Estimating trends in the abundance of threatened bull trout across the Pacific Northwest

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Endangered Species Act of 1973

> The purpose of the ESA is to protect and recover imperiled species and the ecosystems upon which they depend.

There are over 1500 species listed under the Endangered Species Act

ESA status reviews

Required every 5 years to ensure listed species have appropriate protections

Considerations include

- population trends, distribution, demographics & genetics
- habitat conditions
- past conservation measures that have benefited the species
- status & trends of threats

Surely this process is easy given all of the data we have!


DON'T SEE
DON'T HEAR
DON'T SPEAK

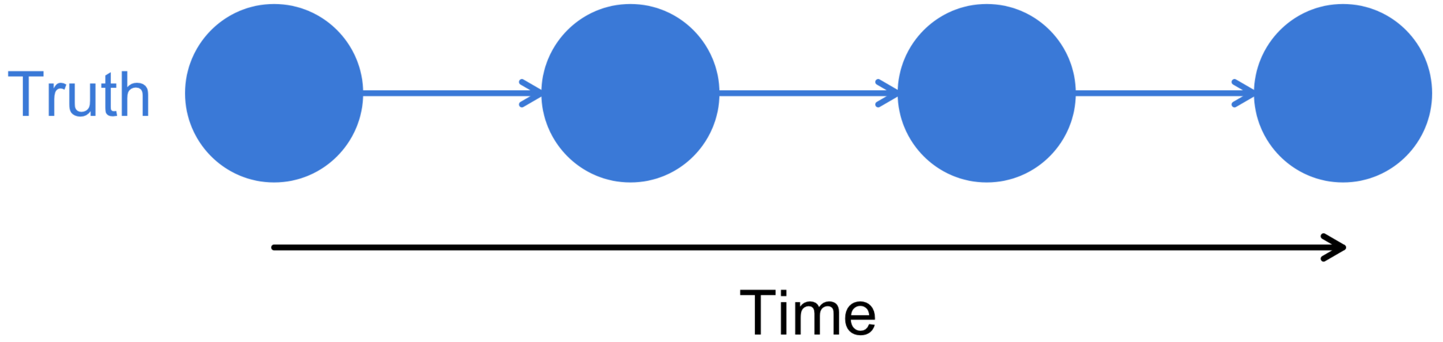
Most of the data are gappy, noisy, and come from disparate sources

Q: How can we use this information to inform decisions?

A: For trends over time, one option is a state-space model

Part 1: State model

Describes the true state of nature over time



States of nature might be

Animal location

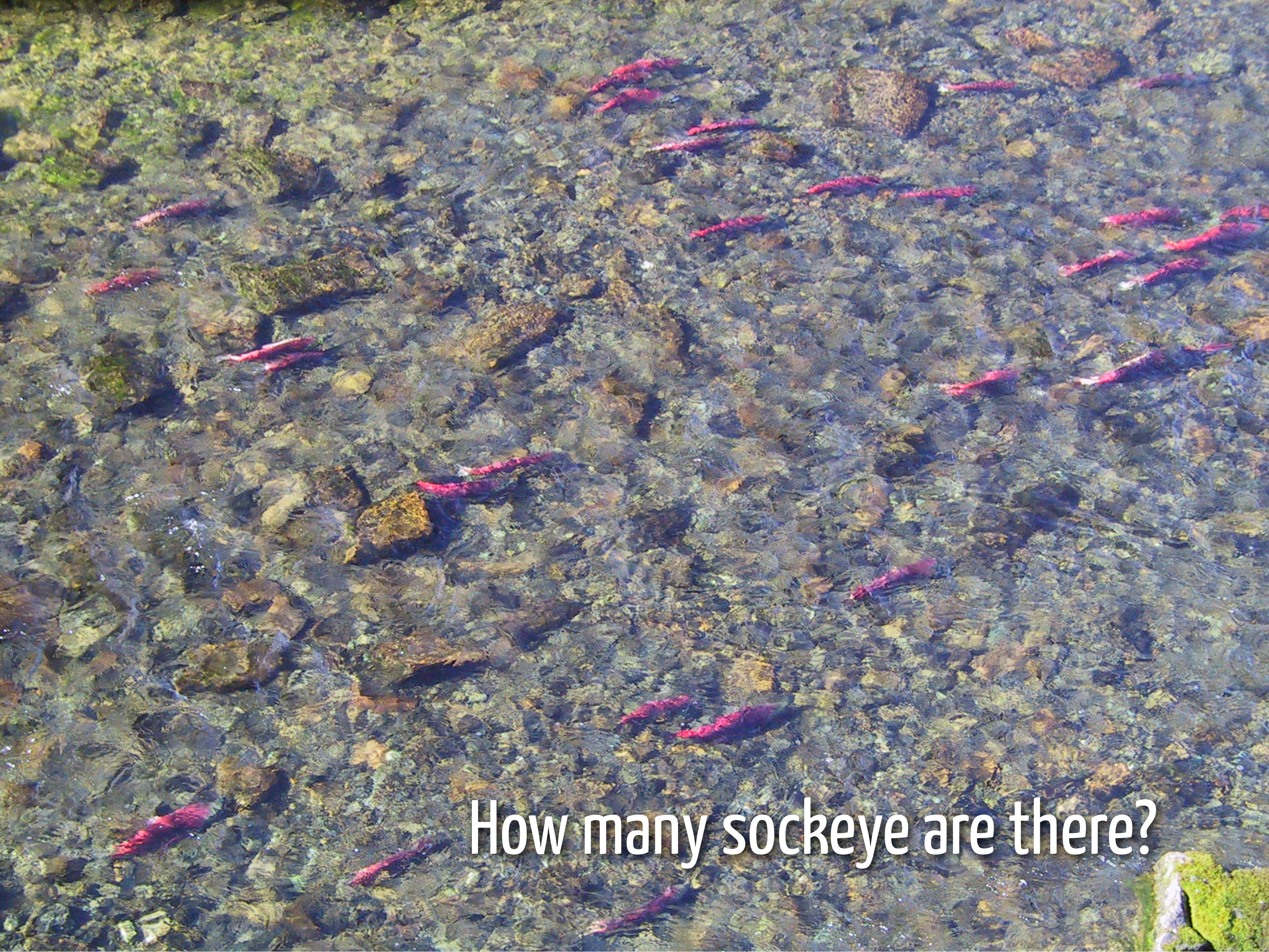
Species density

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

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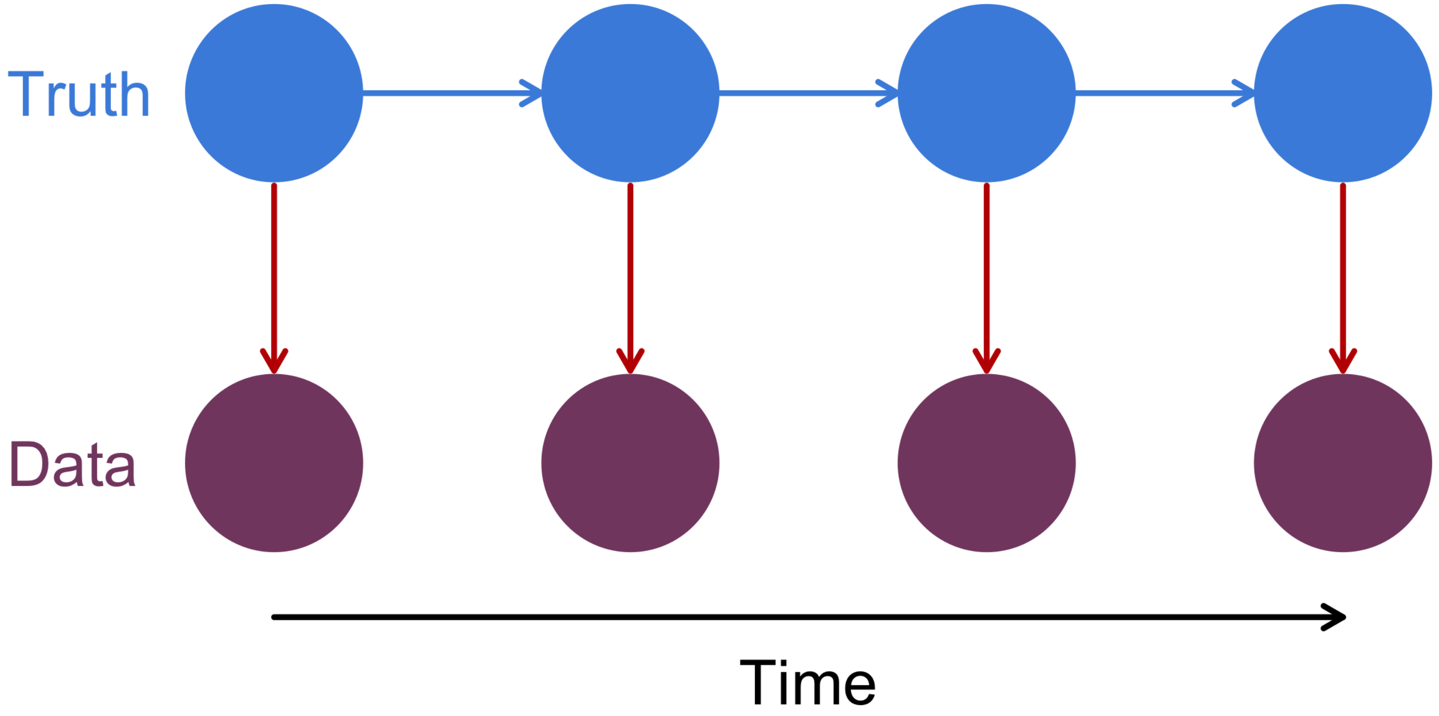
Data = Truth ± Errors



OK, but why bother?

Advantages

1. Can combine many different data types

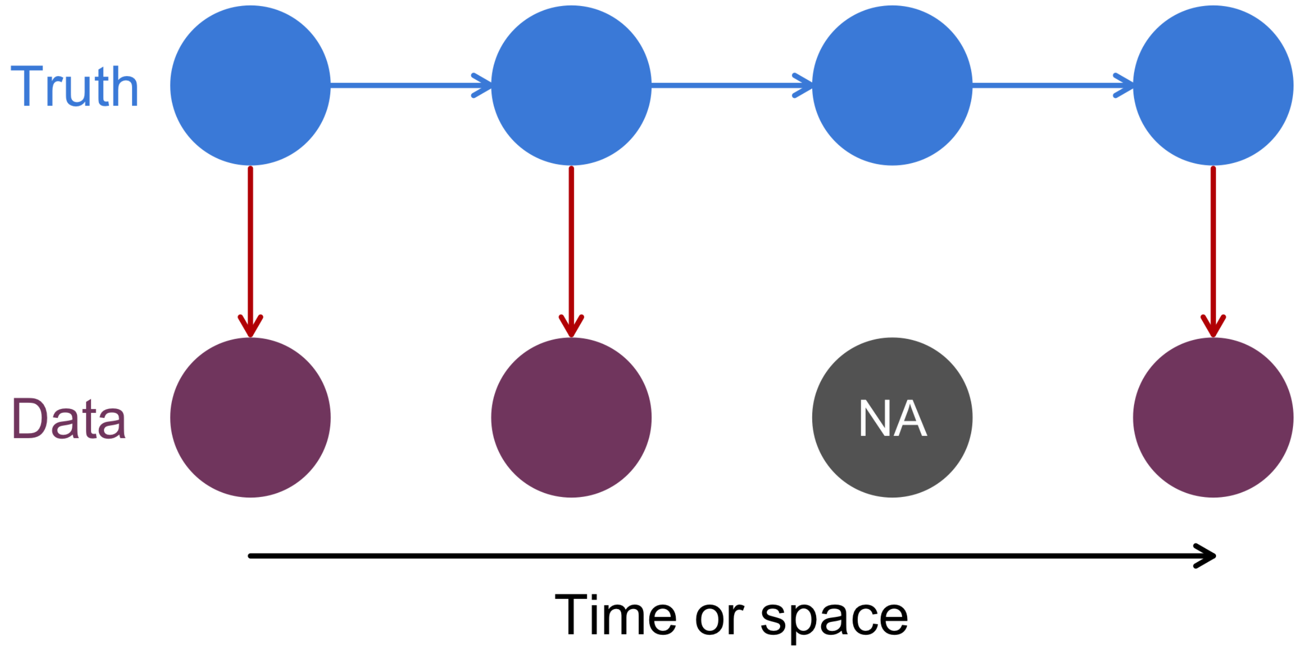
Changes in observers or sensors

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

Bull trout in the Pacific Northwest

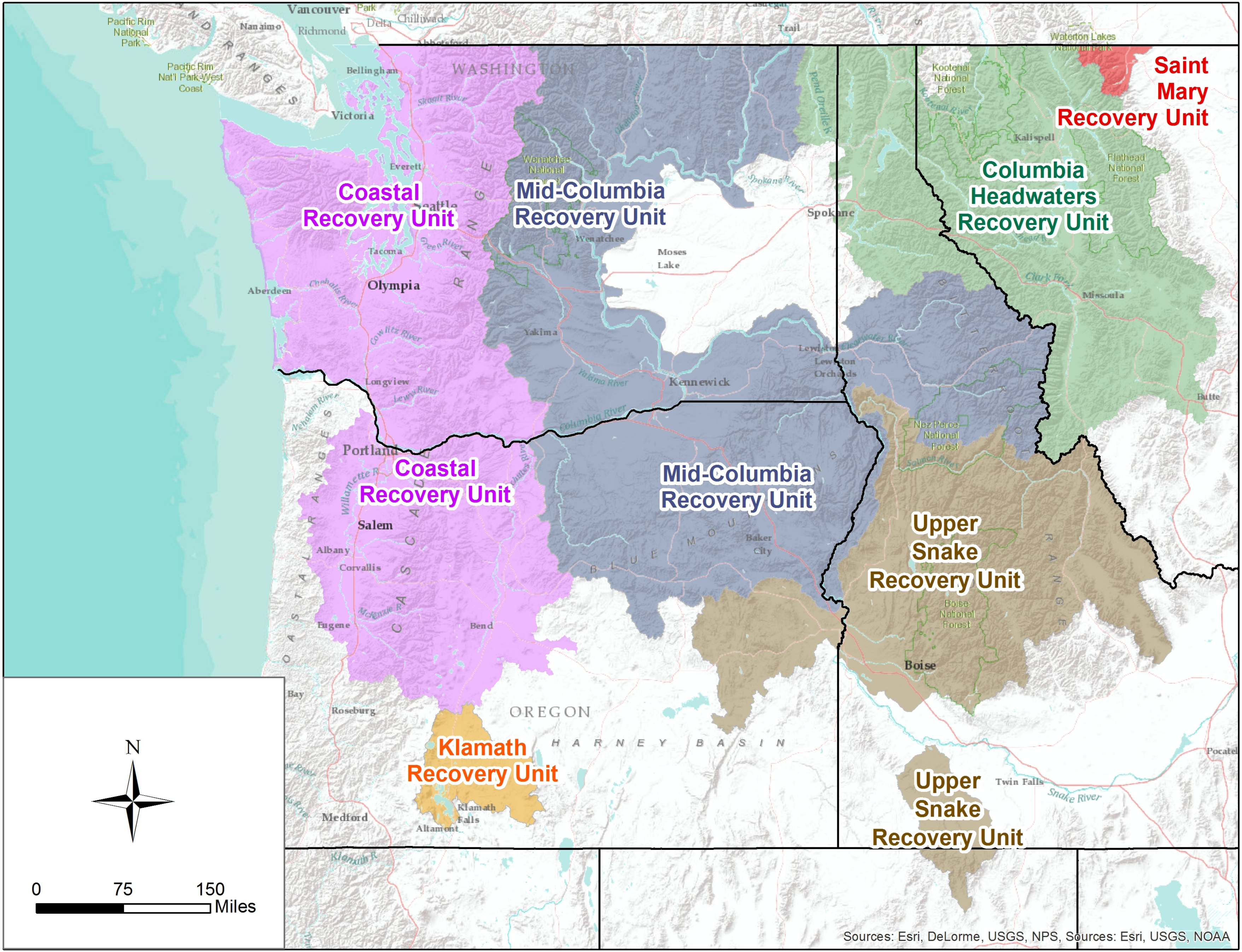
Bull trout *Salvelinus confluentus*

Native to the Pacific Northwest & Canada

4 different life histories (resident, riverine, lacustrine, anadromous)

Mature at 4-7 years of age

Listed as threatened under the ESA in 1999



Coastal Recovery Unit
Mid-Columbia Recovery Unit
Columbia Headwaters Recovery Unit
Saint Mary Recovery Unit
Coastal Recovery Unit
Mid-Columbia Recovery Unit
Upper Snake Recovery Unit
Klamath Recovery Unit
Upper Snake Recovery Unit
WASHINGTON
OREGON
HARNEY BASIN
N
0 75 150 Miles
Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA

Model for the state of nature

Simple model of population dynamics

Exponential growth/decline in continuous time

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

Simple model of population dynamics

In discrete time, with a time step of 1 year

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

Simple model of population dynamics

In discrete time, with a time step of 1 year

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

and on a log scale

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

which we can rewrite as

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

Biased random walk

If we assume that the errors are white noise

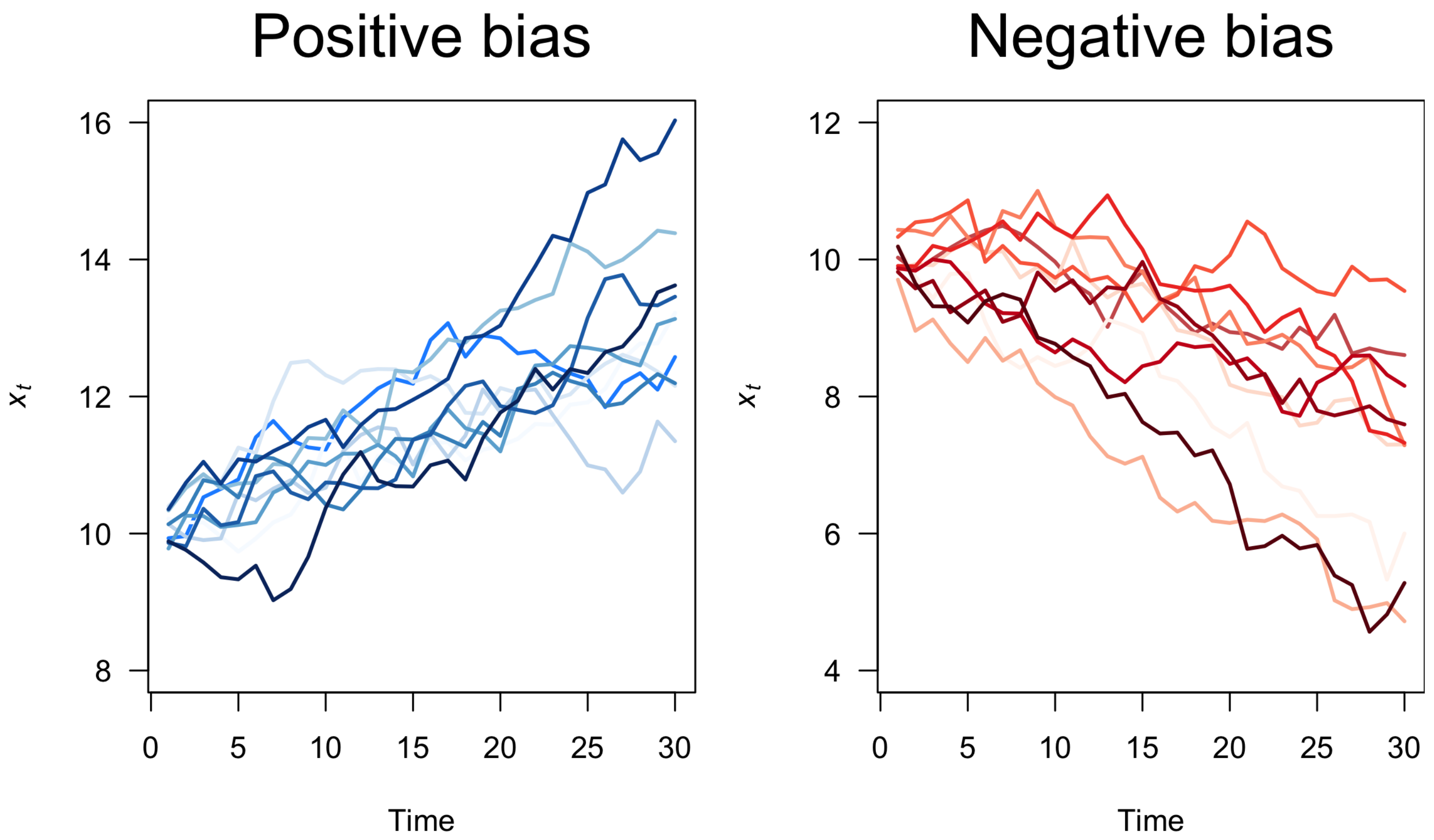
$$w_t \sim \mathrm{N}(0, q)$$

then our model of populations dynamics

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

is a *biased random walk*

Examples of biased random walks



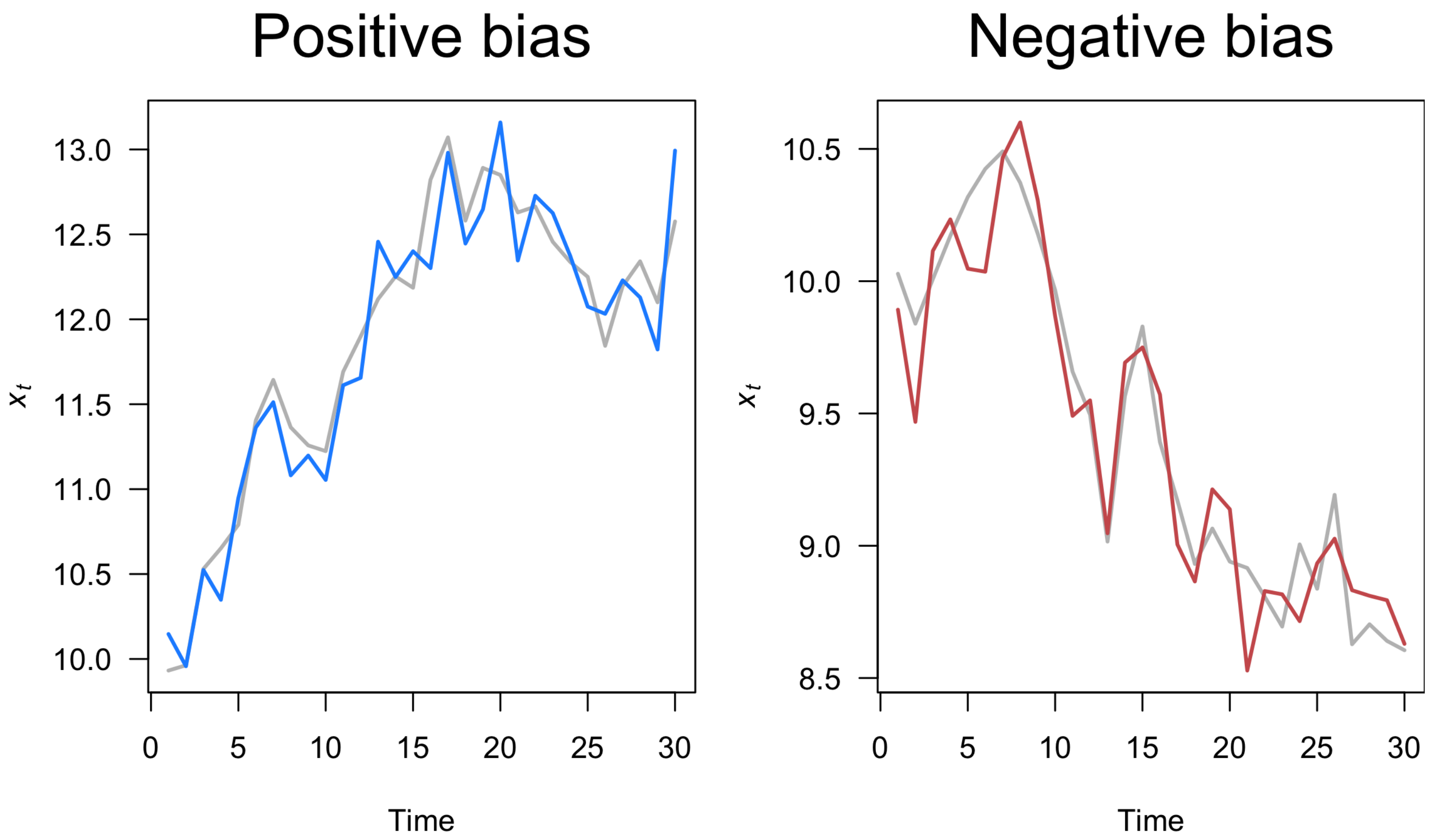
Observation (data) model

Observation model

In log-space

$$\underbrace{y_t}_{\text{observed counts}} = \underbrace{x_t}_{\text{true counts}} + \underbrace{v_t}_{\text{observer error}} \quad \text{with } \; v_t \sim \mathrm{N}(0, r)$$

Example: biased RW's with observation error



Multiple time series of abundance

The survey data are hierarchical

4 states

6 recovery units

62 core areas

242 populations

Expanding our model for multiple core areas

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

Each core area gets its own model

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

Observation model for multiple time series

Core areas have 1-22 populations within them

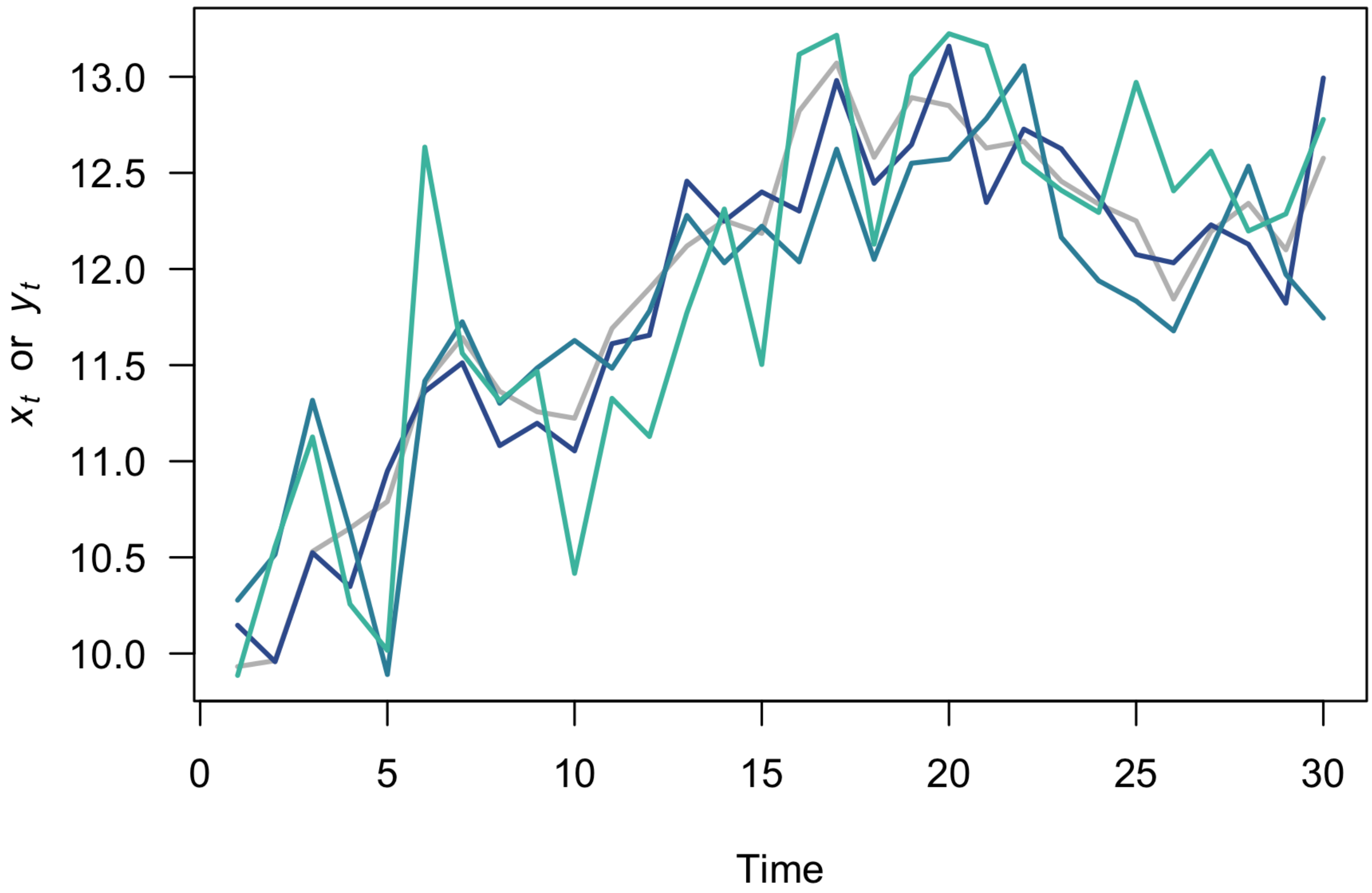
Each population is an observation from its respective core area

Observation model for multiple time series

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

$$
\begin{array}{c}
y_{1,t} = x_A + v_{1,t} \\
y_{2,t} = x_A + v_{2,t} \\
\hline
y_{3,t} = x_B + v_{3,t} \\
y_{4,t} = x_B + v_{4,t} \\
y_{5,t} = x_B + v_{5,t}
\end{array}
$$

Example: 3 observations of a common state



Varying sampling methods

Varying sampling methods

Different methods have different levels of observation errors
(eg, weir counts are more accurate than snorkel surveys)

Multiple surveys of each type help inform the variance estimates

Fitting the models

We used the 30-year time period from 1991-2020

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

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

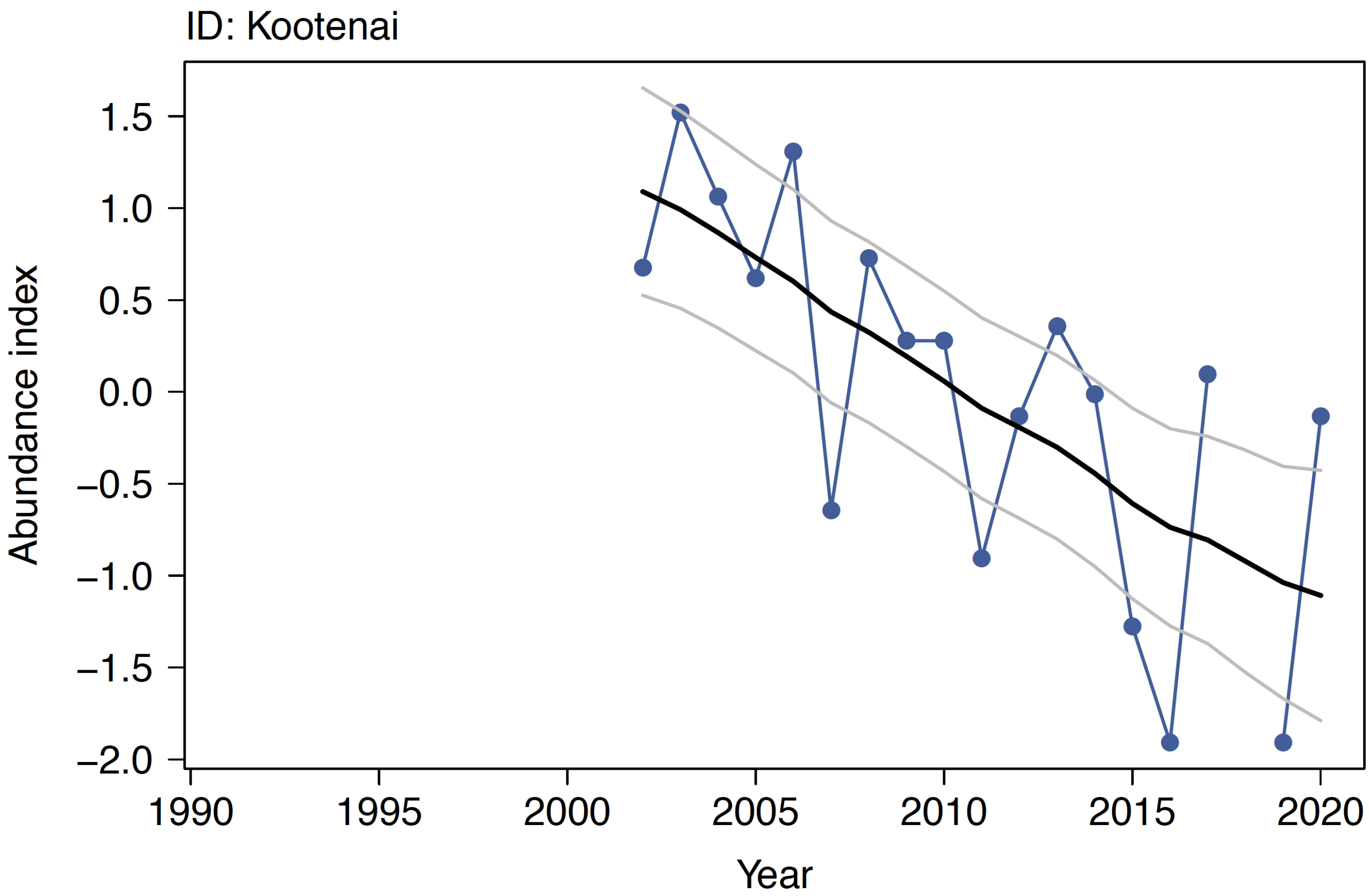
I estimated 90% confidence intervals on bias terms

Bias in trends

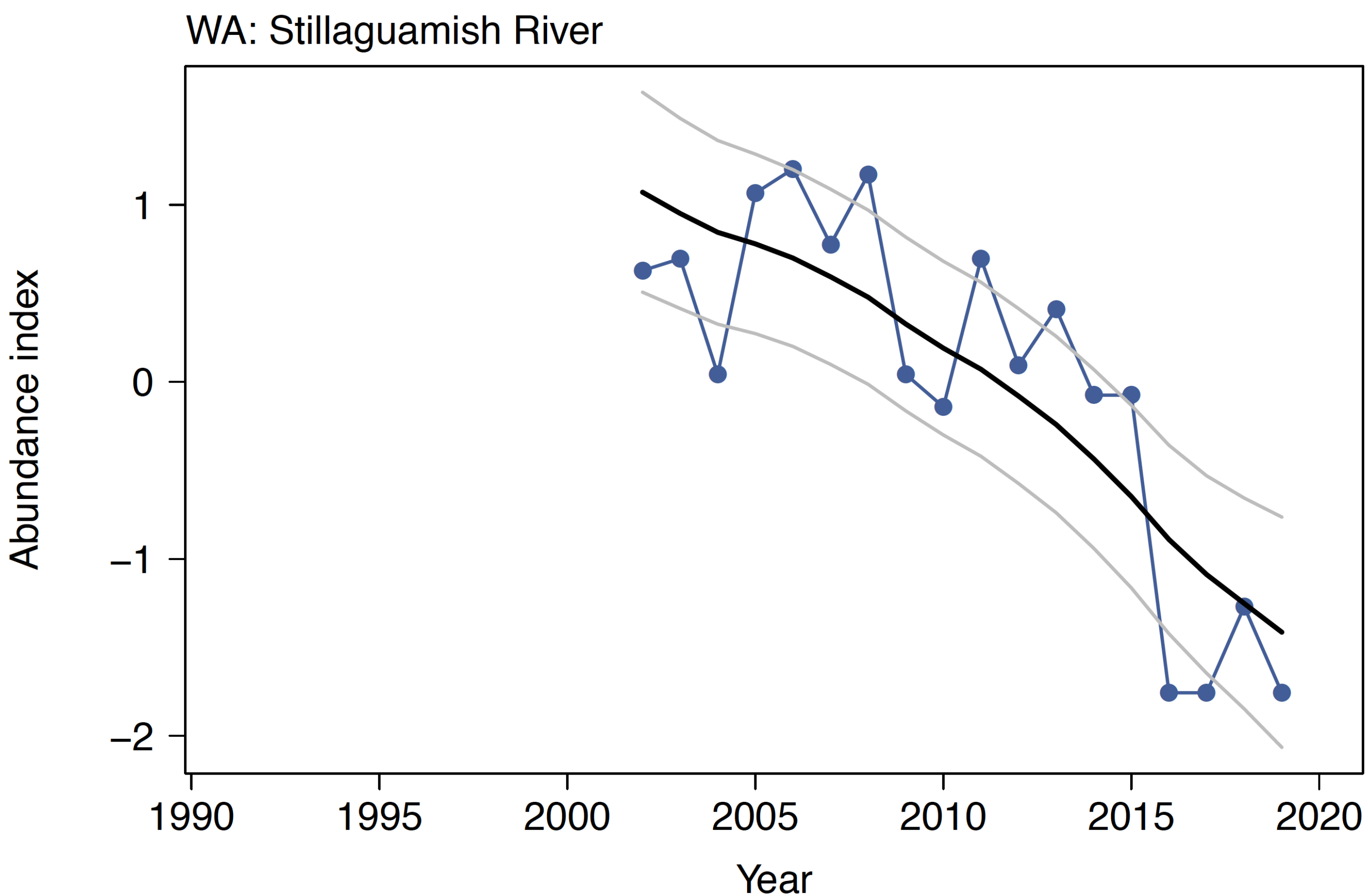
37/62 core areas had a negative trend

but only 3/62 were "significantly" negative

Example of a significant decline



Example of a significant decline



Bias in trends

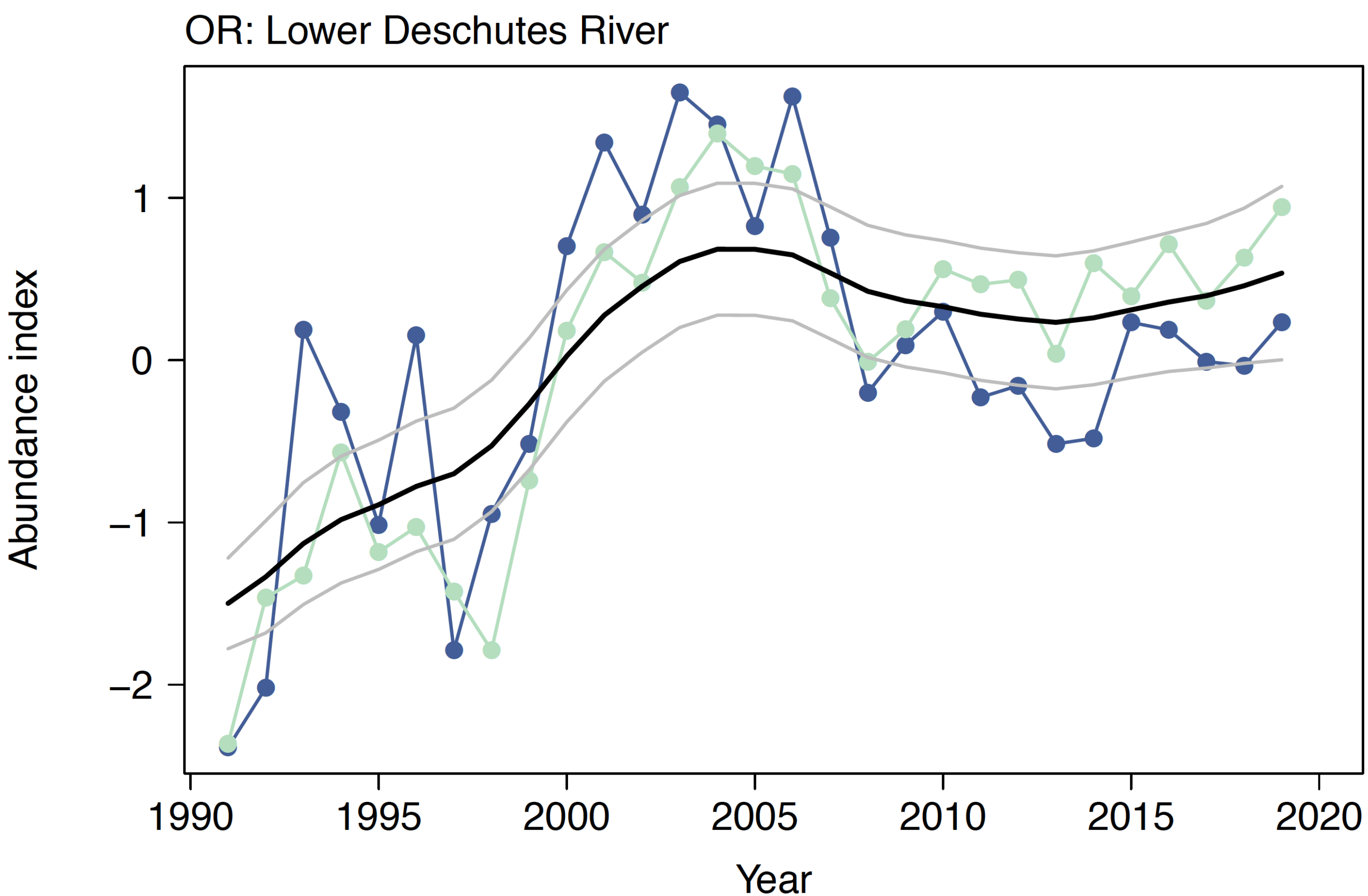
37/62 core areas had a negative trend

but only 3/62 were "significantly" negative

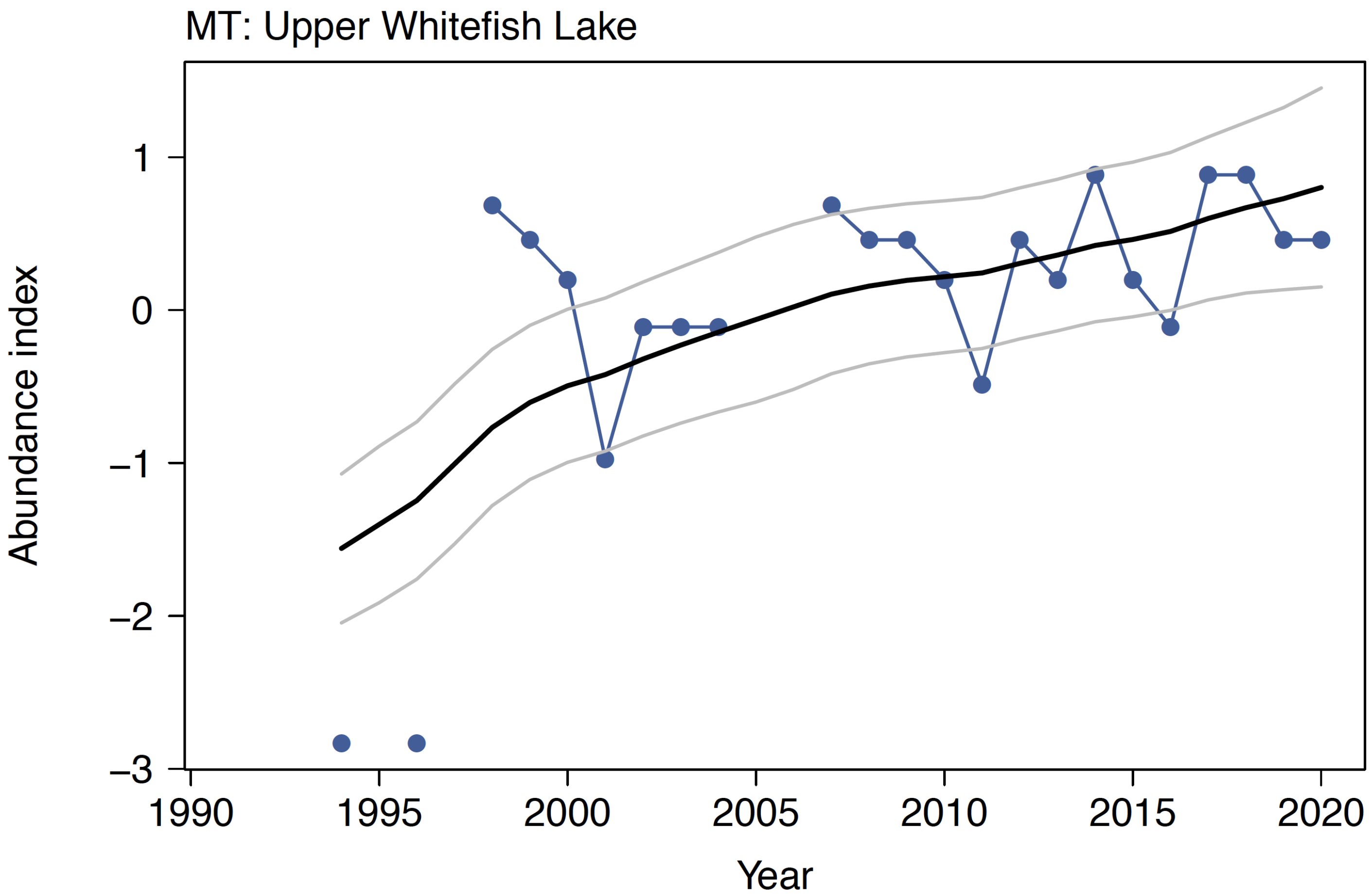
25/62 core areas had a positive trend

but only 5/62 were "significantly" positive

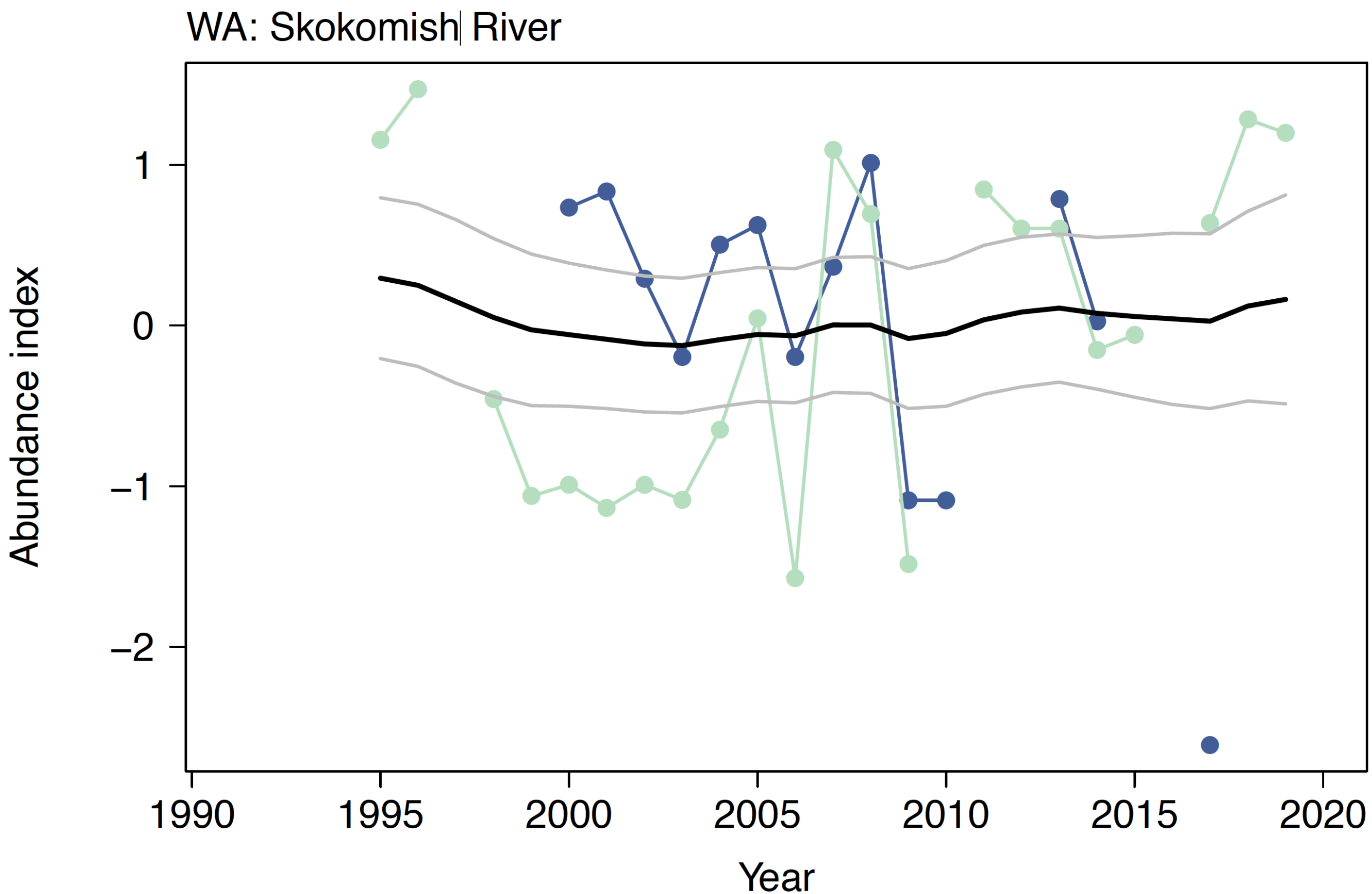
Example of a significant increase



Example of a significant increase

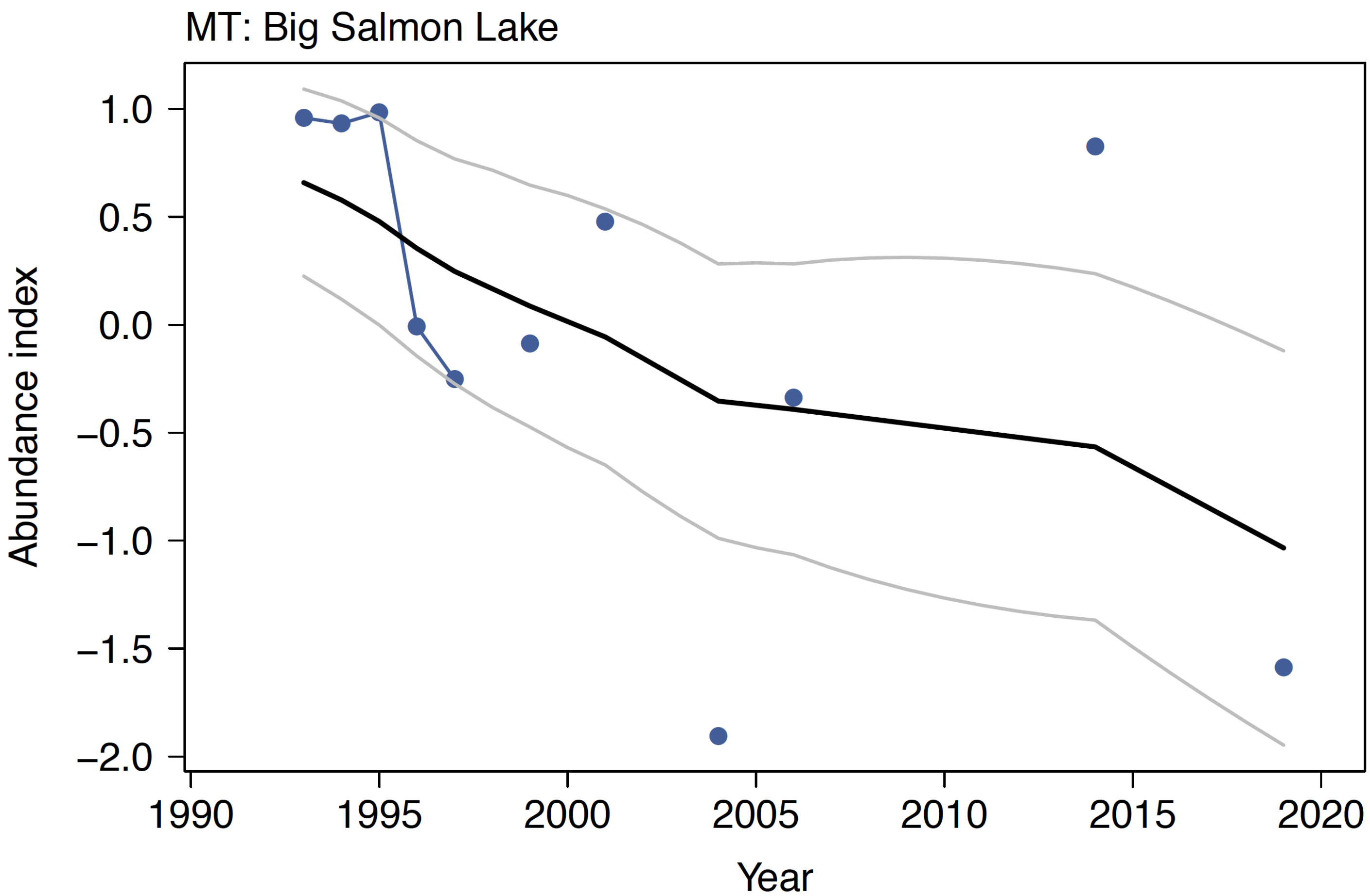


Example of no systematic trend

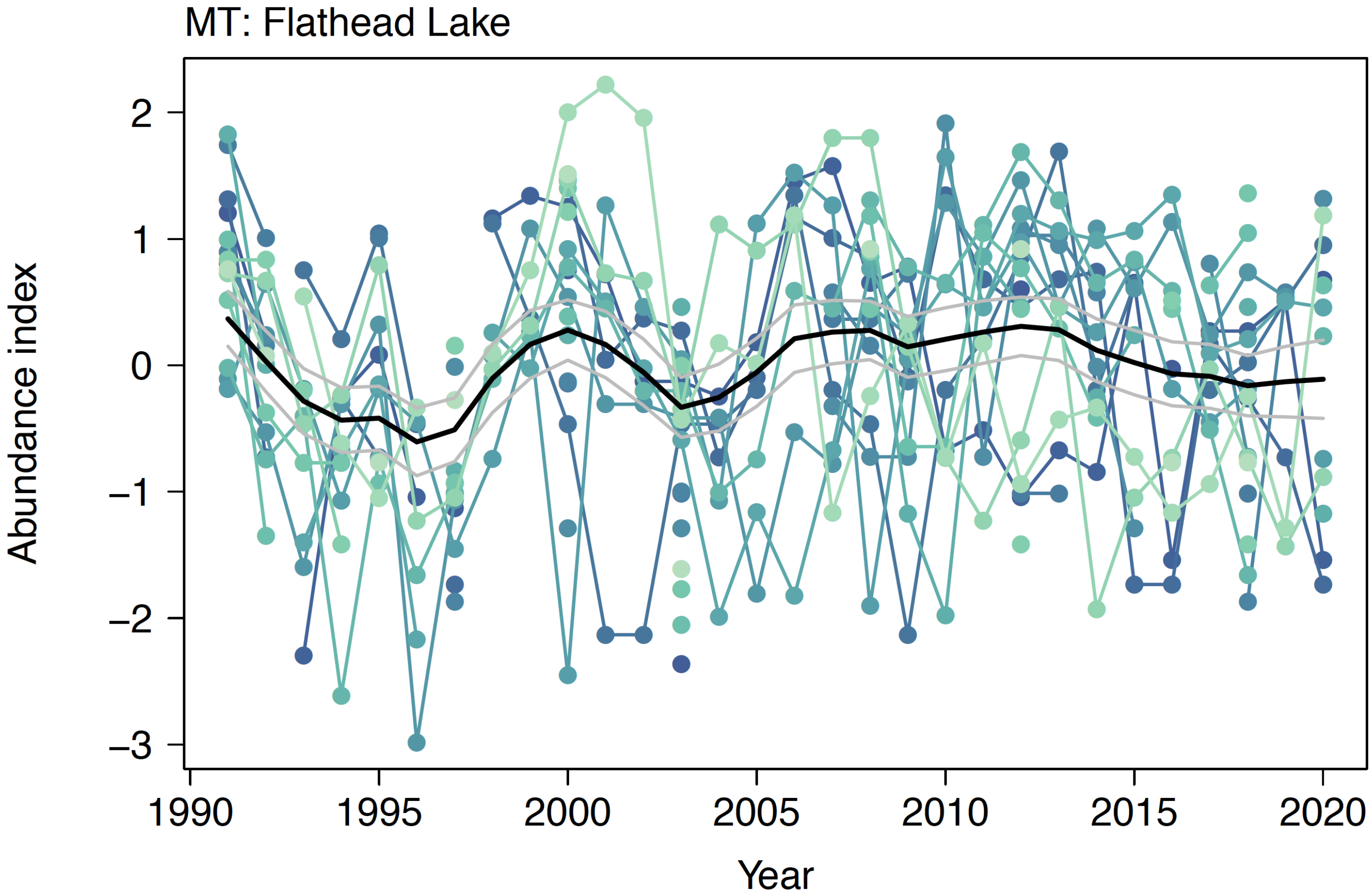


Data quality influences our ability to estimate biases

Example of a data-poor core area



Example of a data-rich core area



Big picture

Status of bull trout in the Pacific Northwest is mixed

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Big picture

Status of bull trout in the Pacific Northwest is mixed

Data quality affects our ability to assess trends

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Big picture

Status of bull trout in the Pacific Northwest is mixed

Data quality affects our ability to assess trends

State-space models can help

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Open science

https://github.com/mdscheuerell/bulltrout

Image credits

Chimps: ***Lantern Press***

Carnival: ***Frank Kovalchek***

Robin Hood: ***John Escott***

Bull trout sampling: ***Brett Bowersox***

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