Population trend analysis for bull trout in Oregon, Washington, Idaho & Montana

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Bull trout assessment team

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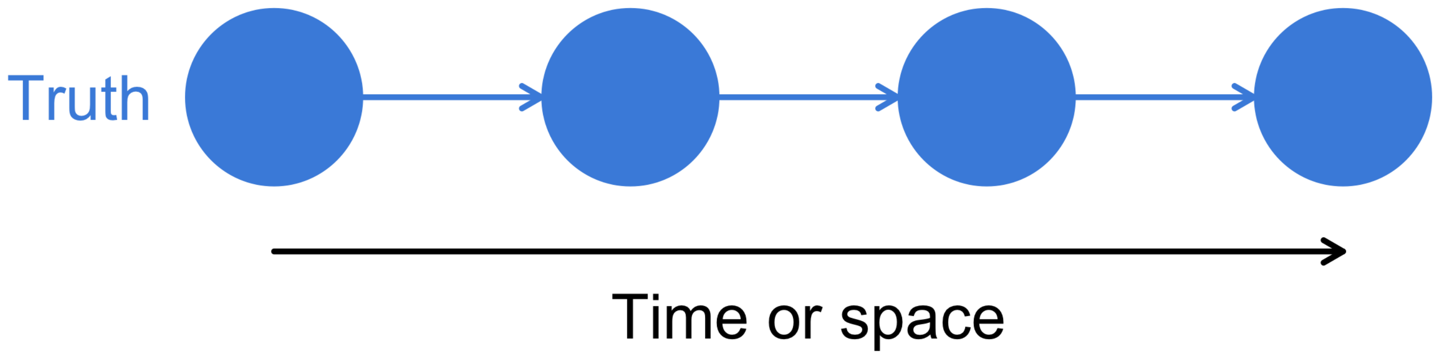
A model for estimating population trends with 2 general parts

Part 1: State model

Describes the true state of nature over time or space



States of nature might be

Animal location

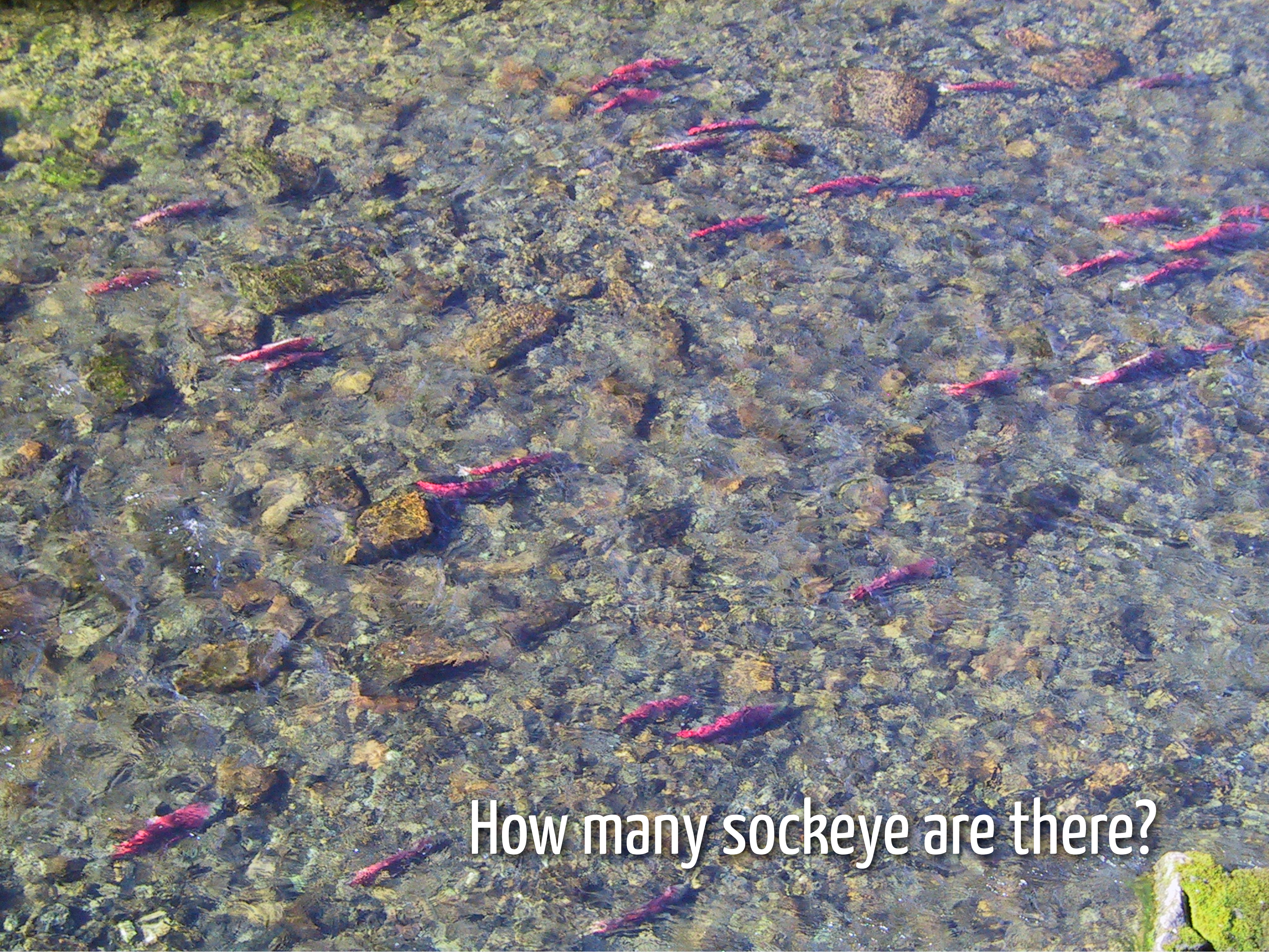
Species density

Age structure

Reproductive status


Revealing the true state requires observations

Observing nature can be easy


How many sockeye are there?

Observing nature can also be hard

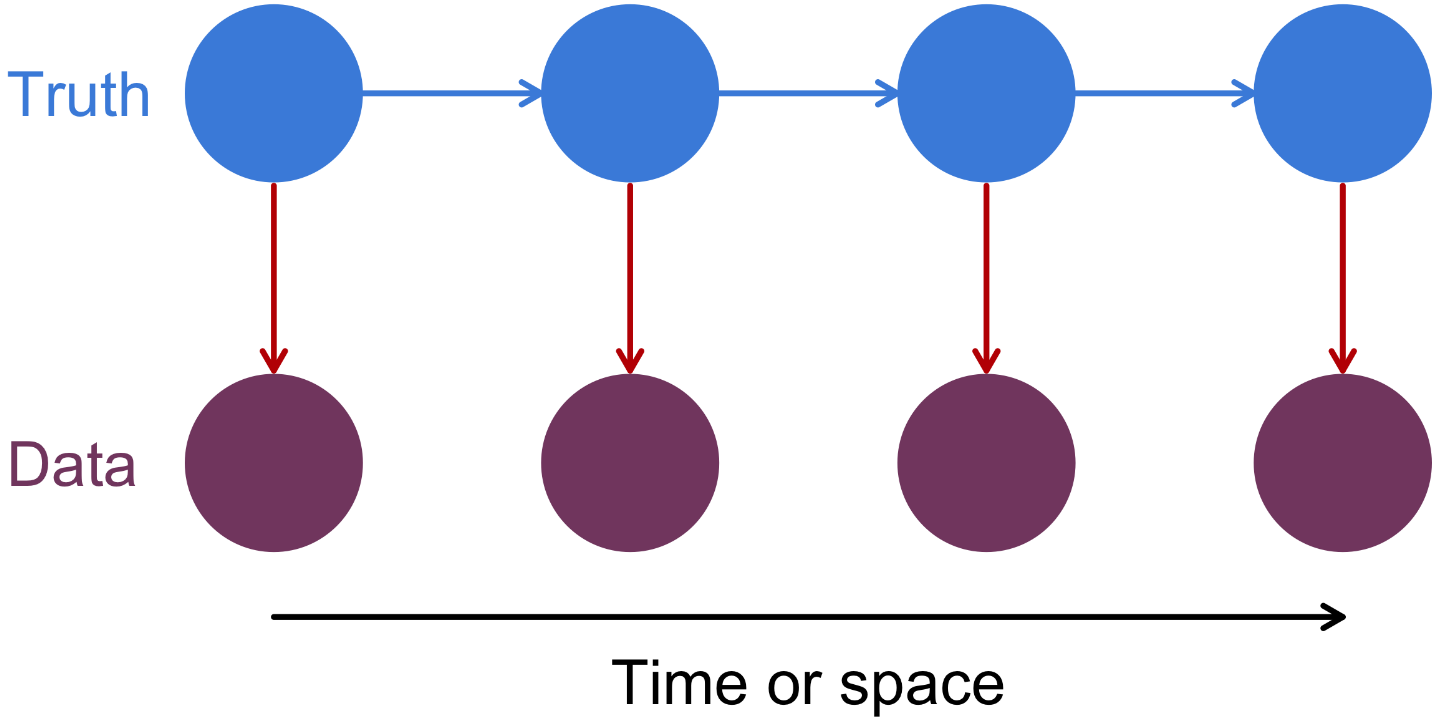

How many mayflies are there?

Part 2: Observation model

Data = Truth ± Errors

Part 2: Observation model

Data = Truth ± Errors



OK, but why bother?

Advantages

1. Can combine many different data types

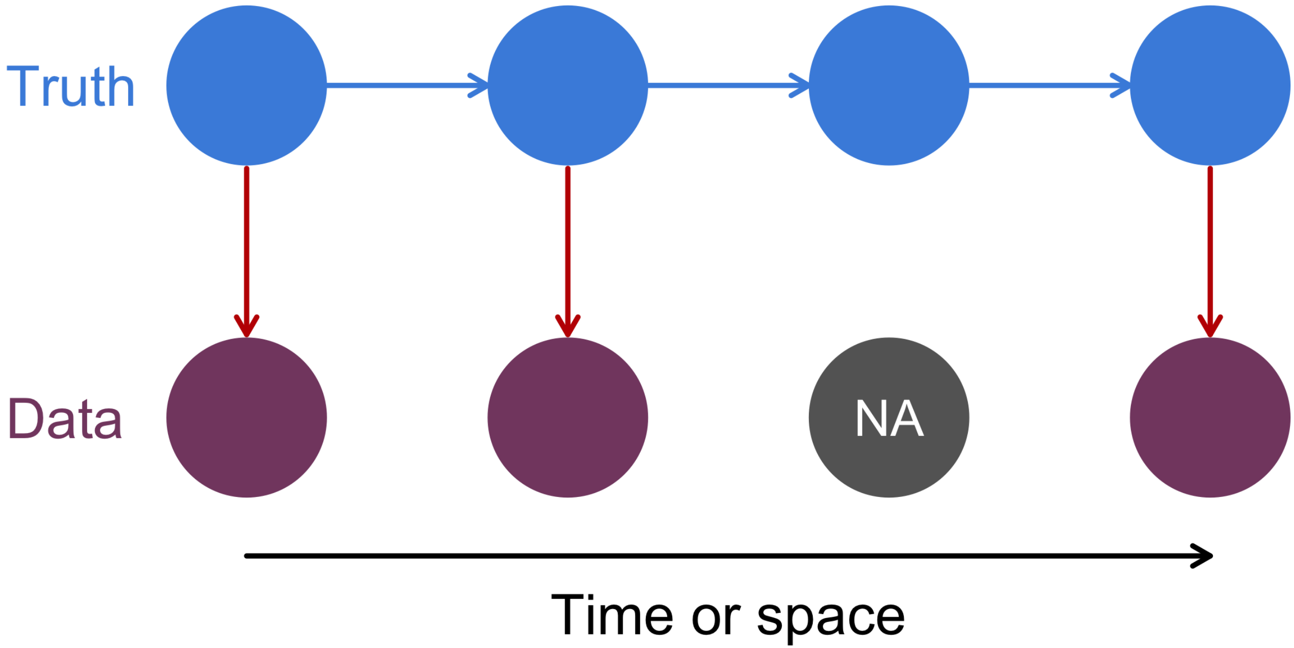
Changes in observers or sensors

Varying survey locations & effort

Direct & remote sampling

Advantages

2. Missing data are easily accommodated



Advantages

3. Improved accuracy & precision

Article | OPEN | Published: 08 February 2016

Joint estimation over multiple individuals improves behavioural state inference from animal movement data

Ian Jonsen

Scientific Reports **6**, Article number: 20625 (2016) | Download Citation

Advantages

4. Data-poor benefit from data-rich

Model for the state of nature

Population dynamics

Exponential growth/decline in continuous time

$$N(t) = N_0 \exp(u) \exp(wt)$$

Population dynamics

Exponential growth/decline in continuous time

$$N(t) = N_0 \underbrace{\exp(u)}_{\substack{\text{growth}\\ \text{rate}}} \exp(wt)$$

Population dynamics

Exponential growth/decline in continuous time

$$N(t) = N_0 \exp(u) \underbrace{\exp(wt)}_{\substack{\text{stochastic} \\ \text{environment}}}$$

Population dynamics

Exponential growth/decline in continuous time

$$N(t) = N_0 \exp(u) \exp(wt)$$

In discrete time, with a time step of 1 year

$$N_t = N_{t-1} \exp(u + w_t)$$

Population dynamics

In discrete time, with a time step of 1 year, the model is

$$N_t = N_{t-1} \exp(u + w_t)$$

Taking the logarithm of both sides yields

$$\log(N_t) = \log(N_{t-1}) + u + w_t$$

Population dynamics

We can define

$$x = \log(N)$$

such that

$$\log(N_t) = \log(N_{t-1}) + u + w_t$$
$$\Downarrow$$
$$x_t = x_{t-1} + u + w_t$$

Biased random walk

If we assume that the errors are white noise

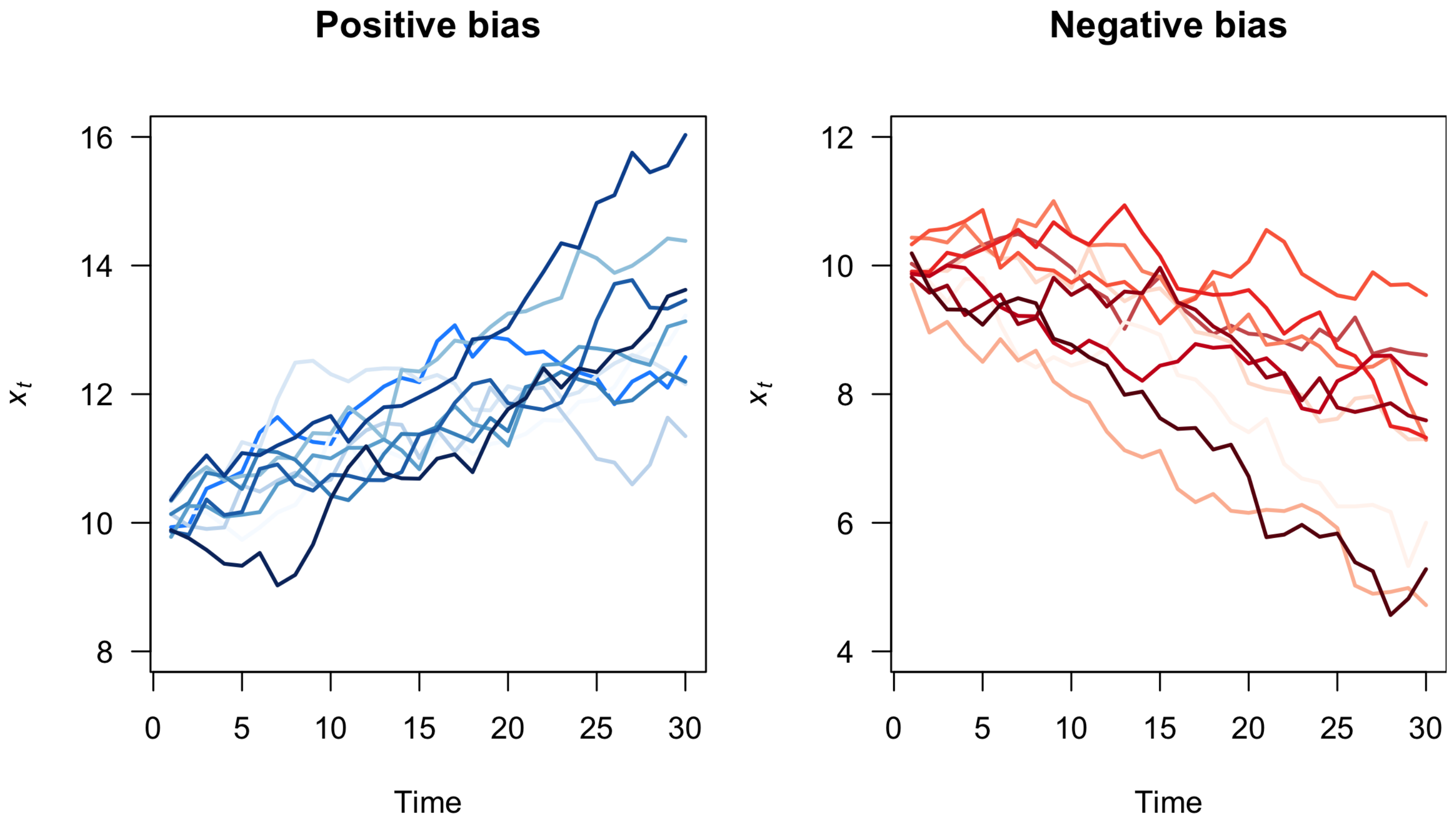
$$w_t \sim \mathrm{N}(0, q)$$

then our model of populations dynamics

$$x_t = x_{t-1} + u + w_t$$

is a so-called *biased random walk*

Examples of biased random walks



Observation (data) model

Observation model

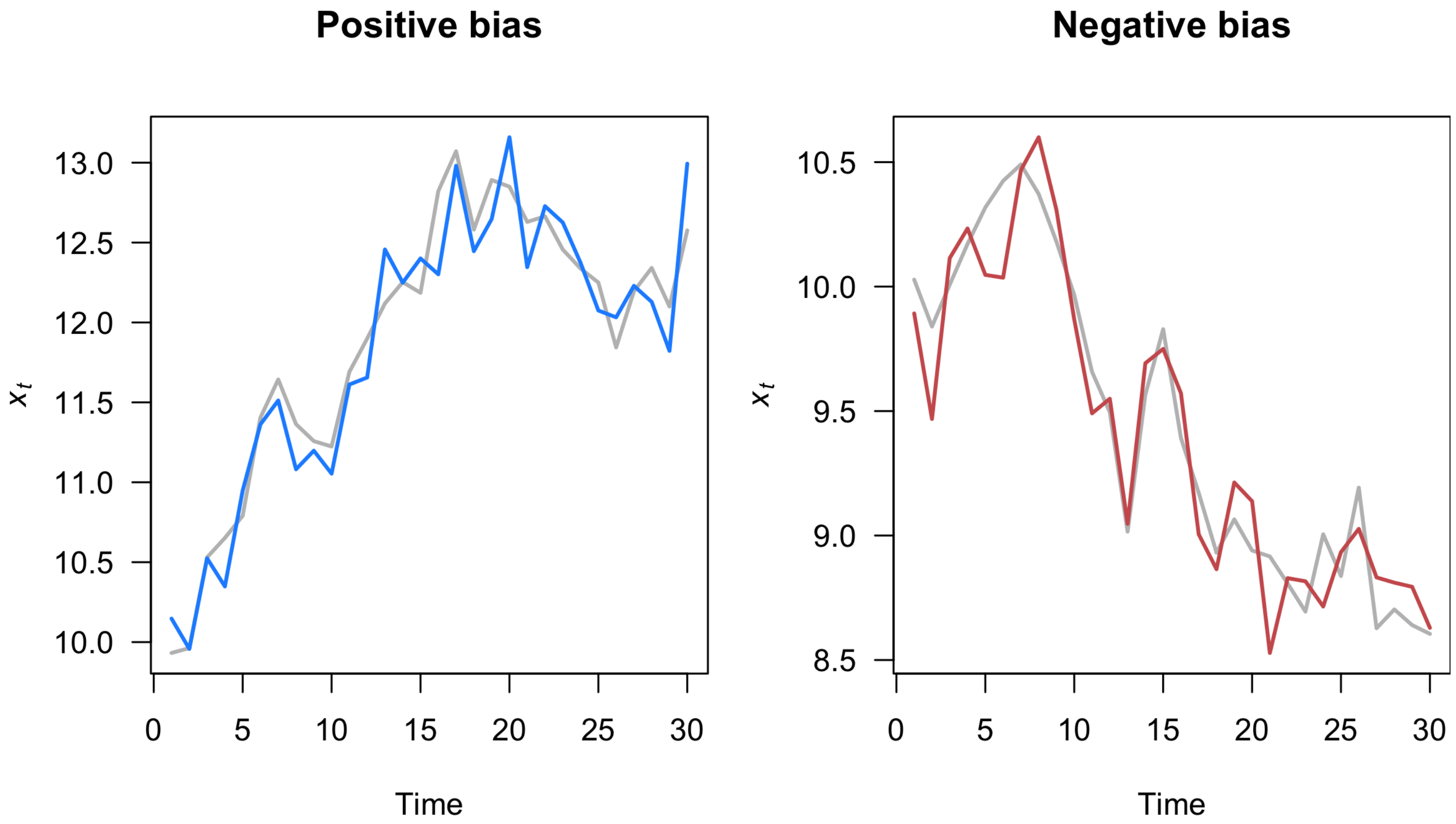
In log-space

$$\underbrace{y_t}_{\substack{\text{observed}\\\text{counts}}} = \underbrace{x_t}_{\substack{\text{true}\\\text{counts}}} + \underbrace{v_t}_{\substack{\text{observer}\\\text{error}}}$$

where

$$v_t \sim \mathrm{N}(0, r)$$

Examples with observation error



Multiple time series of abundance

Many populations within many core areas

4 states

8 recovery units

61 core areas

242 populations

Expanding our model for multiple core areas

We're estimating population trends at the level of *core areas*

$$
\begin{aligned}
x_{1,t} &= x_{1,t-1} + u_1 + w_{1,t} \\
x_{2,t} &= x_{2,t-1} + u_2 + w_{2,t} \\
&\vdots \\
x_{n,t} &= x_{n,t-1} + u_n + w_{n,t}
\end{aligned}
$$

Expanding our model for multiple core areas

In matrix notation we have

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}_t = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}_{t-1} + \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{bmatrix} + \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}_t$$

Observation model for multiple time series

Core areas have from 1-22 populations within them

We need a way to map populations to their respective core area

Observation model for multiple time series

Example with 5 popns (1-5) and 2 core areas (A & B)

$$
\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix}_t = \begin{bmatrix} x_A \\ x_A \\ x_B \\ x_B \\ x_B \end{bmatrix}_t + \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \end{bmatrix}_t
$$

Full state-space form

Mapping populations onto core areas

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix}_t = \underbrace{\begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}}_{\substack{\text{rows are popns} \\ \text{cols are cores}}} \begin{bmatrix} x_A \\ x_B \end{bmatrix}_t + \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \end{bmatrix}_t$$

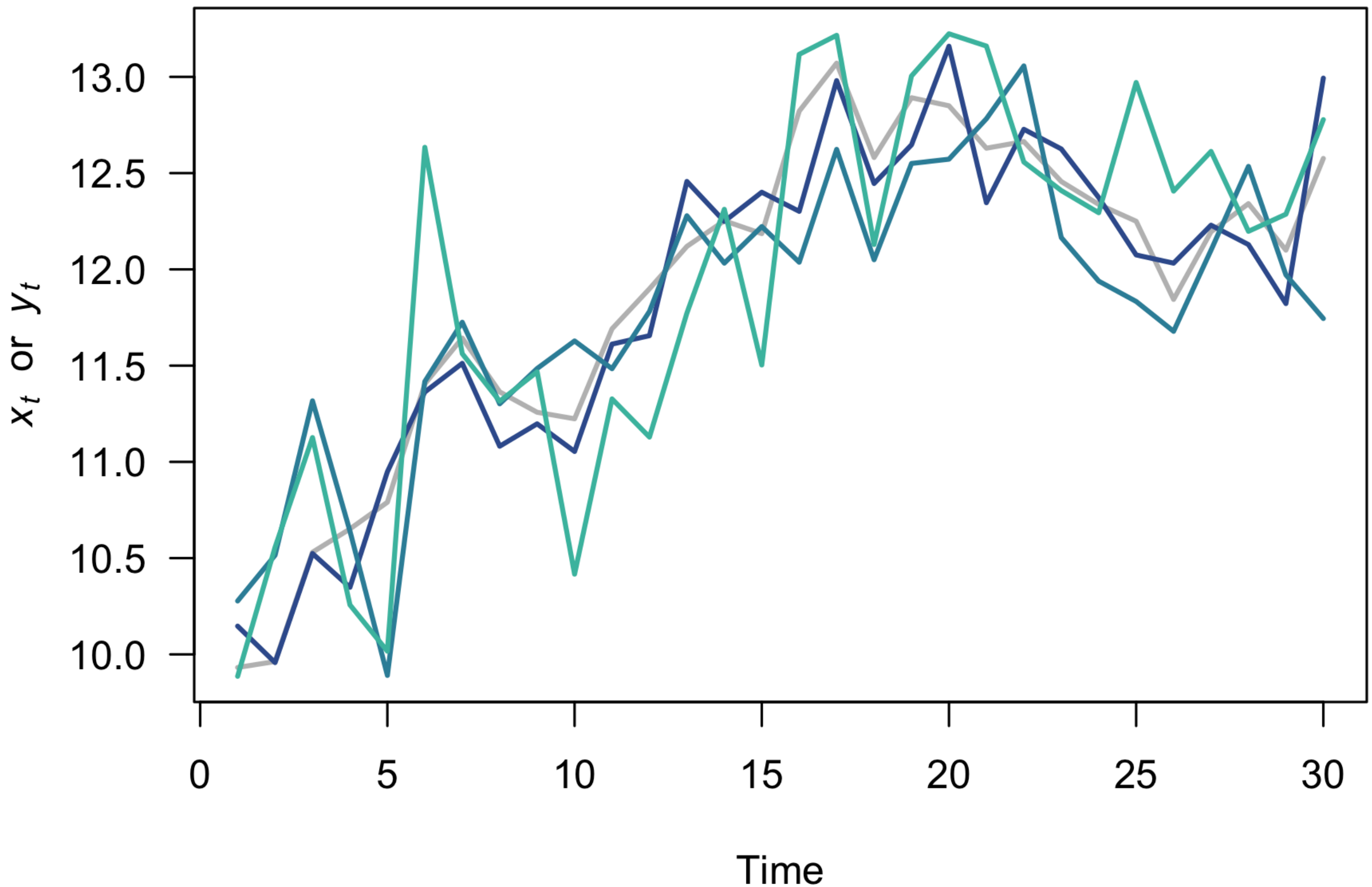
Full state-space form

Combining the observation & state models

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix}_t = \begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_A \\ x_B \end{bmatrix}_t + \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} + \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \end{bmatrix}_t$$

$$\begin{bmatrix} x_A \\ x_B \end{bmatrix}_t = \begin{bmatrix} x_A \\ x_B \end{bmatrix}_{t-1} + \begin{bmatrix} u_A \\ u_B \end{bmatrix} + \begin{bmatrix} w_A \\ w_B \end{bmatrix}_t$$

Example of 3 observations of a state



Different survey methods have different observation variances

For example, weir counts are more accurate than snorkel surveys

Multiple surveys of each type help inform the variance estimates

Fitting the models

We used the time period from 1991-2020

Time series needed at least 10 years of non-missing data

Fitting the models

We used the time period from 1991-2020

Time series needed at least 10 years of non-missing data

All models were fit in **R** using the `{MARSS}` package

I estimated 90% confidence intervals on bias terms

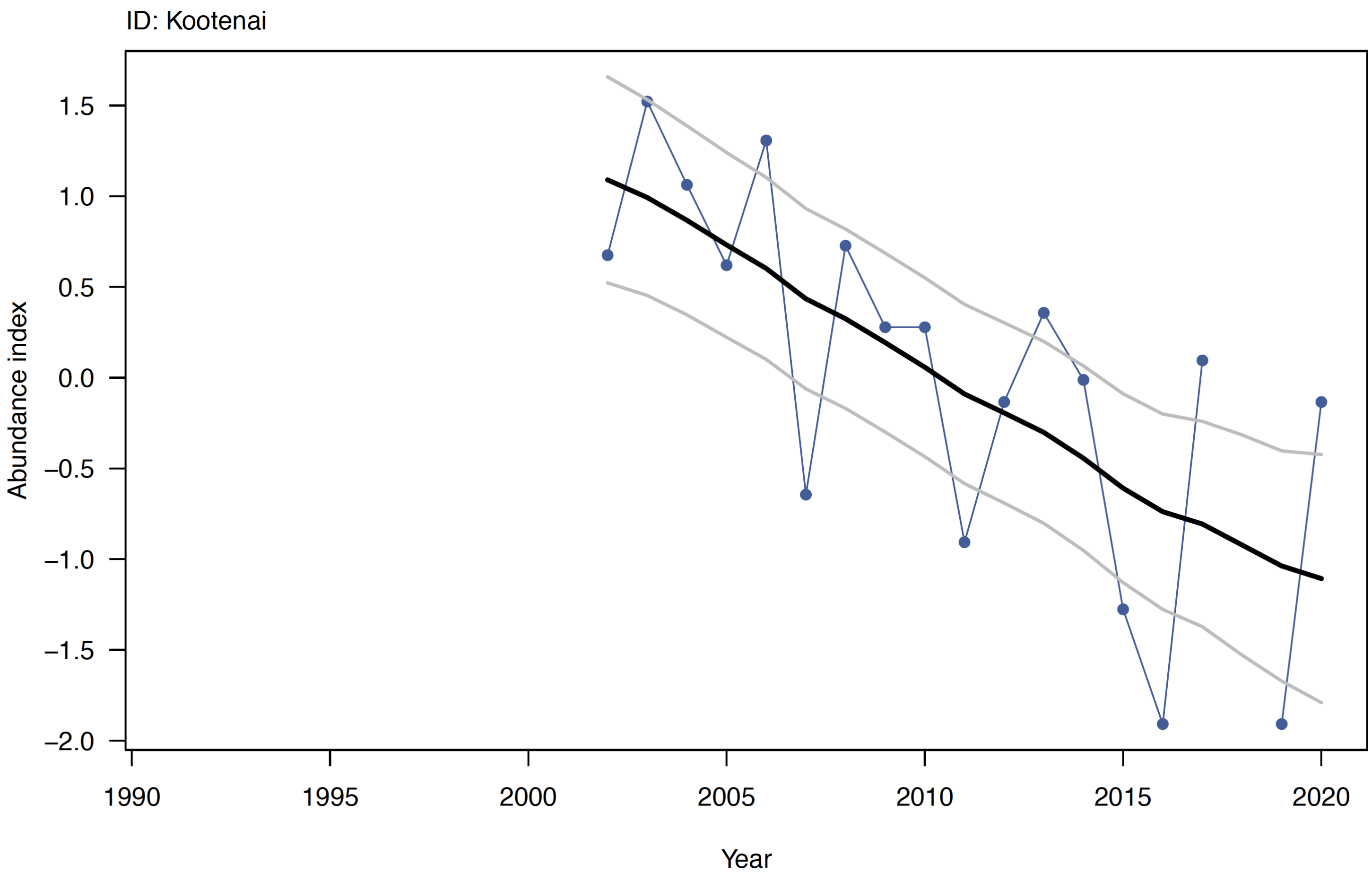
RESULTS

Bias in trends

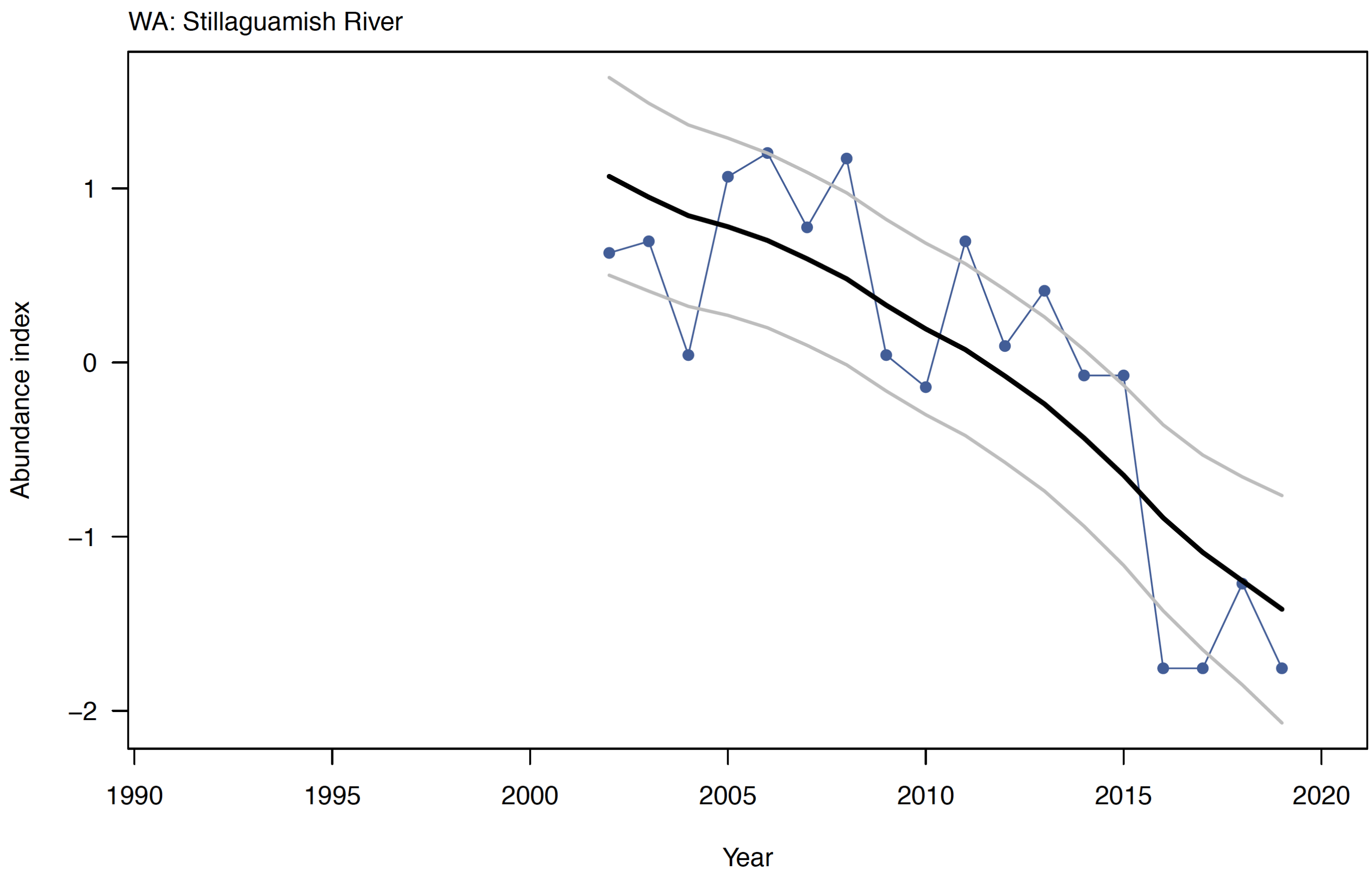
35/61 core areas had a negative trend

But only 3/61 were "signficantly" negative

Example of a significant decline



Example of a significant decline



Bias in trends

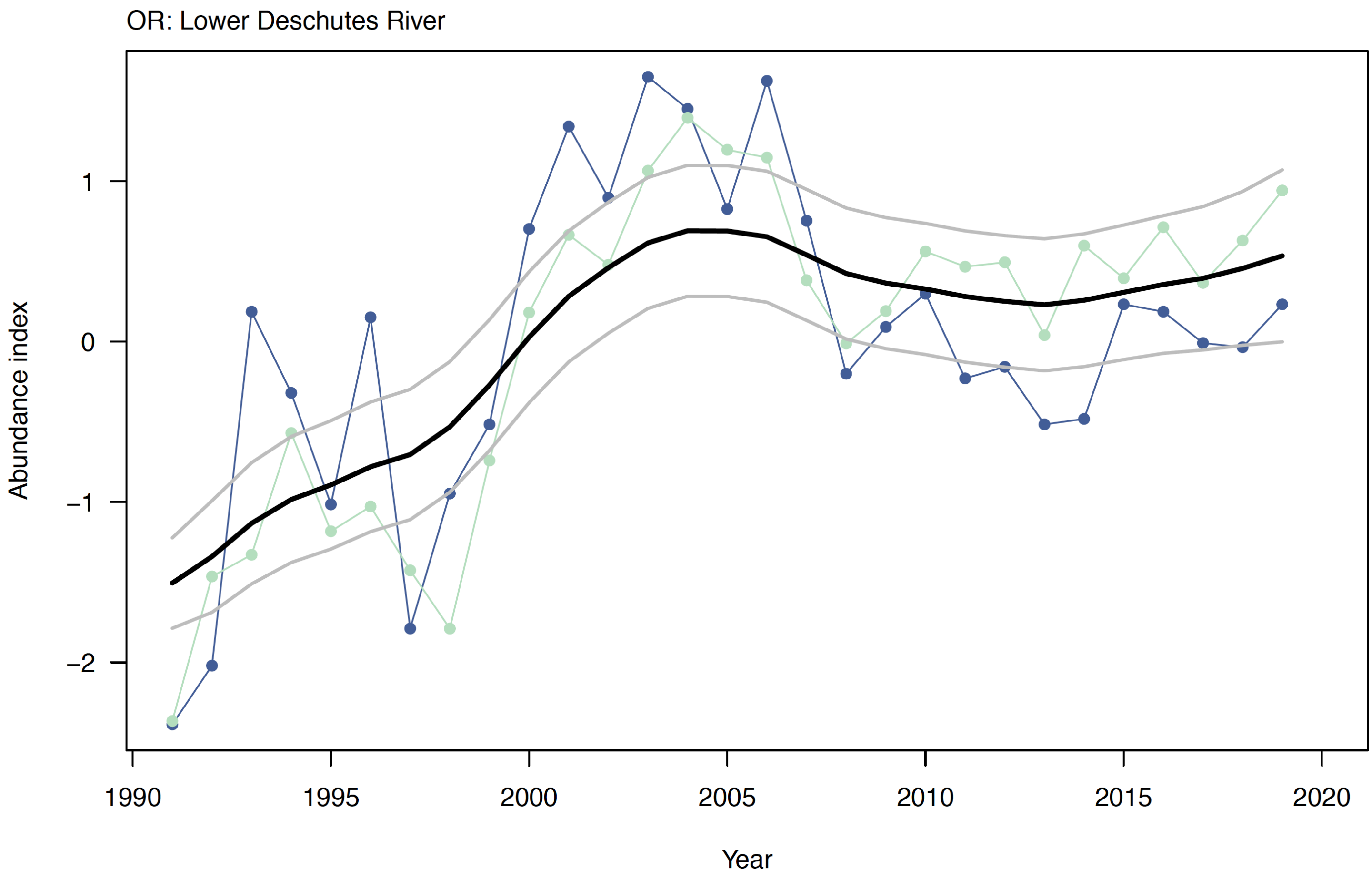
35/61 core areas had a negative trend

But only 3/61 were "signficantly" negative

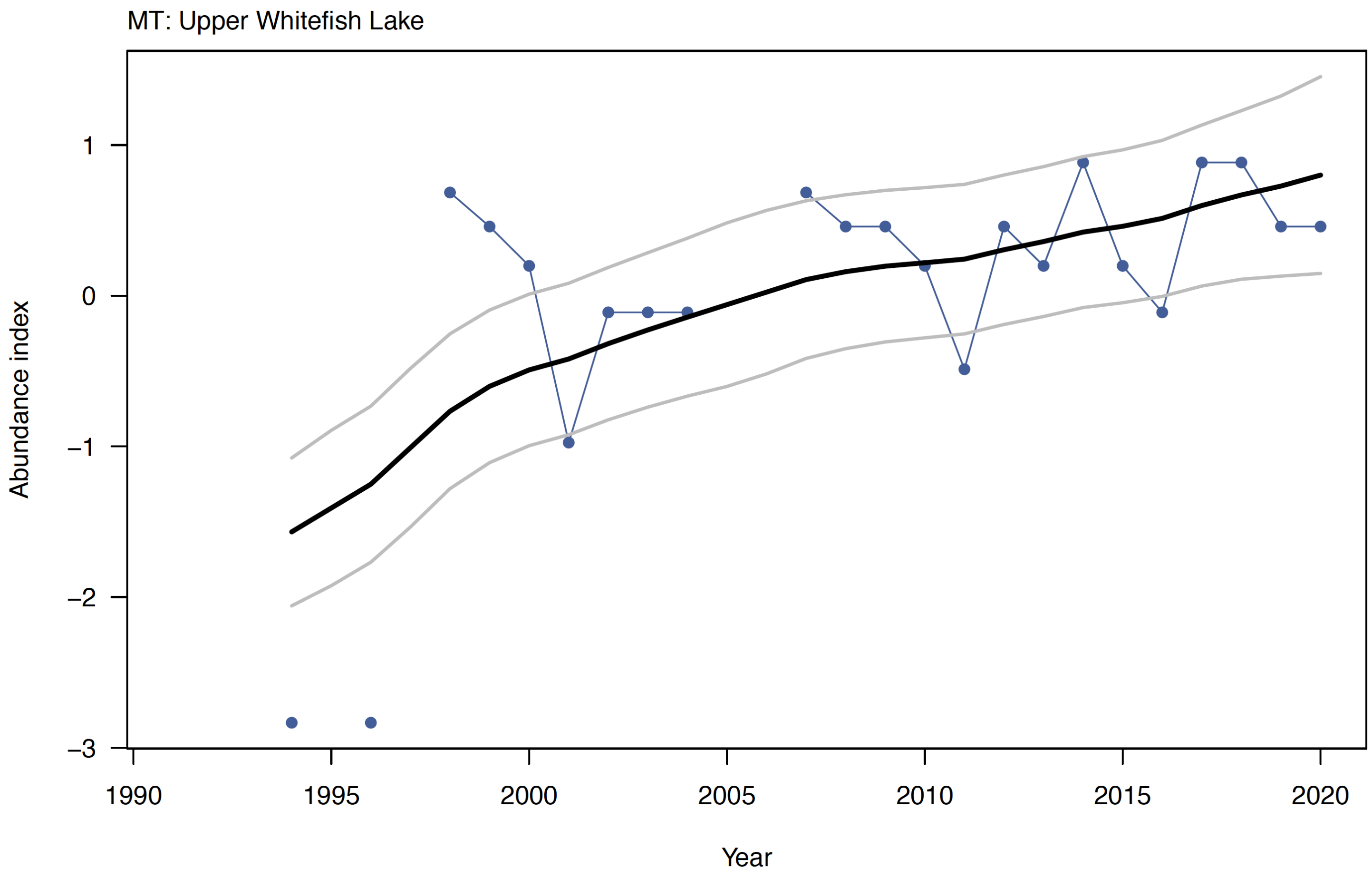
26/61 core areas had a positive trend

But only 6/61 were "signficantly" positive

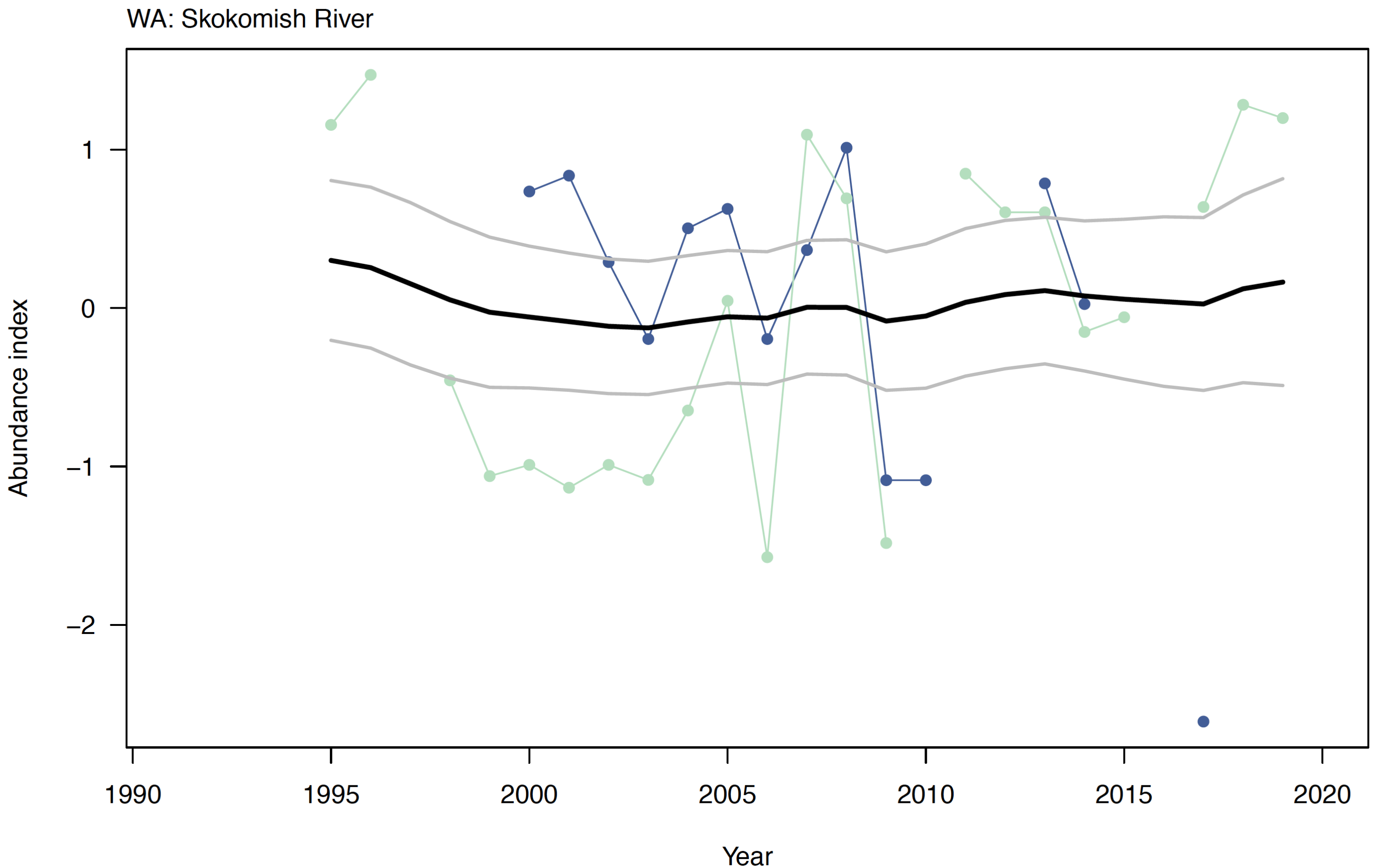
Example of a significant increase



Example of a significant increase

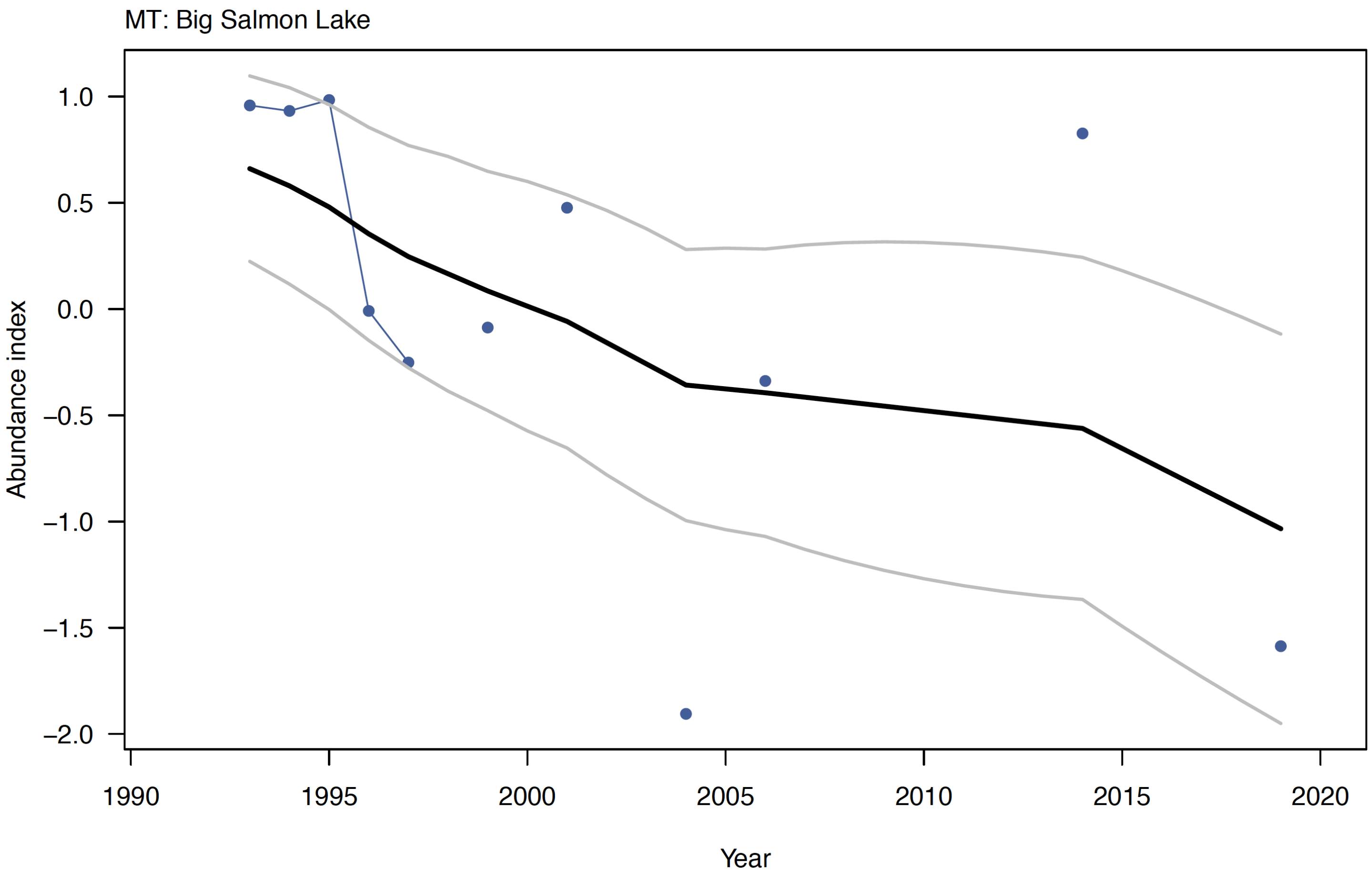


Example of no systematic trend

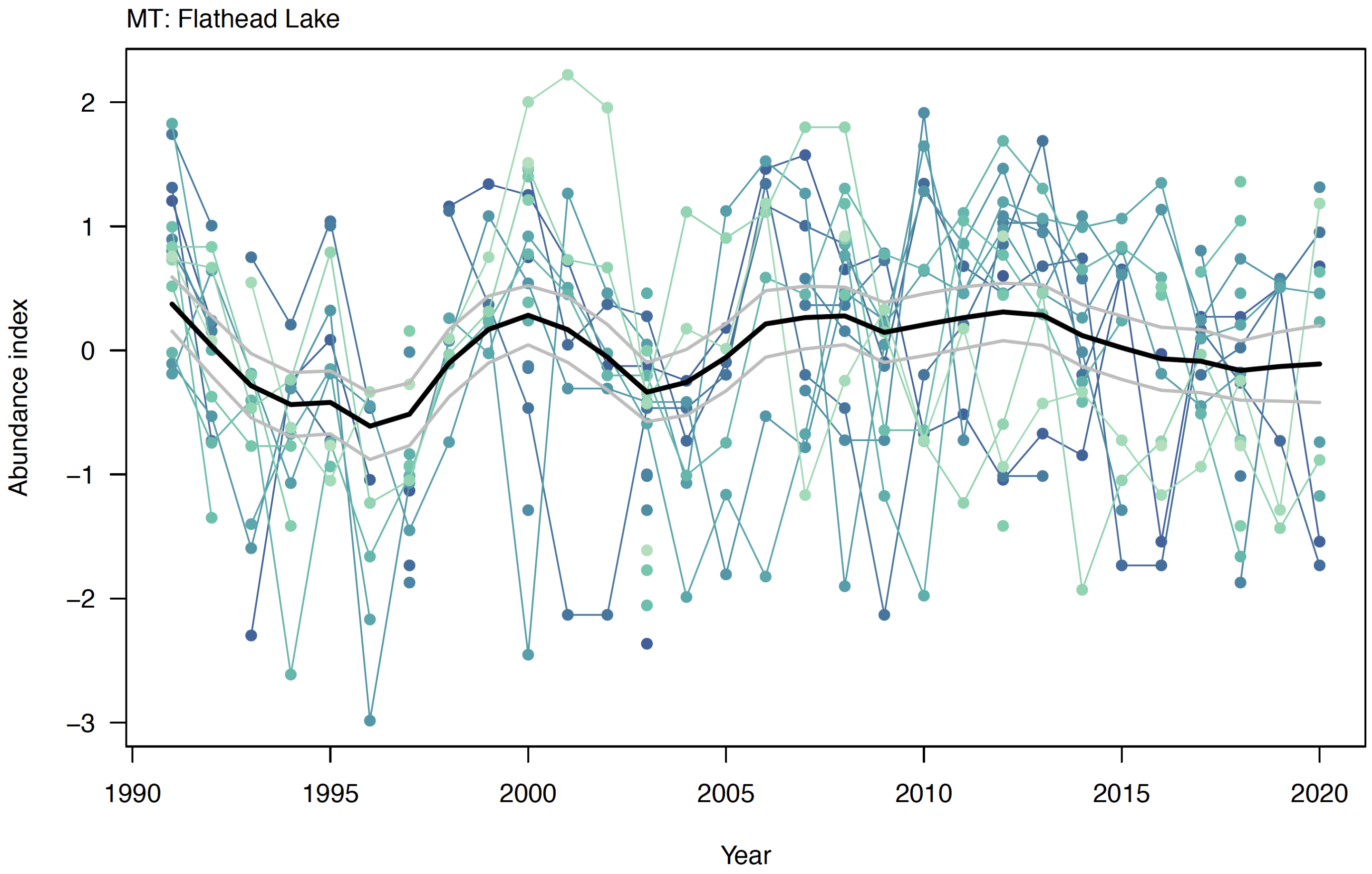


Data quality influences our ability to estimate biases

Example of a data-poor core area



Example of a data-rich core area



In summary

We found minimal evidence of systematic biases in estimated trends

~5% of core areas were declining signficantly

~10% of core areas were increasing signficantly

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Next steps

Complete a similar analysis with juvenile data

Use fitted models to project trends into the future

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Open science

https://github.com/mdscheuerell/bulltrout

Image sources

Carnival: *Frank Kovalchek (2010)*
Robin Hood: *John Escott*

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