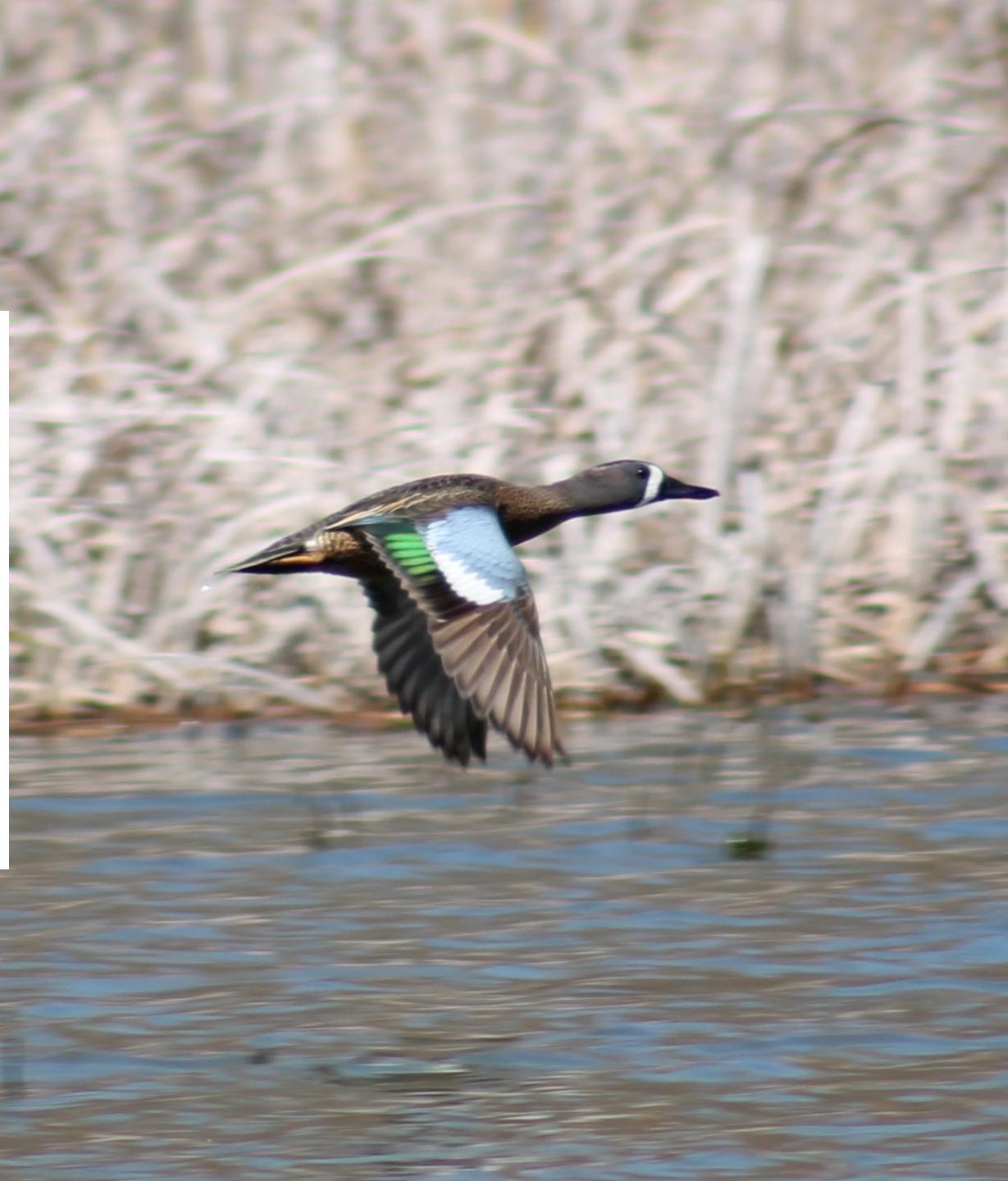


# MOVEMENT MODELS



# Model types

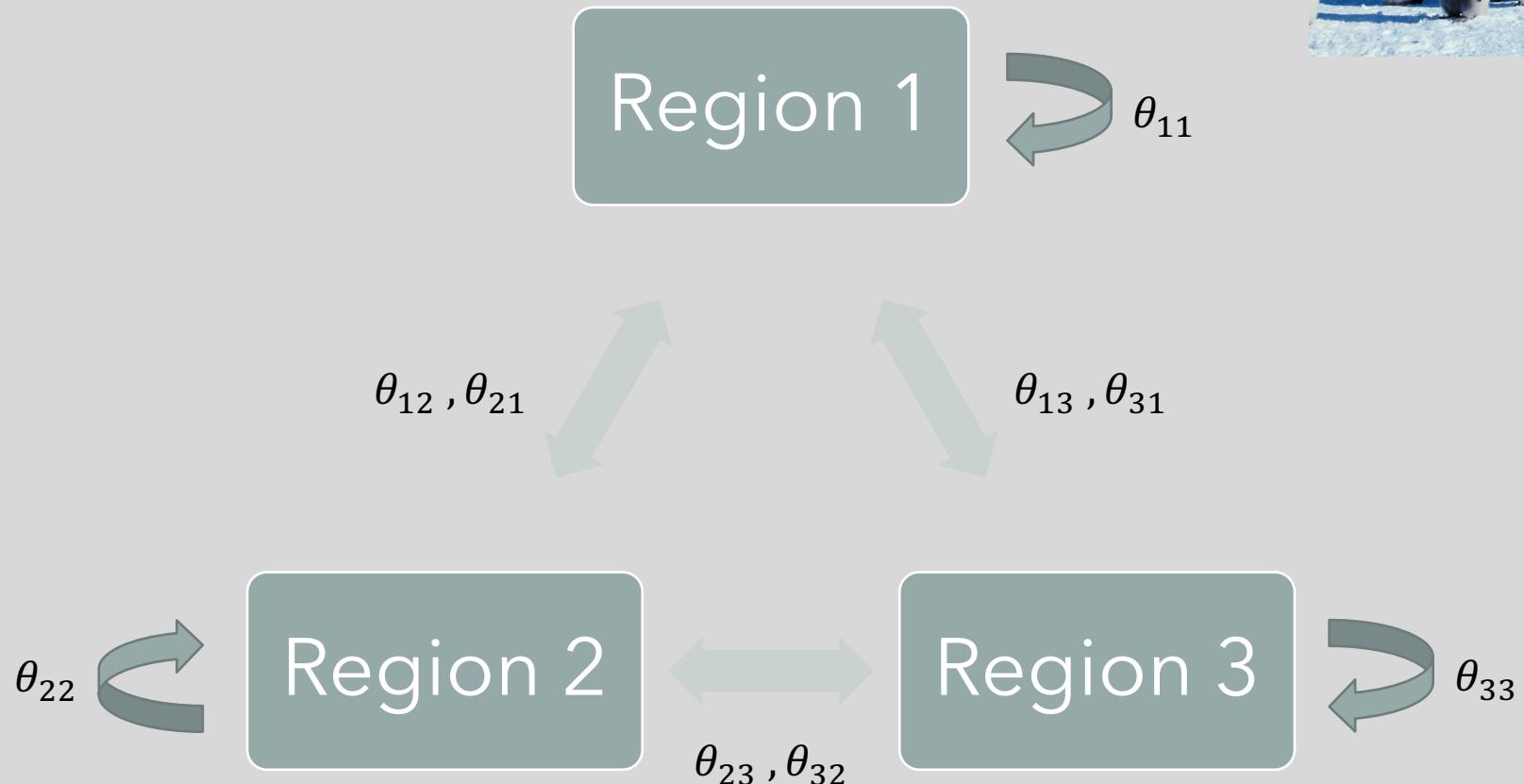
## Discrete

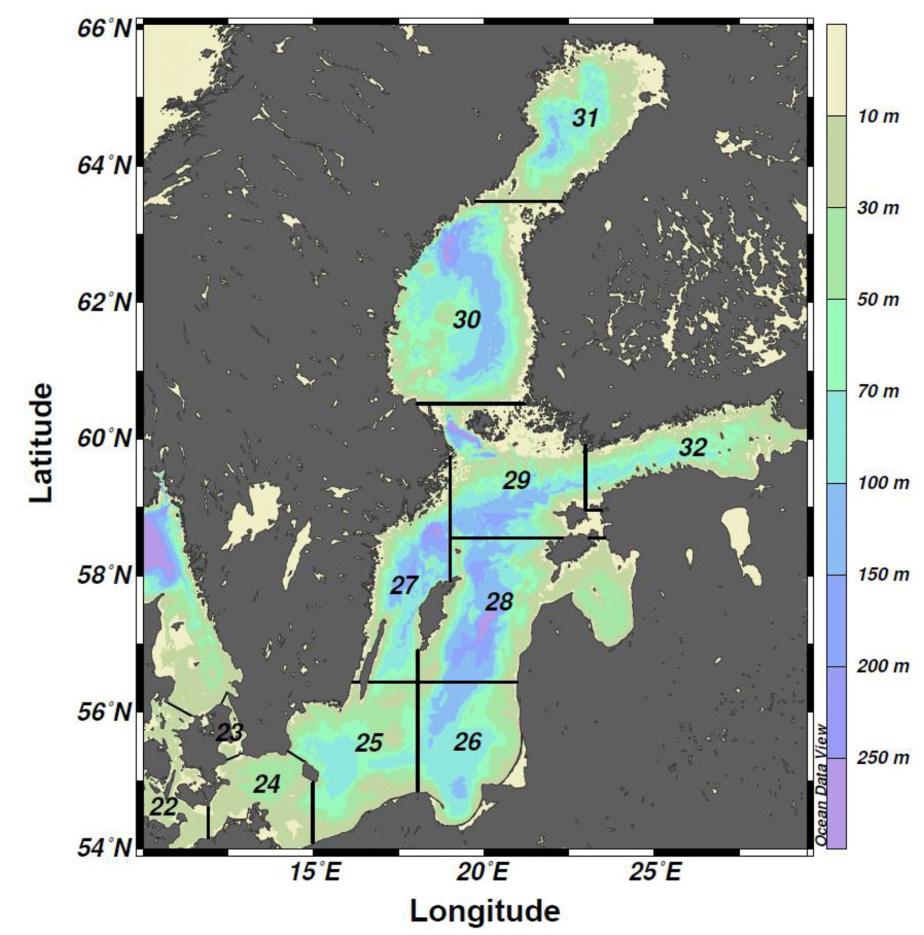
- Time
  - Evenly spaced time steps
  - Transition matrix and initial distribution
- Space
  - Homogeneous regions
  - Sets of environmental variables

## Continuous

- Time
  - Random waiting times between jumps
  - Transition matrix, initial distribution, and distribution for waiting times
- Space
  - Variable habitat
  - Environment depends on organism perception

# Between regions





# Spatial methods

- Separate models by regions
  - If movement is negligible and regions are definable
  - Stratified random sampling
- Data: mark-Recapture
  - Modifications for estimating movement among regions e.g. Darroch method
- Markov process
  - If movement among different regions is significant
  - Discrete or continuous depending on data source and organism
- Considerations
  - Jurisdiction
  - More parameters means more data

# How do we include movement?

- It can be included in just about any of the population models we've talked about
- Often treated as a probability or proportion moving among discrete regions
  - Perhaps augmented by habitat data
- Often treated as a continuous diffusion-like process
  - Sometimes with attractors
- Need estimates of movement within the population **at the proper scale**
- Let's do an example with...



Leslie matrix models! (redux redux<sub>redux</sub>)

$$N_{t+1} = MN_t$$

Recall...

$$\mathbf{N}_{t+1} = \mathbf{M}\mathbf{N}_t$$
$$\begin{pmatrix} N_{1,t+1} \\ N_{2,t+1} \\ N_{3,t+1} \\ \vdots \\ N_{A,t+1} \end{pmatrix} = \begin{pmatrix} S_0f_1 & S_0f_2 & S_0f_3 & \cdots & S_0f_A \\ S_1 & 0 & 0 & \cdots & 0 \\ 0 & S_2 & 0 & 0 & \cdots & 0 \\ \vdots & 0 & \ddots & \vdots & & \vdots \\ 0 & 0 & 0 & S_{A-1} & 0 \end{pmatrix} \begin{pmatrix} N_{1,t} \\ N_{2,t} \\ N_{3,t} \\ \vdots \\ N_{A,t} \end{pmatrix}$$

$f_i$ : fecundity of age class  $i$

$S_i$ : survival probability of age class  $i$

# Assuming 2 regions

$$\begin{bmatrix} N_{1,t+1,1} \\ N_{2,t+1,1} \\ \vdots \\ N_{a,t+1,1} \\ N_{1,t+1,2} \\ \vdots \\ N_{a,t+1,2} \end{bmatrix} = \begin{bmatrix} \mathbf{M}_{11} & \mathbf{M}_{21} \\ \mathbf{M}_{12} & \mathbf{M}_{22} \end{bmatrix} \begin{bmatrix} N_{1,t,1} \\ N_{2,t,1} \\ \vdots \\ N_{a,t,1} \\ N_{1,t,2} \\ \vdots \\ N_{a,t,2} \end{bmatrix}$$

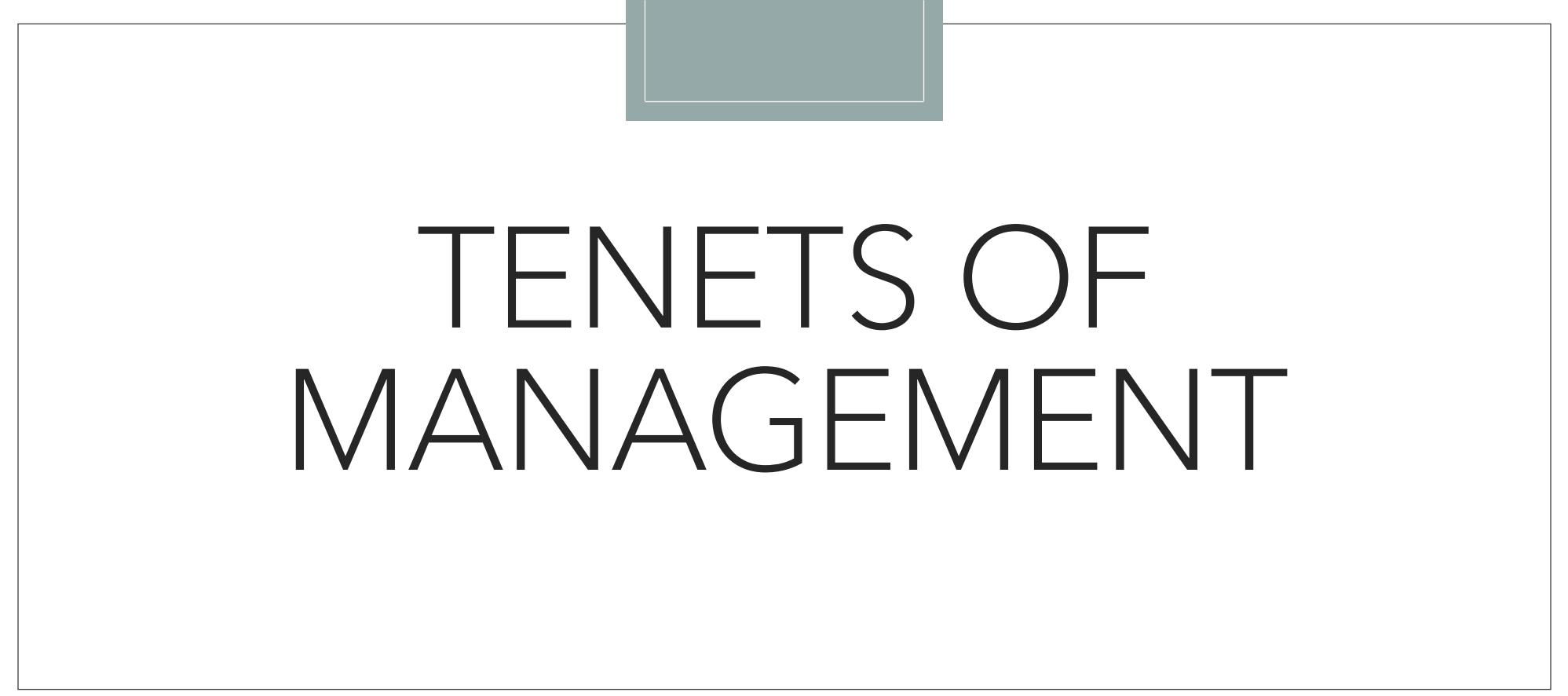
$N_{\text{age},\text{time},\text{region}}$   
 $\mathbf{M}_{\text{region origin},\text{region destination}}$

# Add movement probability

$$\mathbf{M}_{11} = \begin{pmatrix} S_{0,1}f_{1,1} & S_{0,1}f_{2,1} & S_{0,1}f_{3,1} & \cdots & S_{0,1}f_{A,1} \\ S_{1,1}\theta_{1,1 \rightarrow 1} & 0 & 0 & \cdots & 0 \\ 0 & S_{2,1}\theta_{2,1 \rightarrow 1} & 0 & 0 \cdots & 0 \\ \vdots & 0 & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & S_{A-1,1}\theta_{A-1,1 \rightarrow 1} & 0 \end{pmatrix}$$

*age, area*

$$\theta_{\text{age, region a} \rightarrow \text{region b}}$$



# TENETS OF MANAGEMENT

# Units of interest

- Population: individuals of a single species inhabiting a given area
- Meta-population: groups of spatially separated populations which interact in some way
- Community: interacting groups of populations in a given area
- Stock: management unit of one or more species grouped by a relationship relevant to the way in which it is harvested

Biosphere

Biome

Ecosystem

Community

Population

Individual



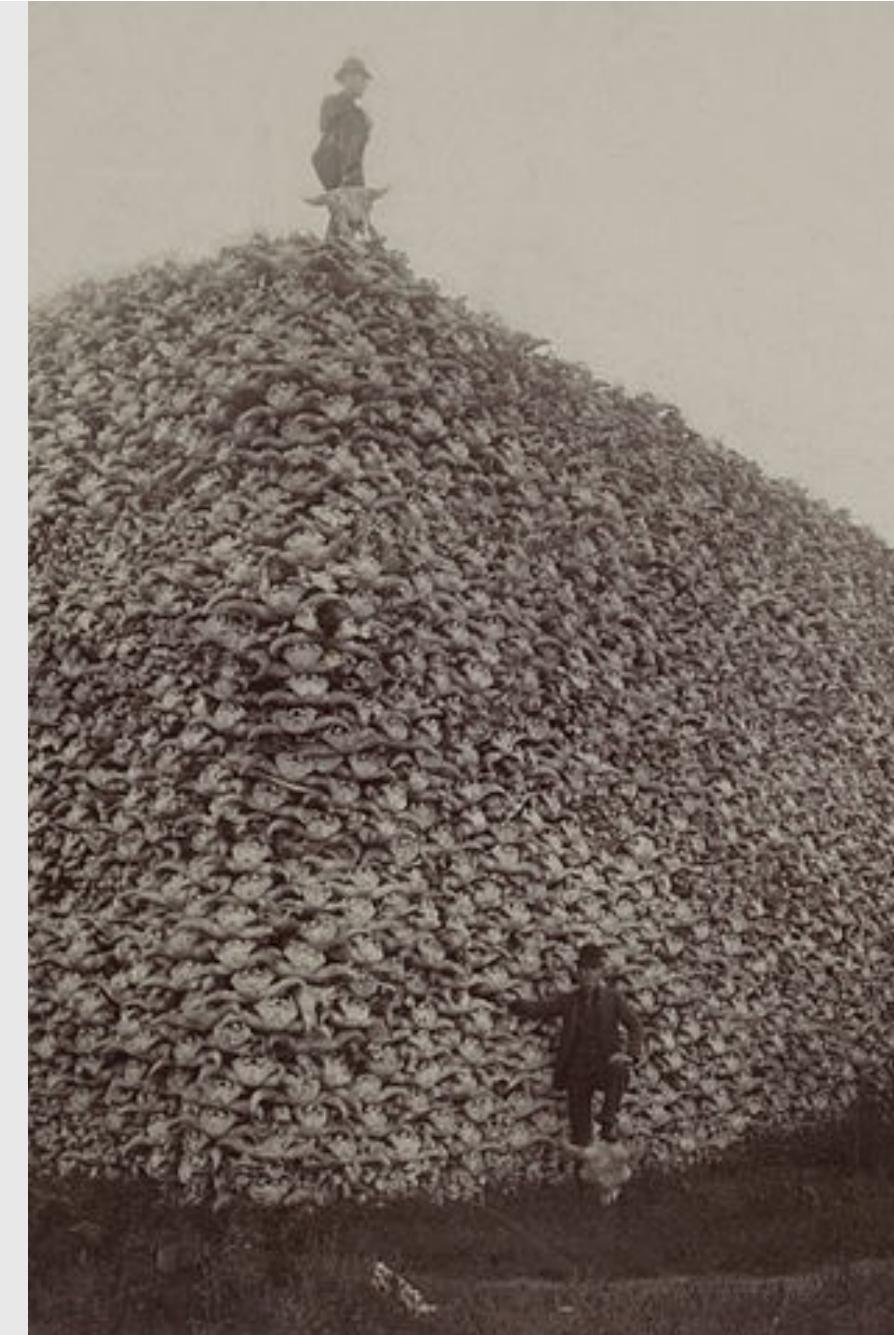
Gene

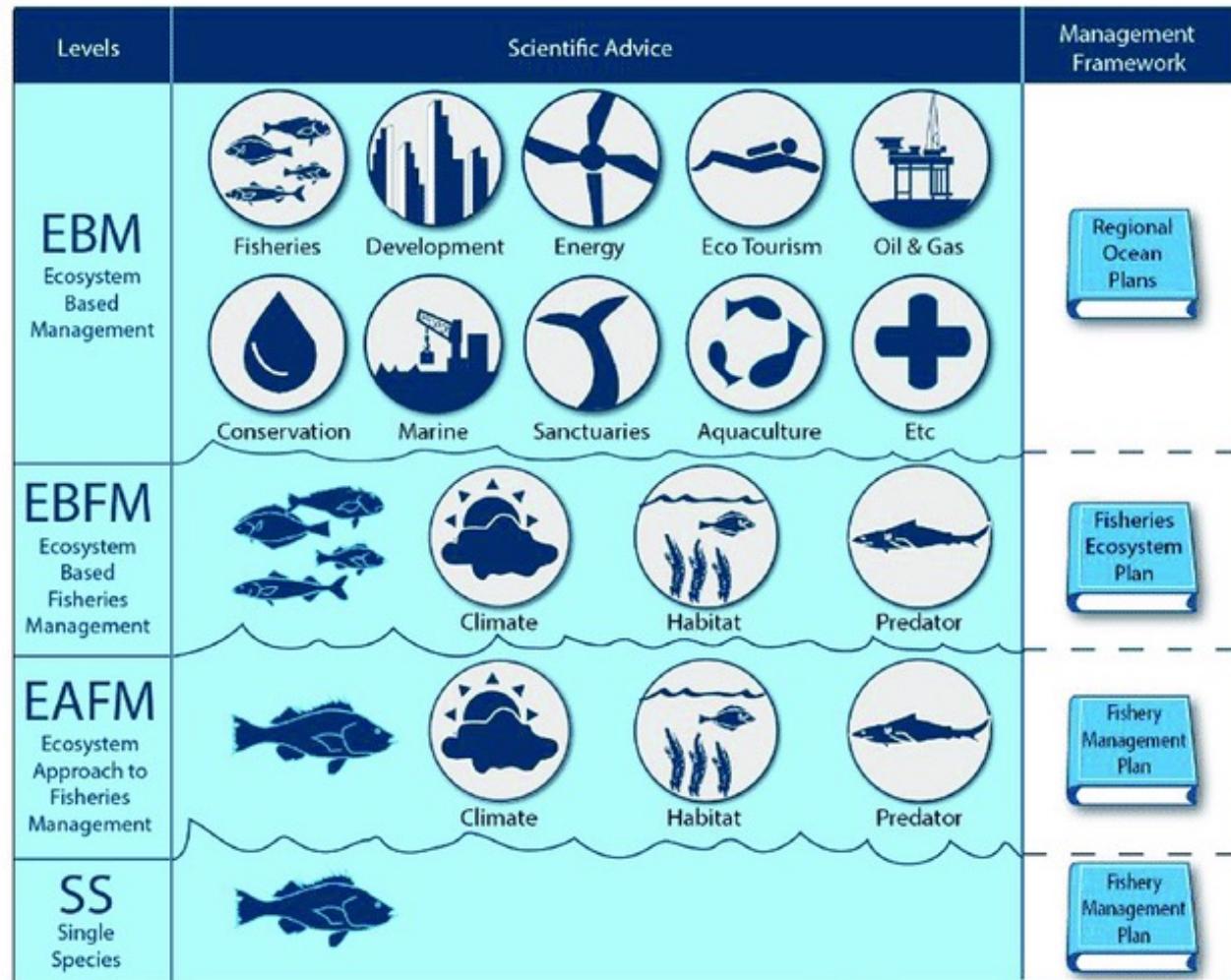
# Data sources

- Harvest data
  - In fisheries, we call this fishery-dependent
  - Can introduce bias if effort and changes in space in time are not accounted for
- Statistical surveys
  - In fisheries, this is fishery-independent data
  - Theoretically unburdened by bias

# Reference points

- We often manage populations relative to some desirable outcome
  - Abundance
  - Biomass
  - Growth
  - Reproduction
  - Harvest
- When populations are harvested too intensely (overexploitation), they can suffer from:
  1. Stunted size (growth overfishing)
  2. Low reproduction (recruitment overfishing)
  3. Altered ecosystem (ecosystem overfishing)





## Considerations

- Level of biological organization
- **Uncertainty**
- Harvest throughout history
- Scale and cost of data collection
- Consistency of data sources
- Stakeholder interests
- Political status of states involved in harvest
- Broader ecological impacts
- Many, many things!