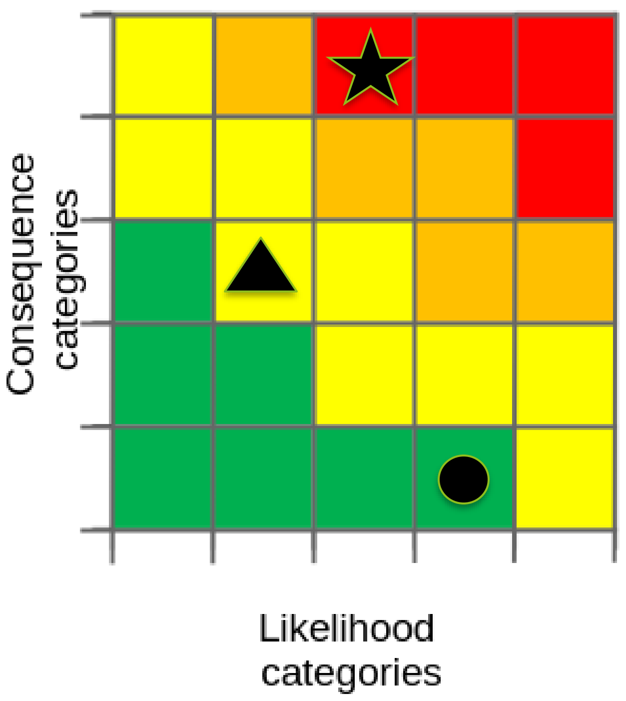
Standard risk matrix

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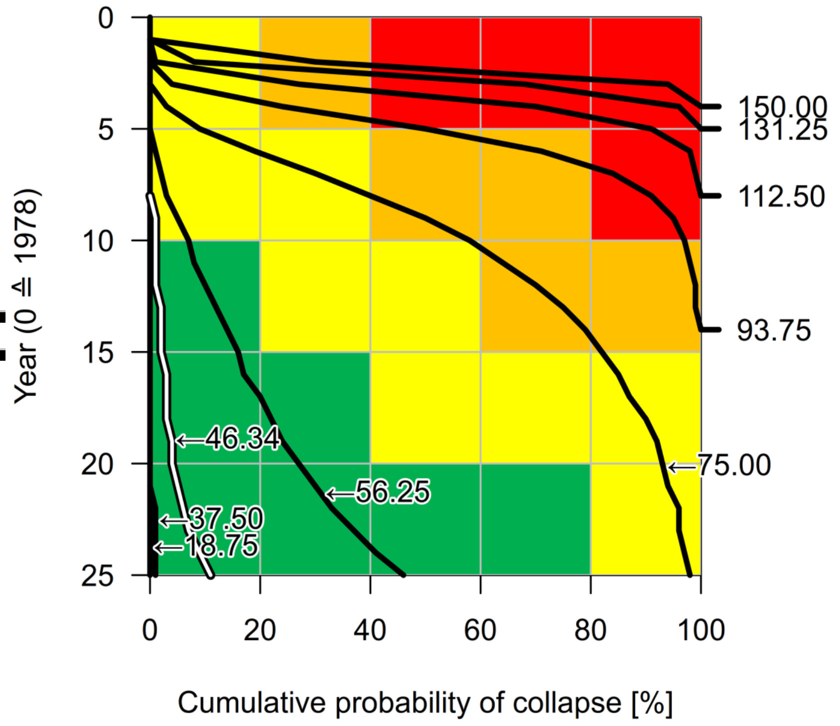
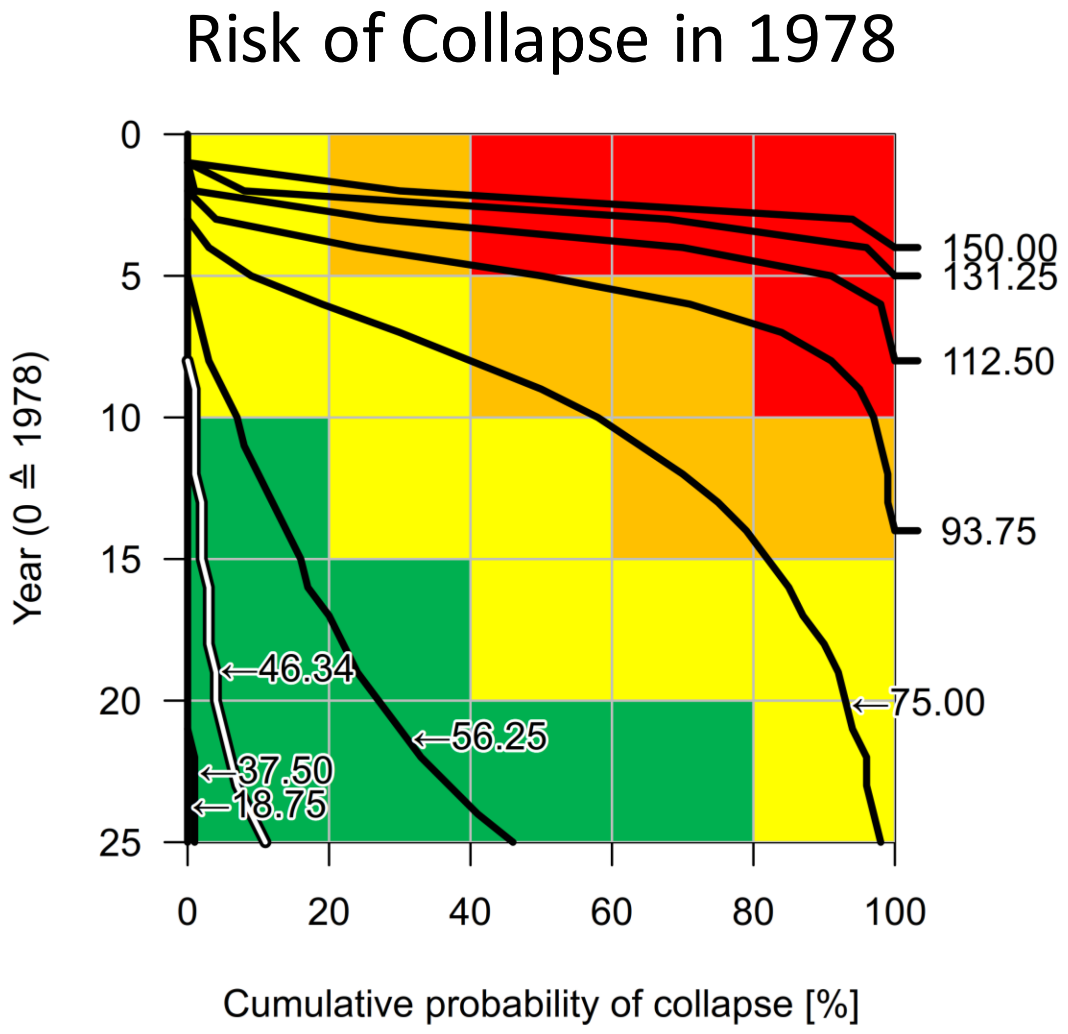
Cumulative Risk of Stock Collapse over Time



# Cumulative Risk of Collapse over Time



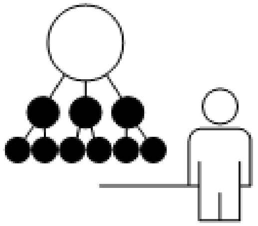
- The standard risk matrix does not show probabilistic outcomes for a single action.
- We extend the risk matrix to show the outcome probability of different actions over time.
- Each line represents the consequences of **maintaining a harvest level through time**.
- Risk preferences, the colouring, must come from the decision makers!
- Colours and time horizon used here are for illustration.




Cumulative risk of collapse over 20k times 3125 SOW runs for each harvest level. Floating labels indicate harvests in 1,000t.

# Risk Management Process





Fisheries Policy

Policy Context

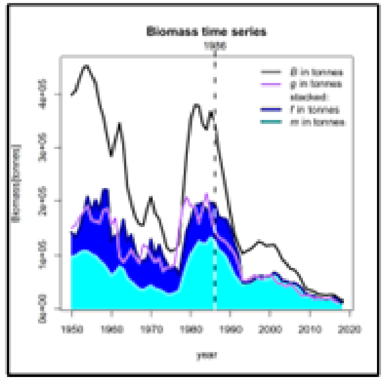
Fisheries Policy Objectives

| |
|---|
| Catastrophic |
| Major |
| Moderate |
| Negligible |

Scientific Advice

Risk Identification

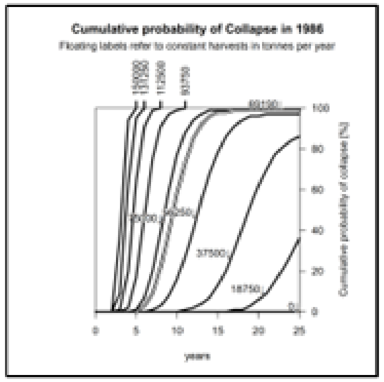
Stock Status

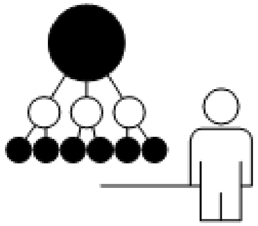



Scientific Advice

Risk Analysis

Harvest Levels

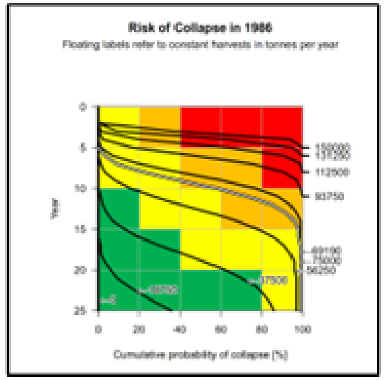


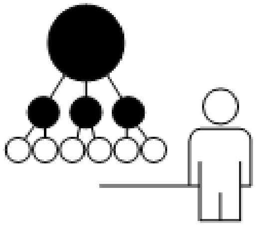



Fisheries Management

Risk Evaluation

Fishery Management Plan

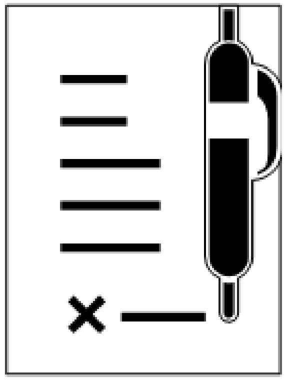


Fisheries Allocations

Risk Treatment

Harvest Levels Allocations



**Proposed risk analysis and risk evaluation steps**

# Case Study:
# Cod Stocks in the Southern Gulf of St. Lawrence



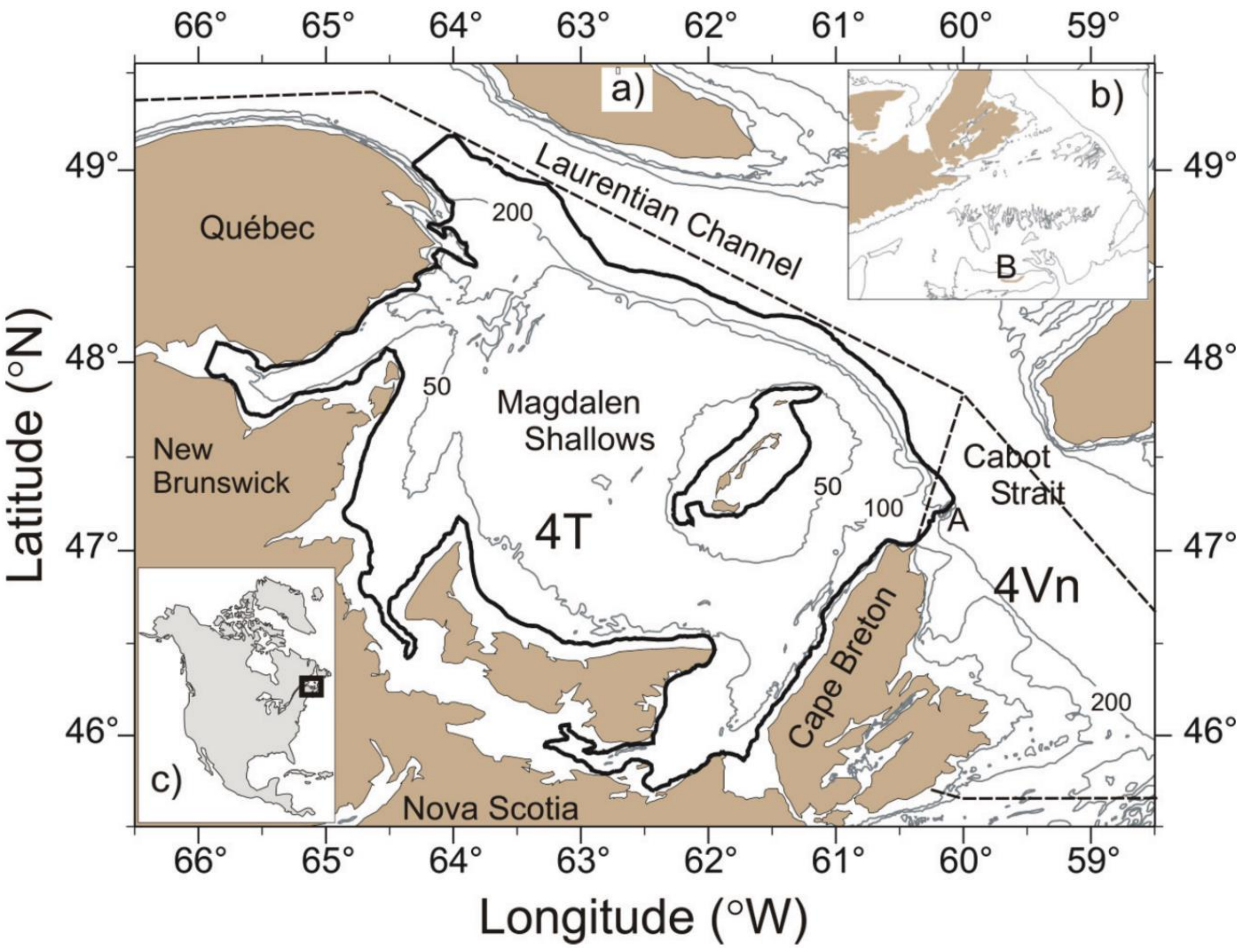
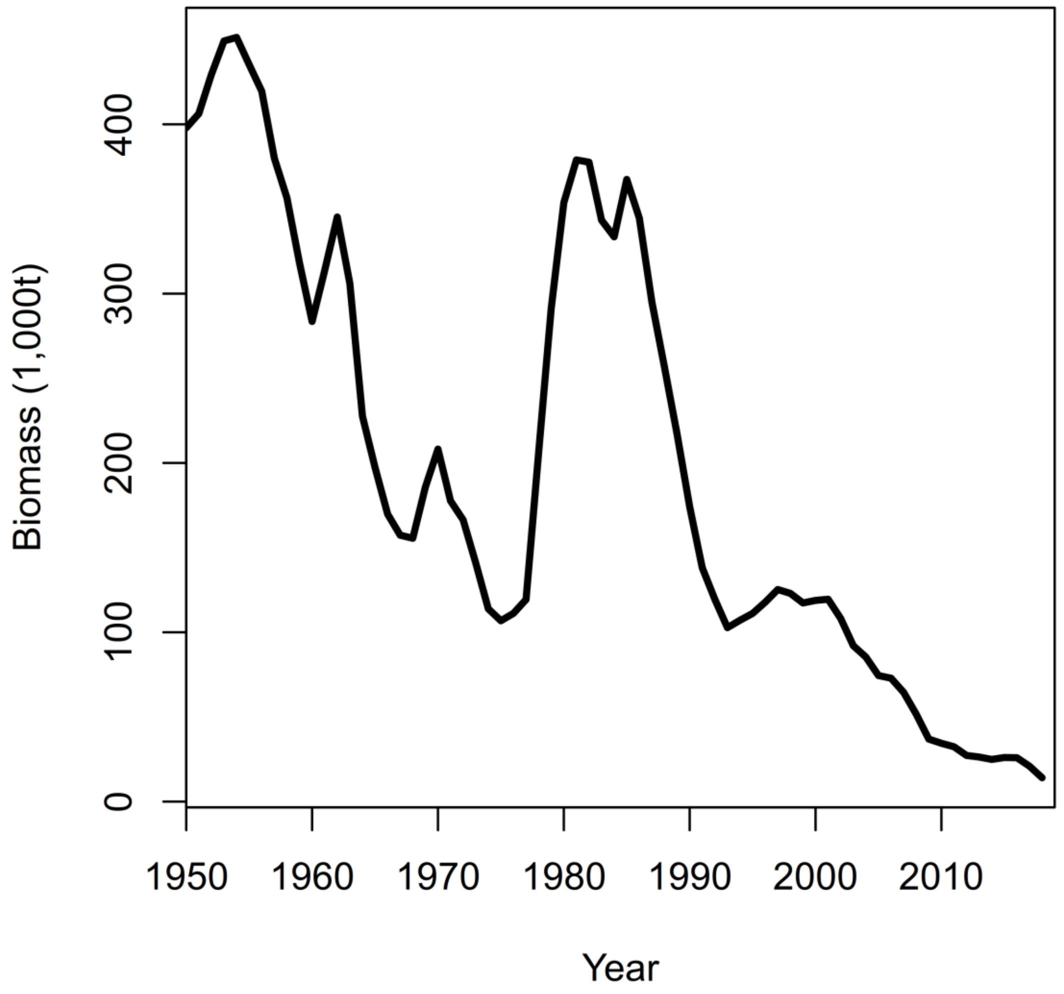



Figure from Neuenhoff et al. 2019

Cod Stock Biomass Aged 5+




Cod Biomass aged five plus. Data from Swain et al. 2019

# Case Study:
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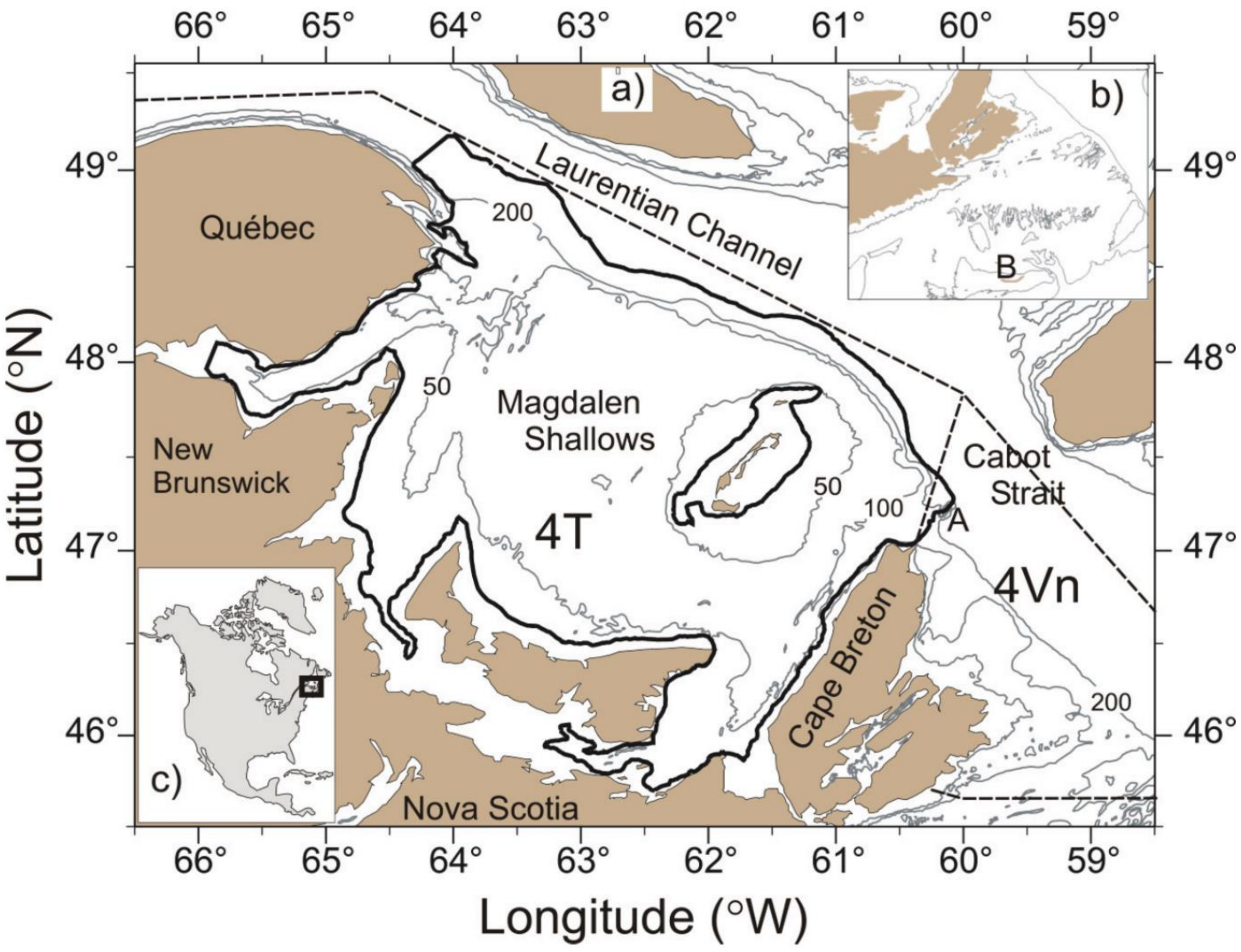


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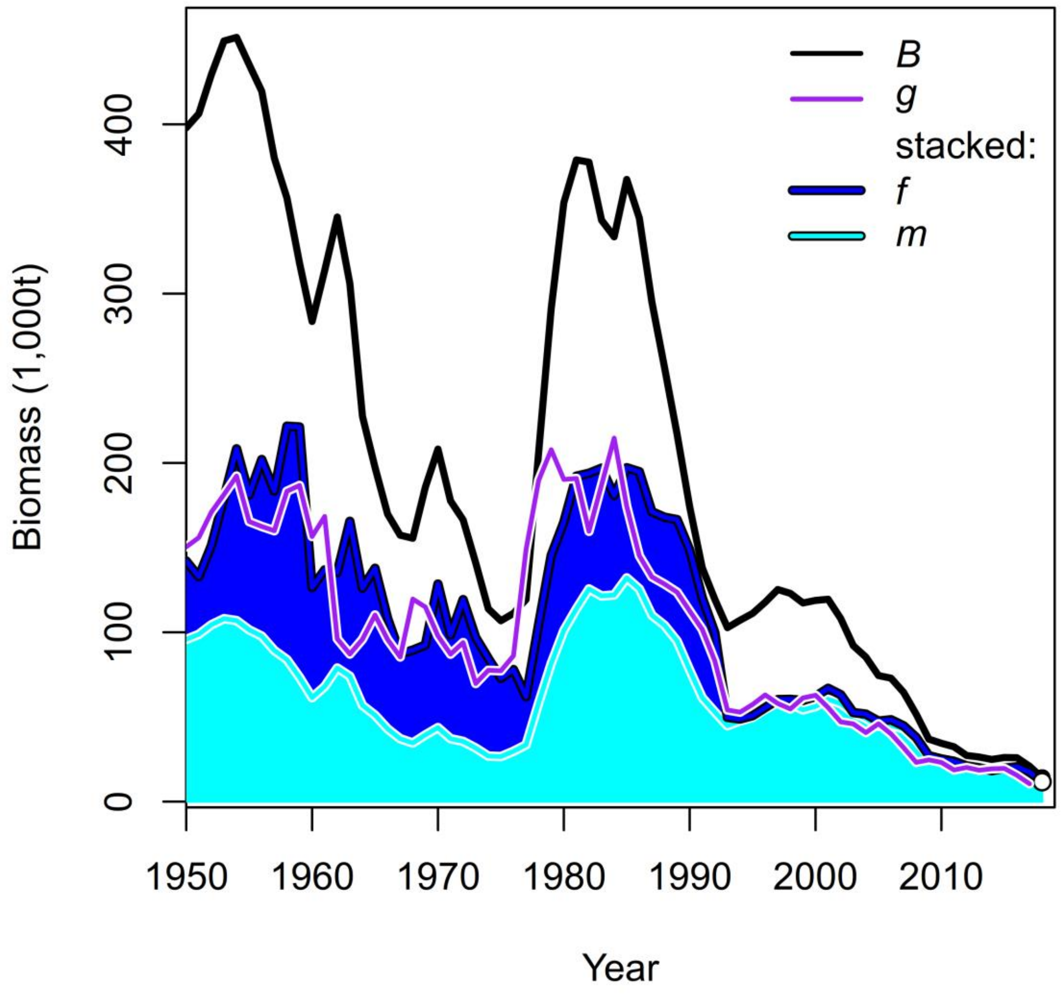
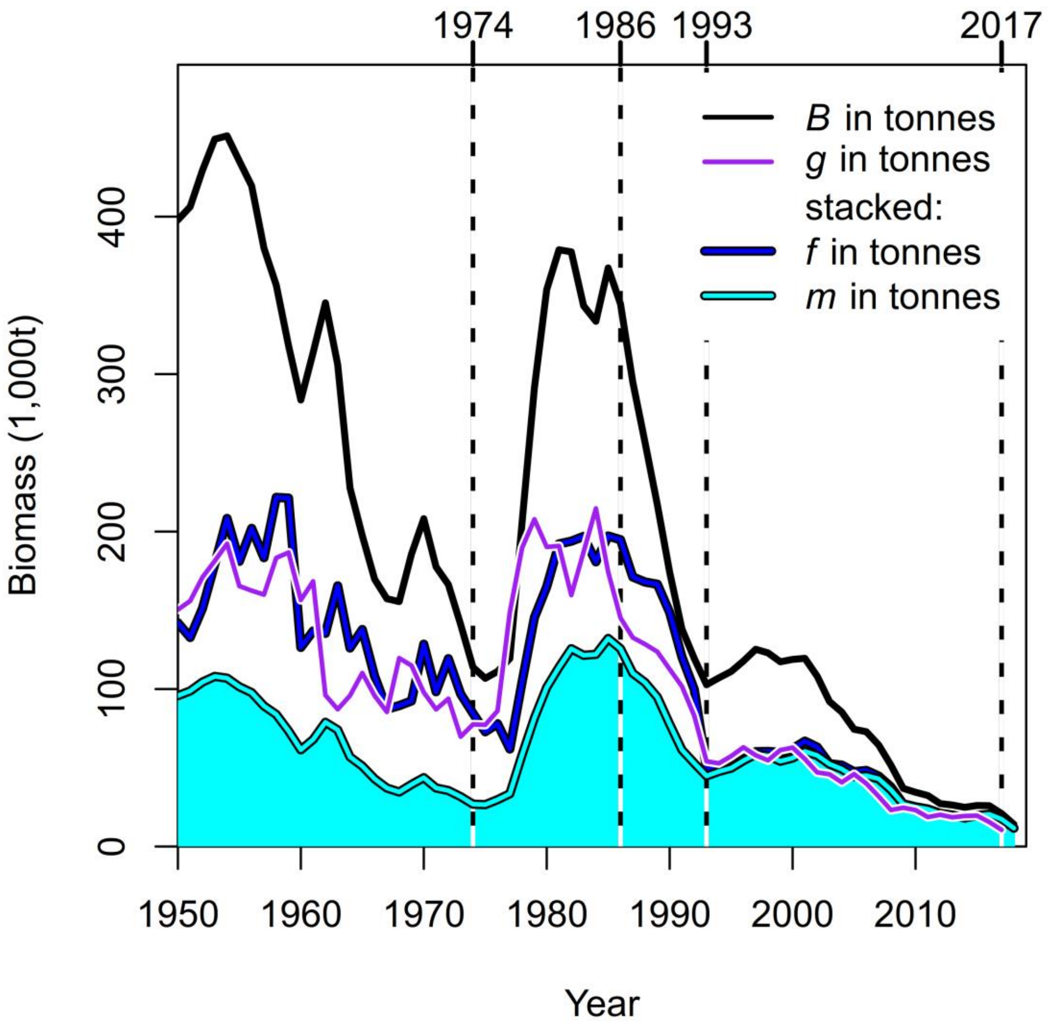
## Cod Stock Biomass Aged 5+

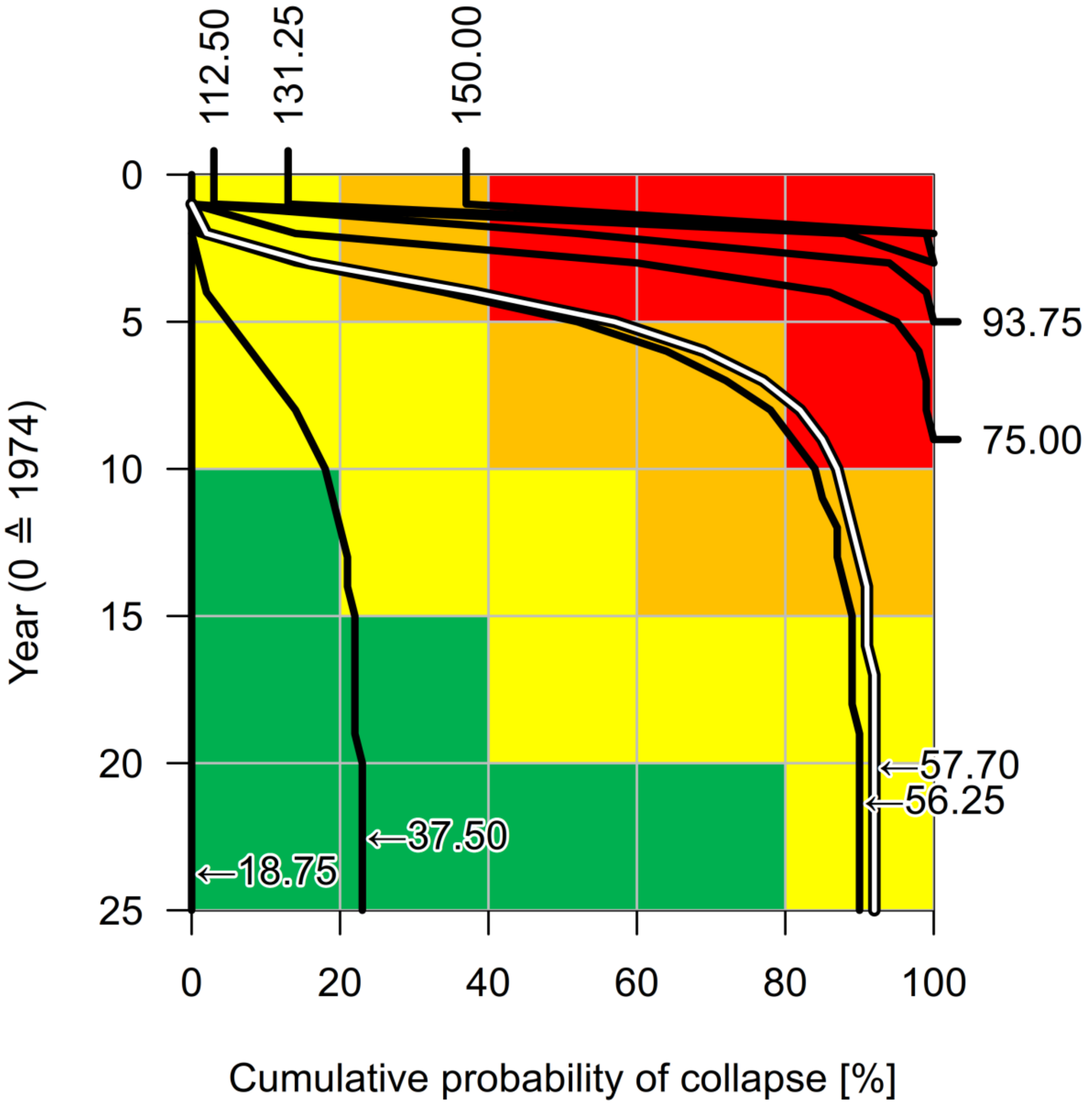



Biomass aged five plus, growth, fisheries, and mortality measured in biomass. Data from Swain et al. 2019

# The Risk of Collapse in 1974

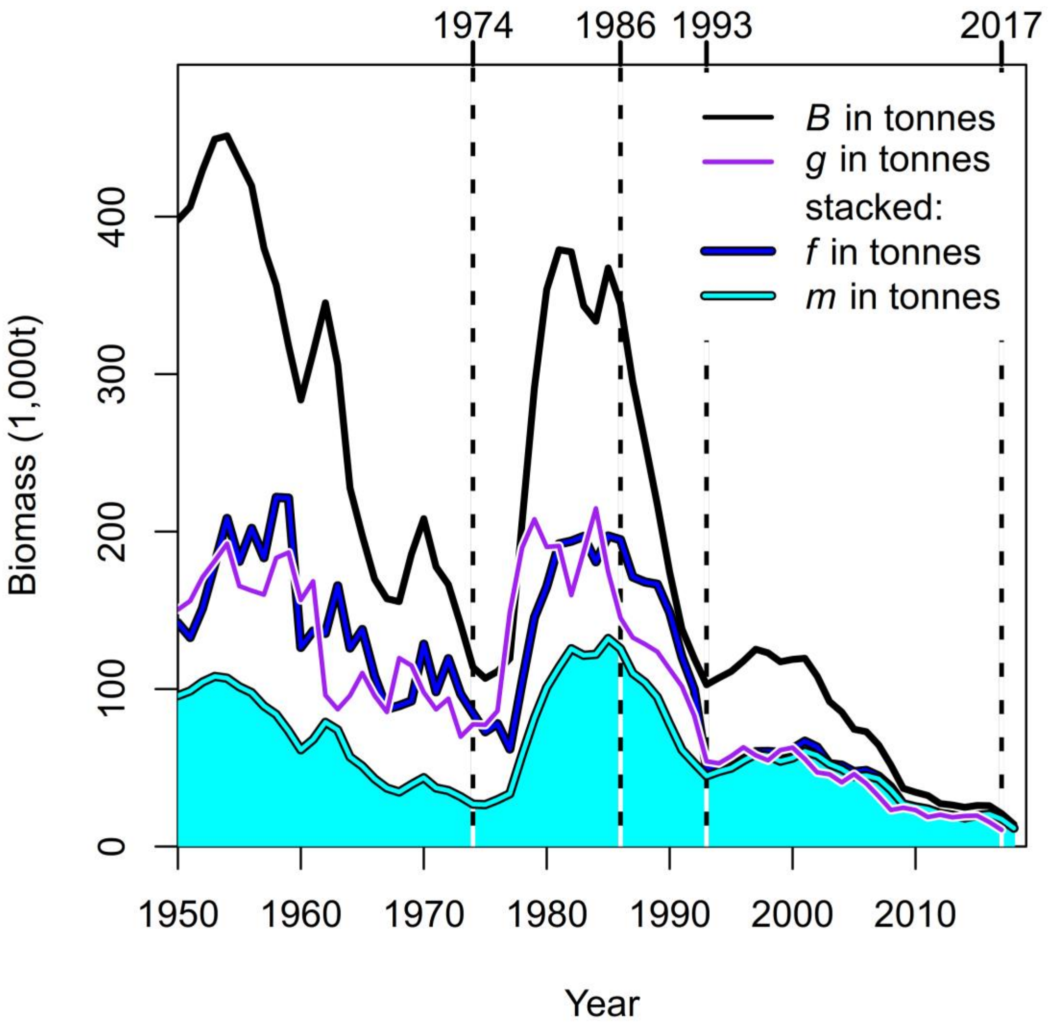


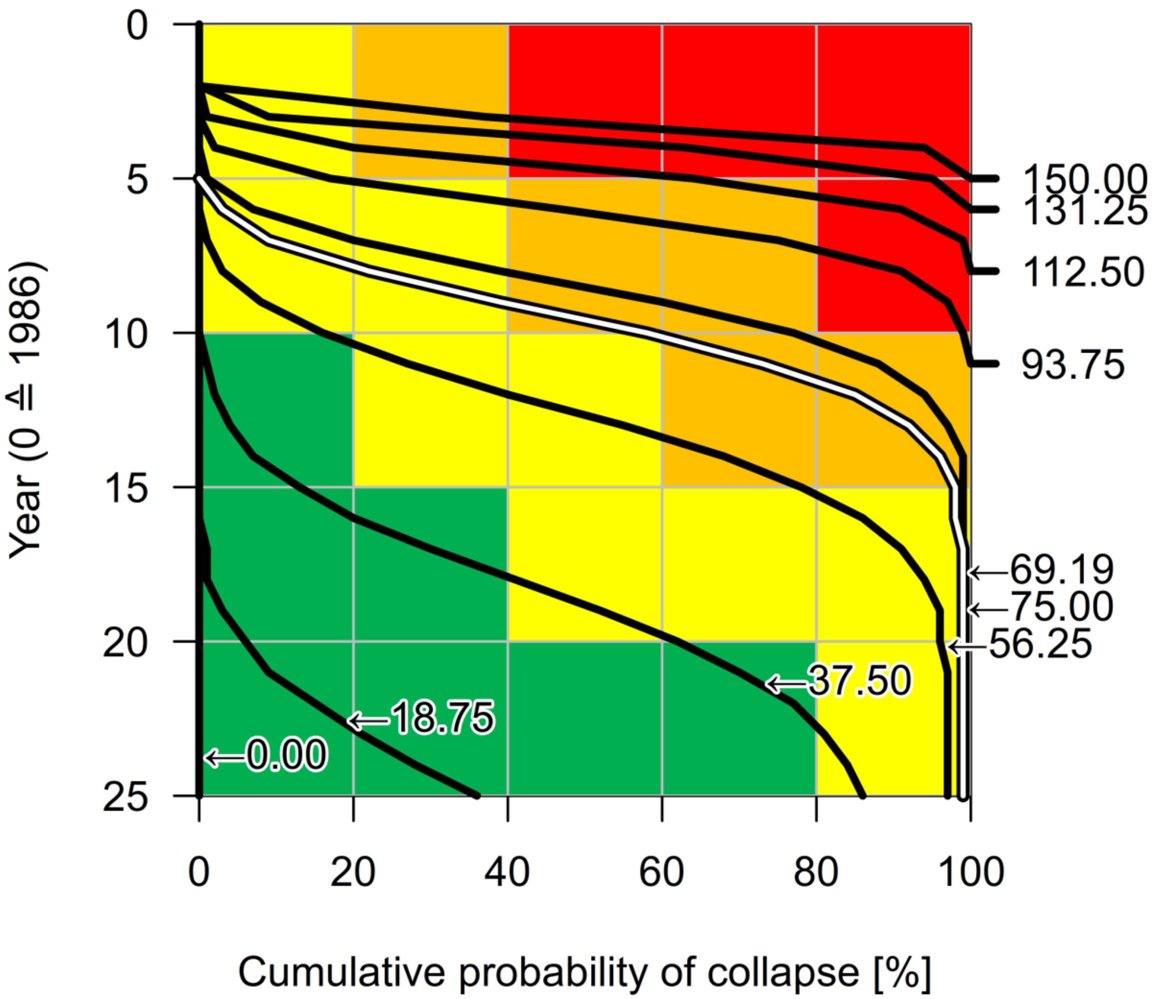


# The Risk of Collapse in 1986





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# The Risk of Collapse in 1993

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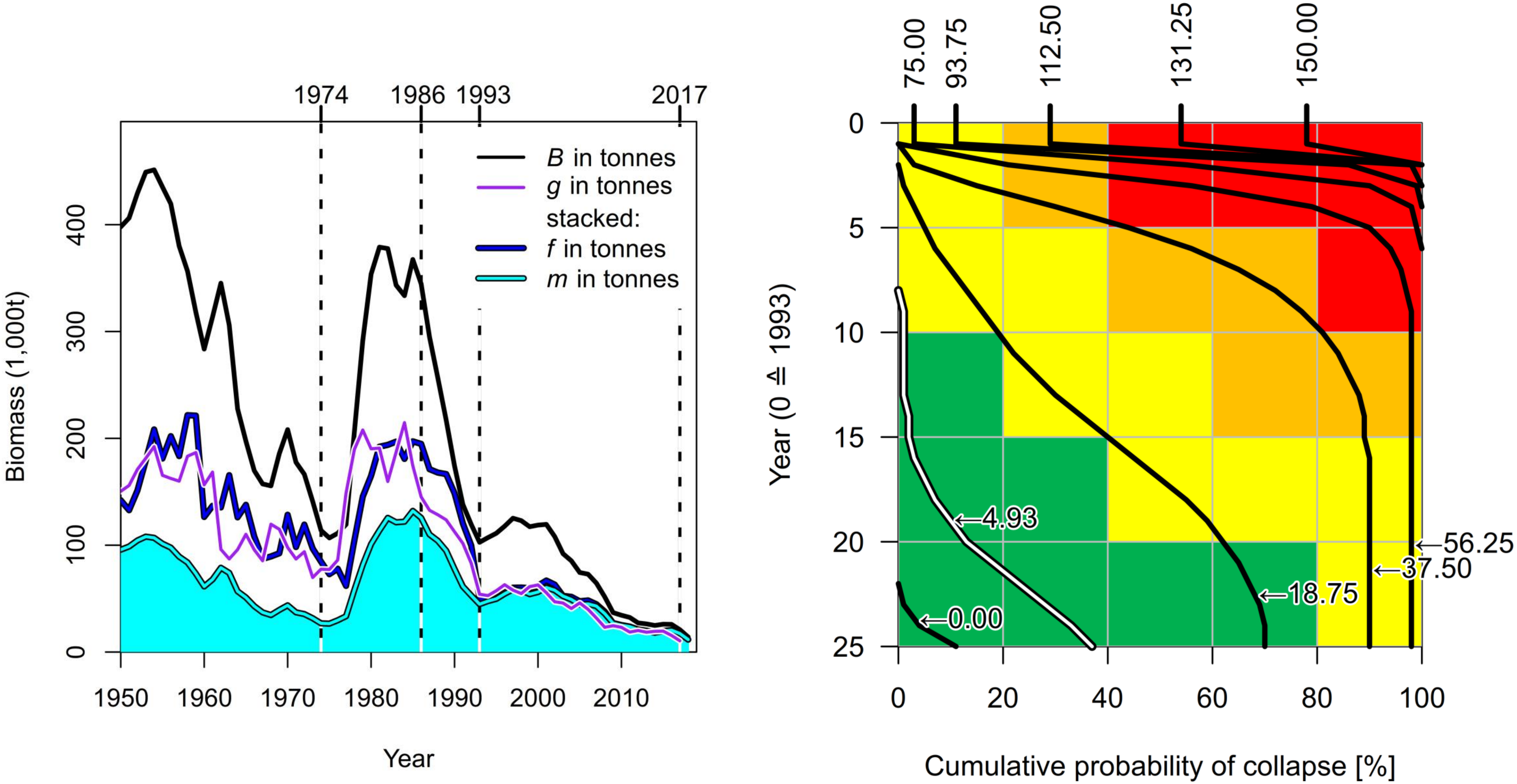
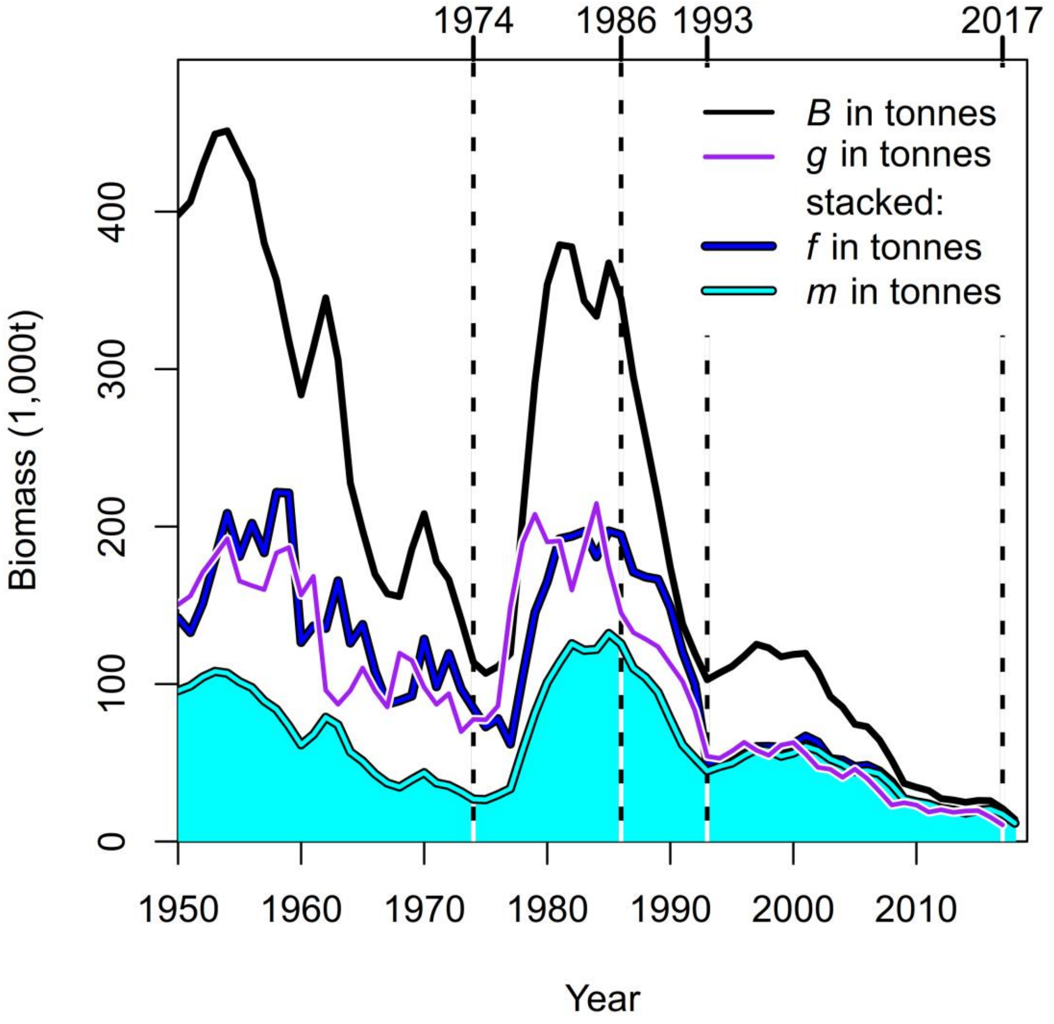
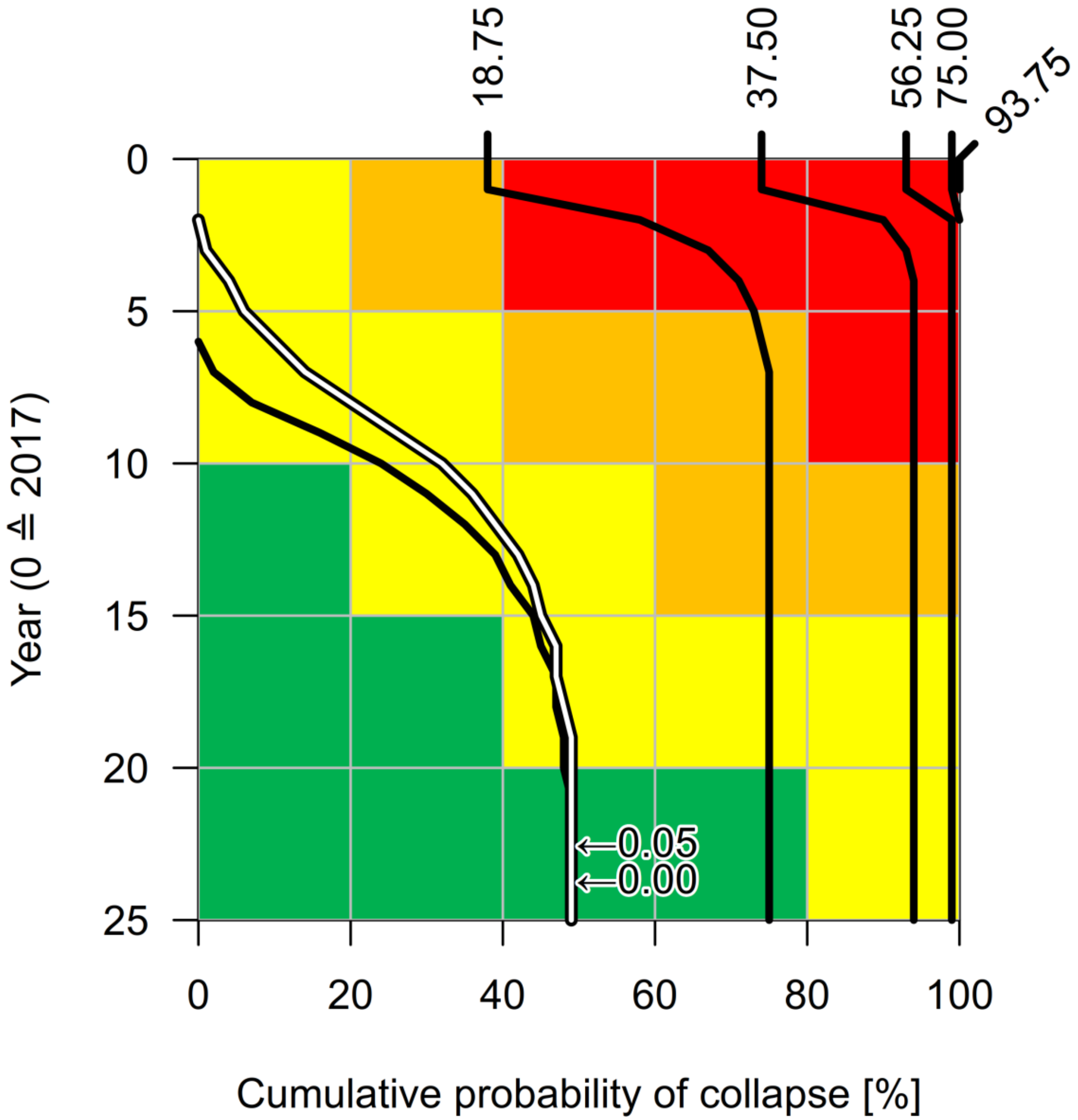


# The Risk of Collapse in 2017





# Conclusion



- The shape of the cumulative distribution of collapse is responsive to the state of the stock.
  - As the collapse draws closer, the lines shift toward the top right corner of the matrix
  - As the uncertainty is reduced, the lines flatten/spread across less time

- The relative positioning of the CDFs for the different harvest levels gives a good indication of the effectiveness of the harvest (or other management measure)
  - E.g. in 1986 the decision maker could achieve almost any risk level by setting the harvest rate. In 1993 this ability is severely constrained.

# Take Home Messages



- The cumulative probability of collapse within a given time frame:
  - Incorporates and visualizes uncertainty present in the predictions
  - Shows how risk is affected by management choices
  - Does not require in depth knowledge from the user
    - It does require quite some knowledge from the modeler though

- In combination with pre-determined risk tolerances, it can show compliance or noncompliance of a proposed harvest level with the defined risk tolerances.

- We propose adding this visualization to existing stock advice procedures, based on projections made using existing state of the art models for the respective species.
  - The most recent stock assessment of Cod stocks in the

- More details in our upcoming paper:
  - Accepted for publication in the ICES Journal of Marine Science

# Thank you for your attention!

How long do you want (to be able) to fish?

Benjamin.Blanz@uni-hamburg.de

SeaUseTip

Fisheries and Oceans
Canada

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Bundesministerium
für Bildung
und Forschung

# The Proof-of-Concept Model



- To investigate the time to collapse as a communication tool in fisheries management we built a simple model of the sGSL cod stocks. Calibrated to Stock timeseries 1950 – 2017
- This model has the general properties of this fish stock
  - Increasing rate of natural mortality
  - Ricker recruitment
  - Random shocks to both natural mortality and growth
- We include two sources of uncertainty
  - Parametric, i.e. uncertainty about the calibration
  - Stochastic, i.e. irreducible uncertainty stemming from randon fluctuations

- This model is used only for illustration purposes. Application of the probabilistic time to collapse (or to recovery as was proposed in the session) in stock advice would be based on existing state-of-the-art models.
- Other sources of uncertainty, can be incorporated analogous to the parametric and stochastic uncertainty demonstrated here.

# The Proof-of-Concept Model



- To investigate the time to collapse as a communication tool in fisheries management we built a simple model of the sGSL cod stocks. Calibrated to Stock timeseries 1950 – 2017

Biomass in the next year:
current biomass + growth
– natural mortality – harvests

$$B_{t+1} = B_t + g(B_t) - m(B_t, t) - f_t$$

Ricker growth function with random shocks

$$g(B_t) = \max(\alpha B_t \mathrm{e}^{-\beta B_t} + \epsilon_t^g, 0)$$

Time varying rate of natural mortality with random shocks

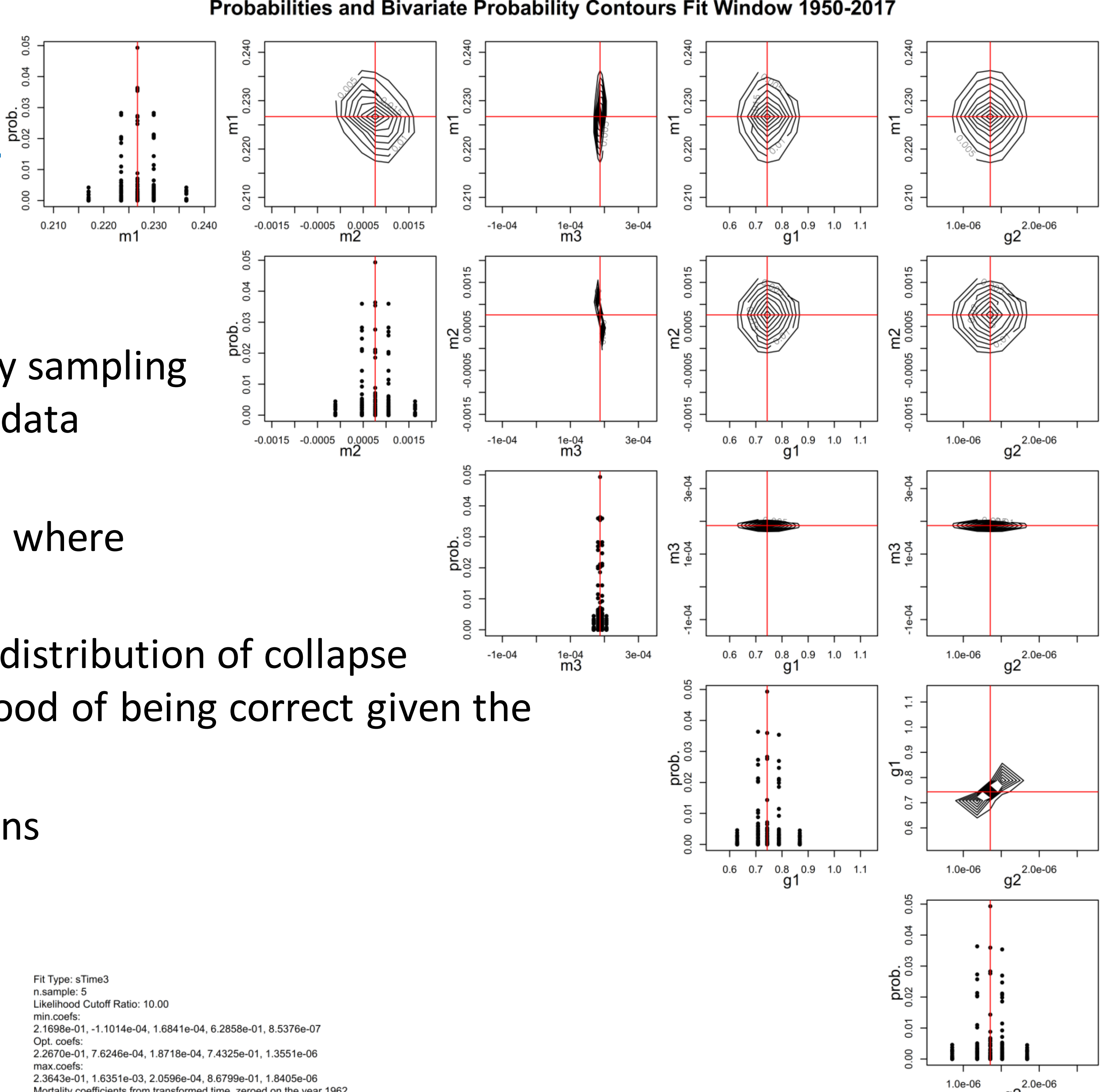
$$m(B_t, t) = \max((\gamma_1 + \gamma_2 t + \gamma_3 t^2 + \epsilon_t^m) B_t, 0)$$

Random shocks, allowing for correlation.

$$(\epsilon_t^g \quad \epsilon_t^m) \overset{\text{i.i.d.}}{\sim} \mathcal{N}\left(\mu = (0 \quad 0),\ \Sigma = \begin{pmatrix} s_{g,g} & s_{g,m} \\ s_{g,m} & s_{m,m} \end{pmatrix}\right)$$

## Parametric Uncertainty

- Parameter uncertainty is modelled by sampling the joint model likelihood, given the data available in a given year.
- Each of the parameters of the model where sampled five times equidistantly.
  - Their contribution to the overall distribution of collapse times is weighted by their likelihood of being correct given the data.
- 3125 possible parameter combinations



# Model Calibration



- The model for each year is calibrated only to the part of the time series available at that year.
- 25 years of data as the minimum for calibration means 1974 is the first year for analysis.
- In 1974 the increasing natural mortality rate is not yet reflected in the data, and hence also not in the calibrated model. Consequently, the predicted collapse time distributions do also not reflect that natural mortality will increase within the predicted time frame.
    - None the less, the produced risk assessment reflects the state of the knowledge at that time, including the uncertainty.
- With additional data points, the parametric uncertainty is reduced, but the uncertainty about future stock states from random shocks can not be reduced.

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# Calibration 1974

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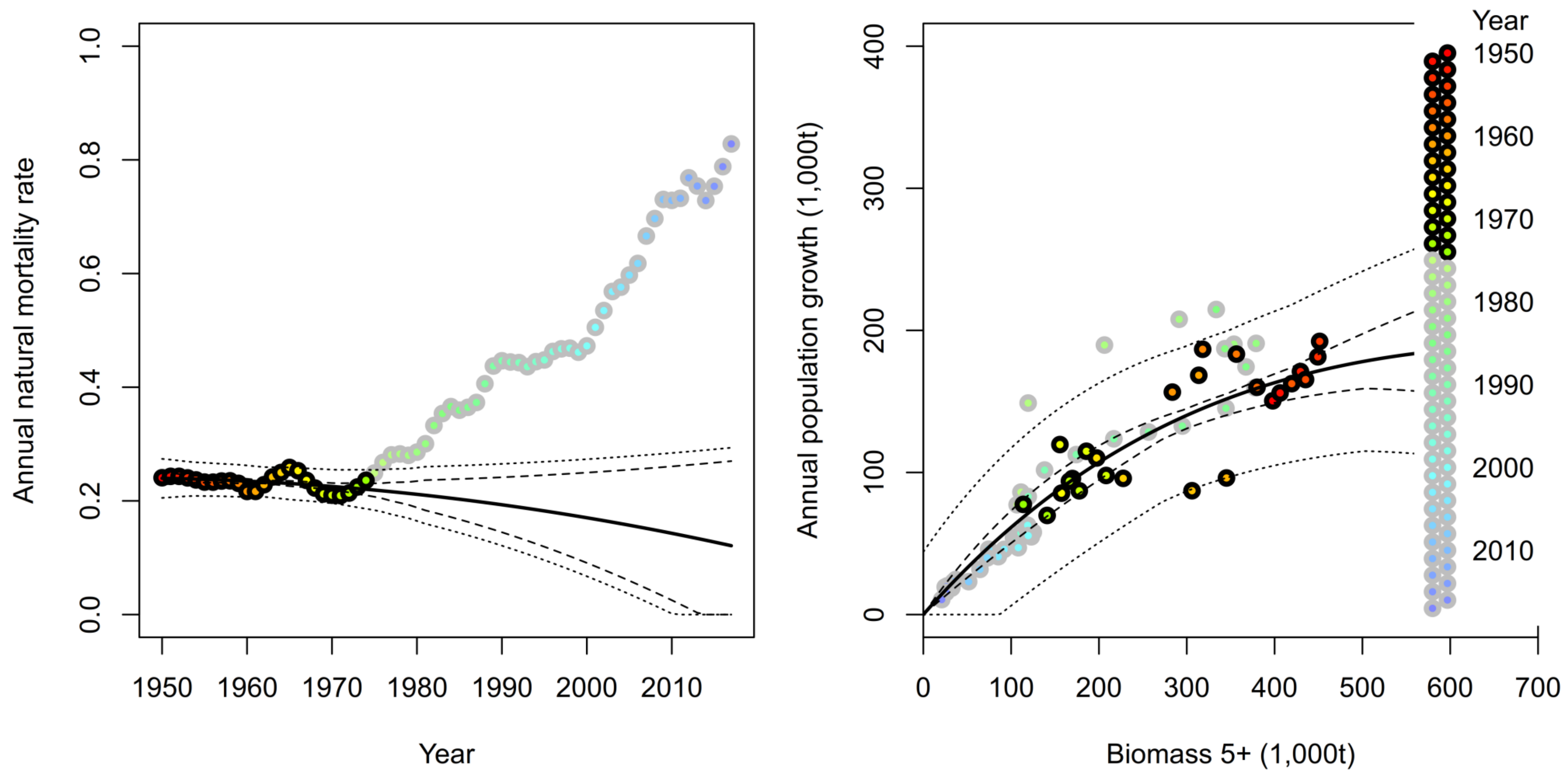
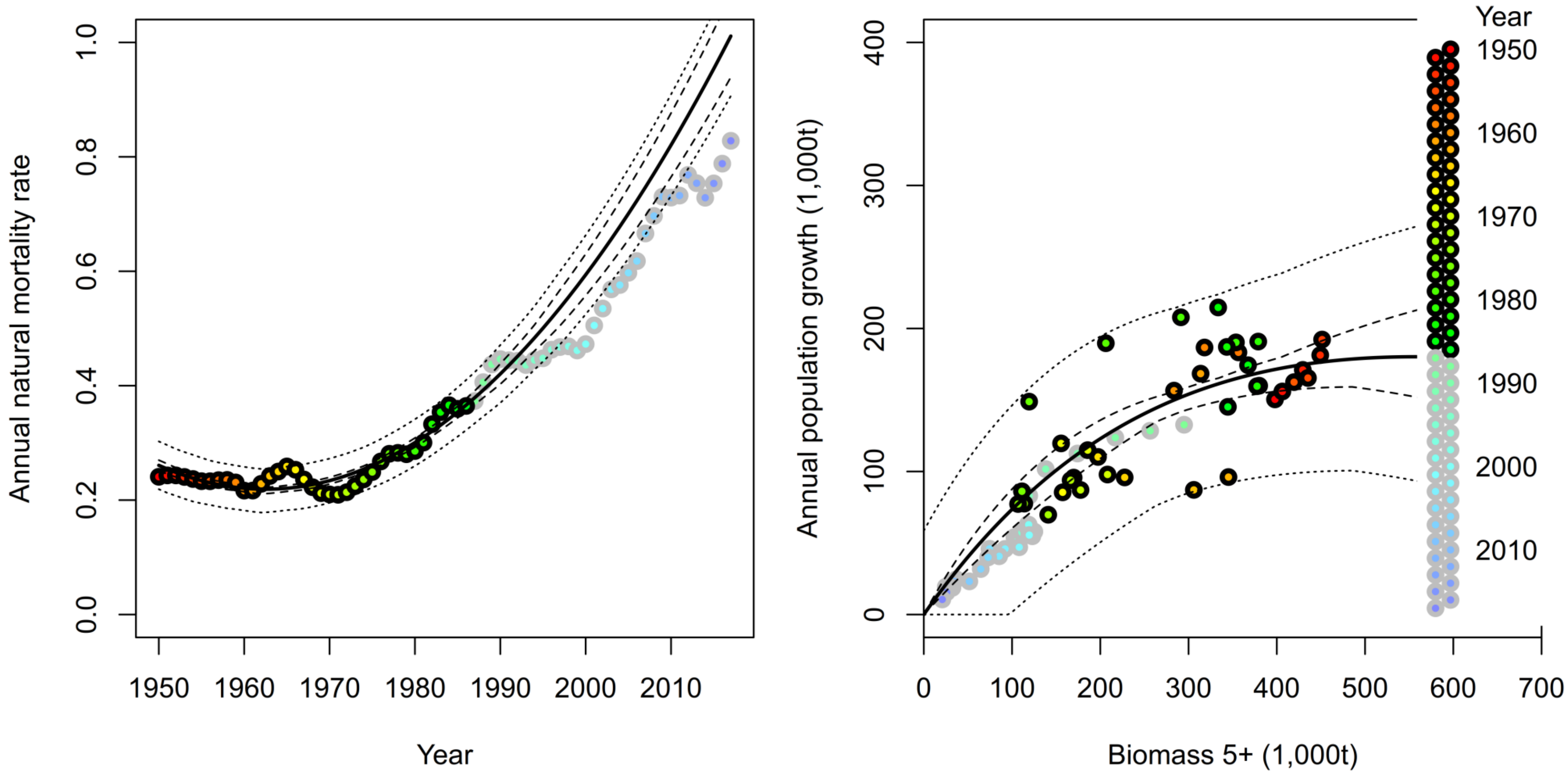



Data points, maximum likelihood fit, and prediction interval for the model calibrated to the years 1950 – 1974 (shown in saturated colours) the remaining data points are shown for context (in desaturated colours). The dashed lines show the 95% confidence interval of the model fit, the dotted lines additionally show the 95% confidence interval of the yearly shocks. The left panel shows the annual rate of biomass losses due to natural mortality. The right panel shows annual biomass gain due to natural growth.

# Calibration 1986

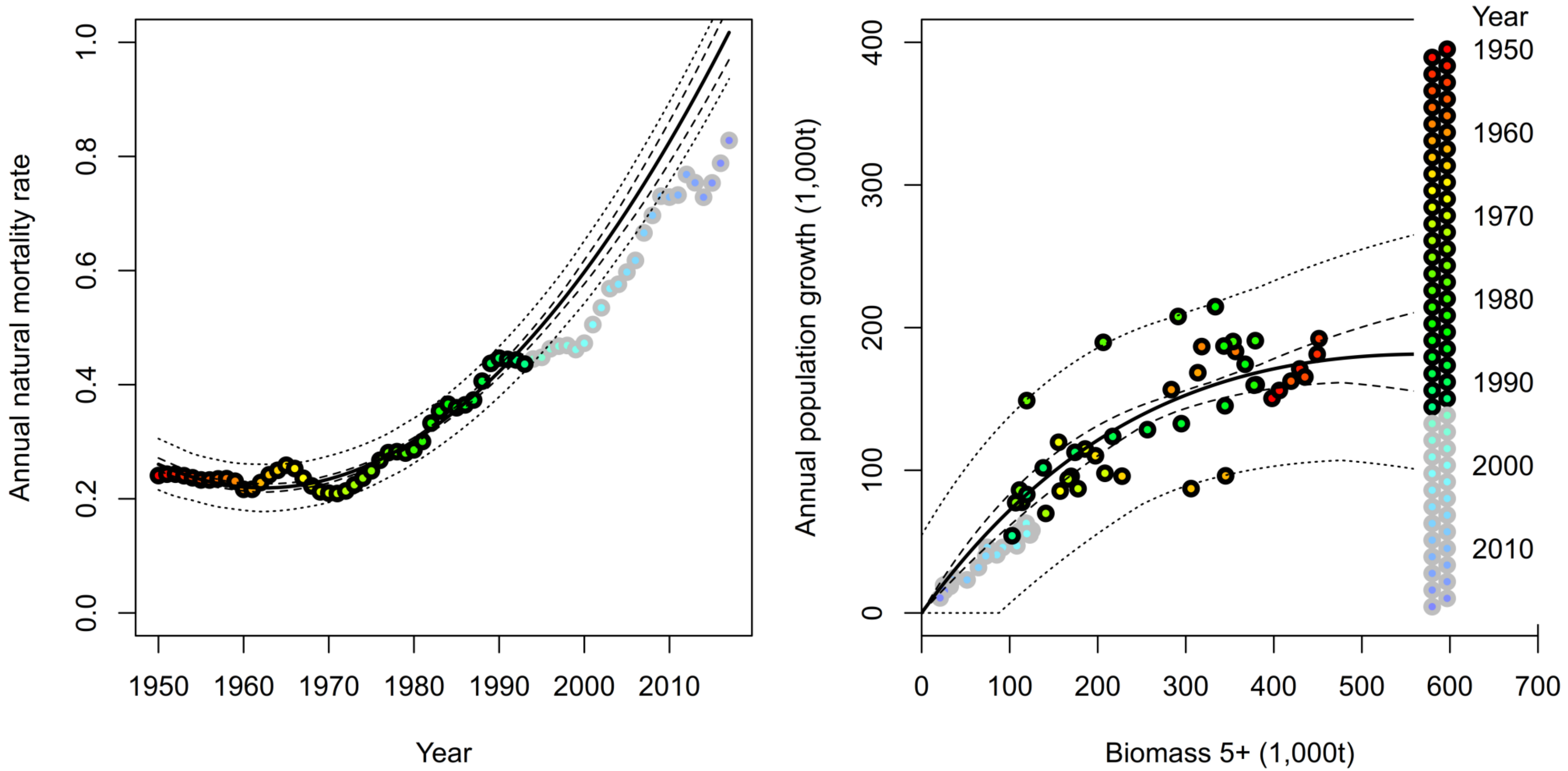





Data points, maximum likelihood fit, and prediction interval for the model calibrated to the years 1950 – 1986 (shown in saturated colours) the remaining data points are shown for context (in desaturated colours). The dashed lines show the 95% confidence interval of the model fit, the dotted lines additionally show the 95% confidence interval of the yearly shocks. The left panel shows the annual rate of biomass losses due to natural mortality. The right panel shows annual biomass gain due to natural growth.

# Calibration 1993

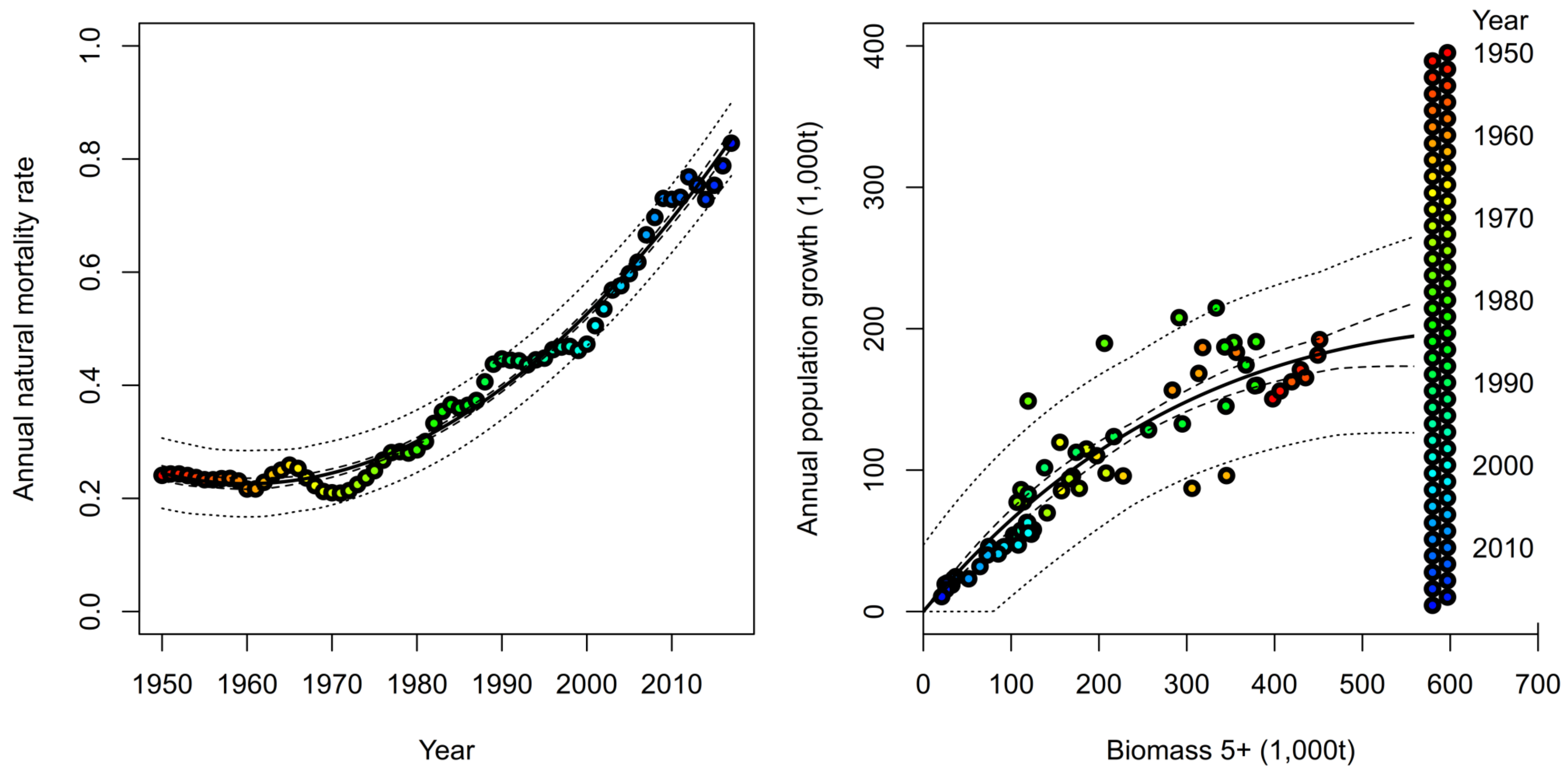





Data points, maximum likelihood fit, and prediction interval for the model calibrated to the years 1950 – 1993 (shown in saturated colours) the remaining data points are shown for context (in desaturated colours). The dashed lines show the 95% confidence interval of the model fit, the dotted lines additionally show the 95% confidence interval of the yearly shocks. The left panel shows the annual rate of biomass losses due to natural mortality. The right panel shows annual biomass gain due to natural growth.

# Calibration 2017






Data points, maximum likelihood fit, and prediction interval for the model calibrated to the years 1950 – 2017 (shown in saturated colours) the remaining data points are shown for context (in desaturated colours). The dashed lines show the 95% confidence interval of the model fit, the dotted lines additionally show the 95% confidence interval of the yearly shocks. The left panel shows the annual rate of biomass losses due to natural mortality. The right panel shows annual biomass gain due to natural growth.

# Mortality and Growth Shocks



- The shocks of the 20,000 stochastic runs are generated with the same statistical properties as the model fit residuals.
- In the modelling framework chosen for our proof-of-concept model, the model fit residuals conceptually correspond to the shocks, the non-deterministic part of growth and mortality.

- Shock uncertainty in stock predictions is included in the model through 20,000 stochastic runs for each of the 3125 parameter combinations.
  - 62.5 million runs per harvest level for each of the 44 analysed years
  - 2.75 billion runs over all for the paper.