Reading for Thursday (3/14):

Reading Response Due

LETTER

doi:10.1038/nature10285

Transient dynamics of an altered large marine ecosystem

Kenneth T. Frank[1], Brian Petrie[1], Jonathan A. D. Fisher[2] & William C. Leggett[2]

Overfishing of large-bodied benthic fishes and their subsequent population collapses on the Scotian Shelf of Canada's east coast[1,2] and elsewhere[3,4] resulted in restructuring of entire food webs now dominated by planktivorous, forage fish species and macroinvertebrates. Despite the imposition of strict management measures in force since the early 1990s, the Scotian Shelf ecosystem has not reverted back to its former structure. Here we provide evidence of the transient nature of this ecosystem and its current return path towards benthic fish species domination. The prolonged duration of the altered food web, and its current recovery, was and is being governed by the oscillatory, runaway consumption dynamics of the forage fish complex. These erupting forage species, which reached biomass levels 900% greater than those prevalent during the pre-collapse years of large benthic predators, are now in decline, having outstripped their zooplankton food supply. This dampening, and the associated reduction in the intensity of predation, was accompanied by lagged increases in species abundances at both lower and higher trophic levels, first witnessed in zooplankton and then in large-bodied predators, all consistent with a return towards the earlier ecosystem structure. We conclude that the reversibility of perturbed ecosystems can occur and that this bodes well for other collapsed fisheries.

The recent demonstration that overfishing of large-bodied predators in the northwest Atlantic initiated a trophic cascade, typified by reciprocal changes in biomass between adjacent trophic levels extending to the base of the food web[1,2], overturned the long-held view that large marine ecosystems are resistant to restructuring[5]. It has been proposed[6,7] that such trophic cascades are characteristic of ecosystems that have been transformed into undesirable states involving large changes in ecological functions and/or economic resources[8,9]. Although the excessive consumption characteristic of trophic cascades may be unstable[6], whether, how, and on what time scales such altered, diverse food webs and their key species and functional groups will recover remains unknown[1,3,4]. This has led to controversy regarding the efficacy of and experimentation with strategies based on conventional management approaches such as moratoria on exploitation, culling and re-stocking intended to return ecosystems to their former structure[10–13]. Using four decades of high quality, annual, fishery-independent data (see Methods) representative of multiple trophic levels on the eastern Scotian Shelf (Supplementary Fig. 1), we document the transient nature of its altered ecosystem and its return towards dominance by large-bodied predators.

The collapse of the northwest Atlantic cod (*Gadus morhua*) and several other large predatory fishes in the early 1990s (Fig. 1a), caused principally by over-fishing[14,15], precipitated the first documented open ocean trophic cascade in a large marine ecosystem[1]. The total biomass of cod, one of the ecosystem's dominant species, has hovered at less than 5% of pre-collapse levels for almost two decades despite the implementation of strict regulations forbidding their capture[15].

Recent investigations[13,16] have provided strong evidence that, following these collapses, the eastern Scotian Shelf, and other northwest Atlantic ecosystems in which similar collapses occurred, moved to apparent alternate states in which planktivorous forage fishes and macroinvertebrates became the dominant predators[3]. Released from predation on the eastern Scotian Shelf, the biomass of forage fishes increased by 900% (Fig. 1b) and macroinvertebrates by 200% compared to the pre-collapse years[13]. They then competed directly with and/or preyed upon the early life stages of their once benthic predators, a phenomenon termed predator–prey reversal[17] which seems to be one of the leading causes of the delayed recovery of the benthic fish complex in this and other large marine ecosystems[4,17,18]. Although forage fish constitute approximately half the diet of an expanding, resident grey seal (*Halichoerus grypus*) population, estimates of their consumption of pelagic fish species (1995–2000) were only 35% of the benthic

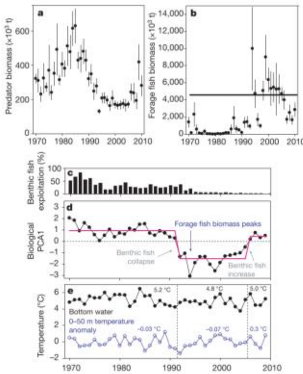


Figure 1 | Variability of the eastern Scotian Shelf ecosystem. a–e, Data (Supplementary Fig. 1) based on large-bodied benthic fish (**a**), their prey (forage fishes, **b**) with estimated carrying capacity (dashed line), benthic fish exploitation history expressed as annual per cent biomass removal (**c**), changing ecosystem structure based on the leading mode (PCA1) of biotic data spanning four trophic levels and the demarcation of regimes[29] of 22, 14 and 4 years duration (pink solid line) (**d**), and temperatures with averages shown for the three regimes (dashed vertical lines) (**e**). Vertical bars in **a** and **b** show ±s.e.m. ($n = 27$).

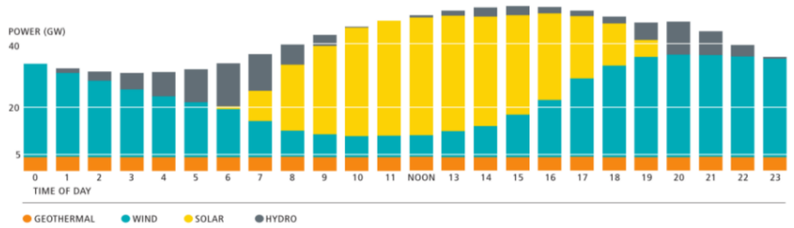
[1]Ocean Sciences Division, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada. [2]Department of Biology, Queen's University, Kingston, Ontario K7L 3N6, Canada.

Frank et al. 2011

Synthesis Question 5

5. As we've read and discussed, one of the major hurdles for renewable electric power is its consistency and reliability: cloudy days with no wind aren't very helpful. Jacobson and Delucchi (2009) suggest that different sources of renewable energy can be leveraged at different times of day to collectively become more reliable. For this question, you'll examine the reliability of renewables with your solar panel and wind turbine models from lab applied to a location of your choice. Although there will be specific questions outlined below, the overall motivating question of this section is:

How does electricity produced by solar panels and wind turbines compare to electricity *demand*?



(Jacobson and Delucchi 2009)

To address the next set of questions you'll need to **download data for a location of your choosing** by going to https://wellesley.shinyapps.io/es-220-midterm.

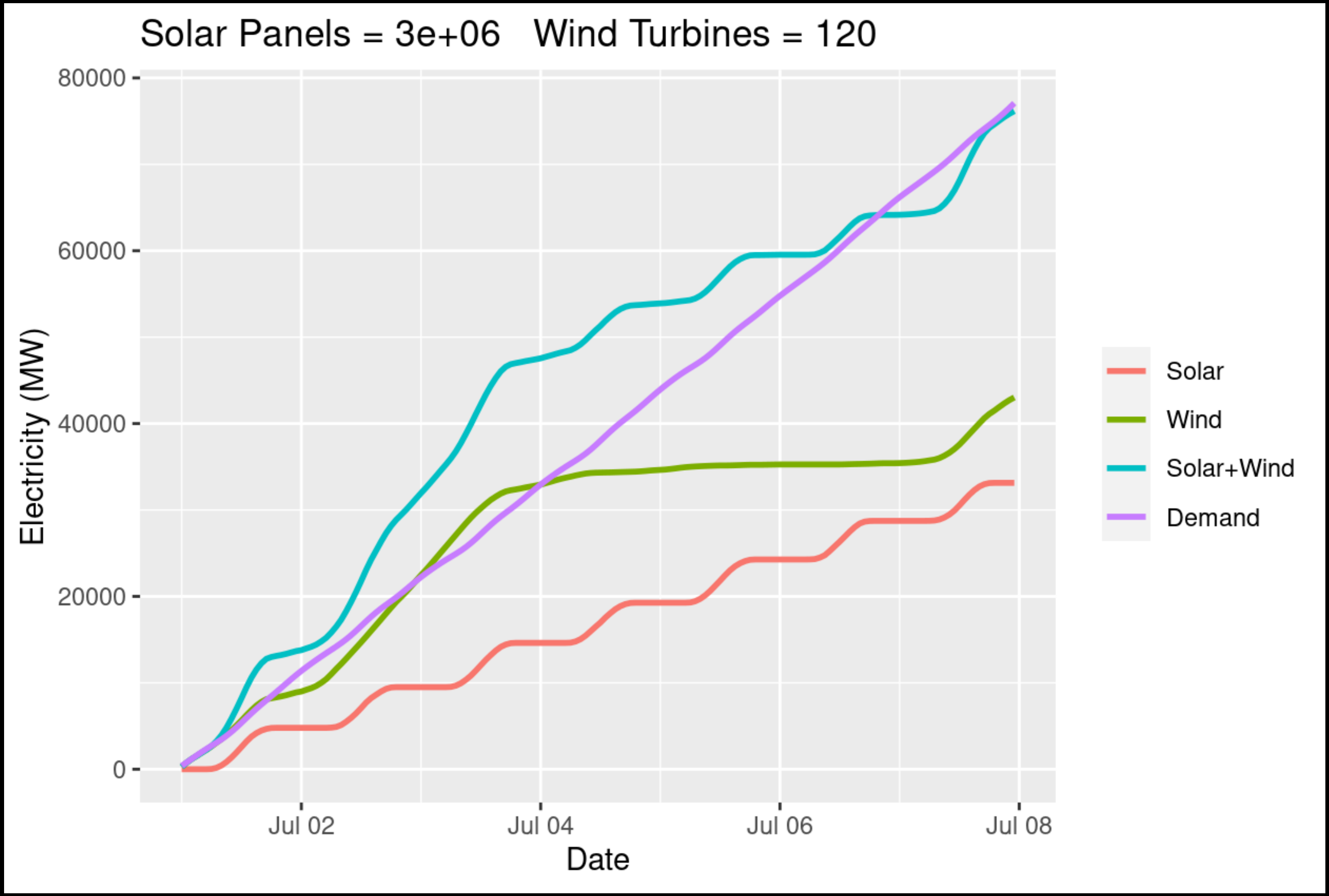
Be sure to refer to the following documents:

- **Question 5 Download Instructions.pdf** (detailed instructions for how to download data)
- **Question 5 Synthesis Tips.pdf** (tips and information)

wellesley.shinyapps.io/es-220-midterm/

Undisclosed location with 550,000 people…

(5c) 3 pts Create a plot (or plots) that shows (1) cumulative electricity from solar, (2) cumulative electricity from wind, (3) cumulative renewable electricity (wind + solar), and (4) the cumulative electricity demand.



Fisheries Science

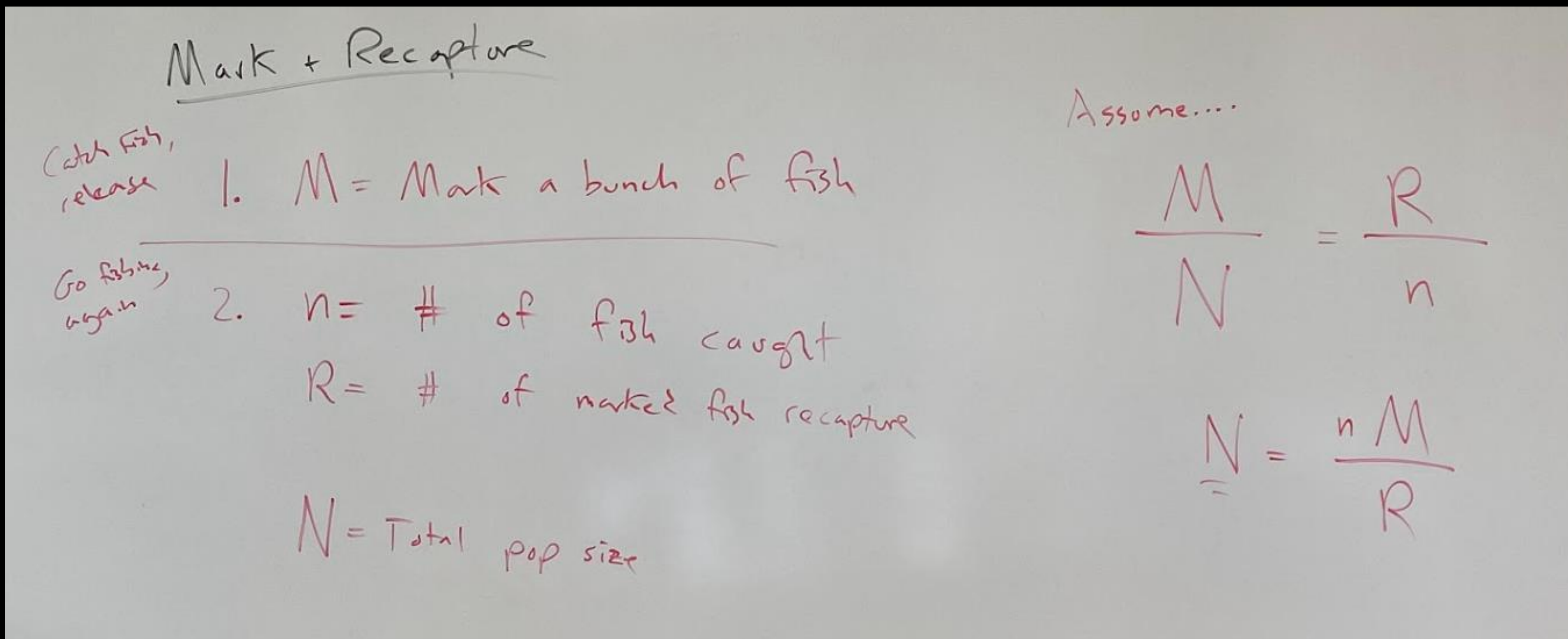
Practical / proximate questions:

How many fish are out there? (Population size)

How many can we take? (Harvest rate)

How many fish are out there?

Mark and Recapture



Mark and Recapture

Step 1: Mark/tag a bunch of fish

Step 2: Go fishing and see how many marked fish are recaptured

M = # of marked fish (step 1)

n = total fish caught (step 2)

R = # of marked fish recaptured (step 2)

N = total population size (unknown)

$$\frac{M}{N} = \frac{R}{n} \qquad N = \frac{nM}{R}$$

https://wellesley.shinyapps.io/gofish

Mark and Recapture - Google Sheets

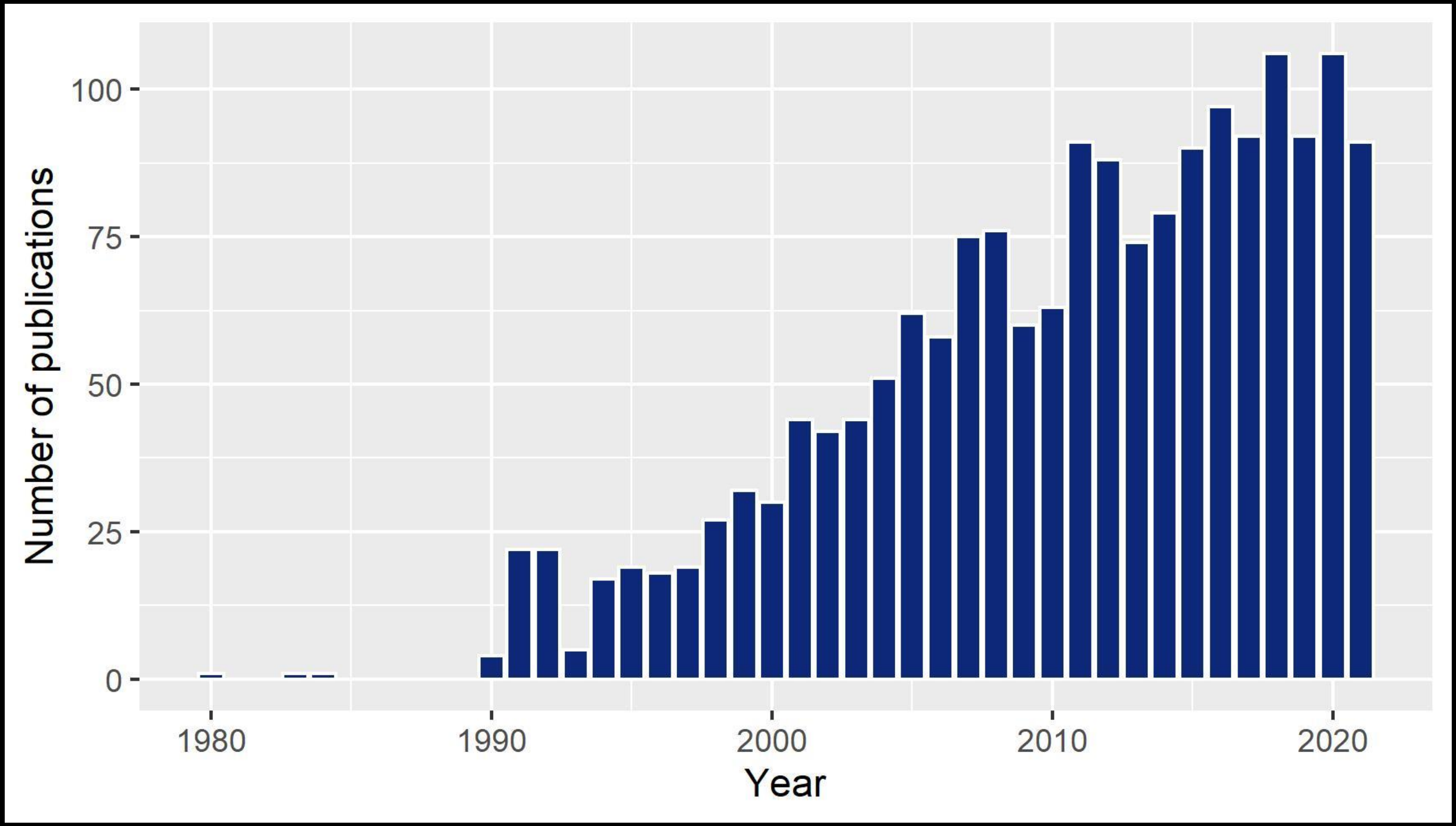
Mark and Recapture

	Marked Fish (M)	Total Caught (n)	Total Recaptured (R)	Population Size Estimate (N)
Alden	50	220	5	2200
Soph	350	340	63	1889
Isabella	89	460	22	1861
Frida	80	160	7	1829
Akari	250	200	19	2632
Julia K	400	240	40	2400
Julia R	100	440	17	2588
Charlotte	411	200	54	1522
Melissa	300	300	32	2813
Amelia	500	200	51	1961
			Average:	**2169**

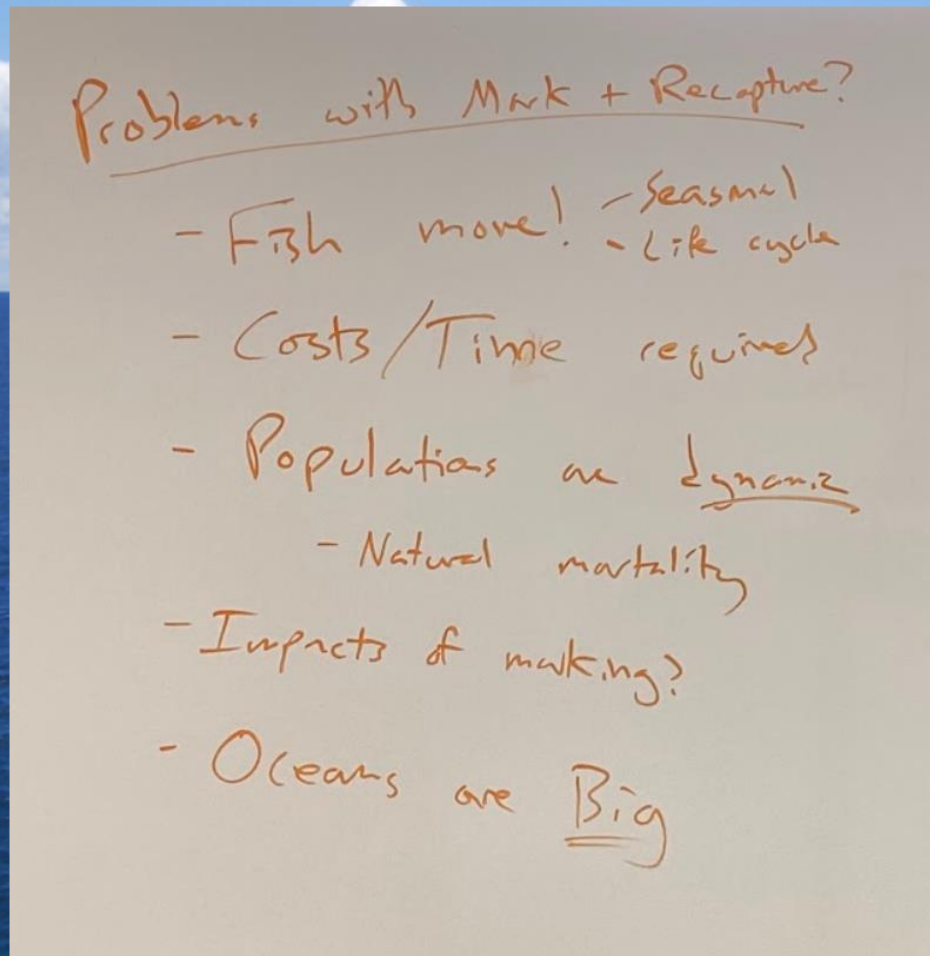
Actual Fish = 2000

Search of peer reviewed publications for: (fish* and mark and recapture)

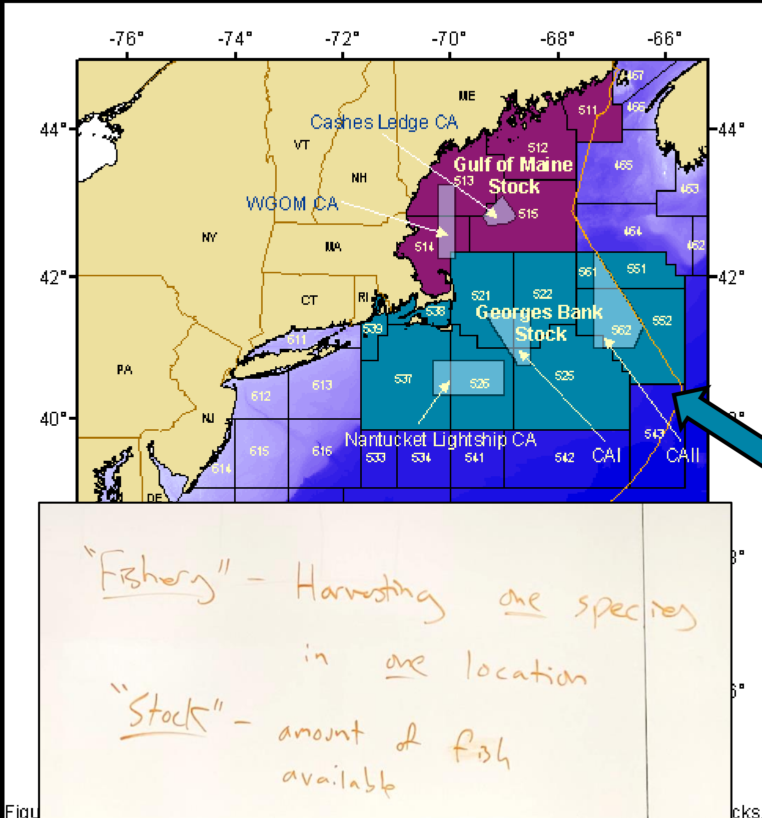
Total = 1,807 publications



Problems with mark and recapture?



Sampling fisheries standing biomass (stock) using trawling tows



"Fishery" – Harvesting one species in one location

"Stock" – amount of fish available

Atlantic Cod *(Gadus morhua)*

(NOAA)

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

Georges Bank Atlantic cod

2017 Assessment Update Report

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

Compiled August 2017

Sampling fisheries standing biomass (stock) using trawling tows

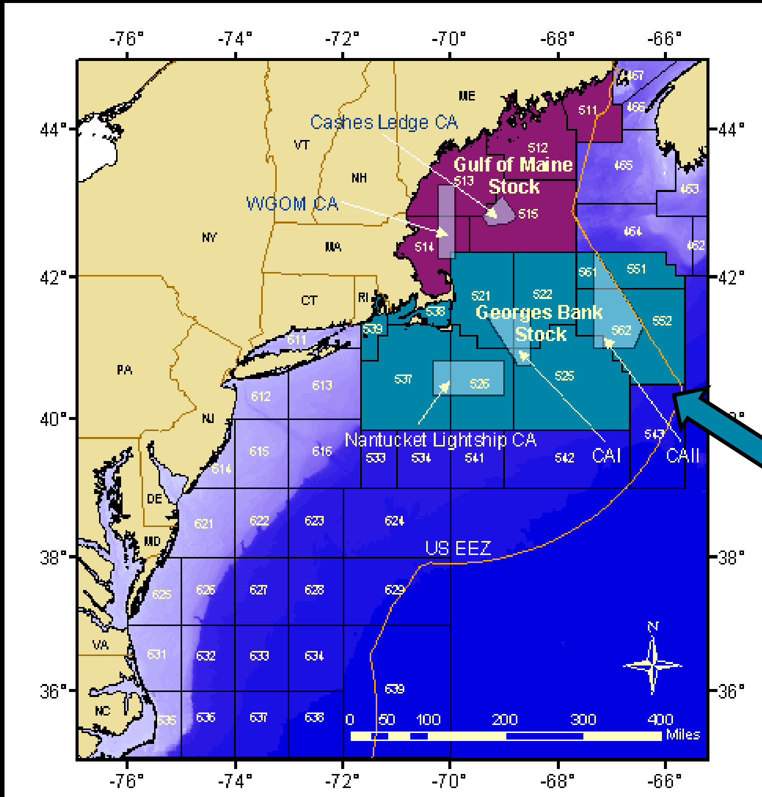


Figure 1.1. Statistical areas used to define the Gulf of Maine and Georges Bank cod stocks.

Atlantic Cod *(Gadus morhua)*

(NOAA)

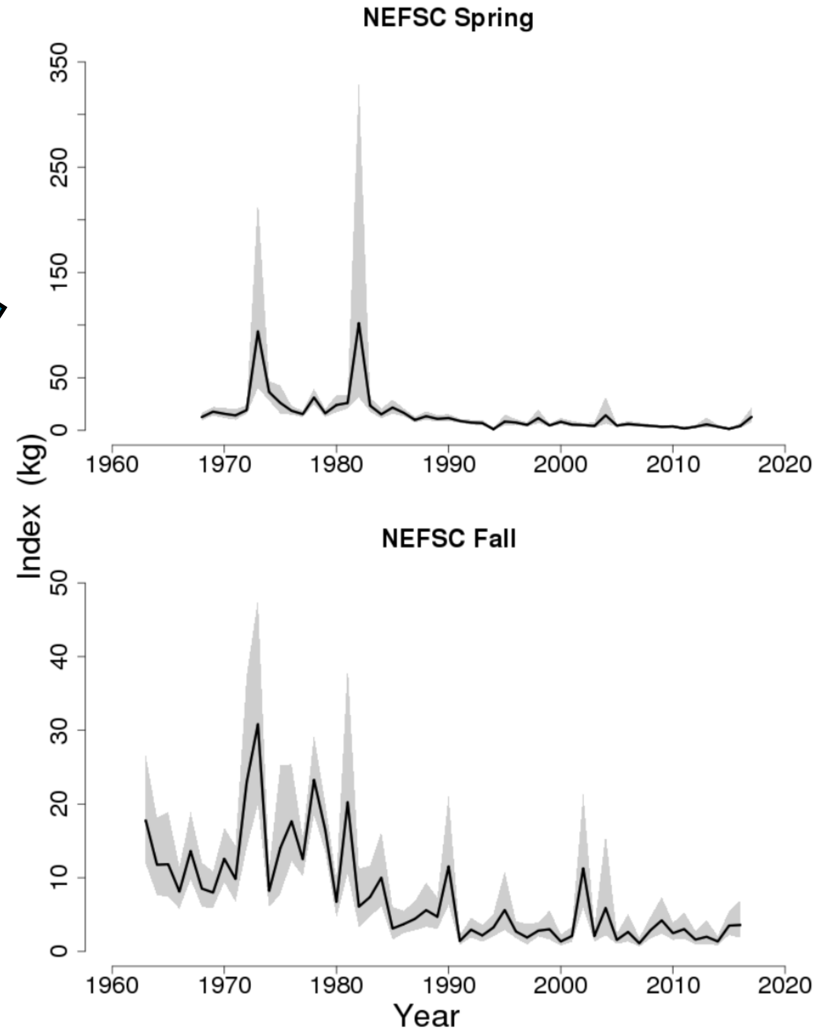


Figure 4: Indices of biomass for the Georges Bank Atlantic cod between 1963 and 2017 for the Northeast Fisheries Science Center (NEFSC) spring and fall trawl surveys. The approximate 90% lognormal confidence intervals are shown.

Sampling fisheries standing biomass (stock) using trawling tows

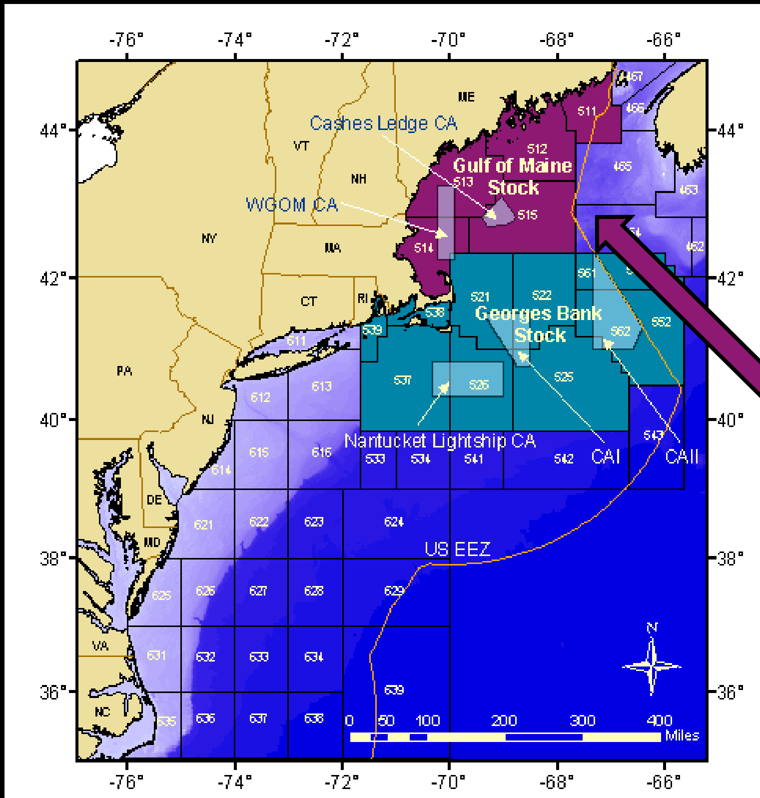


Figure 1.1. Statistical areas used to define the Gulf of Maine and Georges Bank cod stocks.

Atlantic Cod *(Gadus morhua)*

(NOAA)

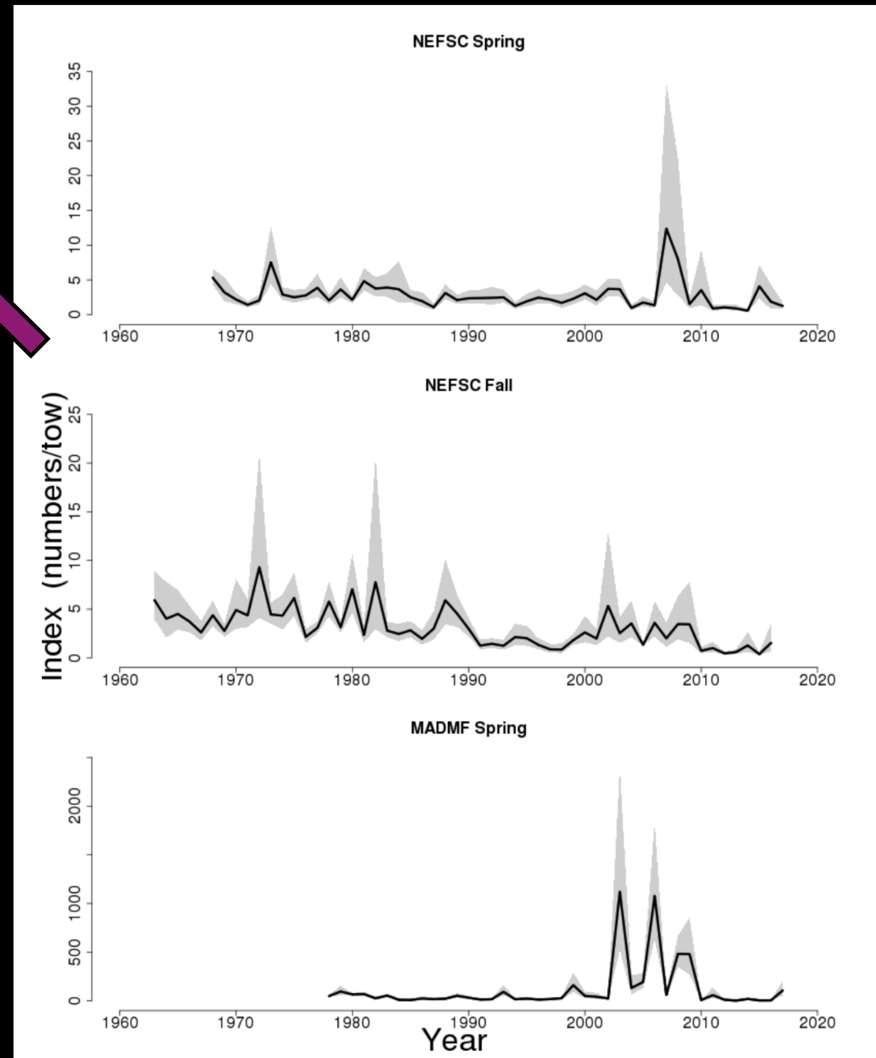


Figure 5: Indices of biomass for the Gulf of Maine Atlantic cod between 1963 and 2017 for the Northeast Fisheries Science Center (NEFSC) spring and fall bottom trawl surveys and Massachusetts Division of Marine Fisheries (MADMF) spring bottom trawl survey. The 90% lognormal confidence intervals are shown.

How many fish can we catch?

Theoretical framework of Maximum Sustainable Yield (MSY)

Maximum Sustainable Yield (MSY)

When is the population most productive?
When does it add/produce the most fish?

Logistic Model

- N (Total Pop)
- λ_{obs}
- # Added

N

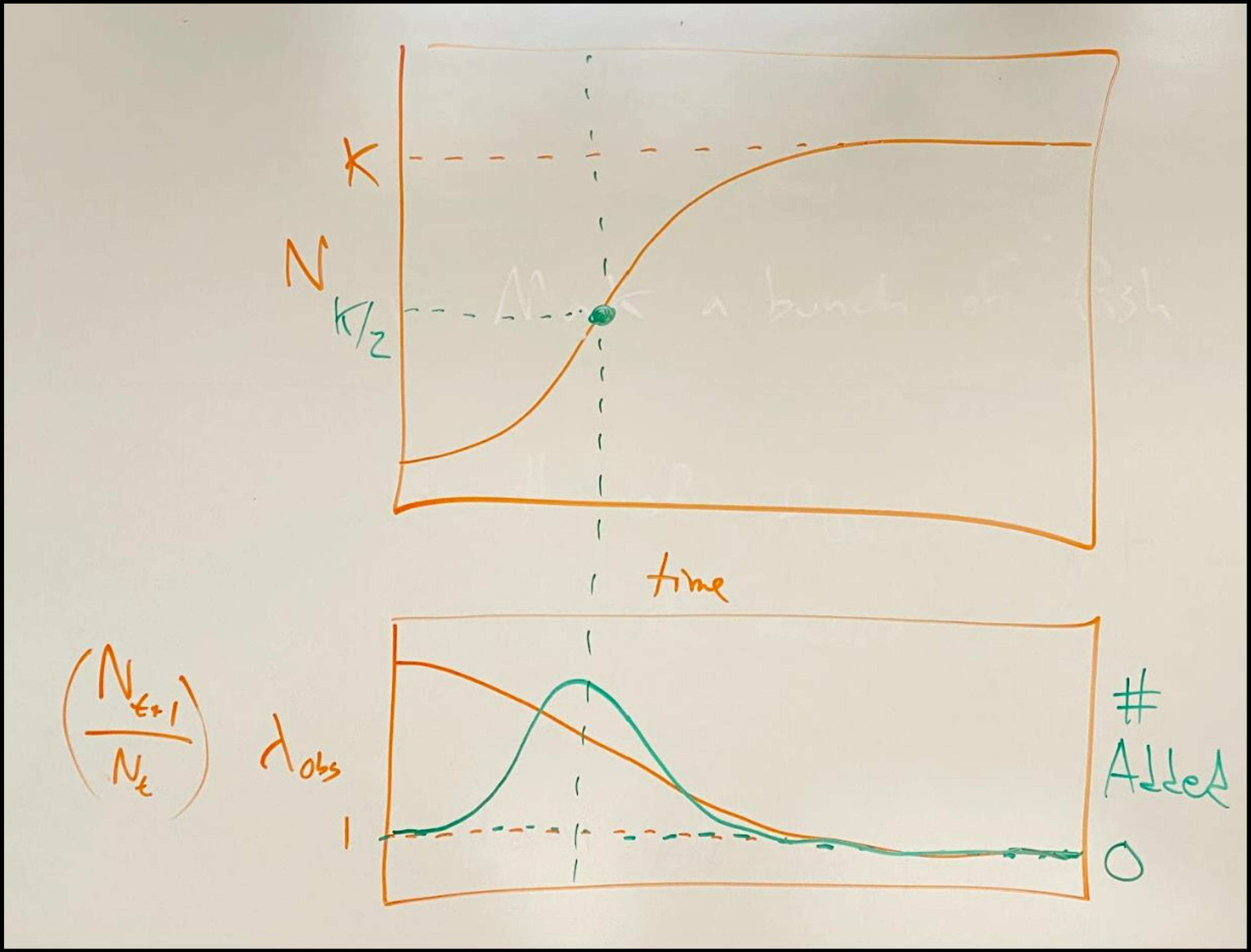
Time

λ_{obs}

Added

Time

Maximum Sustainable Yield (MSY)



Maximum Sustainable Yield (MSY)

$$N_{t+1} = N_t + N_t(\lambda - 1)\left(1 - \frac{N_t}{K}\right)$$

current population

maximum added to population

"check"

- limits population additions
- approaches 0 when N_t approaches K

$$N_{t+1} = N_t + N_t(\lambda - 1)\left(1 - \frac{N_t}{K}\right)$$

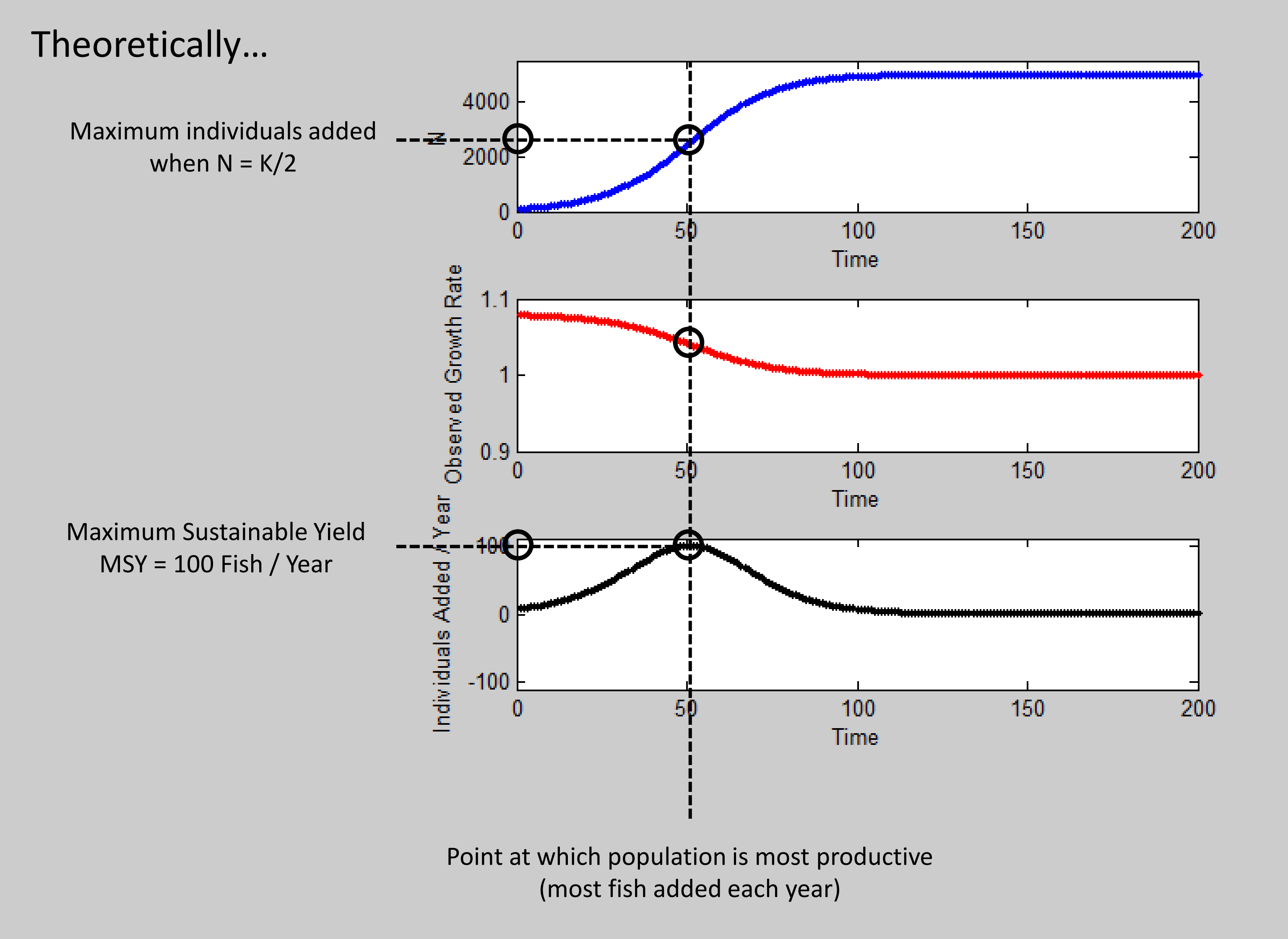
Taken together, these two terms on the right essentially represent λ_{obs}

$$N_{t+1} = N_t + N_t(\lambda_{obs} - 1)$$

Maximum Sustainable Yield (MSY)

$$N_{t+1} = N_t + N_t(\lambda_{obs} - 1)$$

Theoretically…



Maximum Sustainable Yield (MSY)

Starting with the framework of logistic growth…

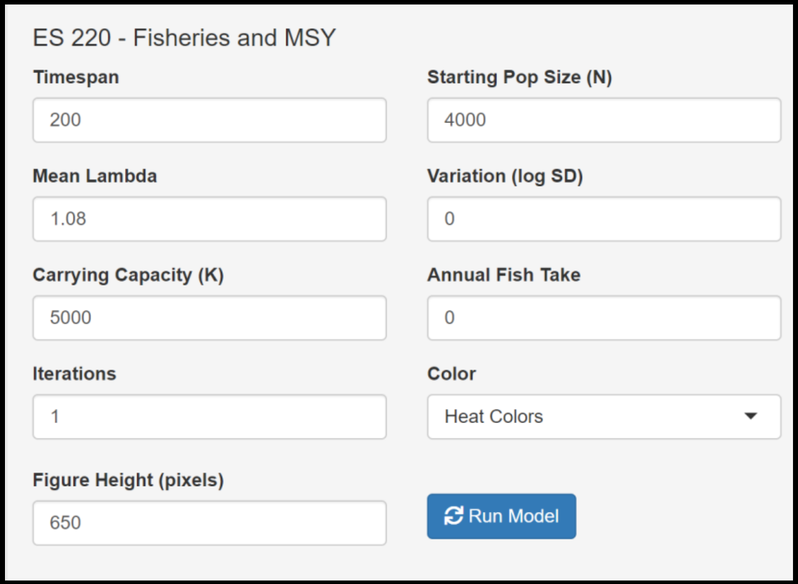
$$N_{t+1} = N_t + \boxed{N_t(\lambda - 1)\left(1 - \frac{N_t}{K}\right)}$$

Maximum $\boxed{\text{individuals are added}}$ when $N_t = K/2$…

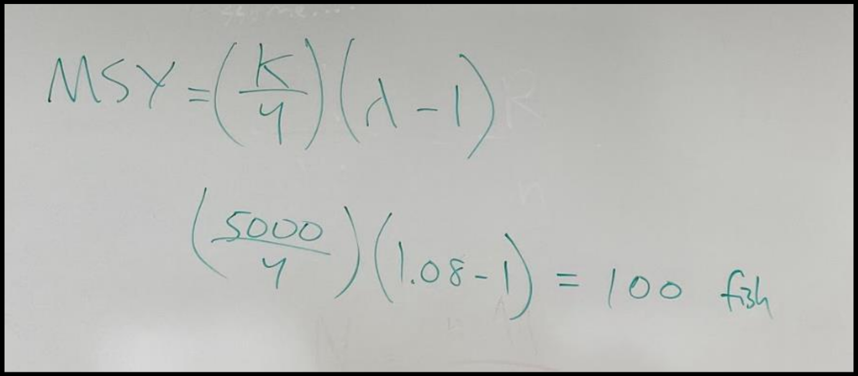
$$MSY = \boxed{\left(\frac{K}{2}\right)(\lambda - 1)\left(1 - \frac{\left(\frac{K}{2}\right)}{K}\right)}$$

$$MSY = \boxed{\left(\frac{K}{4}\right)(\lambda - 1)}$$

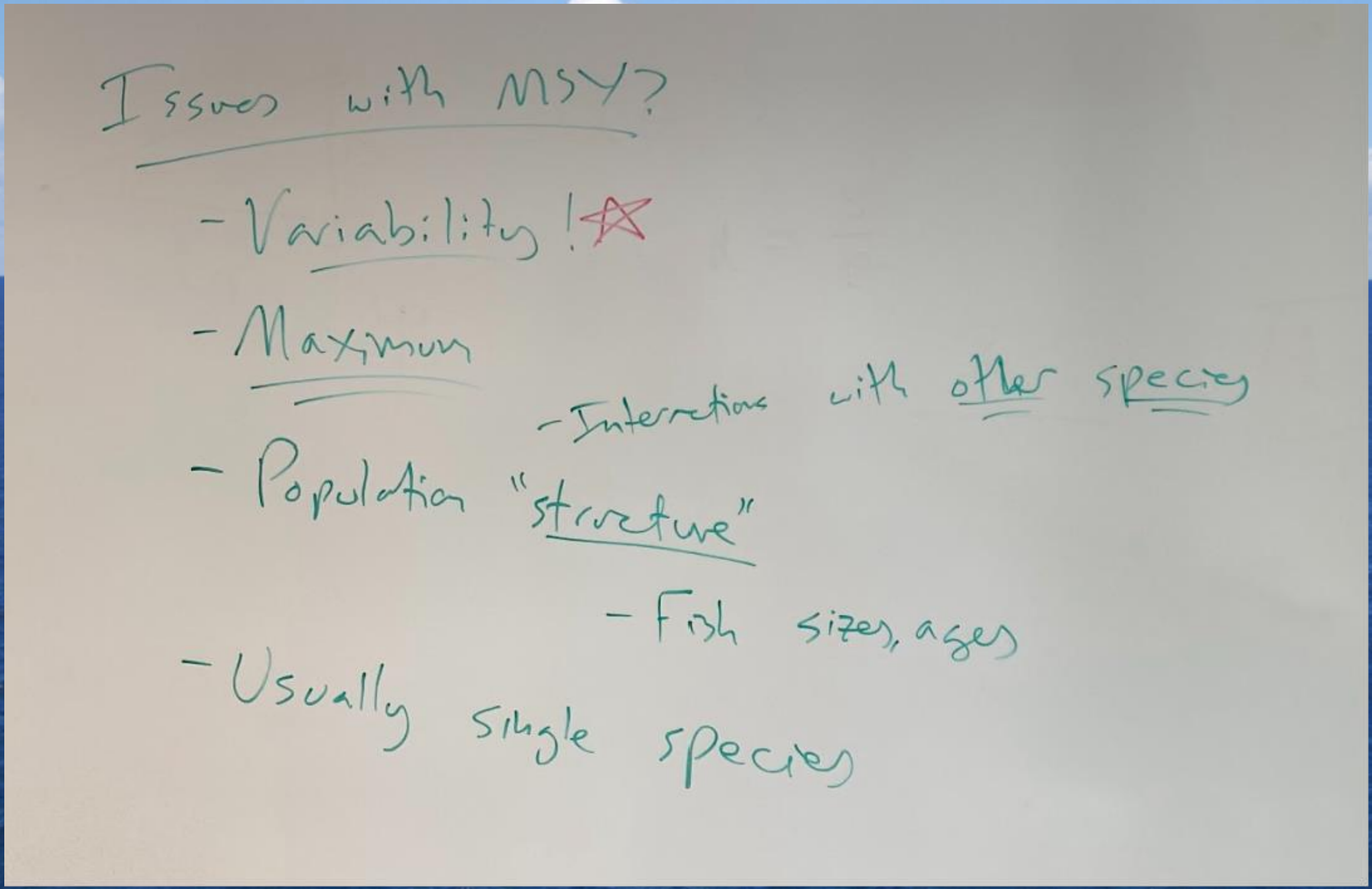
https://wellesley.shinyapps.io/fish-msy/

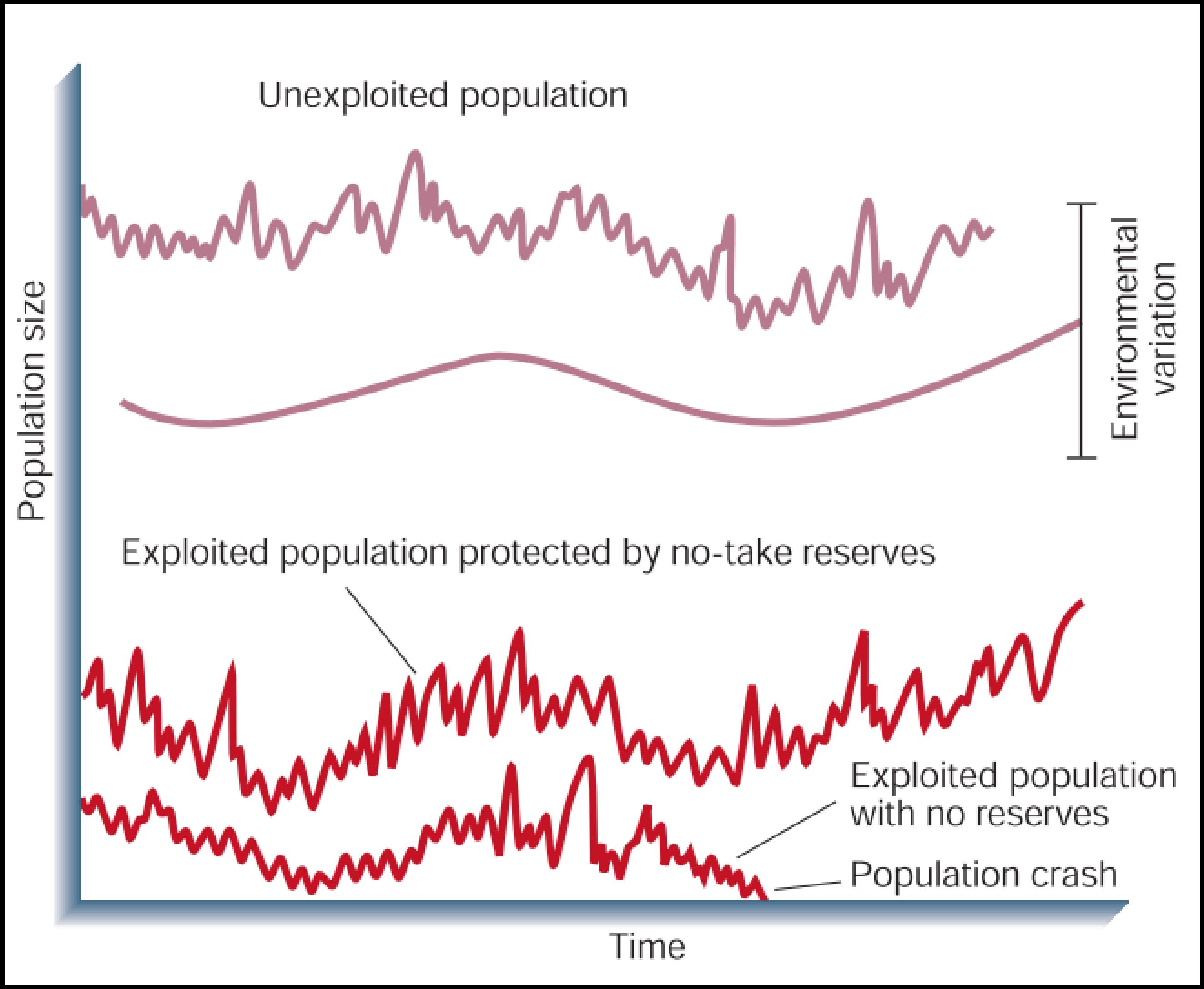


$$MSY = \left(\frac{K}{4}\right)(\lambda - 1)$$



Problems with MSY?





Pauly et al 2002

Rebuilding Global Fisheries

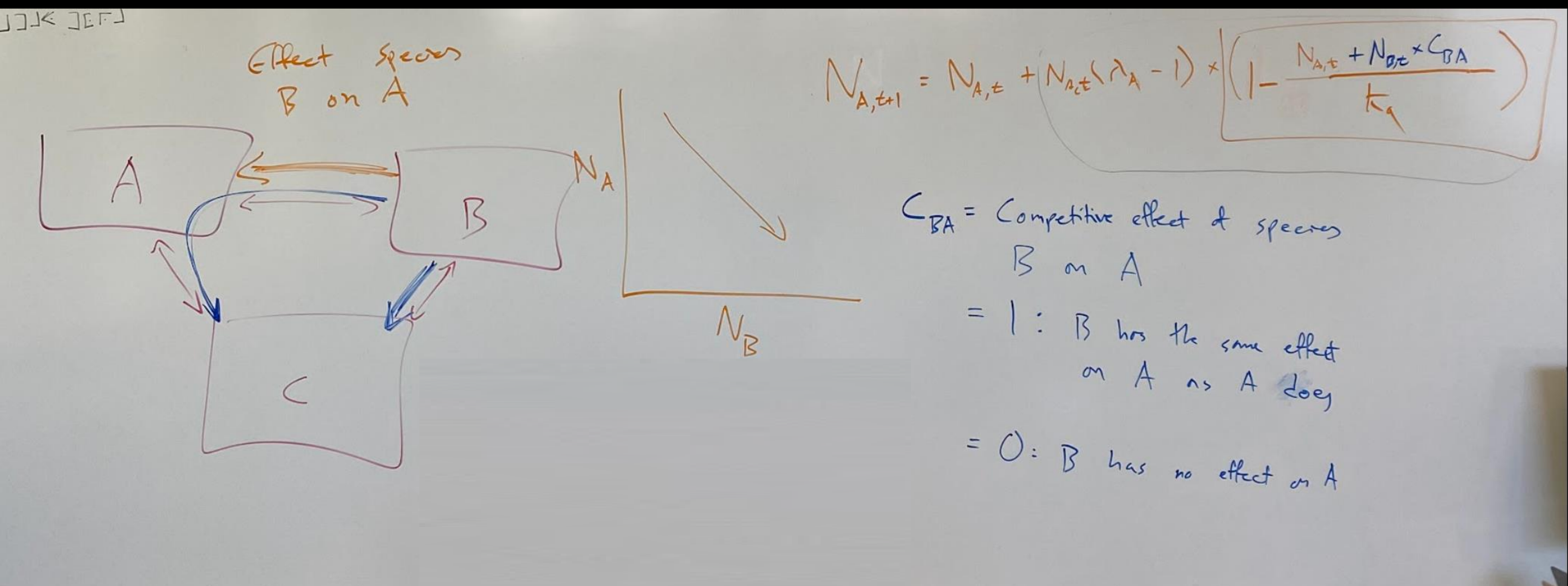
Boris Worm,[1*] Ray Hilborn,[2*] Julia K. Baum,[3] Trevor A. Branch,[2] Jeremy S. Collie,[4] Christopher Costello,[5] Michael J. Fogarty,[6] Elizabeth A. Fulton,[7] Jeffrey A. Hutchings,[1] Simon Jennings,[8,9] Olaf P. Jensen,[2] Heike K. Lotze,[1] Pamela M. Mace,[10] Tim R. McClanahan,[11] Cóilín Minto,[1] Stephen R. Palumbi,[12] Ana M. Parma,[13] Daniel Ricard,[1] Andrew A. Rosenberg,[14] Reg Watson,[15] Dirk Zeller[15]

Considering Multiple Species?

Modeling multiple species: competition

Logistic Model: competition within a species

$$N_{t+1} = N_t + N_t(\lambda - 1)\left(1 - \frac{N_t}{K}\right)$$



Modeling multiple species: competition

Logistic Model: competition within **Species A**

$$N_{a,t+1} = N_{a,t} + N_{a,t}(\lambda_a - 1)\left(1 - \frac{N_{a,t}}{K_a}\right)$$

Modified to include competition between **Species A** and **Species B**

$$N_{a,t+1} = N_{a,t} + N_{a,t}(\lambda_a - 1)\left(1 - \frac{N_{a,t} + C_{ba}N_{b,t}}{K_a}\right)$$

$N_{b,t}$ Number of Species B

C_{ba} Per capita effect of Species B on Species A

- 0.5 means that an individual of Species B has *half* the effect of an individual of Species A

K_a Carrying capacity of Species A in the absences of Species B

Relating MSY to important fisheries metrics

Actual Values:

B = stock biomass (total biomass of fish population) (or total number of fish, **N**)

F or μ = "exploitation rate", "fishing mortality" (expressed as fraction of stock harvested each year)

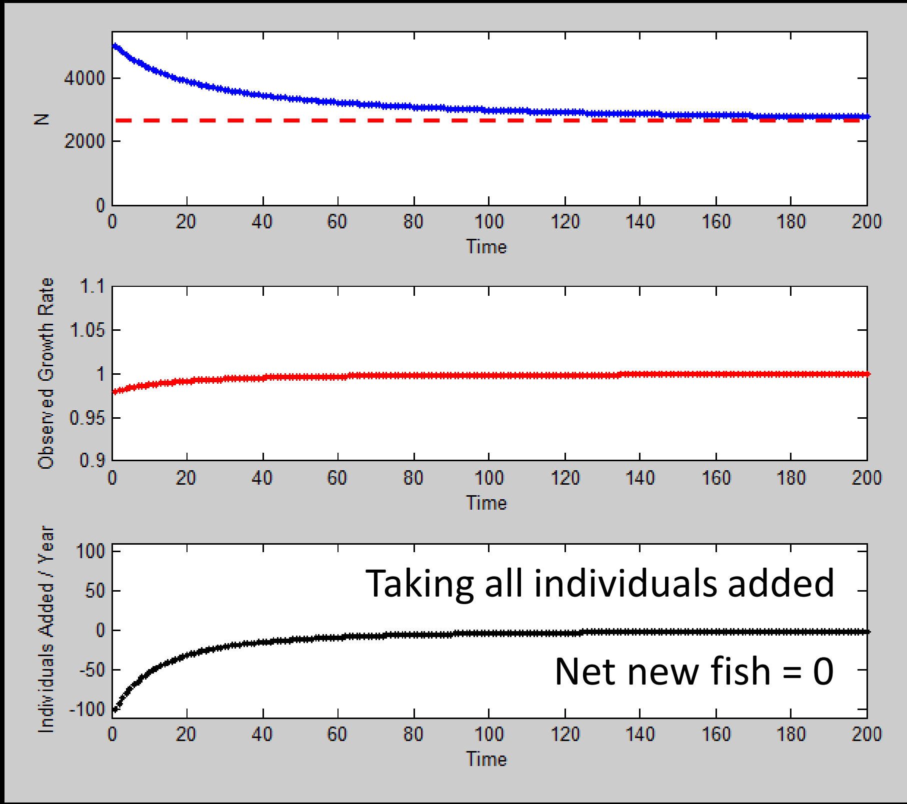
Theoretical Values:

B_{msy} = B value when harvesting at MSY (stock biomass that produces maximum yield)

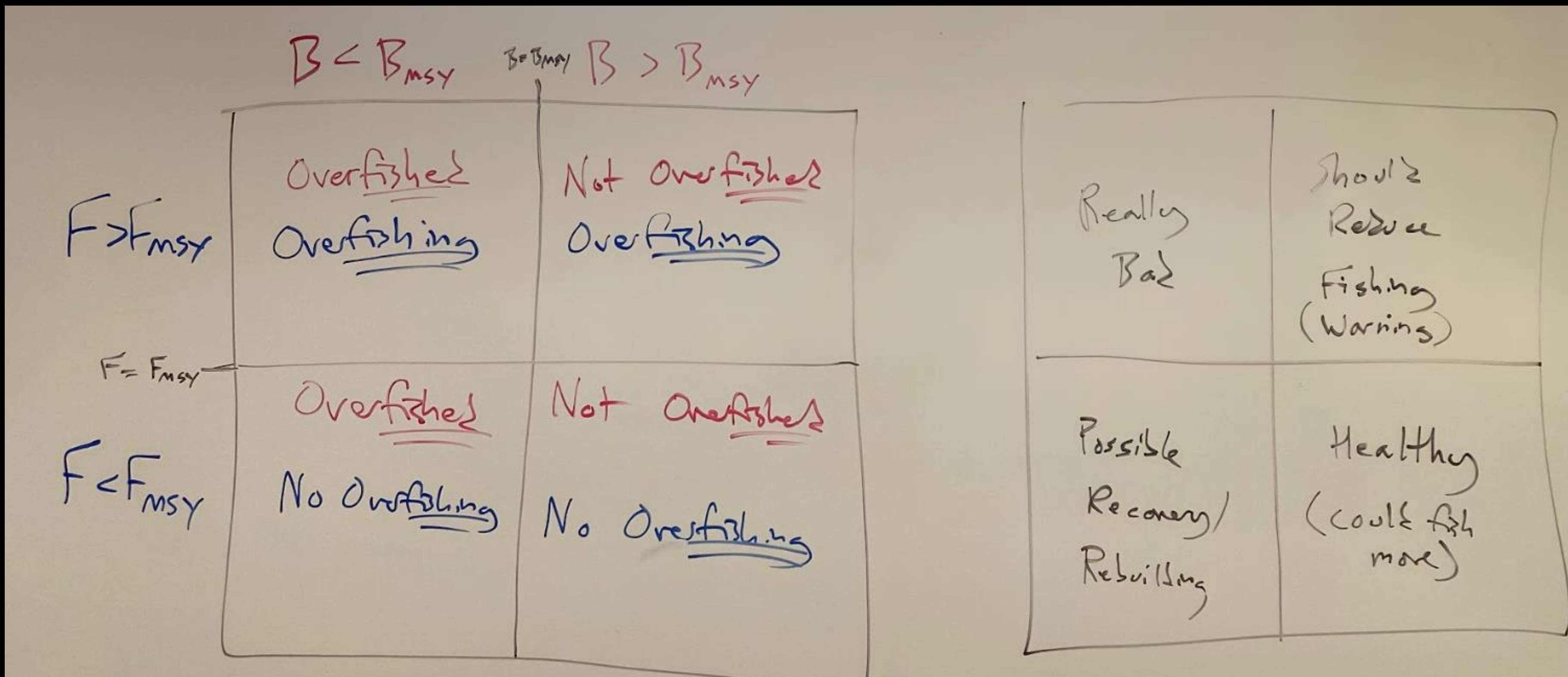
B_{msy} = 2500 fish

F_{msy} = F value when harvesting at MSY (maximum sustainable F value)

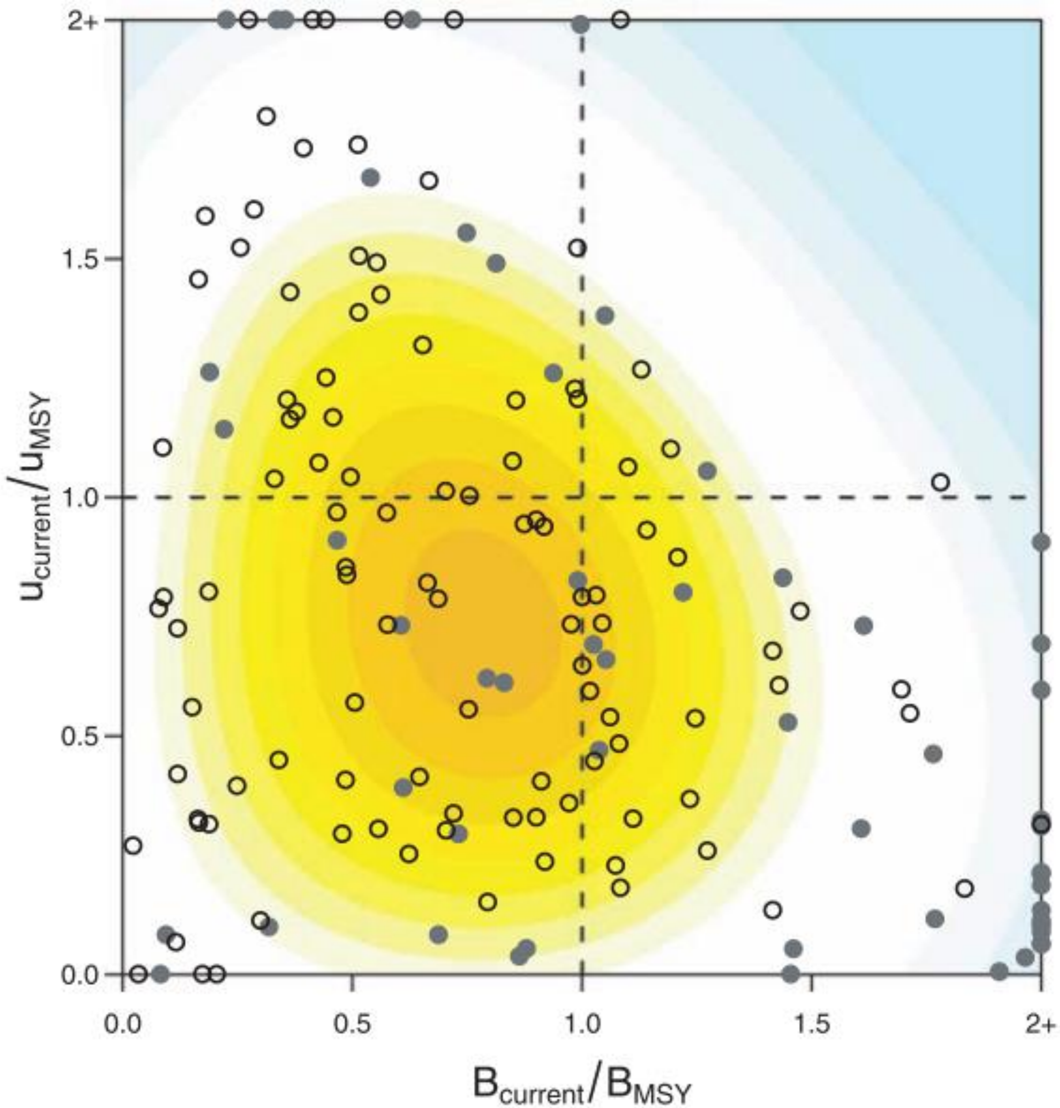
F_{msy} = 100 / 2500 = 0.04



Assessing the state of fisheries



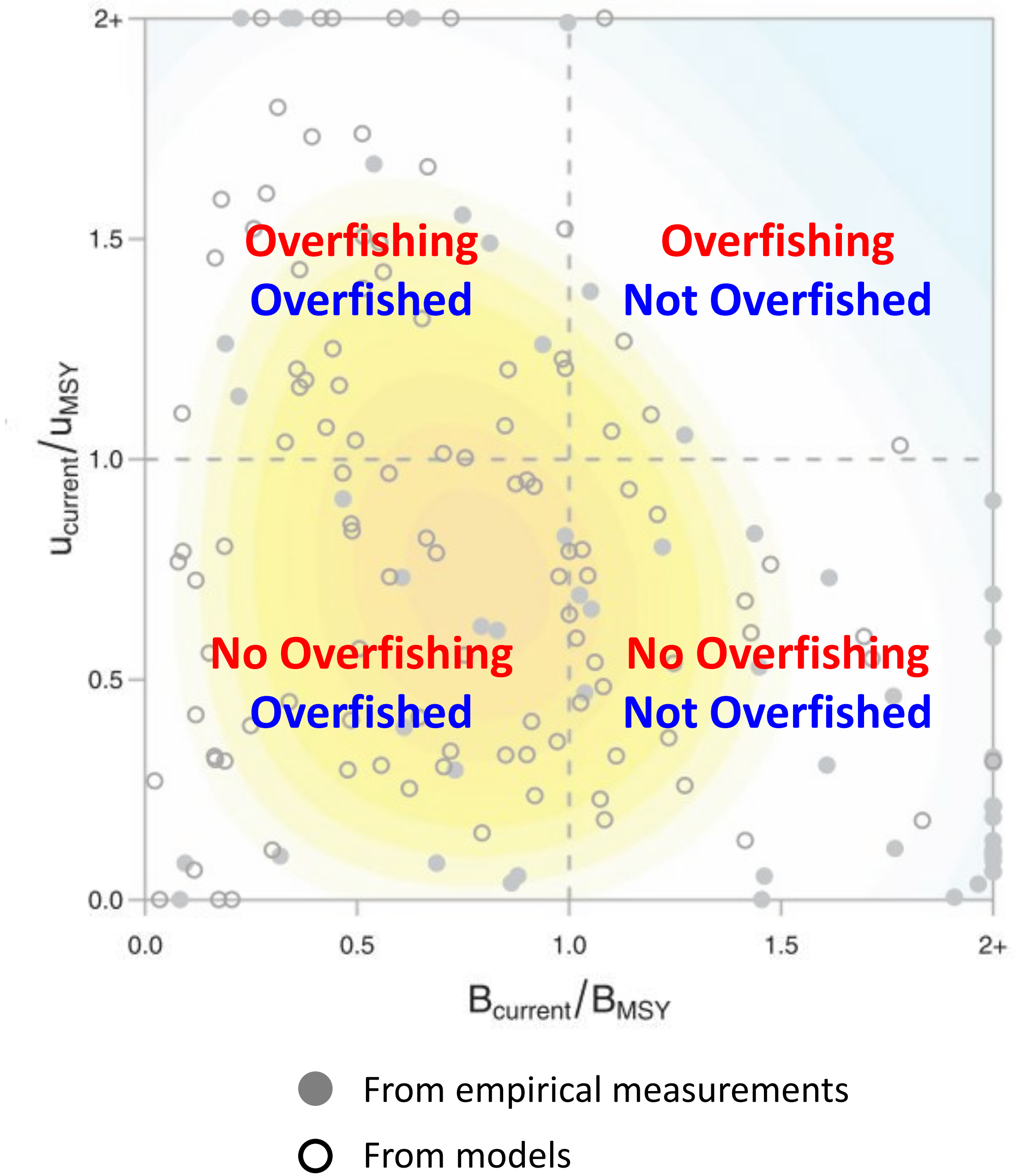
166 Fisheries



From empirical measurements

From models

166 Fisheries



Georges Bank

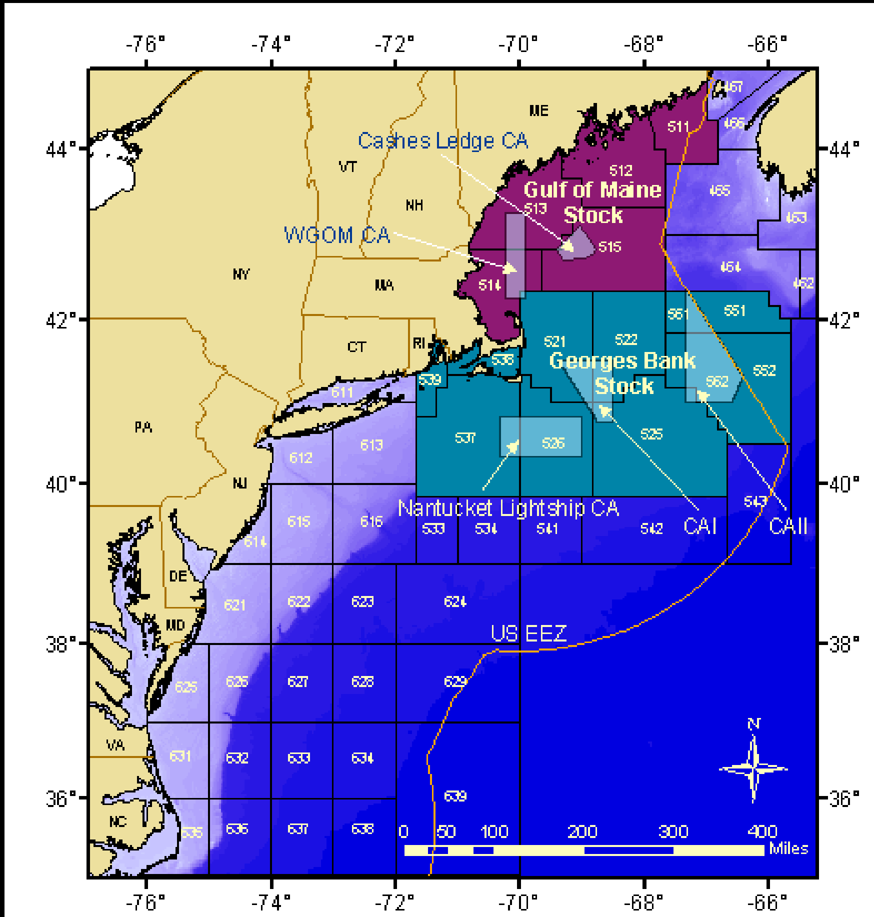
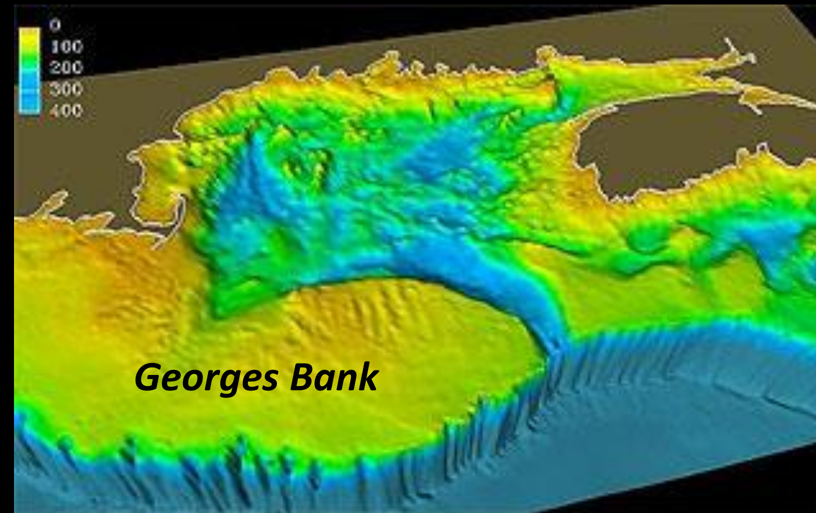


Figure 1.1. Statistical areas used to define the Gulf of Maine and Georges Bank cod stocks.

(NOAA)



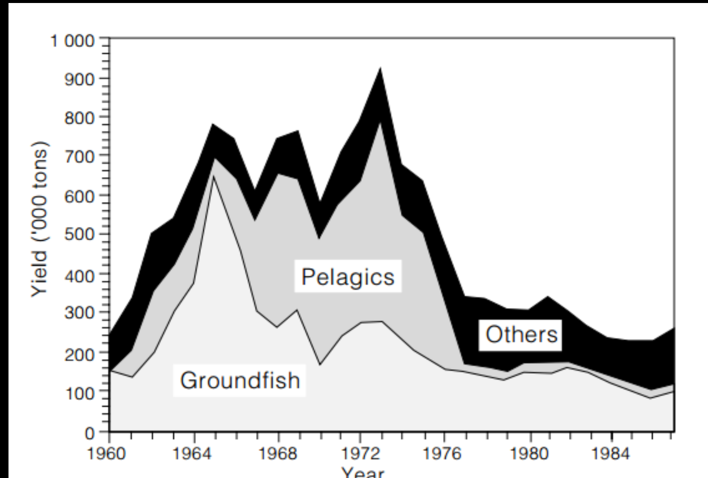
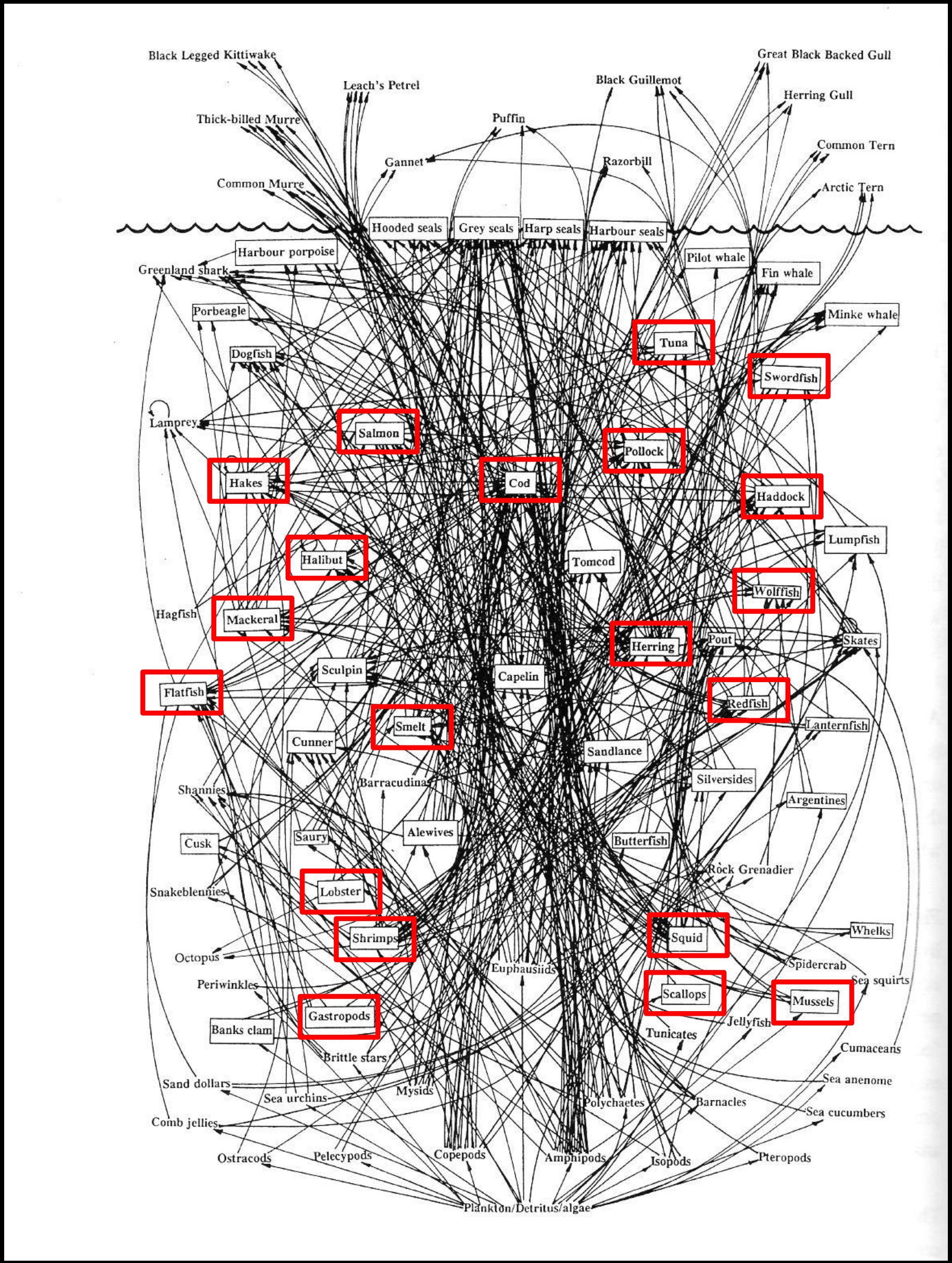


Fig. 2. Total nominal catches from Georges Bank (NAFO Div. 5Z) fisheries, 1960–87. Aggregate yields are presented by fishery components: groundfish, pelagic and 'other'.

Considering and managing an ECOSYSTEM

(Mayo et al. 1992)

Northwest Atlantic Food Web



(Lavigne)

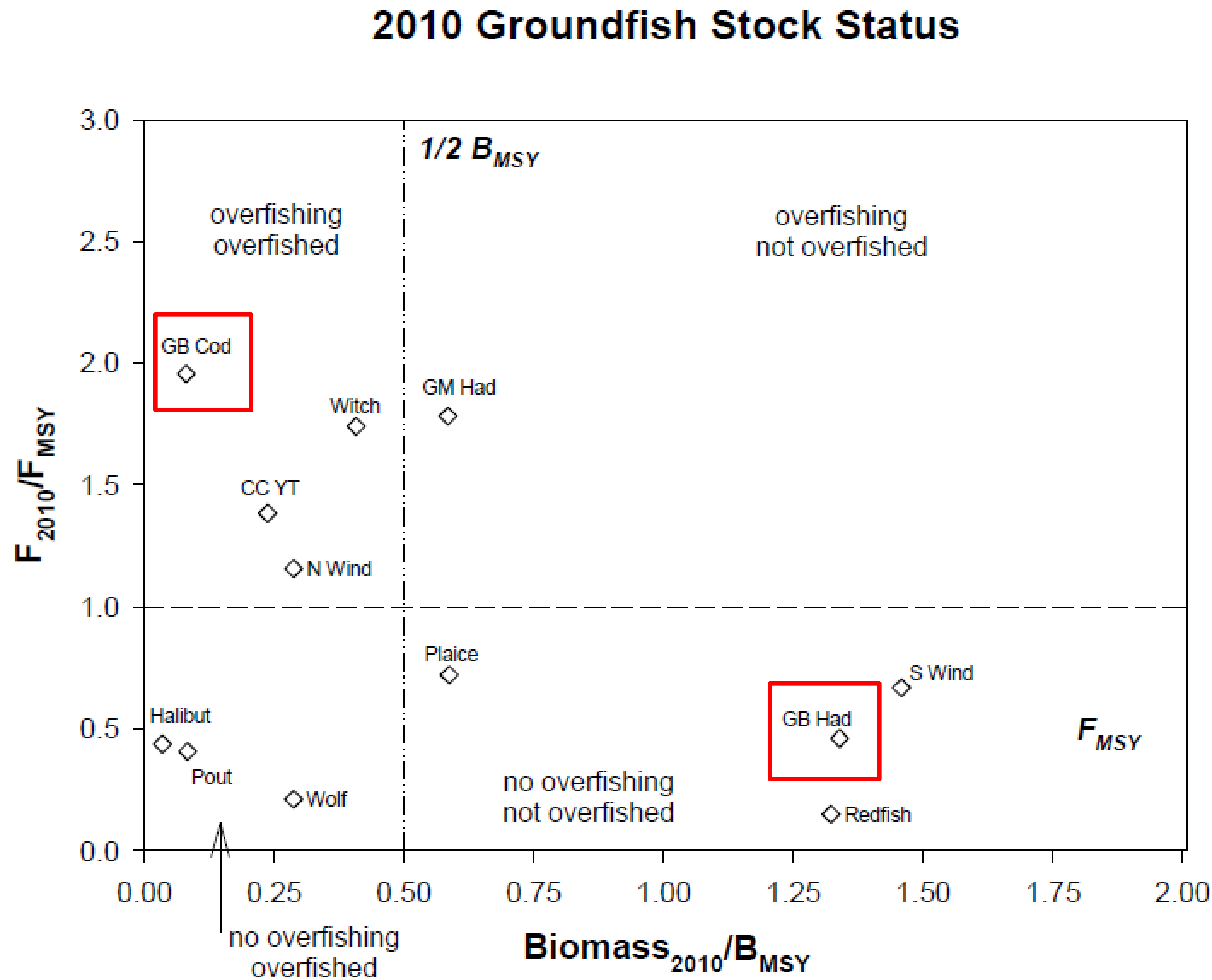


Figure 1. Status of 12 groundfish stocks in 2010 with respect to F_{MSY} and B_{MSY} proxies.

(NMFS)

Vol. 16: 9–20, 1984 | MARINE ECOLOGY – PROGRESS SERIES
Mar. Ecol. Prog. Ser. | Published February 29

The feeding habits of co-occurring cod and haddock larvae from Georges Bank*

Joseph Kane

US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Center, Narragansett Laboratory, Narragansett, Rhode Island 02882, USA

ABSTRACT: Types, number, size, biomass, and selection of food items by the larvae of Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* were determined by examination of gut contents from co-occurring larvae captured in plankton samples from Georges Bank. Eggs, nauplii, and copepodite stages of copepods were the predominant food items for both larvae, but cod consumed larger prey at an earlier age than haddock. The smallest larvae were the most euryphagous, haddock more than cod. Cod and haddock feeding intensity reached a peak shortly before sunset, and both larvae selected against the copepodite stages of *Oithona similis*. Dietary niche breadth and overlap indices indicate that competition is severe between and among similar sized individuals of both species.

INTRODUCTION

The larvae of 2 important commercial fish species, Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* often co-occur in the Northwest

During the spring of 1980 large numbers of co-occurring cod and haddock larvae were collected on Georges Bank. The feeding habits of both species were analysed and compared for differences in diet composition, feeding periodicity, prey-size selection,

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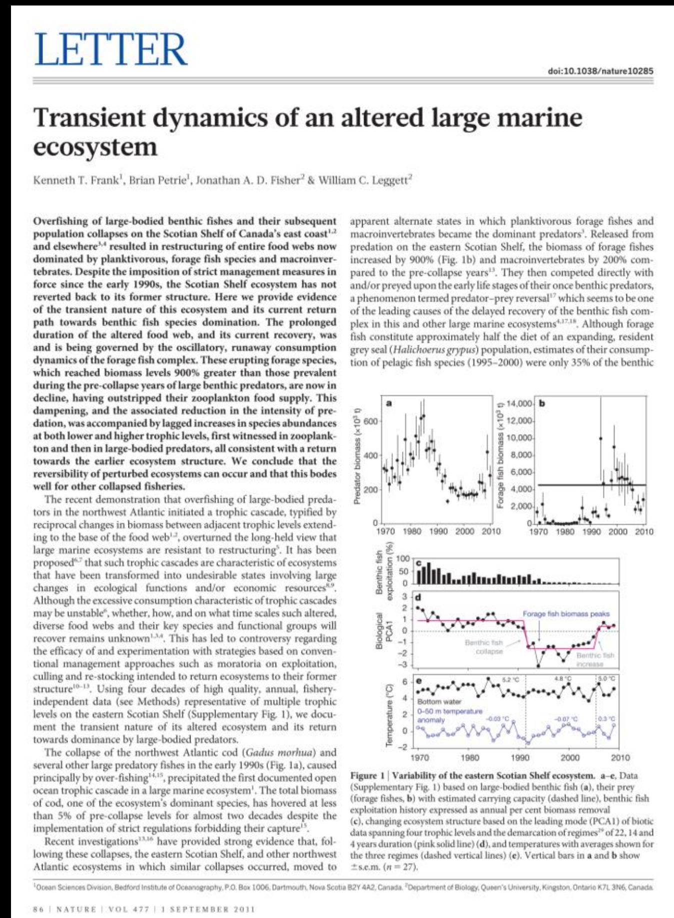

LETTER

doi:10.1038/nature10285

Transient dynamics of an altered large marine ecosystem

Kenneth T. Frank[1], Brian Petrie[1], Jonathan A. D. Fisher[2] & William C. Leggett[2]

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The recent demonstration that overfishing of large-bodied predators in the northwest Atlantic initiated a trophic cascade, typified by reciprocal changes in biomass between adjacent trophic levels extending to the base of the food web[1,2], overturned the long-held view that large marine ecosystems are resistant to restructuring[5]. It has been proposed[6,7] that such trophic cascades are characteristic of ecosystems that have been transformed into undesirable states involving large changes in ecological functions and/or economic resources[8,9]. Although the excessive consumption characteristic of trophic cascades may be unstable[6], whether, how, and on what time scales such altered, diverse food webs and their key species and functional groups will recover remains unknown[1,3,4]. This has led to controversy regarding the efficacy of and experimentation with strategies based on conventional management approaches such as moratoria on exploitation, culling and re-stocking intended to return ecosystems to their former structure[10–13]. Using four decades of high quality, annual, fishery-independent data (see Methods) representative of multiple trophic levels on the eastern Scotian Shelf (Supplementary Fig. 1), we document the transient nature of its altered ecosystem and its return towards dominance by large-bodied predators.

The collapse of the northwest Atlantic cod (*Gadus morhua*) and several other large predatory fishes in the early 1990s (Fig. 1a), caused principally by over-fishing[14,15], precipitated the first documented open ocean trophic cascade in a large marine ecosystem[1]. The total biomass of cod, one of the ecosystem's dominant species, has hovered at less than 5% of pre-collapse levels for almost two decades despite the implementation of strict regulations forbidding their capture[15].

Recent investigations[13,16] have provided strong evidence that, following these collapses, the eastern Scotian Shelf, and other northwest Atlantic ecosystems in which similar collapses occurred, moved to apparent alternate states in which planktivorous forage fishes and macroinvertebrates became the dominant predators[3]. Released from predation on the eastern Scotian Shelf, the biomass of forage fishes increased by 900% (Fig. 1b) and macroinvertebrates by 200% compared to the pre-collapse years[13]. They then competed directly with and/or preyed upon the early life stages of their once benthic predators, a phenomenon termed predator–prey reversal[17] which seems to be one of the leading causes of the delayed recovery of the benthic fish complex in this and other large marine ecosystems[4,17,18]. Although forage fish constitute approximately half the diet of an expanding, resident grey seal (*Halichoerus grypus*) population, estimates of their consumption of pelagic fish species (1995–2000) were only 35% of the benthic

Figure 1 | Variability of the eastern Scotian Shelf ecosystem. a–e, Data (Supplementary Fig. 1) based on large-bodied benthic fish (**a**), their prey (forage fishes, **b**) with estimated carrying capacity (dashed line), benthic fish exploitation history expressed as annual per cent biomass removal (**c**), changing ecosystem structure based on the leading mode (PCA1) of biotic data spanning four trophic levels and the demarcation of regimes[29] of 22, 14 and 4 years duration (pink solid line) (**d**), and temperatures with averages shown for the three regimes (dashed vertical lines) (**e**). Vertical bars in **a** and **b** show ±s.e.m. ($n = 27$).

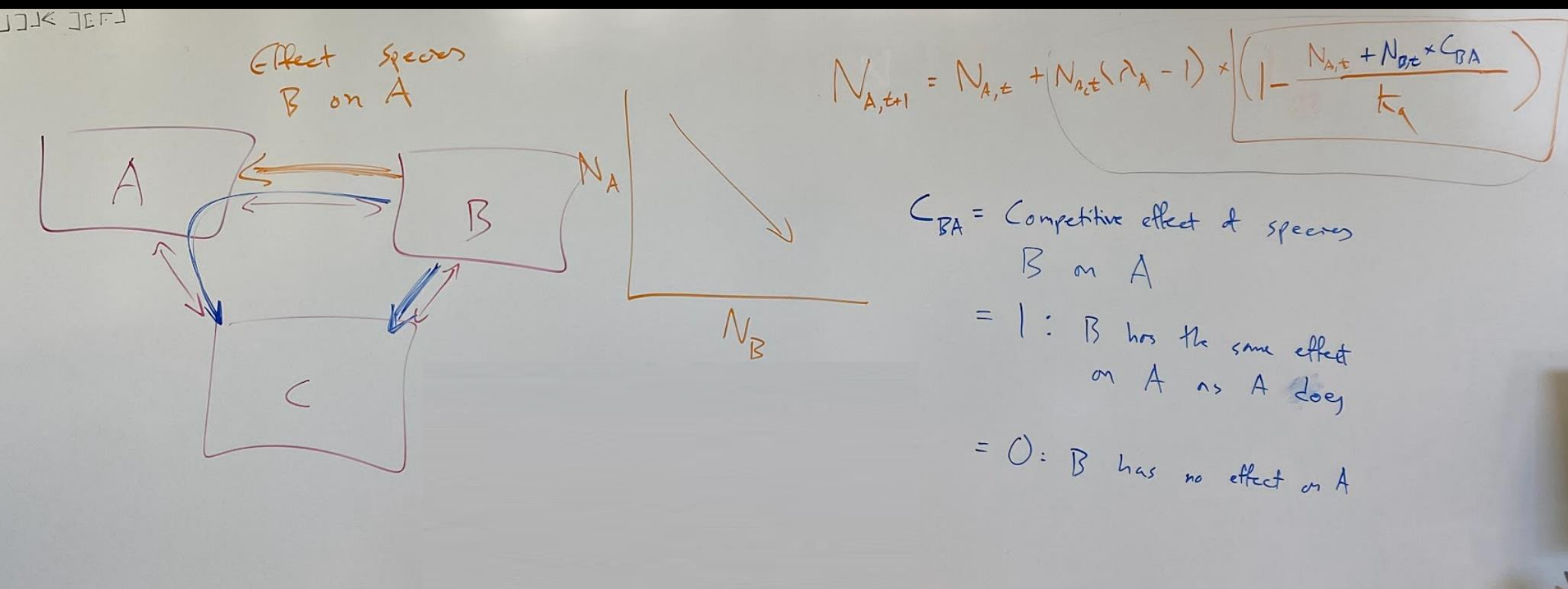
[1]Ocean Sciences Division, Bedford Institute of Oceanography, P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2, Canada. [2]Department of Biology, Queen's University, Kingston, Ontario K7L 3N6, Canada.

Frank et al. 2011

Modeling multiple species: competition

Logistic Model: competition within a species

$$N_{t+1} = N_t + N_t(\lambda - 1)\left(1 - \frac{N_t}{K}\right)$$



Modeling multiple species: competition

Logistic Model: competition within **Species A**

$$N_{a,t+1} = N_{a,t} + N_{a,t}(\lambda_a - 1)\left(1 - \frac{N_{a,t}}{K_a}\right)$$

Modified to include competition between **Species A** and **Species B**

$$N_{a,t+1} = N_{a,t} + N_{a,t}(\lambda_a - 1)\left(1 - \frac{N_{a,t} + C_{ba}N_{b,t}}{K_a}\right)$$

$N_{b,t}$ Number of Species B

C_{ba} Per capita effect of Species B on Species A

- 0.5 means that an individual of Species B has *half* the effect of an individual of Species A

K_a Carrying capacity of Species A in the absences of Species B

Relating MSY to important fisheries metrics

Actual Values:

B = stock biomass (total biomass of fish population) (or total number of fish, **N**)

F or μ = "exploitation rate", "fishing mortality" (expressed as fraction of stock harvested each year)

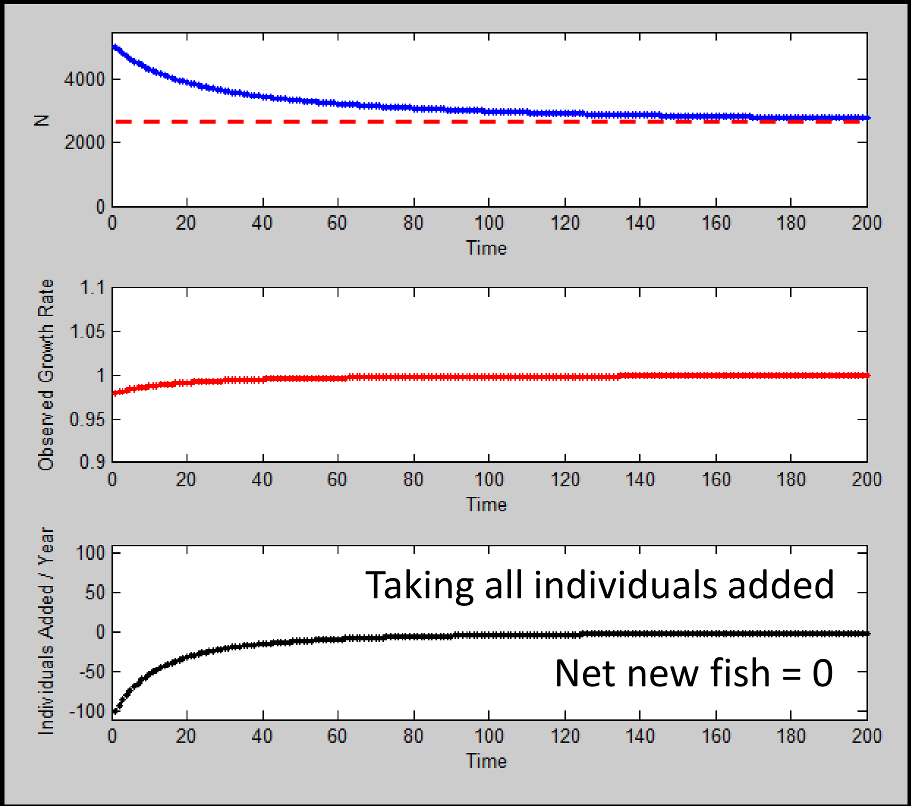
Theoretical Values:

B_{msy} = B value when harvesting at MSY (stock biomass that produces maximum yield)

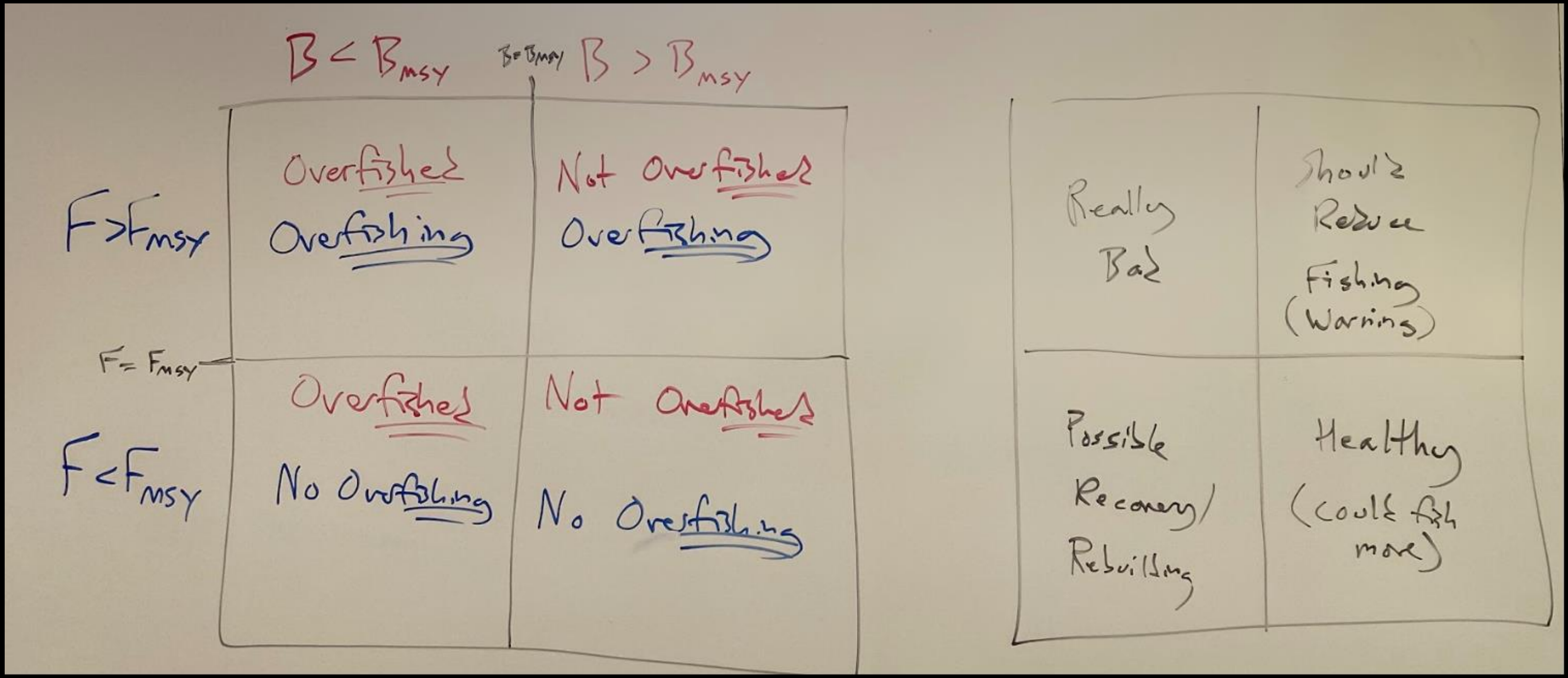
B_{msy} = 2500 fish

F_{msy} = F value when harvesting at MSY (maximum sustainable F value)

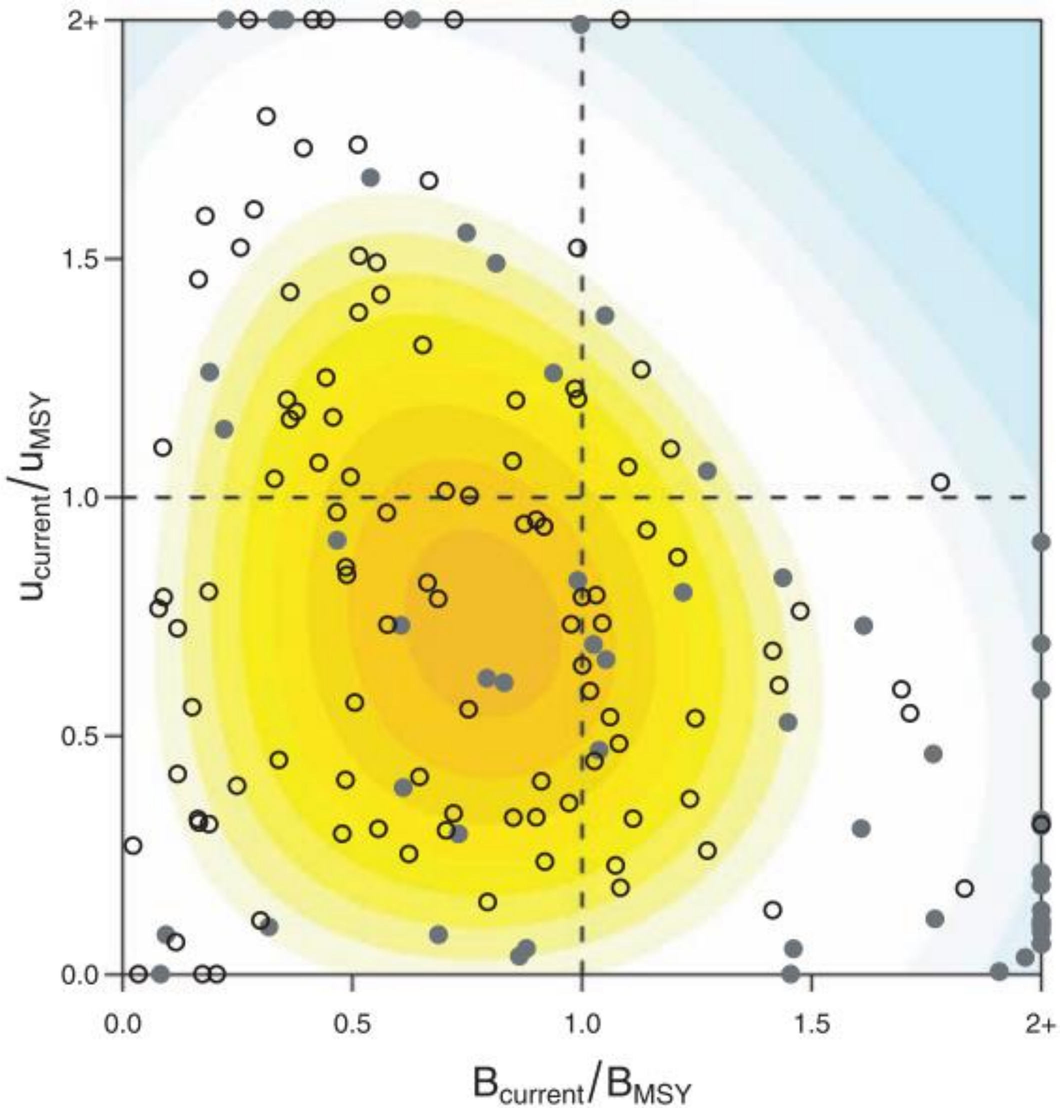
F_{msy} = 100 / 2500 = 0.04



Assessing the state of fisheries



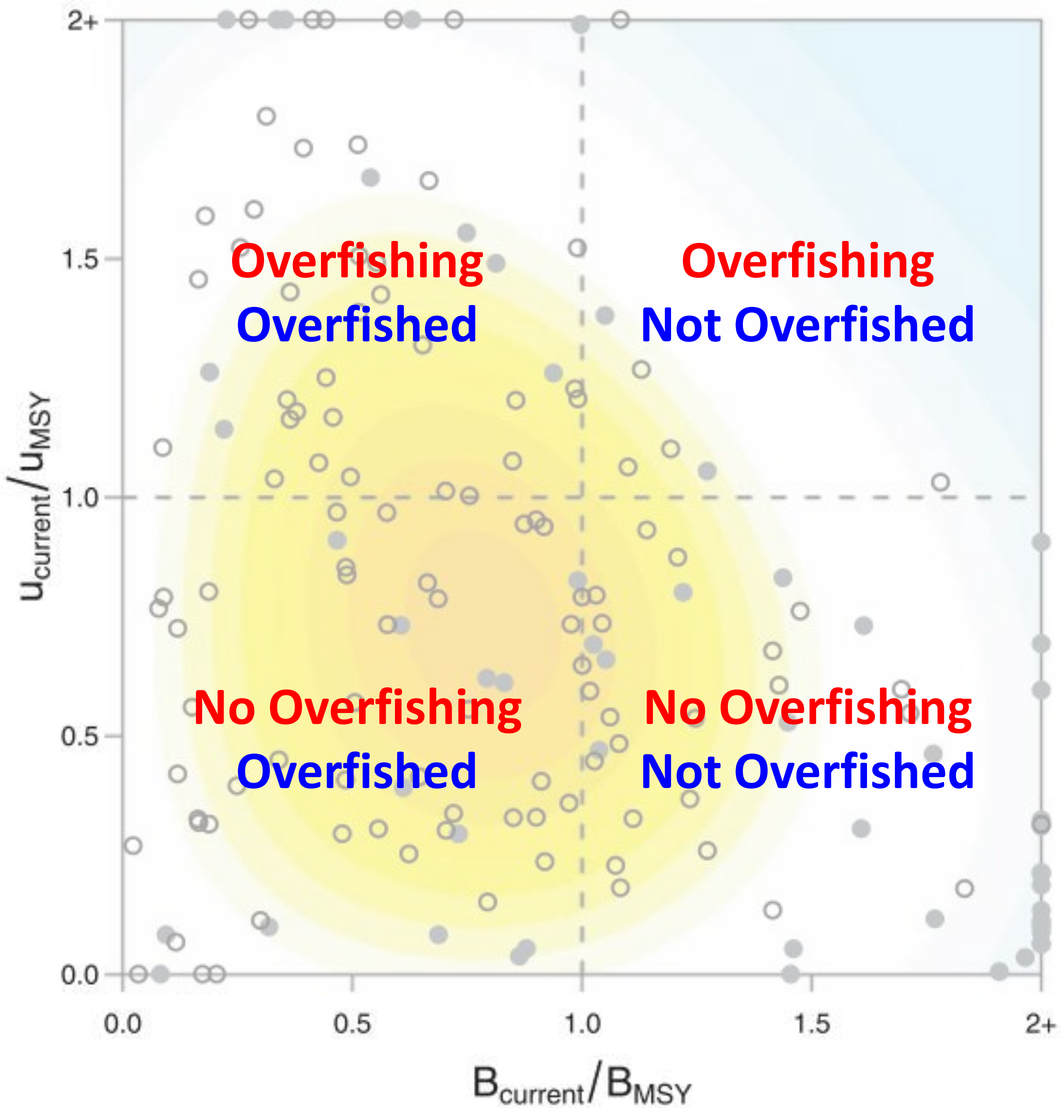
166 Fisheries



From empirical measurements

From models

166 Fisheries



From empirical measurements

From models

Georges Bank

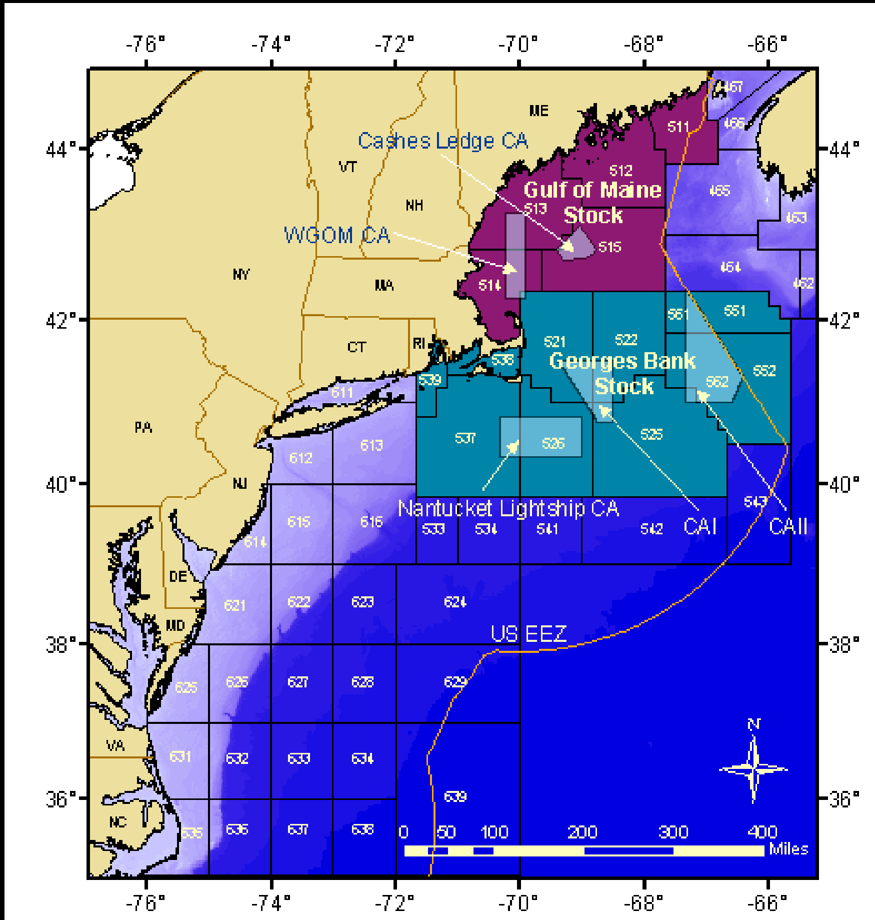
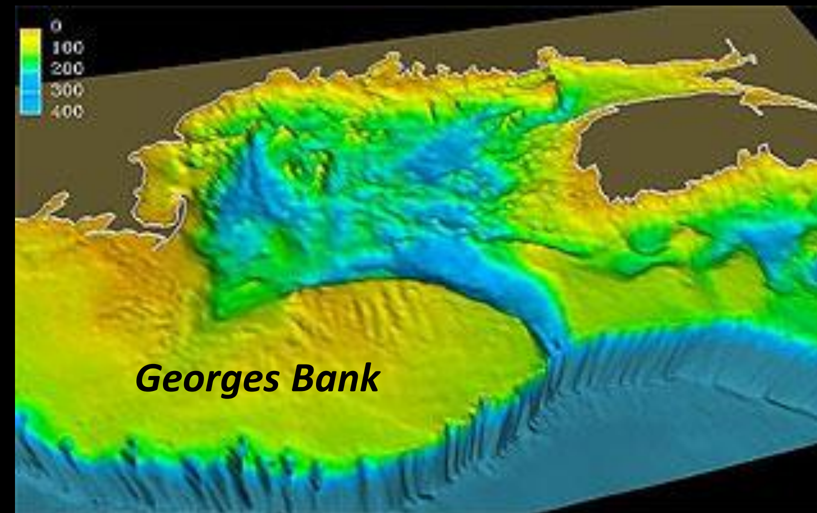


Figure 1.1. Statistical areas used to define the Gulf of Maine and Georges Bank cod stocks.

(NOAA)



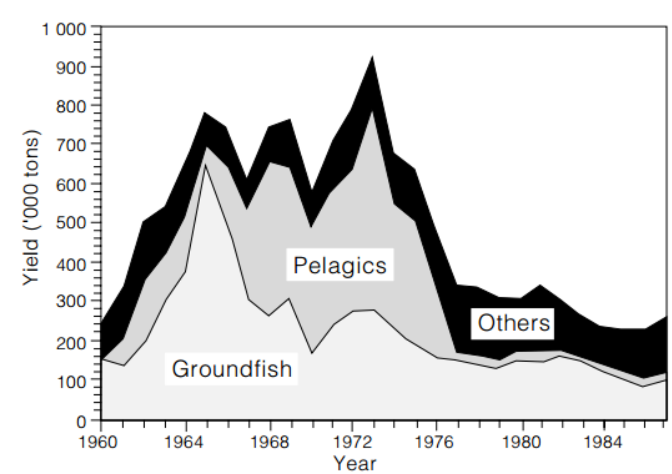
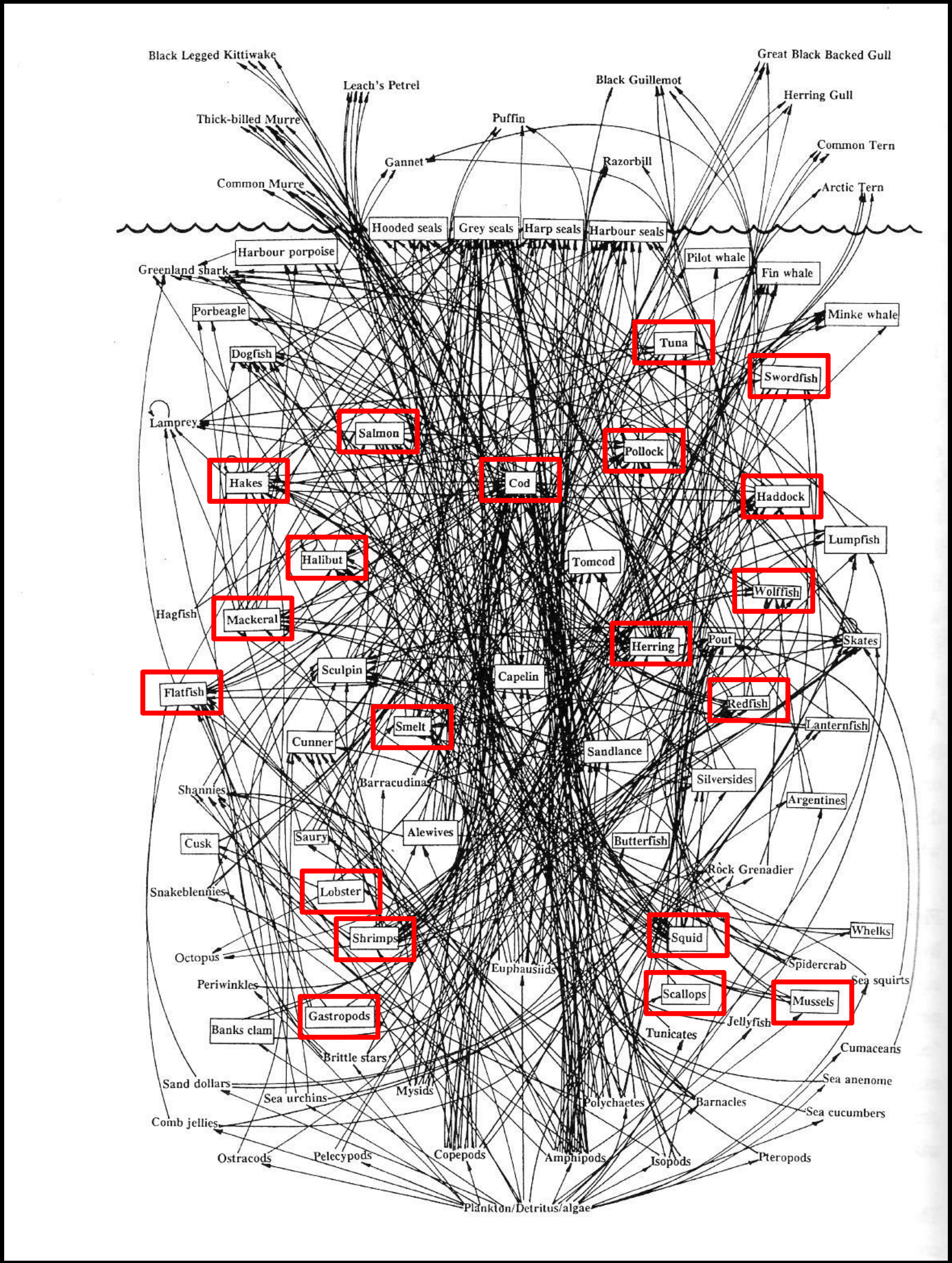


Fig. 2. Total nominal catches from Georges Bank (NAFO Div. 5Z) fisheries, 1960–87. Aggregate yields are presented by fishery components: groundfish, pelagic and 'other'.

(Mayo et al. 1992)

Considering and managing an ECOSYSTEM

Northwest Atlantic Food Web



(Lavigne)

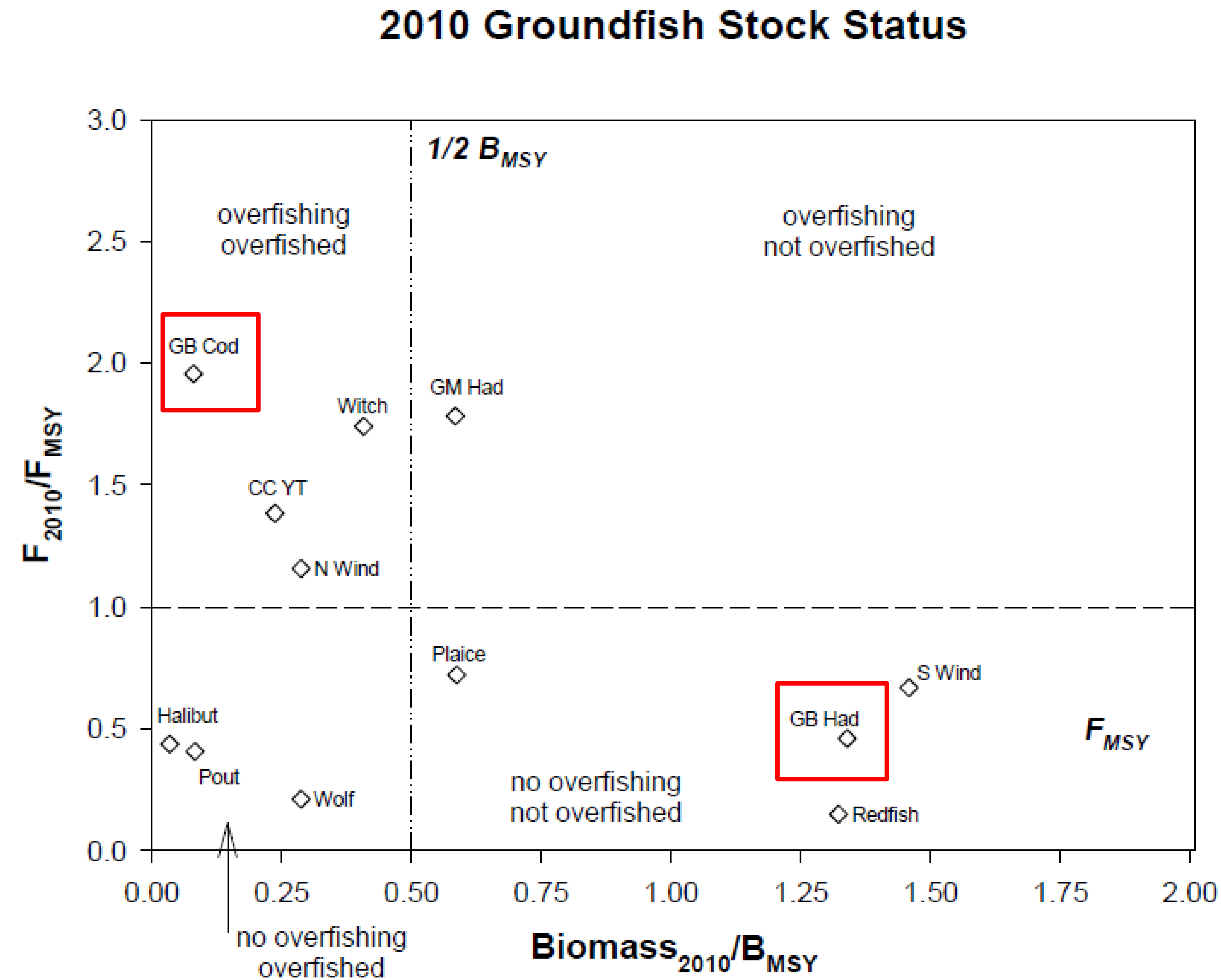


Figure 1. Status of 12 groundfish stocks in 2010 with respect to F_{MSY} and B_{MSY} proxies.

(NMFS)

Vol. 16: 9–20, 1984 | MARINE ECOLOGY – PROGRESS SERIES
Mar. Ecol. Prog. Ser. | Published February 29

The feeding habits of co-occurring cod and haddock larvae from Georges Bank*

Joseph Kane

US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Center, Narragansett Laboratory, Narragansett, Rhode Island 02882, USA

ABSTRACT: Types, number, size, biomass, and selection of food items by the larvae of Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* were determined by examination of gut contents from co-occurring larvae captured in plankton samples from Georges Bank. Eggs, nauplii, and copepodite stages of copepods were the predominant food items for both larvae, but cod consumed larger prey at an earlier age than haddock. The smallest larvae were the most euryphagous, haddock more than cod. Cod and haddock feeding intensity reached a peak shortly before sunset, and both larvae selected against the copepodite stages of *Oithona similis*. Dietary niche breadth and overlap indices indicate that competition is severe between and among similar sized individuals of both species.

INTRODUCTION

The larvae of 2 important commercial fish species, Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* often co-occur in the Northwest

During the spring of 1980 large numbers of co-occurring cod and haddock larvae were collected on Georges Bank. The feeding habits of both species were analysed and compared for differences in diet composition, feeding periodicity, prey-size selection, Reading for Monday 3/25

What Is Conservation Science?

PETER KAREIVA AND MICHELLE MARVIER

In 1985, Michael Soulé asked, "What is conservation biology?" We revisit this question more than 25 years later and offer a revised set of core principles in light of the changed global context for conservation. Most notably, scientists now widely acknowledge that we live in a world dominated by humans, and therefore, the scientific underpinnings of conservation must include a consideration of the role of humans. Today's conservation science incorporates conservation biology into a broader interdisciplinary field that explicitly recognizes the tight coupling of social and natural systems. Emerging priorities include pursuing conservation within working landscapes, rebuilding public support, working with the corporate sector, and paying better attention to human rights and equity. We argue that in conservation, strategies must be promoted that simultaneously maximize the preservation of biodiversity and the improvement of human well-being.

Keywords: conservation science, Anthropocene, biodiversity, ecosystem resilience, ecosystem services

Soulé (1985) helped define the emerging field of conservation biology with an essay that has been read by generations of students and that is now a science citation classic. However, a lot has happened in the world since 1985, and conservation, like any professional and scientific endeavor, needs to continually refresh its intellectual and academic framework to accommodate new ideas and information.

When Soulé wrote his now classic essay, the Society for Conservation Biology (SCB) did not exist, and the journal *Conservation Biology* had not yet been published. Today SCB boasts more than 10,000 members and has grown from an essentially North American society to one that is increasingly global. With over 25 years having passed since the publication of Soulé's foundational essay, it is worth exploring how his early vision for conservation biology might be updated in light of recent developments. In particular, Soulé envisioned the emerging field of conservation biology as the application of biological science to address

and safety were the only goal of conservation science, we would probably label it *environmental science.* The distinguishing feature is that in conservation science, strategies to jointly maximize benefits to people and to biodiversity are pursued; it is a discipline that requires the application of both natural and social sciences to the dynamics of coupled human–natural systems.

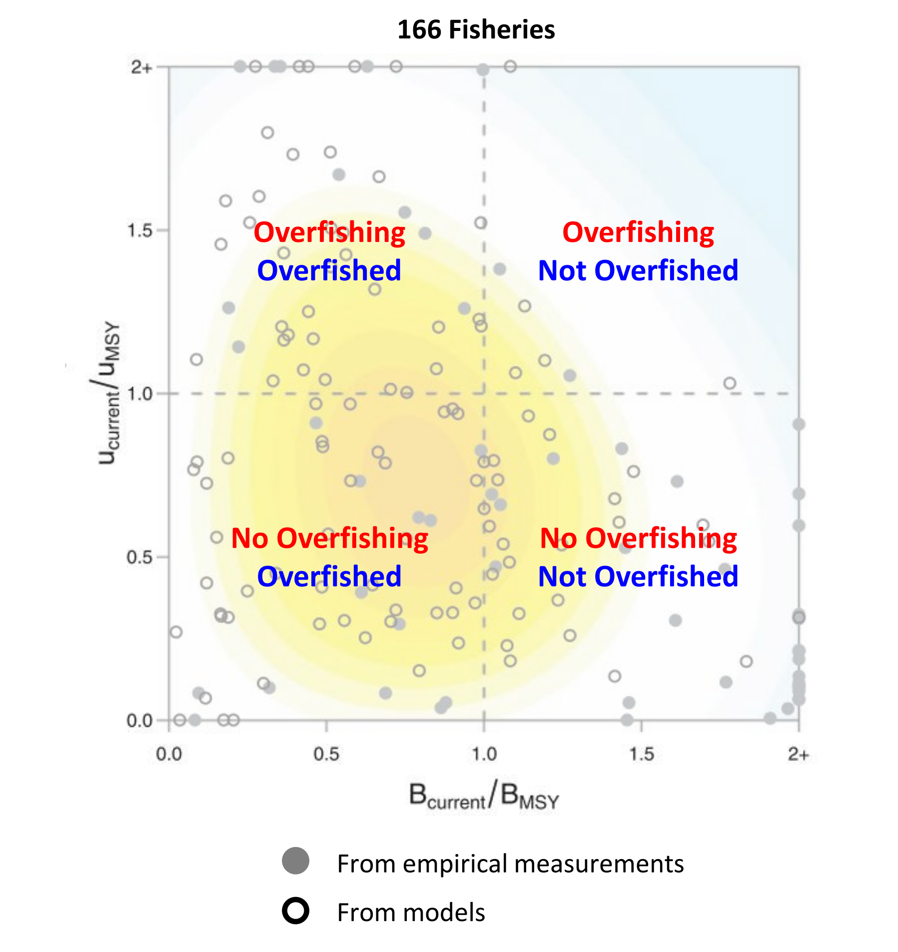
Still a crisis discipline but evidence based

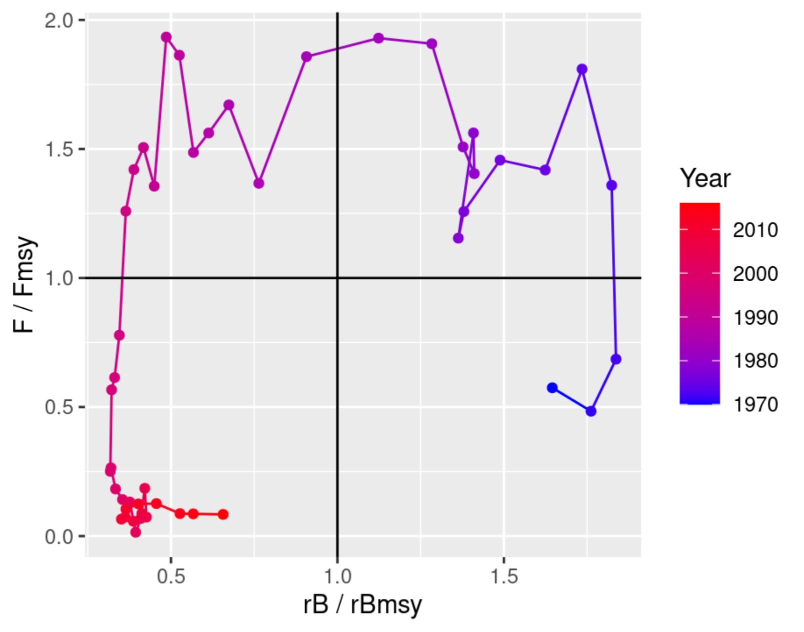
Soulé (1985) argued that conservation biology differs from many other scientific endeavors because it is a "crisis discipline." According to this line of reasoning, conservation biologists, like medical doctors, are often called on to act rapidly and without complete knowledge of the situation. We agree. However, since Soulé's essay, medicine has undergone a revolution whereby its practitioners increasingly rely on systematically accumulated evidence and meta-analyses of collections of studies rather than on personal experience and word of mouth (Evidence-Based Medicine Working

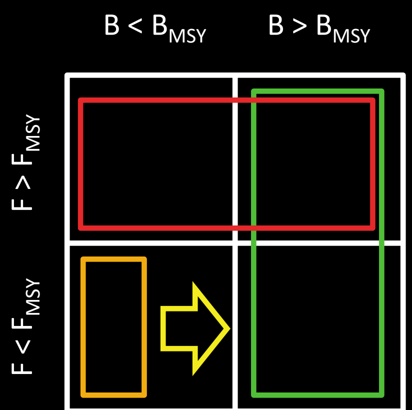
Kareiva and Marvier (2012)

Rebuilding Global Fisheries

Boris Worm,[1*] Ray Hilborn,[2*] Julia K. Baum,[3] Trevor A. Branch,[2] Jeremy S. Collie,[4] Christopher Costello,[5] Michael J. Fogarty,[6] Elizabeth A. Fulton,[7] Jeffrey A. Hutchings,[1] Simon Jennings,[8,9] Olaf P. Jensen,[2] Heike K. Lotze,[1] Pamela M. Mace,[10] Tim R. McClanahan,[11] Cóilín Minto,[1] Stephen R. Palumbi,[12] Ana M. Parma,[13] Daniel Ricard,[1] Andrew A. Rosenberg,[14] Reg Watson,[15] Dirk Zeller[15]







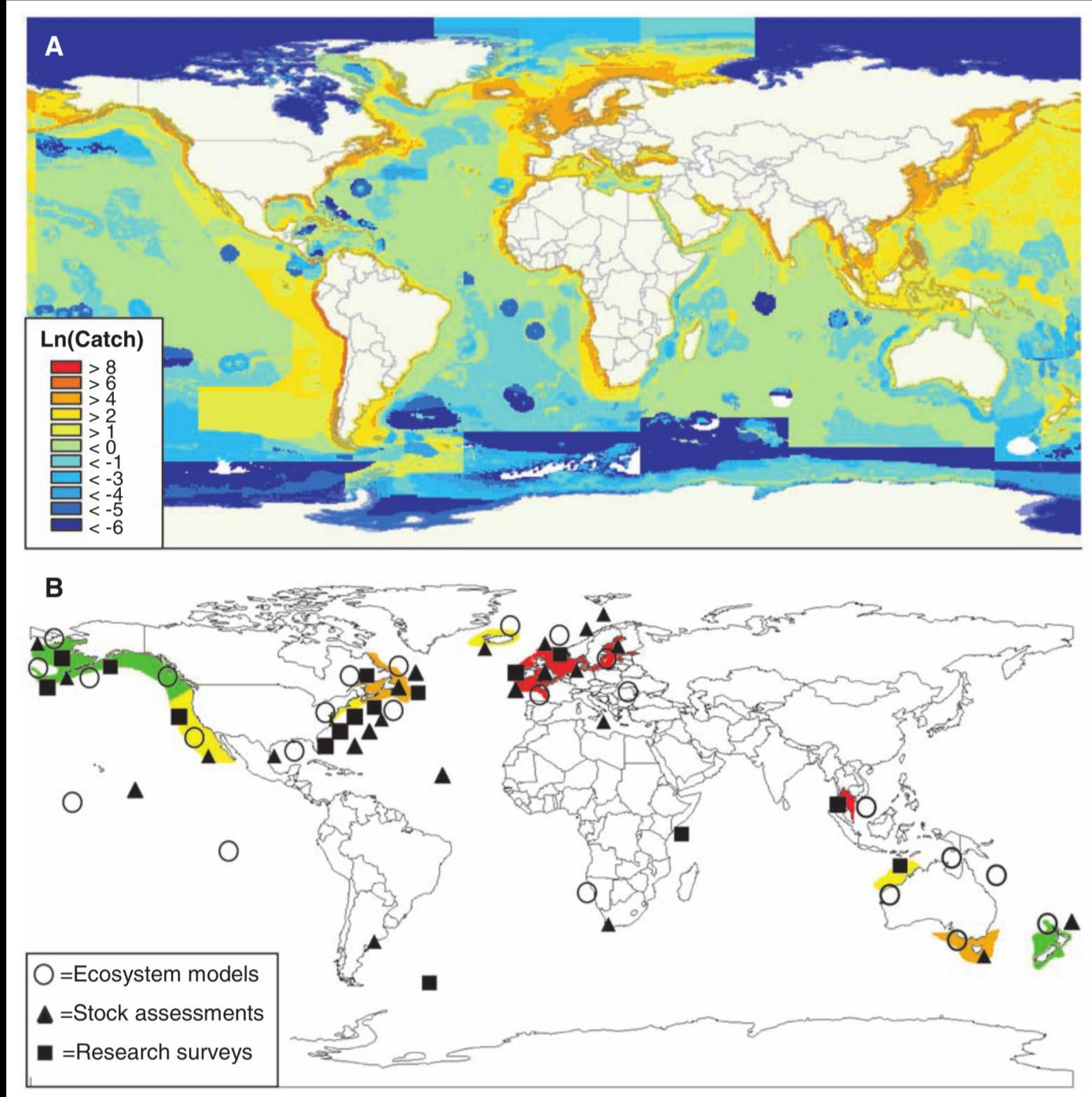
Regions Analyzed:

Not overfished

Rebuilding

Not yet rebuilding

High exploitation rate



nature COMMUNICATIONS

ARTICLE

Received 27 Feb 2015 | Accepted 19 Nov 2015 | Published 19 Jan 2016

DOI: 10.1038/ncomms10244 OPEN

Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining

Daniel Pauly[1] & Dirk Zeller[1]

nature COMMUNIC

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Received 27 Feb 20

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Daniel Pauly[1] &

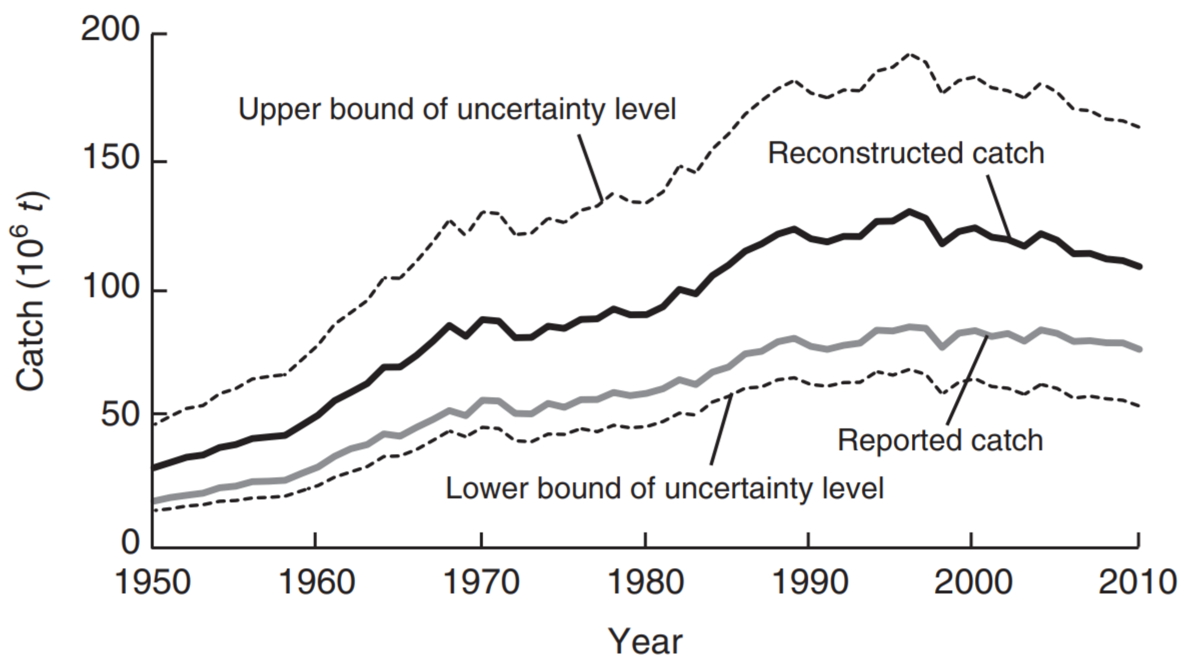


Figure 1 | Trajectories of reported and reconstructed marine fisheries catches 1950–2010. Contrast between the world's marine fisheries catches, assembled by FAO from voluntary submissions of its member countries ('reported') and that of the catch 'reconstructed' to include all fisheries known to exist, in all countries and in the High Sea ('reconstructed' = 'reported' + estimates of 'unreported'). The mean weighted percentage uncertainty of the reconstructed total catches (over all countries and fisheries sectors) based on the quality scores attributed to each sector in each country and territory (dashed line) is also shown.

Rebuilding Global Fisheries

Boris Worm,[1]* Ray Hilborn,[2]* Julia K. Baum,[3] Trevor A. Branch,[2] Jeremy S. Collie,[4] Christopher Costello,[5] Michael J. Fogarty,[6] Elizabeth A. Fulton,[7] Jeffrey A. Hutchings,[1] Simon Jennings,[8,9] Olaf P. Jensen,[2] Heike K. Lotze,[1] Pamela M. Mace,[10] Tim R. McClanahan,[11] Cóilín Minto,[1] Stephen R. Palumbi,[12] Ana M. Parma,[13] Daniel Ricard,[1] Andrew A. Rosenberg,[14] Reg Watson,[15] Dirk Zeller[15]

Multiple Species MSY? (MMSY)

Multispecies model for Georges Bank

(Worm et al.)

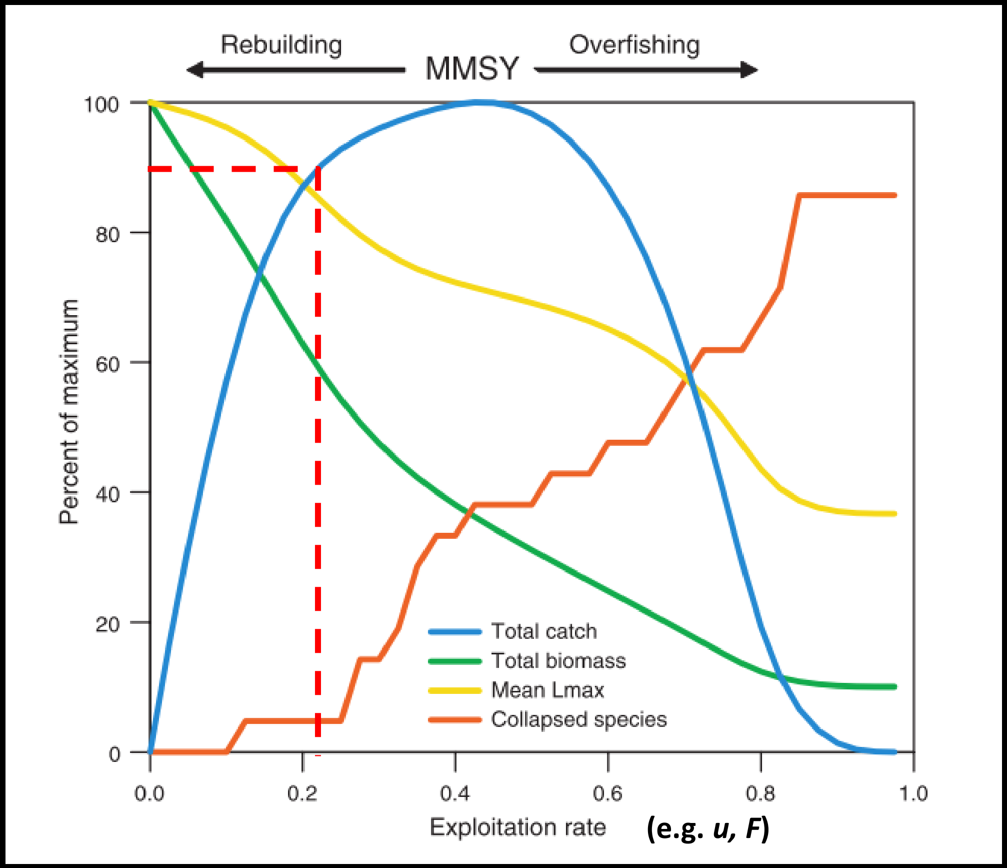


Fig. 2. Effects of increasing exploitation rate on a model fish community. Exploitation rate is the proportion of available fish biomass caught in each year. Mean L_{max} refers to the average maximum length that species in the community can attain. Collapsed species are those for which stock biomass has declined to less than 10% of their unfished biomass. This size-structured model was parameterized for 19 target and 2 nontarget species in the Georges Bank fish community (*13*). It includes size-dependent growth, maturation, predation, and fishing. Rebuilding can occur to the left, overfishing to the right, of the point of maximum catch. Three key objectives that inform current management are highlighted: biodiversity is maintained at low exploitation rate, maximum catch is maintained at intermediate exploitation rate, and high employment is often maintained at intermediate to high exploitation rate, because of the high fishing effort required.

Multispecies model
for Georges Bank

Uncertainty!

(Worm et al.)

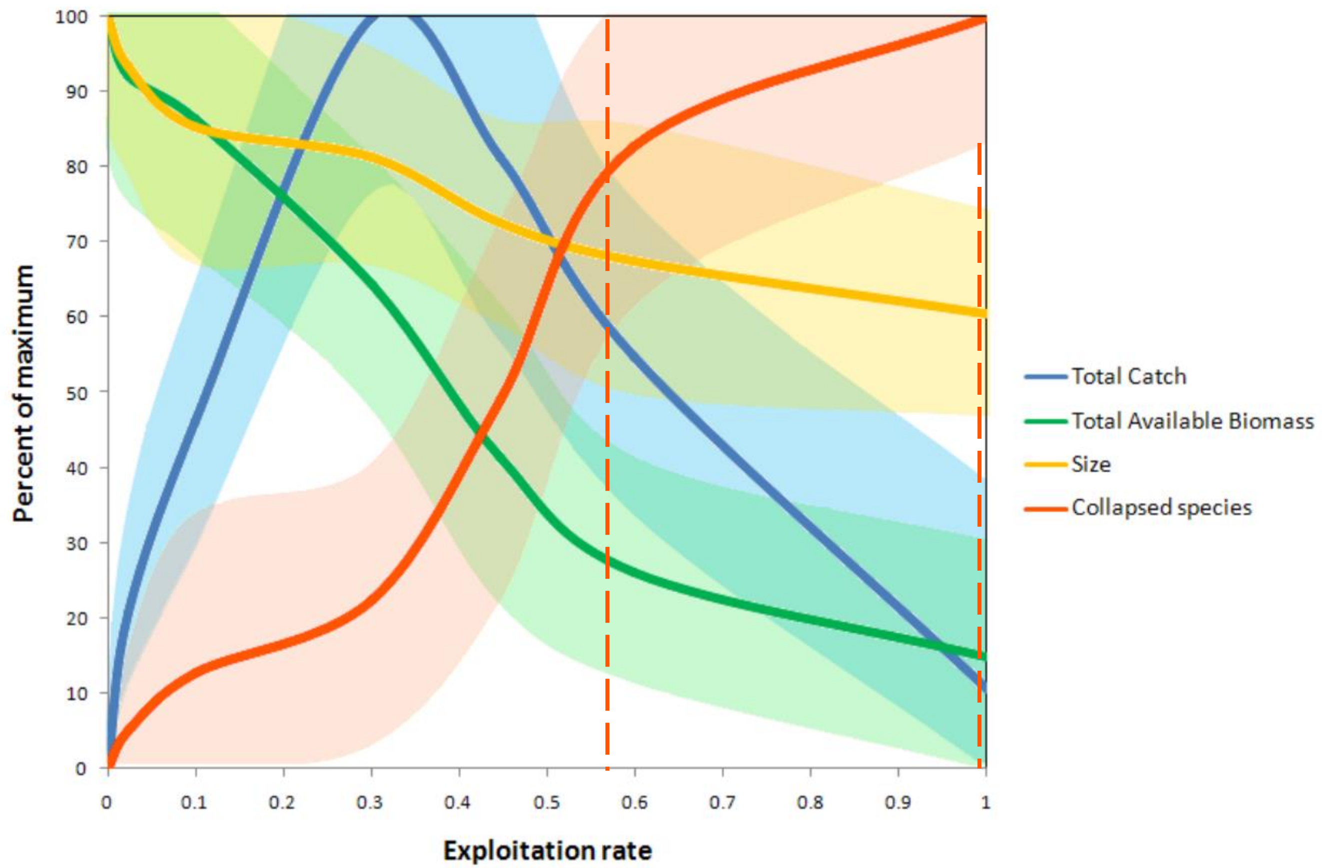


Figure S1: Effects of increasing exploitation rate on 31 model fish communities. Averaged results of ECOSIM models are displayed, shades refer to 95% confidence bounds.

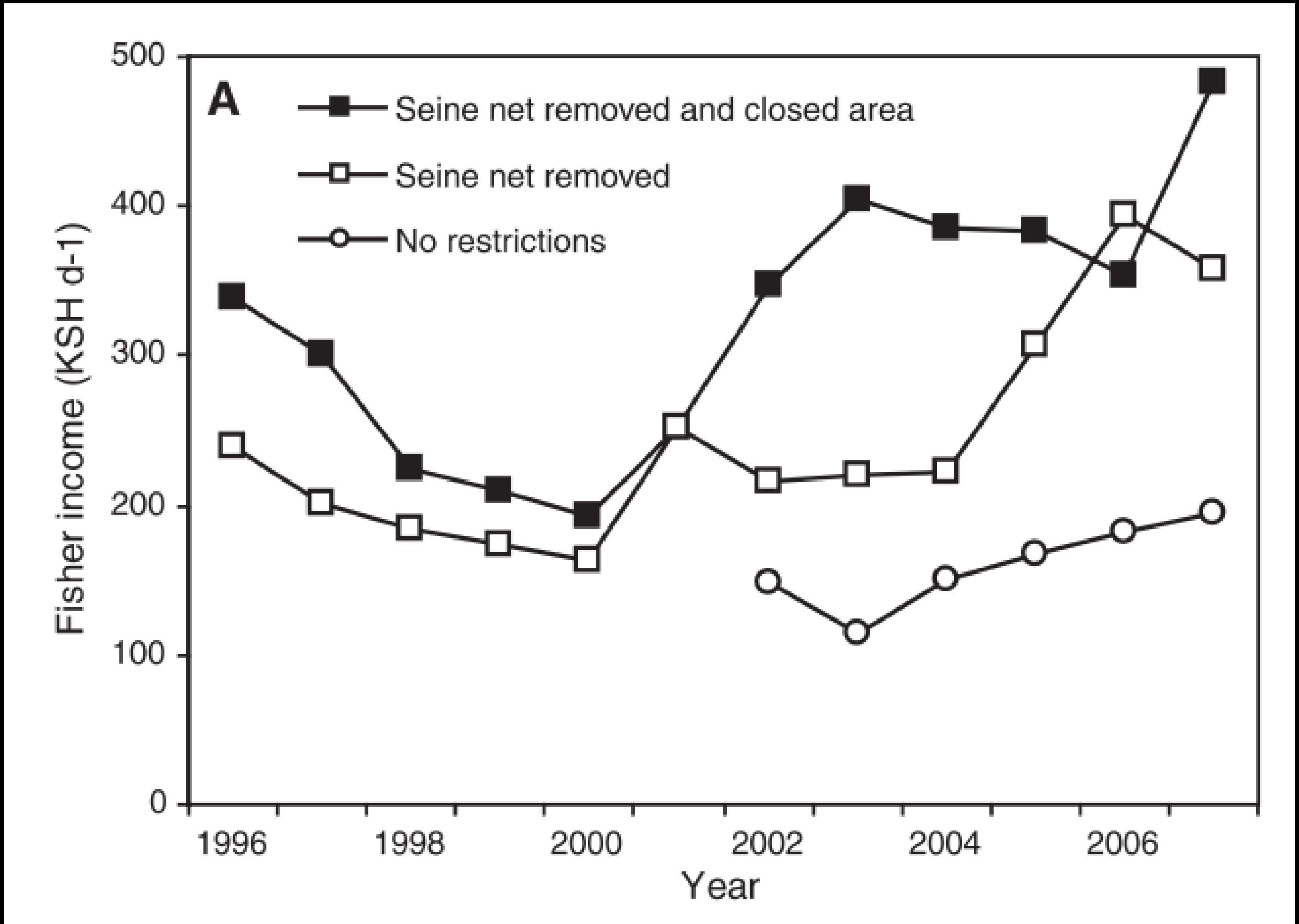
Management Options?

Management Options/Policies?

- Maintaining Fishing Economies

- Catch Limits
  - Ultimately reducing exploitation rate
  - Limit/Ban
  - Time / Space
    - Closed Areas/Marine Protected Areas (MPAs)
      - Local healthy populations → "spillover"
  - "catch shares"
    - ↳ Cap + Trade
- Enforcement?
  - "Top Down"
    - Incentives
    - Monitoring
    - Inspections
  - "Bottom Up"? – "Community-Based Management"

Management case study in Kenya



MAGNUSON-STEVENS FISHERY CONSERVATION AND MANAGEMENT ACT

Public Law 94-265

As amended by the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (P.L. 109-479)

AN ACT

To provide for the conservation and management of the fisheries, and for other purposes.

NOAA

Commerce chief Ross makes waves, roils fisheries rules

Rob Hotakainen, E&E News reporter

Greenwire: Wednesday, September 20, 2017

Commerce Secretary Wilbur Ross extended the Gulf of Mexico season for red snapper by 39 days this year, saying he was responding to frustrated fishermen and following President Trump's lead in cutting "red tape and eliminating failed regulations." His decision alarmed conservationists and fisheries regulators. Distraction Charters/NOAA Fisheries

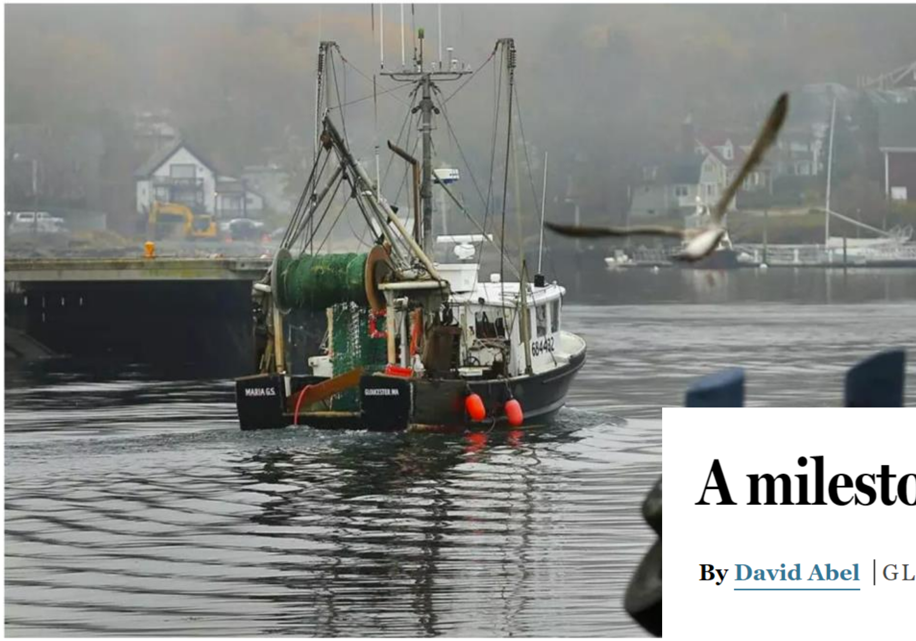
Commerce Secretary Wilbur Ross has wasted little time in giving a jolt to the nation's fisheries.

In June, the 79-year-old billionaire investor who now oversees NOAA Fisheries singlehandedly extended the fishing season for red snapper in the Gulf of Mexico, ignoring protests from scientists and environmentalists that it could spur overfishing of the popular species.

Then in an unprecedented decision in July, he handed a big win to New Jersey fishermen and the state's Republican governor, Chris Christie, by overturning catch limits for summer flounder that had been approved by an interstate fisheries commission.

While Ross wants more fishing and more seafood exports, critics say his early moves have smacked of meddling and favoritism and will ultimately sabotage hard-won conservation gains.

And many fear that states and fishing groups will directly seek political relief instead of following



Fishermen argue that cod's demise has been greatly exaggerated, leading federal officials t the species.

A milestone in the war over the true state of cod

By David Abel | GLOBE STAFF APRIL 03, 2017

For years, fishermen from Gloucester to New Bedford have accused the federal government of relying on faulty science to assess the health of the region's cod population, a fundamental flaw that has greatly exaggerated its demise, they say, and led officials to wrongly ban nearly all fishing of the iconic species.

The fishermen's concerns resonated with Governor Charlie Baker, so last year he commissioned his own survey of the waters off New England, where cod were once so abundant that fishermen would say they could walk across the Atlantic on their backs.

Now, in a milestone in the war over the true state of cod in the Gulf of Maine, Massachusetts scientists have reached the same dismal conclusion that their federal counterparts did: The region's cod are at a historic low — about 80 percent less than the population from just a decade ago.

Cod fishing off New England will be shut down for months

Robert F. Bukaty | AP
In this Oct. 29, 2015, file photo, a cod to be auctioned sits on ice at the Portland Fish Exchange, in Portland, Maine.

The Associated Press • September 27, 2019 12:17 pm
Updated: September 27, 2019 12:20 pm

PORTLAND, Maine — The federal government is shutting down recreational cod fishing in a key fishing area off New England for several months.

[Maine fisheries]

The National Oceanic and Atmospheric Administration says possession of Gulf of Maine cod will be prohibited from Oct. 1 to April 30. The Gulf of Maine touches Maine, Massachusetts and New Hampshire and is a hotbed of a recreational and

FEATURED

Fishery groups question cod limits

By Ethan Forman | Staff Writer Dec 7, 2021

Fresh caught cod wait to be gutted on the F/V Sabrina Maria on Jan. 19, 2018. Two industry groups say the New England Fishery Management Council's Scientific and Statistical Committee lacked “relevant information” to make its determination on catch limits for Georges Bank cod.

Joseph Prezioso/File photo

If You Go

What: New England Fishery Management Council gets recommendations from its Scientific and Statistical Committee on overfishing limits and acceptable biological catches for, among other species, Georges Bank cod and Gulf of Maine cod for fishing years 2022-2024.

When: Wednesday, Dec. 8, at 10:45 a.m.

Webinar link: https://www.nefmc.org/calendar/december-2021-council-meeting.

Two fishing industry trade associations are asking the New England Fishery Management Council to reevaluate its drastically reduced catch limit recommendations on Georges Bank cod.

The groups, the Gloucester-based Northeast Seafood Coalition and the Associated Fisheries of Maine, say the New England Fishery Management Council's Scientific and Statistical Committee lacked “relevant information” to make its determination on an Acceptable Biological Catch for Georges Bank cod. They are asking for a remand.

MAY 15, 2023

New England groundfish fleet faces cod, haddock challenges

National Fisherman published in National Fisherman

SHARE

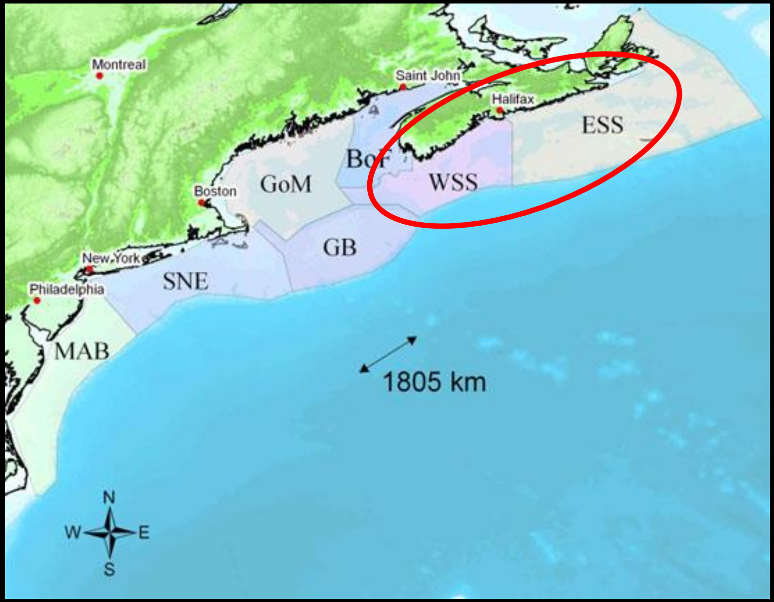
The groundfish fishery in the U.S. Northeast is facing new regulations and management.

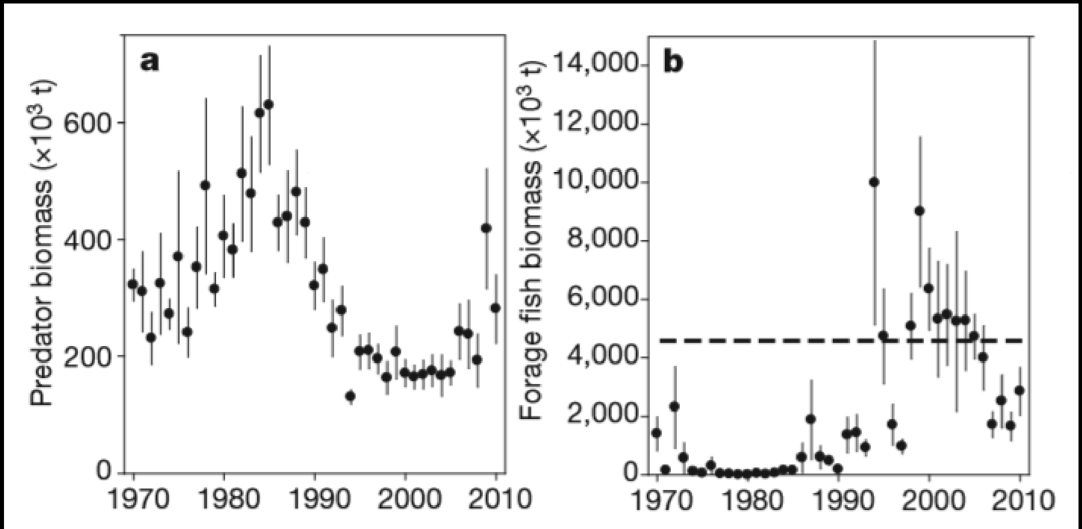
A new plan from New England Fishery Management Council (NEFMC) will implement a decade of low catch limits, with the goal of rebuilding the Gulf of Maine cod stock. It will also guide the 2023 fishing year.

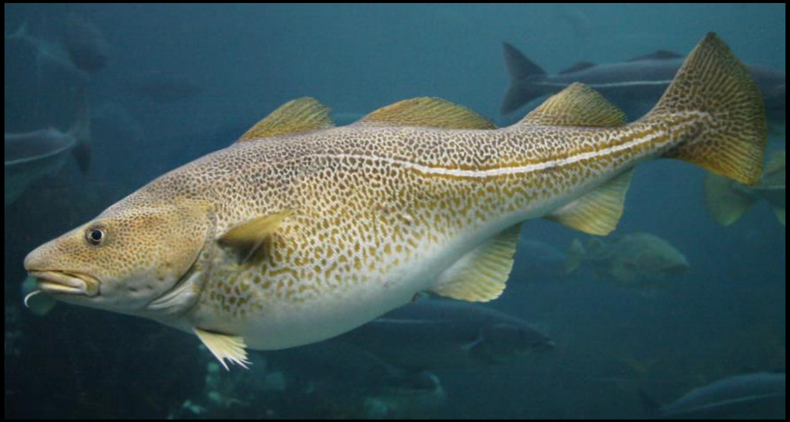
In coordination with various policy, management, and commercial fishing partners, NEFMC has been working for some time to rebuild the Gulf of Maine cod population, initiating a 10-year rebuilding process in December 2022 known as Framework 65.

Transient dynamics of an altered large marine ecosystem

Kenneth T. Frank[1], Brian Petrie[1], Jonathan A. D. Fisher[2] & William C. Leggett[2]







Decreasing abundance of old/large fish

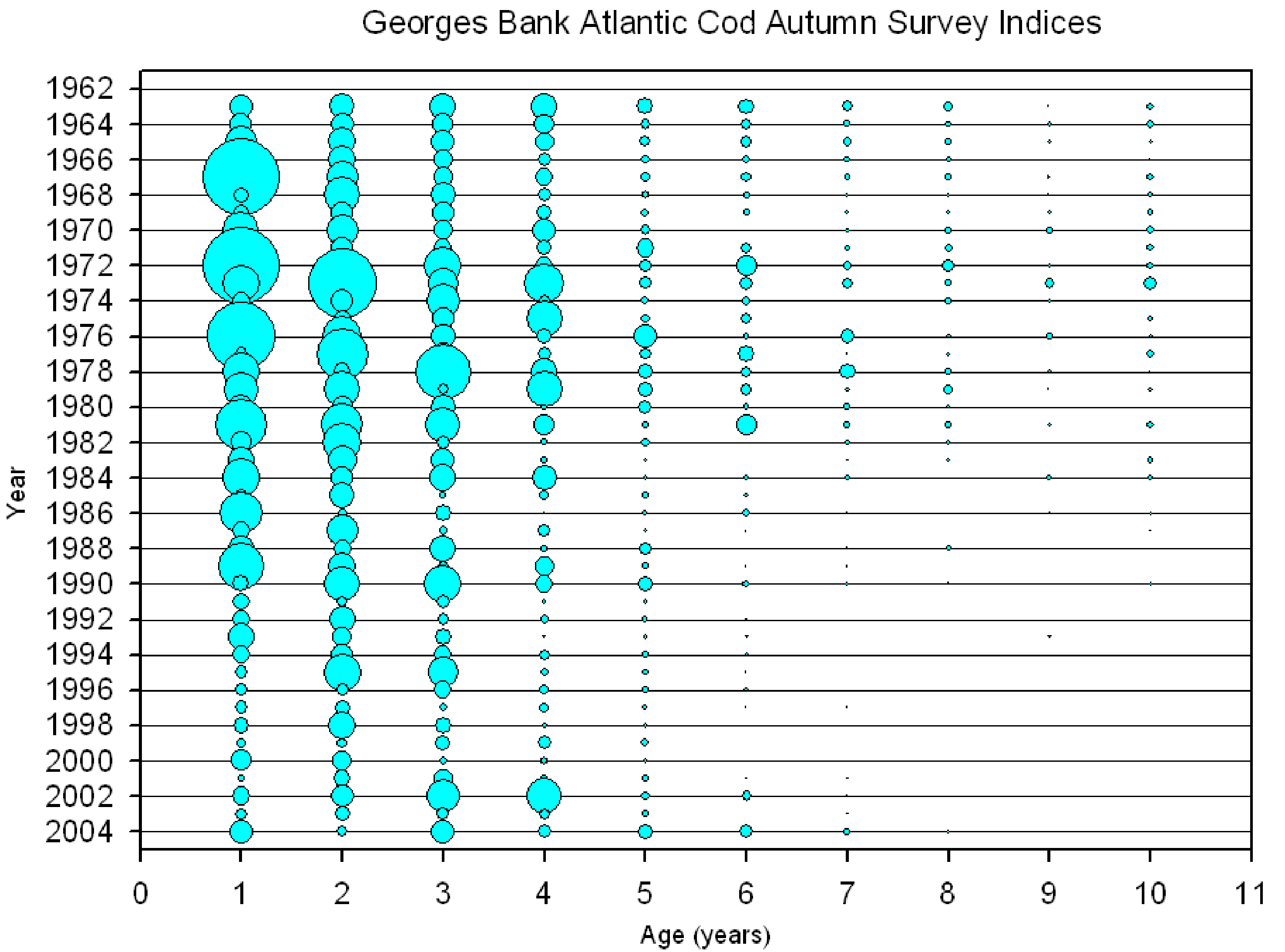
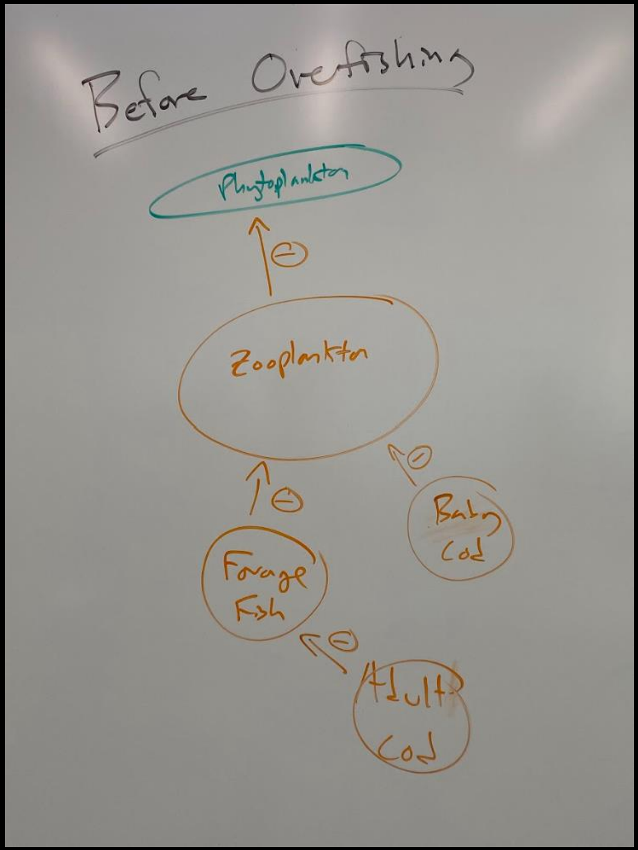
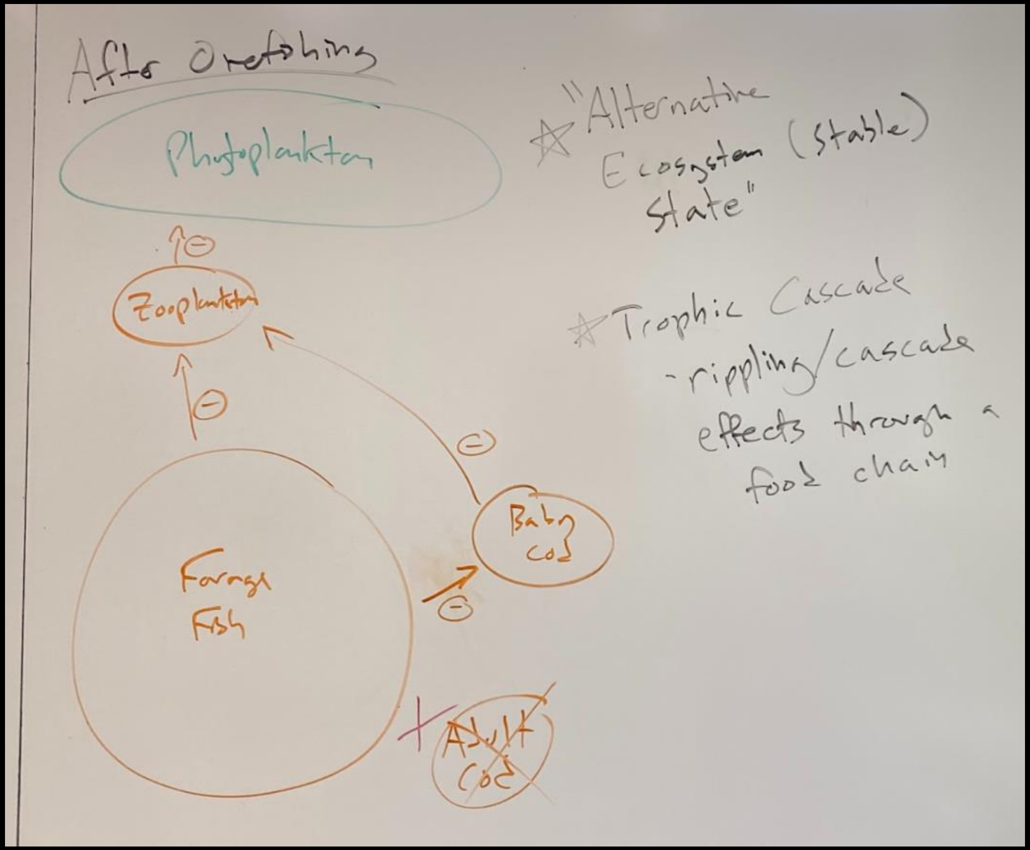


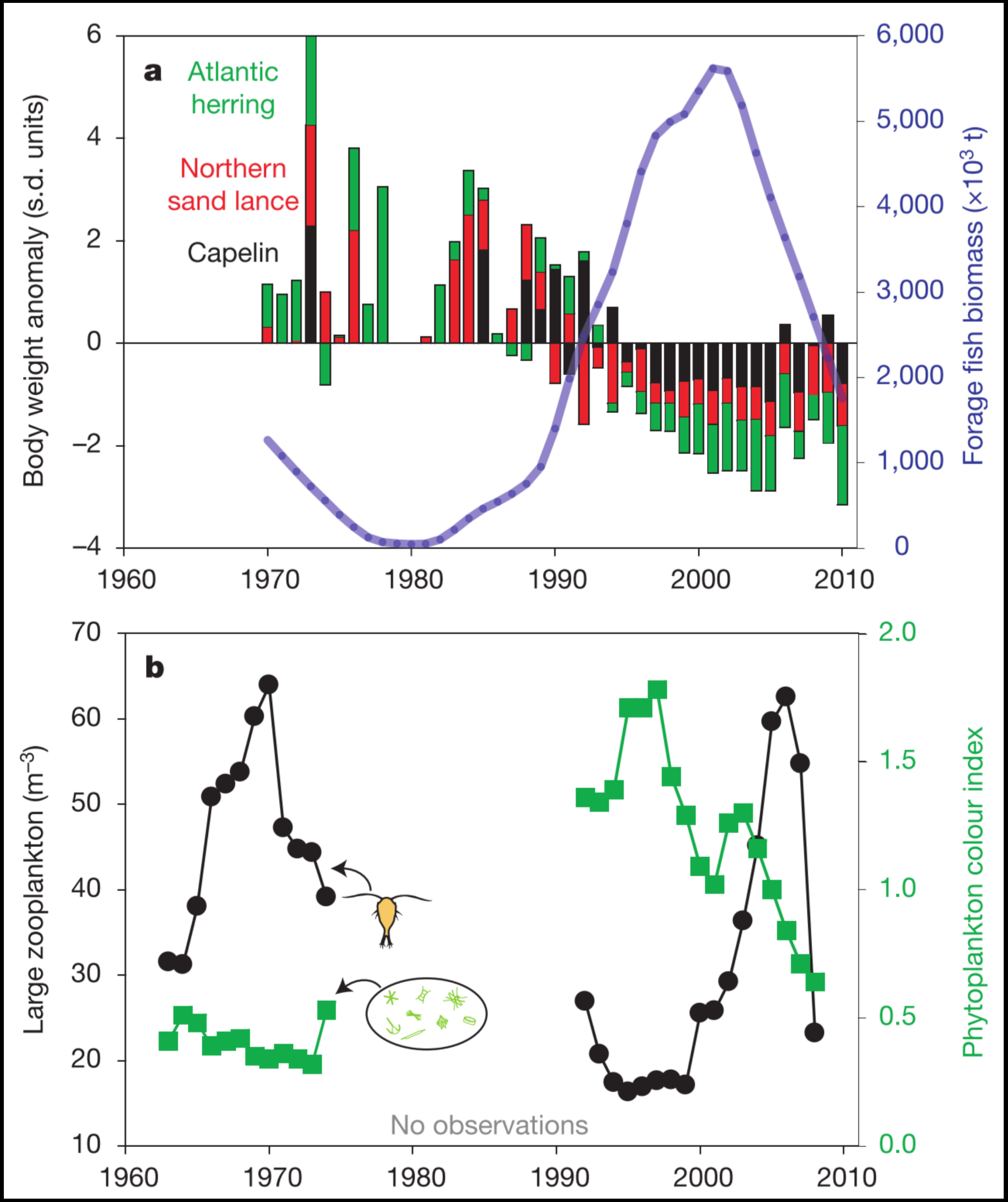
Figure 1.14 . Age structure of Georges Bank Atlantic cod population as indicated by autumn research vessel survey indices of abundance.

(NMFS)

The “State” of an Ecosystem







a
Atlantic herring
Northern sand lance
Capelin
Body weight anomaly (s.d. units)
Forage fish biomass (×10³ t)
6
4
2
0
−2
−4
6,000
5,000
4,000
3,000
2,000
1,000
0
1960
1970
1980
1990
2000
2010
b
Large zooplankton (m⁻³)
Phytoplankton colour index
70
60
50
40
30
20
10
2.0
1.5
1.0
0.5
0.0
No observations
1960
1970
1980
1990
2000
2010

Reading for Thursday (Reading Response Due)

Conservation in Practice

Demography of the California Condor: Implications for Reestablishment

VICKY J. MERETSKY,* NOEL F. R. SNYDER,† STEVEN R. BEISSINGER,‡
DAVID A. CLENDENEN,§ AND JAMES W. WILEY**

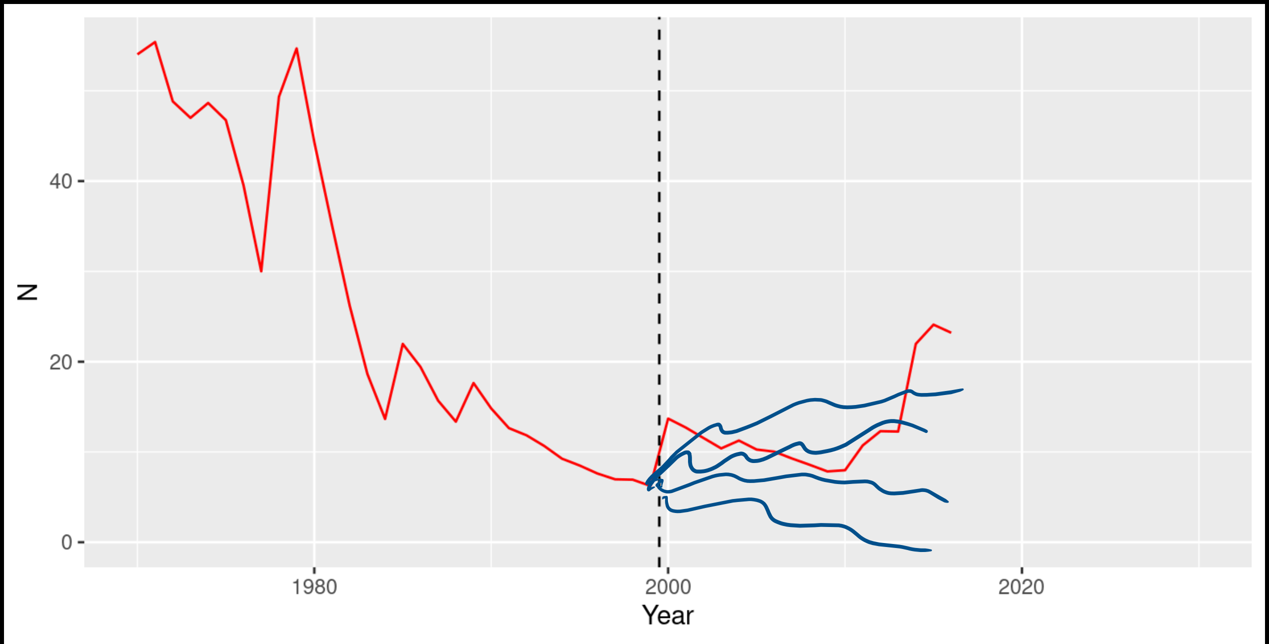
*School of Public and Environmental Affairs, Indiana University, 1315 East 10th Street, Bloomington, IN 47405-1701, U.S.A., email meretsky@indiana.edu
†Wildlife Preservation Trust International, P.O. Box 16426, Portal, AZ 85632, U.S.A.
‡Department of Environmental Science, Policy & Management, 151 Hilgard Hall, University of California, Berkeley, CA 94720-3114, U.S.A.
§Wind Wolves Preserve, P.O. Box 189, Maricopa, CA 93252, U.S.A.
**Grambling Cooperative Wildlife Project, Grambling State University, P.O. Box 841, Grambling, LA 71245, U.S.A.

- Consider how they use a model to help identify unknown or “target” values
- Do a quick web search on organisms affected by lead ammunition

Lab 8

2. Examine a scenario in which fishing restrictions were not implemented in 1999.
[covered in handout]

- Stochastic model from 1999 to 2016 assuming λ values before 1999

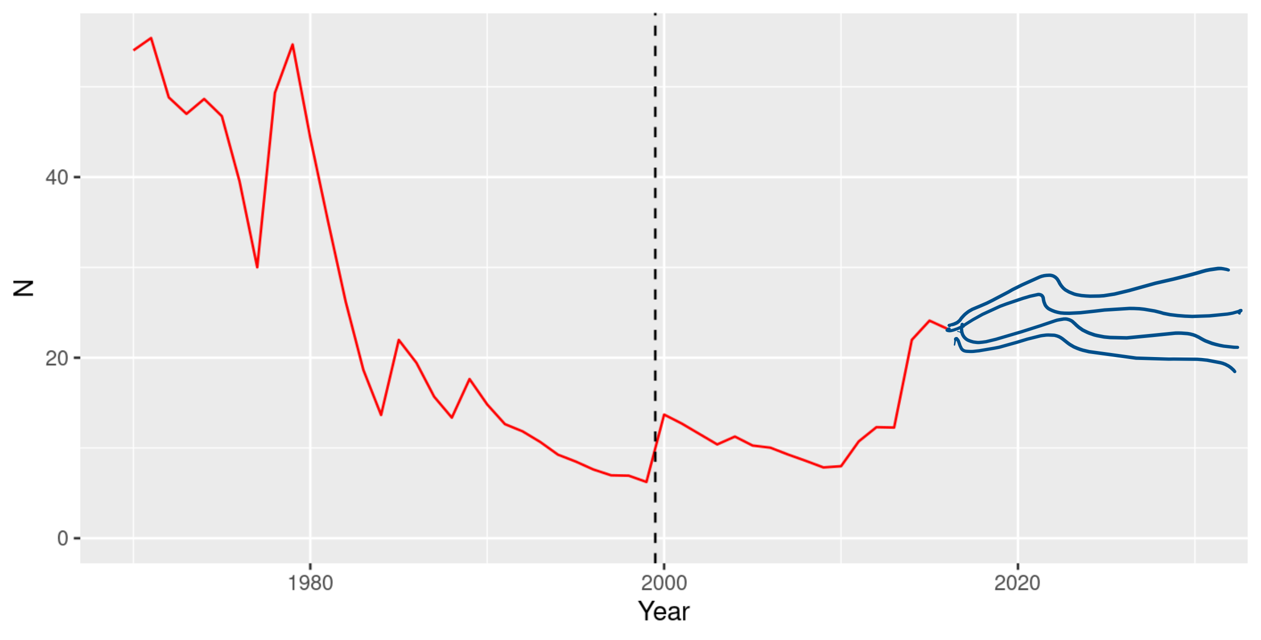


Lab 8

3. What might the future hold for Bocaccio?

- Modify your stochastic model so that it starts in 2016 and projects out to 2030. Be sure to use the λ values from 2000 to 2016 (i.e. *without* fishing). What fraction of modeled iterations remain above the population low point of 1999?
- Add fishing into this model by incorporating an exploitation rate. In other words, what if a fraction of the fish are taken each year? What exploitation rate would result in a reasonably sustainable fishery (i.e. F_{MSY})?

- Stochastic model from 2016 to 2030 assuming λ values after 1999



Lab Final Projects

Your final lab project (due last lab: April 24) will be to formulate and address questions about a "species of concern" using a population modeling approach. The species could be:

- ***Threatened*** (want to increase λ)
- ***Invasive*** (want to decrease λ)

1. Perform **background research** for this species in order to understand the system that you're working with and to generate ideas / relevant questions.

2. Develop **2-3 main questions** that will drive your research. You might want to think about the types of questions that you can address with the following general tools:
   - Population viability analysis (PVA)
   - Sensitivity analysis
   - Assessment of management scenarios to produce a given outcome
   - Influence of environmental factors (e.g. climate, predation, etc.) on vital rates and population growth

3. Your analysis must consist of two parts:

   a. **Review of literature** to examine how others have looked this species. Why are your specific questions relevant?

   b. **Develop a model(s)** and parameterize it using real-world data and/or meaningful scenarios to help address your questions. You will likely have to alter aspects of the model to address different questions.

4. **Analyze and contextualize** the results of both your literature review and your model outputs.

5. Provide **recommendations for the management** of your species that are informed by your conclusions.

This project will be **presented as a poster** on the last laboratory section. (more details to come)

Lab Final Projects

https://wellesley.shinyapps.io/matrix-data

Monday, April 1

- Choose **3** species that interest you from:
  - https://wellesley.shinyapps.io/matrix-data
- These species are included in the COMPADRE and COMADRE databases of plant and animal population matrix model data: http://www.compadre-db.org
- You must include at least one plant or animal.
- It's best to choose species that have multiple years, populations, and/or treatments.
- Submit your species via the form: https://forms.gle/xRJEYNhyxrV3uGn56

Wednesday, April 3

- I will briefly meet with you during lab to help narrow in on your species and help you locate the publication that the dataset comes from.

Monday, April 8

- Turn in a one page "proposal" that includes preliminary research (at least two identified sources) and **clearly specifies your main questions to address**.
- You must include a brief rationale for why you are addressing these questions and how they will help inform the management of this species.

Wednesday, April 10

- We will be smelting copper in lab, but there will be time for me to talk with you about your ideas and give feedback on your proposal.

Wednesday, April 17

- This lab is dedicated entirely to working on your projects. I will come around and meet with you all individually to help.

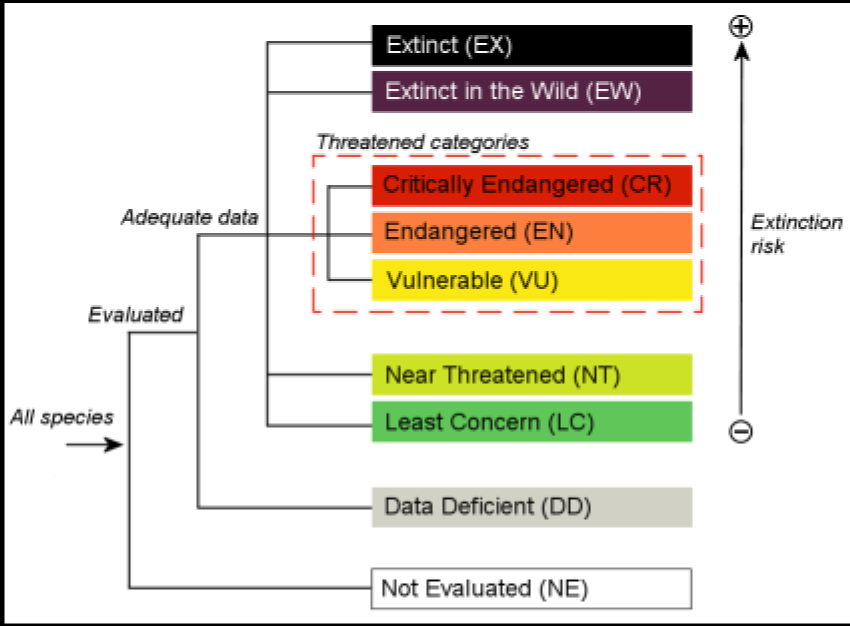
Thursday/Friday, April 18/19

- Drop-in help. I will be available for much of these two days to help with your projects.
- I'll add sign-up slots to my office hours calendar.

Wednesday, April 24

- In class poster presentations and festivities!

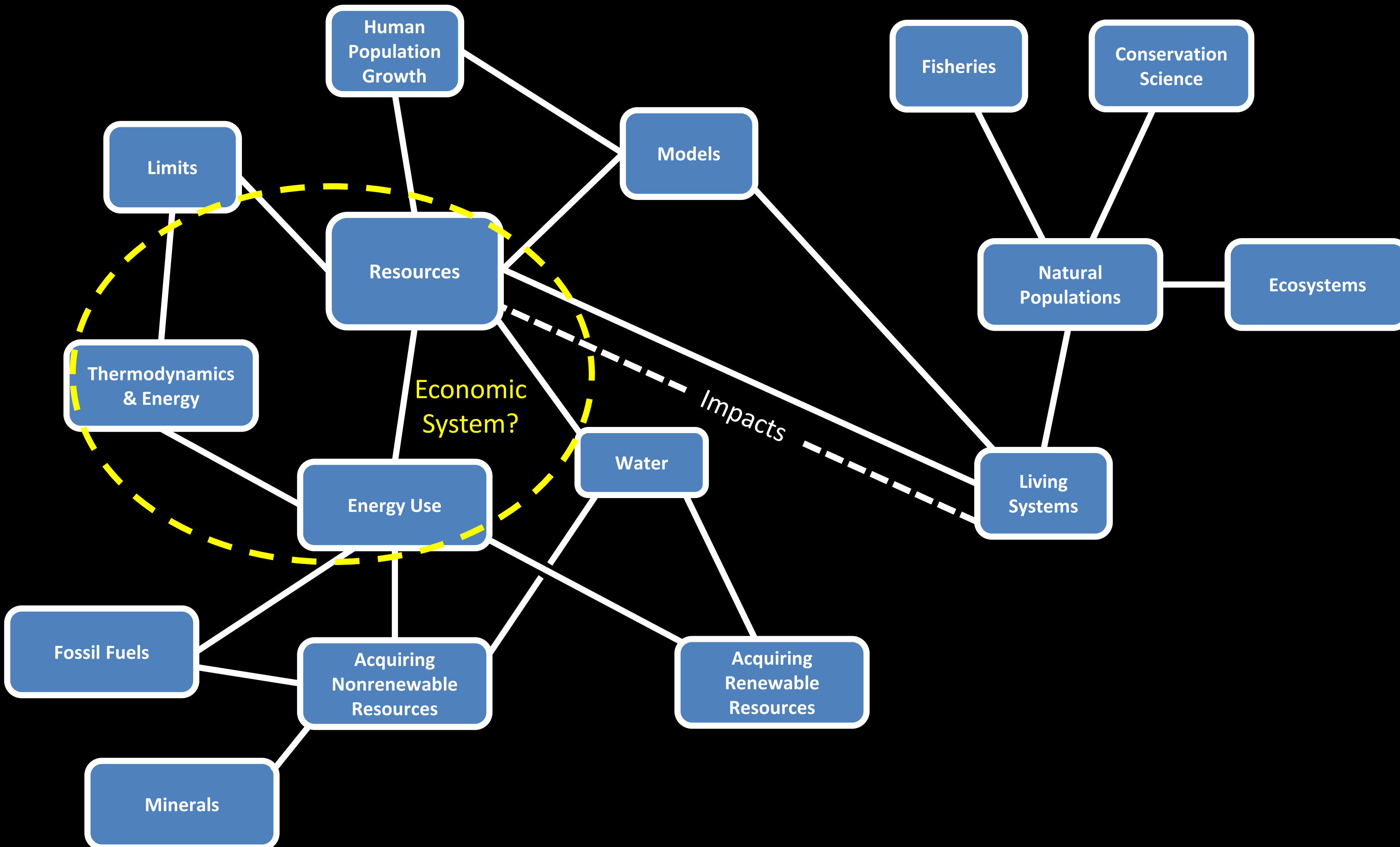
International Union for Conservation of Nature (IUCN)



Invasive Species Specialist Group (ISSG)

	Taxonomic Species	Studies	Matrix Population Models
	792	648	8994
	429	415	3488

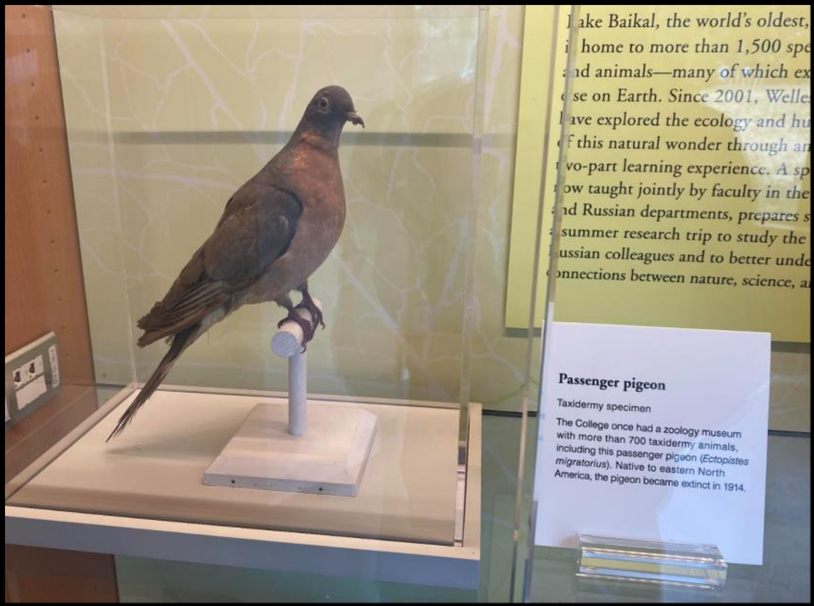
Course Map


Human Population Growth
Fisheries
Conservation Science
Models
Limits
Resources
Natural Populations
Ecosystems
Thermodynamics & Energy
Economic System?
Impacts
Water
Living Systems
Energy Use
Fossil Fuels
Acquiring Nonrenewable Resources
Acquiring Renewable Resources
Minerals

Today's Outline

- Conservation Biology/Science
- Small Populations - Thresholds
- Variability

Passenger pigeon (*Ectopistes migratorius*)



Catastrophic decline (1870–1890)

Slow decline (1800–1870)

Extinction (1890–1910)

1800 1810 1820 1830 1840 1850 1860 1870 1880 1890 1900 1910

1840s – Rail and telegraph

1870s – portable saw mill

1806: Flock estimated at 2.2 billion birds over Kentucky

1813: Flock estimated at 1.1 billion birds over Kentucky: "the sky was black with birds for 3 days" (Audubon, 1831)

1865: Eastern railroad network complete: Every colony within 1-day buggy drive

1866: Flock estimated at 3.7 billion over Ontario

1878: Last huge nesting, Michigan. ~10 million slaughtered

1888: Last "large flocks" reported. Population likely beyond point of recovery.

1900: Last wild specimen shot

1914: Last Passenger Pigeon died in captivity

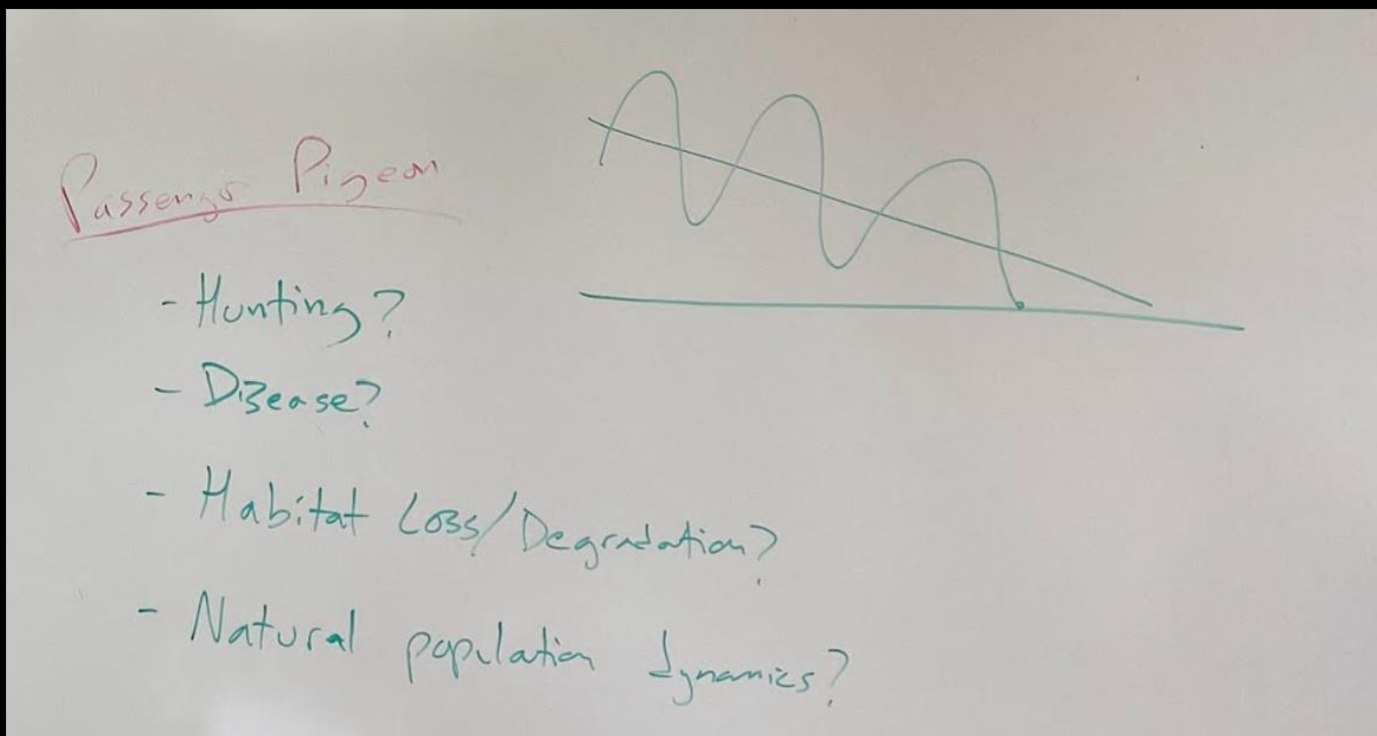
(AAAS)

Depiction of a flock by Tim Hough

1866 flock in Ontario, Canada estimated at:

- 3.7 billion birds
- 1 mile wide by 300 miles long
- 14 hours to pass overhead

How could the most abundant bird species in North America go extinct so quickly?



Suitable breeding habitat

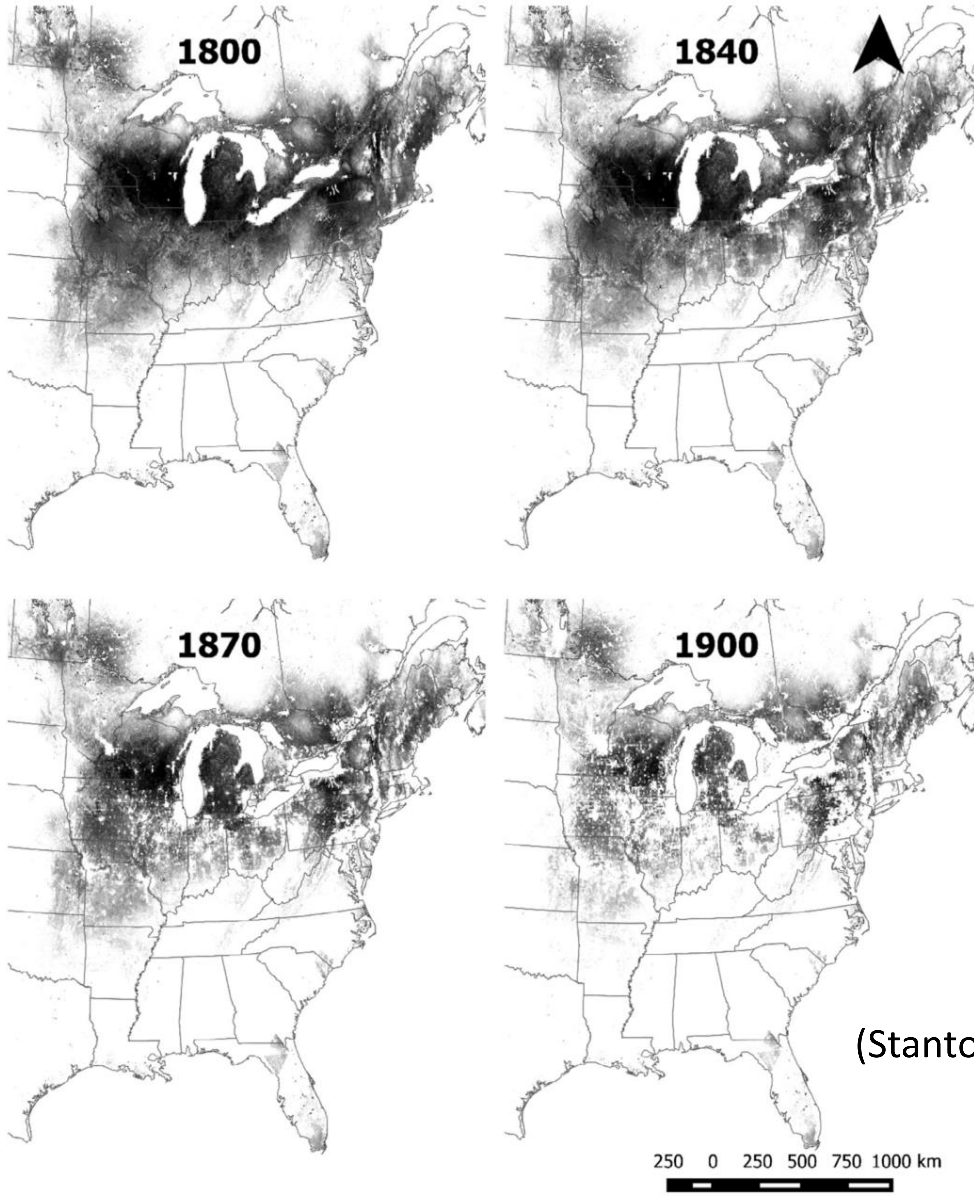
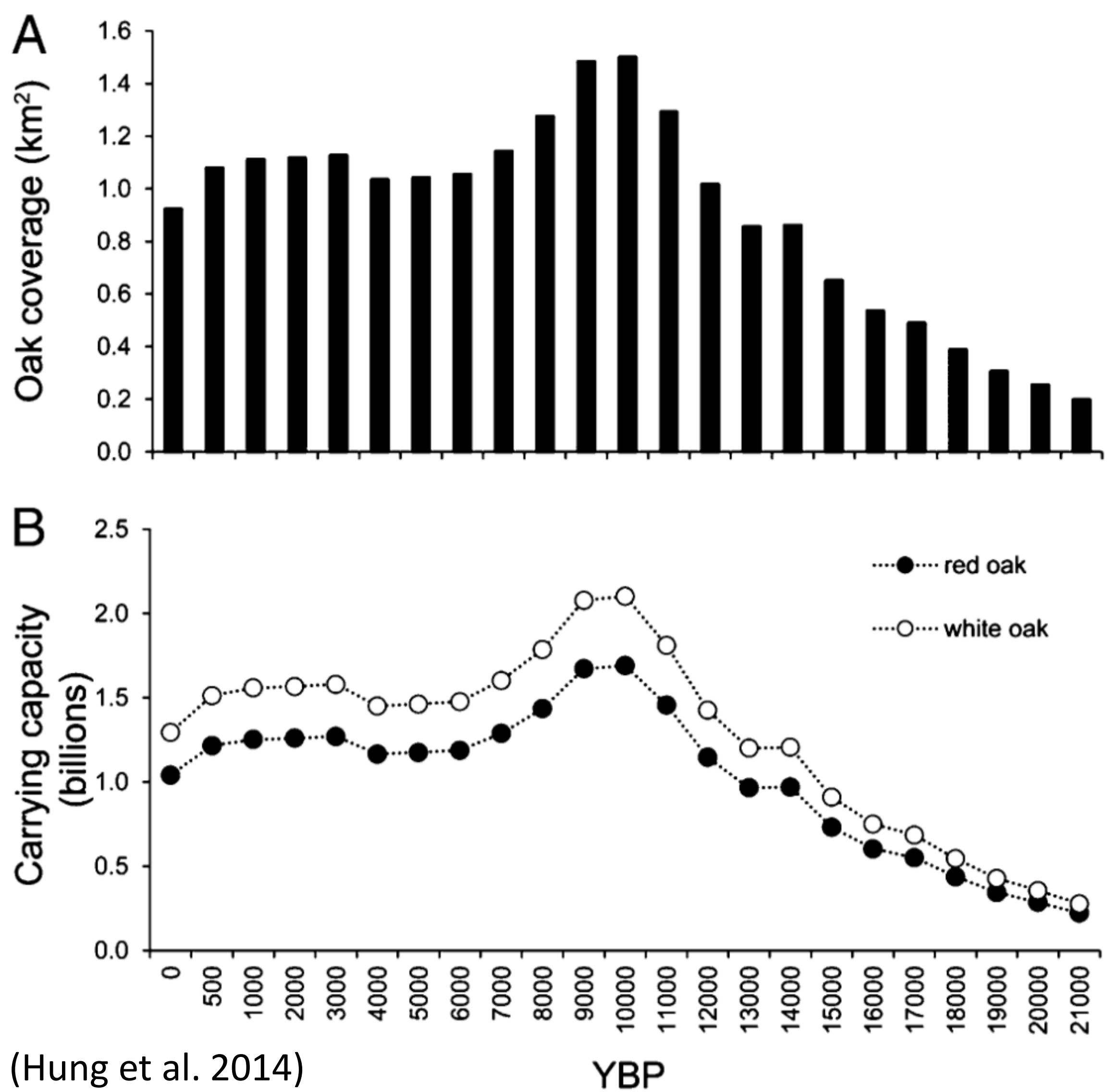


Fig. 2. Predicted available breeding habitat of the passenger pigeon at selected time steps during the 19th century. Darker shade indicates higher suitability score.

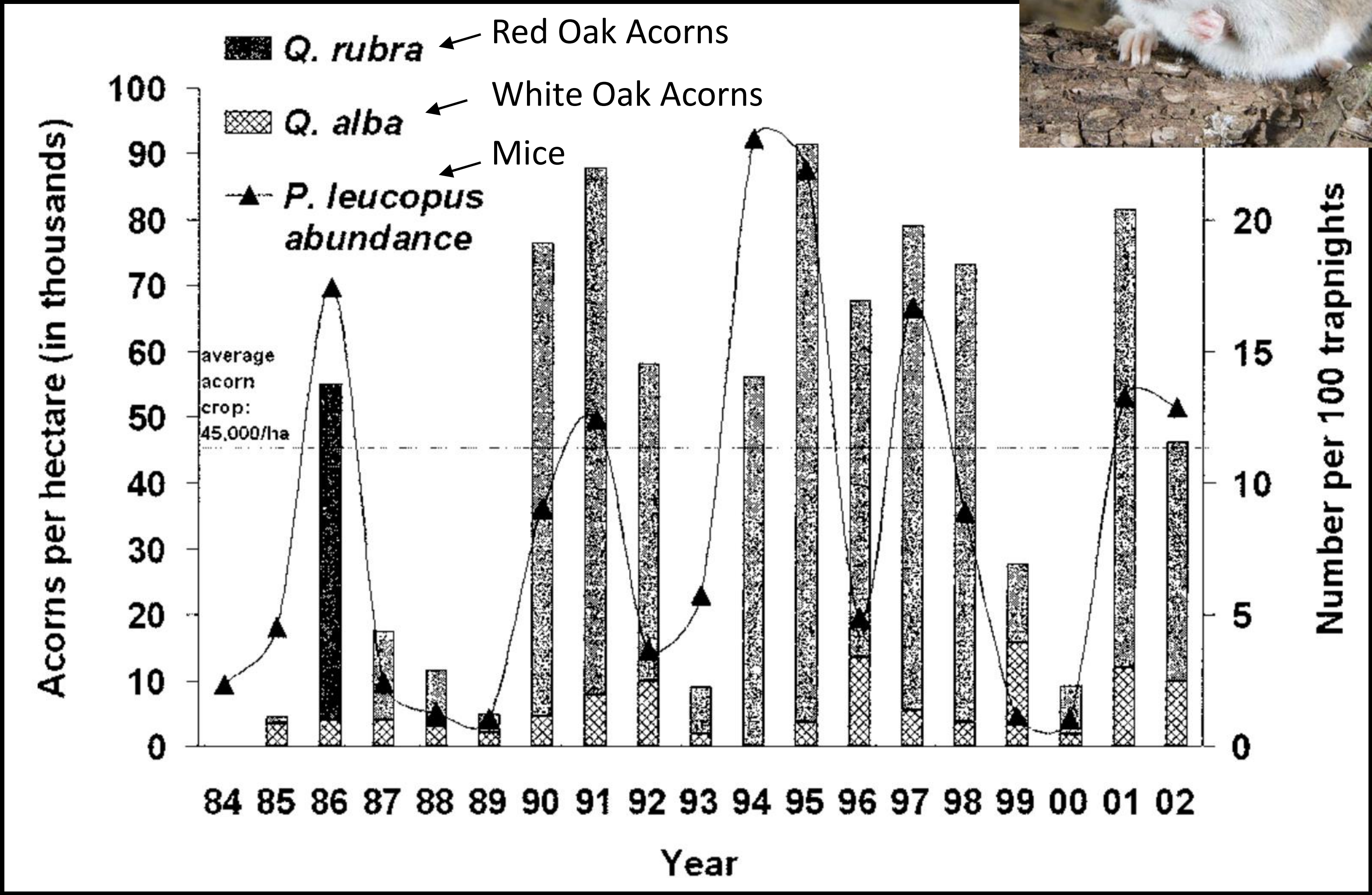
Estimated carrying capacity (long term)



(Hung et al. 2014)

Year to year variability in carrying capacity

White-footed mice in Maine



(Elias et al. 2004)

What is Conservation Biology?

A new synthetic discipline addresses the dynamics and problems of perturbed species, communities, and ecosystems

Michael E. Soulé

Conservation biology, a new stage in the application of science to conservation problems, addresses the biology of species, communities, and ecosystems that are perturbed, either directly or indirectly, by human activities or other agents. Its goal is to provide principles and tools for preserving biological diversity. In this article I describe conservation biology, define its fundamental propositions, and note a few of its contributions. I also point out that ethical norms are a genuine part of conservation biology, as they are in all mission- or crisis-oriented disciplines.

Crisis disciplines

Conservation biology differs from most other biological sciences in one

Although crisis oriented, conservation biology is concerned with the long-term viability of whole systems

ommendations about design and management before he or she is completely comfortable with the theoretical and empirical bases of the analysis (May 1984, Soulé and Wilcox 1980, chap. 1). Tolerating uncertainty is often necessary.

Conservation biologists are being asked for advice by government agencies and private organizations on such problems as the ecological and health

likely that these areas harbored endemic biotas.[1] Reconnaissance later confirmed this. The park boundaries were established in 1981, and subse-

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What Is Conservation Science?

PETER KAREIVA AND MICHELLE MARVIER

In 1985, Michael Soulé asked, "What is conservation biology?" We revisit this question more than 25 years later and offer a revised set of core principles in light of the changed global context for conservation. Most notably, scientists now widely acknowledge that we live in a world dominated by humans, and therefore, the scientific underpinnings of conservation must include a consideration of the role of humans. Today's conservation science incorporates conservation biology into a broader interdisciplinary field that explicitly recognizes the tight coupling of social and natural systems. Emerging priorities include pursuing conservation within working landscapes, rebuilding public support, working with the corporate sector, and paying better attention to human rights and equity. We argue that in conservation, strategies must be promoted that simultaneously maximize the preservation of biodiversity and the improvement of human well-being.

Keywords: conservation science, Anthropocene, biodiversity, ecosystem resilience, ecosystem services

Soulé (1985) helped define the emerging field of conservation biology with an essay that has been read by generations of students and that is now a science citation classic. However, a lot has happened in the world since 1985, and conservation, like any professional and scientific endeavor, needs to continually refresh its intellectual and academic framework to accommodate new ideas and information.

When Soulé wrote his now classic essay, the Society for Conservation Biology (SCB) did not exist, and the journal

and safety were the only goal of conservation science, we would probably label it *environmental science*. The distinguishing feature is that in conservation science, strategies to jointly maximize benefits to people and to biodiversity are pursued; it is a discipline that requires the application of both natural and social sciences to the dynamics of coupled human–natural systems.

Still a crisis discipline but evidence based

Soulé (1985) argued that conservation biology differs from

Conservation Biology

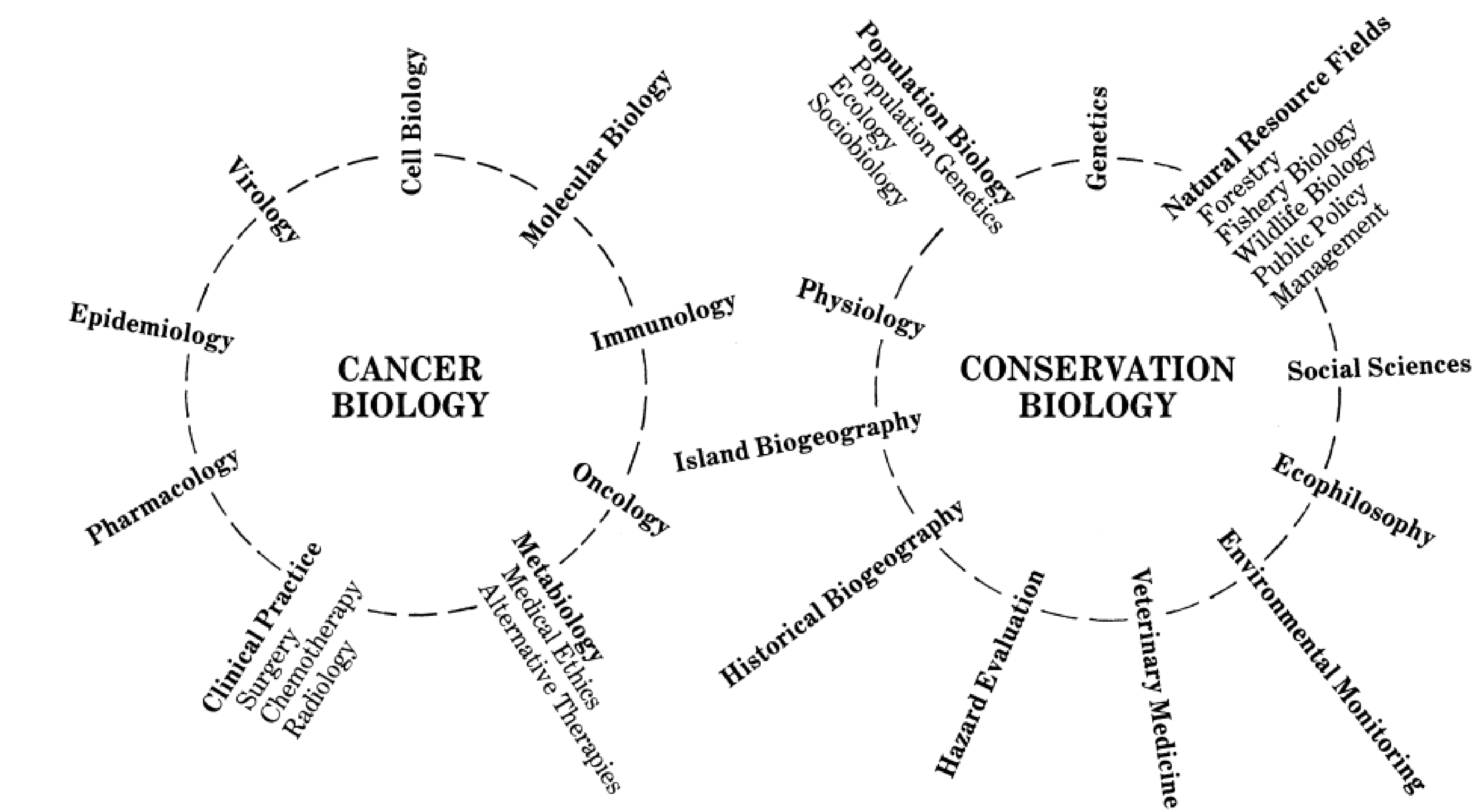
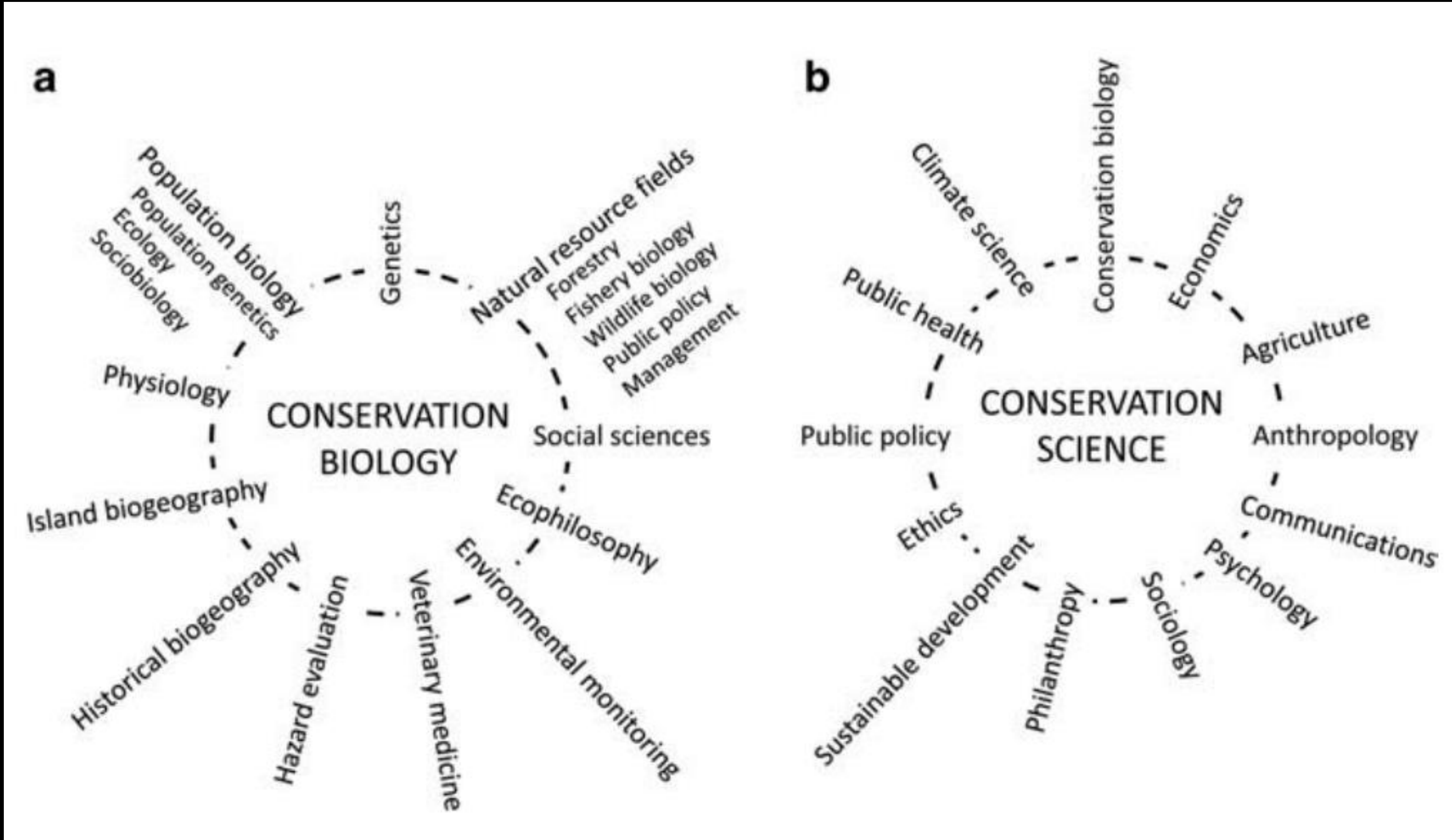


Figure 1. Cancer biology and conservation biology are both synthetic, multidisciplinary sciences. The dashed line indicates the artificial nature of the borders between disciplines and between "basic" and "applied" research. See text.

(Soulé 1985)



(Kareiva and Marvier 2012)

Soulé's Postulates (1985)

Box 1. Functional and normative postulates for the field of conservation biology (Soulé 1985).

Functional postulates

Many of the species that constitute natural communities are the products of coevolutionary processes.

Many, if not all, ecological processes have thresholds below and above which they become discontinuous, chaotic, or suspended.

Genetic and demographic processes have thresholds below which nonadaptive, random forces begin to prevail over adaptive, deterministic forces within populations.

Nature reserves are inherently disequilibrial for large, rare organisms.

Normative postulates

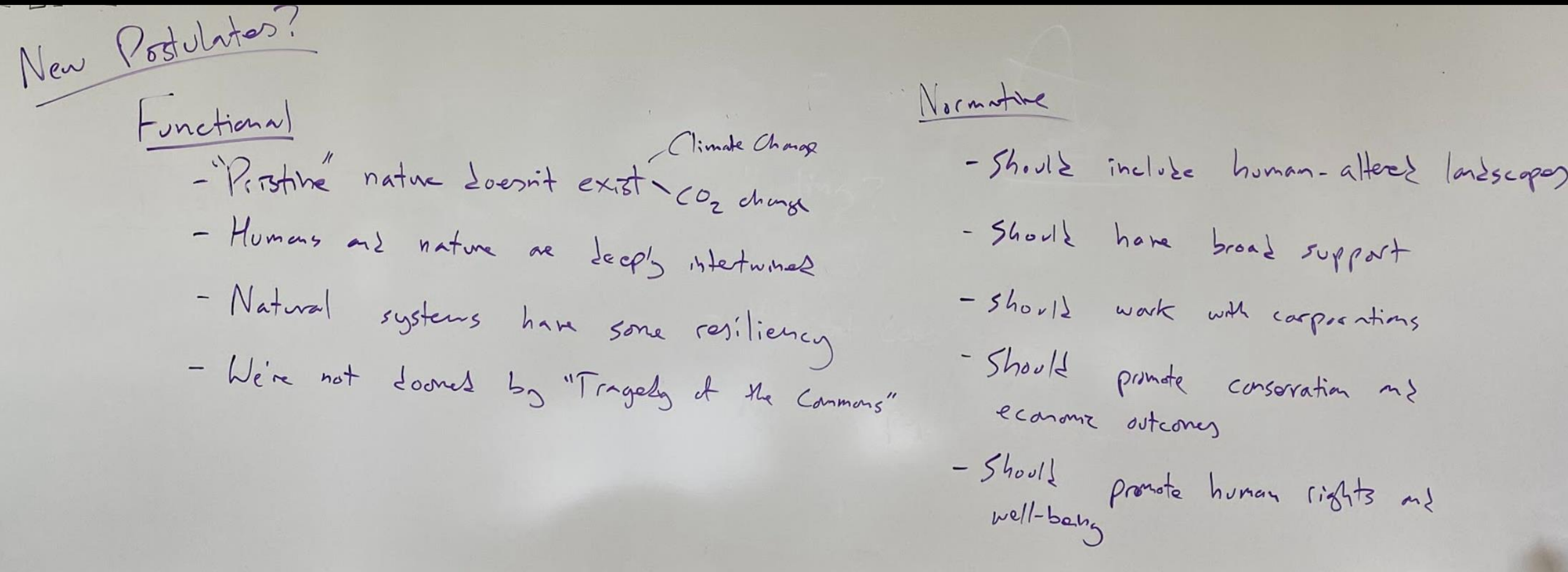
Diversity of organisms is good.

Ecological complexity is good.

Evolution is good.

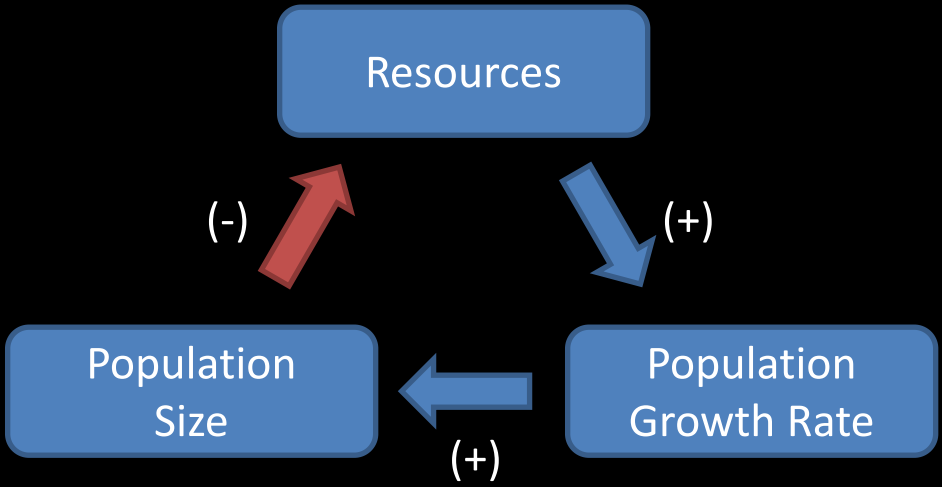
Biotic diversity has intrinsic value, irrespective of its instrumental or utilitarian value.

New Postulates

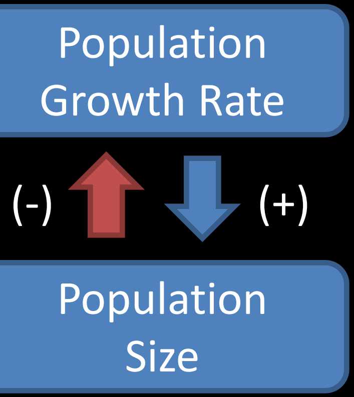


Density Dependence

Example of <u>Negative</u> Density Dependence (e.g. competition for resources):



<u>Simplifies to</u>:

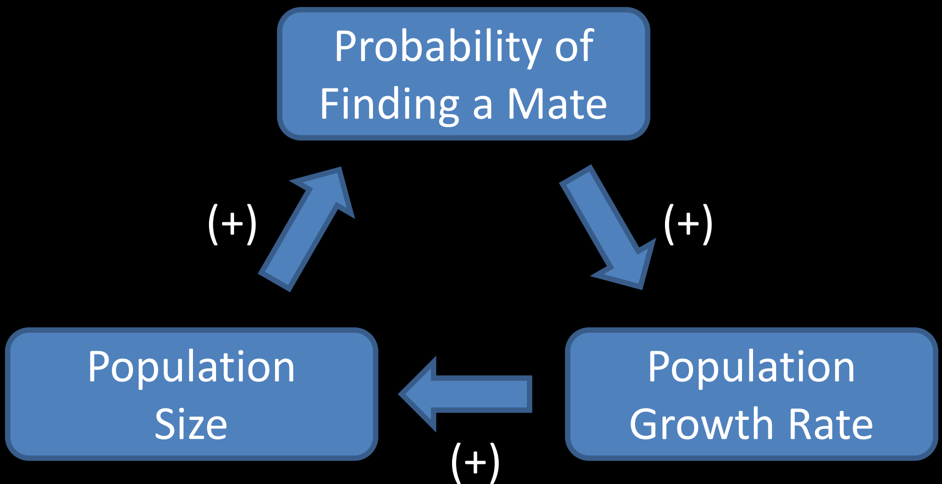


<u>This is A Negative Feedback Loop</u>

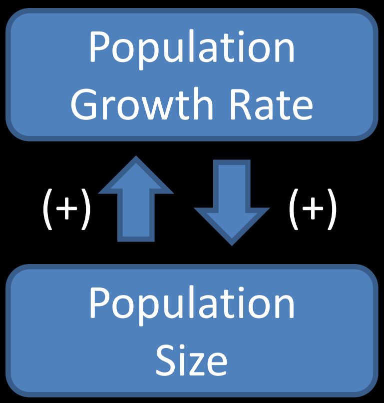
- Will <u>dampen/diminish *change*</u> and stabilize a population.
    - As population size increases, this will reduce resources, which will reduce population growth, and eventually stabilize the population.
    - If the population size is suddenly decreased, we'd be back where we started: an increasing population that then limits itself and stabilizes.

Density Dependence

Example of <u>Positive</u> Density Dependence (e.g. finding a mate):



<u>Simplifies to</u>:



<u>This is A Positive Feedback Loop</u>

- Will <u>amplify/augment *change*</u> and destabilize a population.
    - As population size increases, this will increase the probability of finding a mate, which will increase the population growth rate, further increasing the population size, and on and on…
    - As population size decreases, this will decrease the probability of finding a mate, which will decrease the population growth rate, further decreasing the population size, and on and on…

Small Population

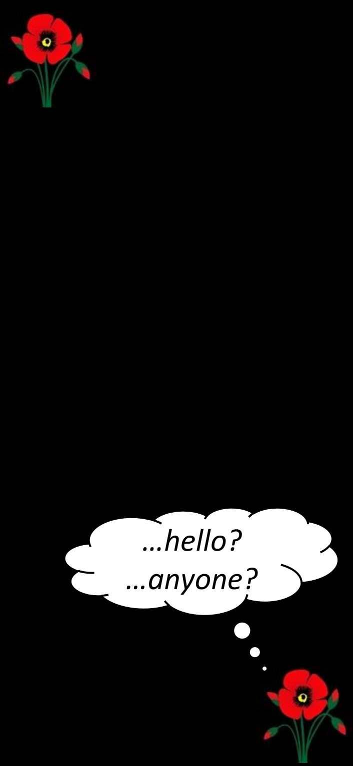
Strong Positive Density Dependence

- Hard to find a mate

Weak Negative Density Dependence

- Little competition

Destabilizing Outcome: A declining population could decline rapidly or a growing population could grow rapidly



Medium Population

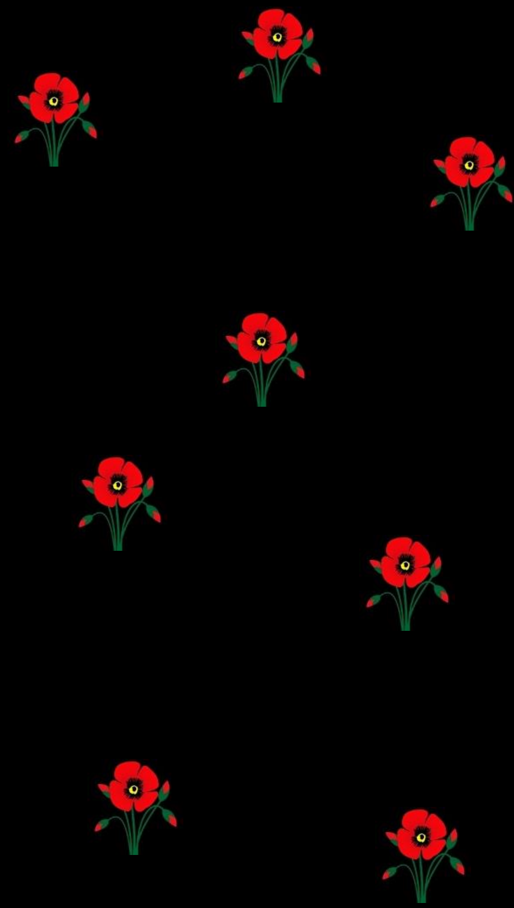
Weak Positive Density Dependence

- Easy to find a mate

Weak Negative Density Dependence

- Little competition

Little Density Dependence: Population growth rate is largely unaffected by population size



Large Population

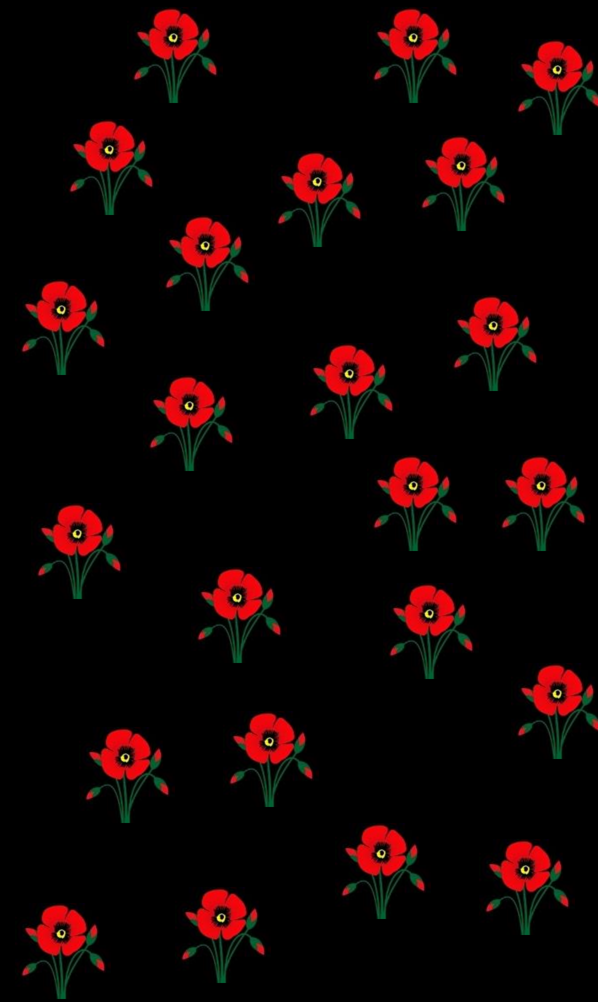
Weak Positive Density Dependence

- Easy to find a mate

Strong Negative Density Dependence

- Intense competition

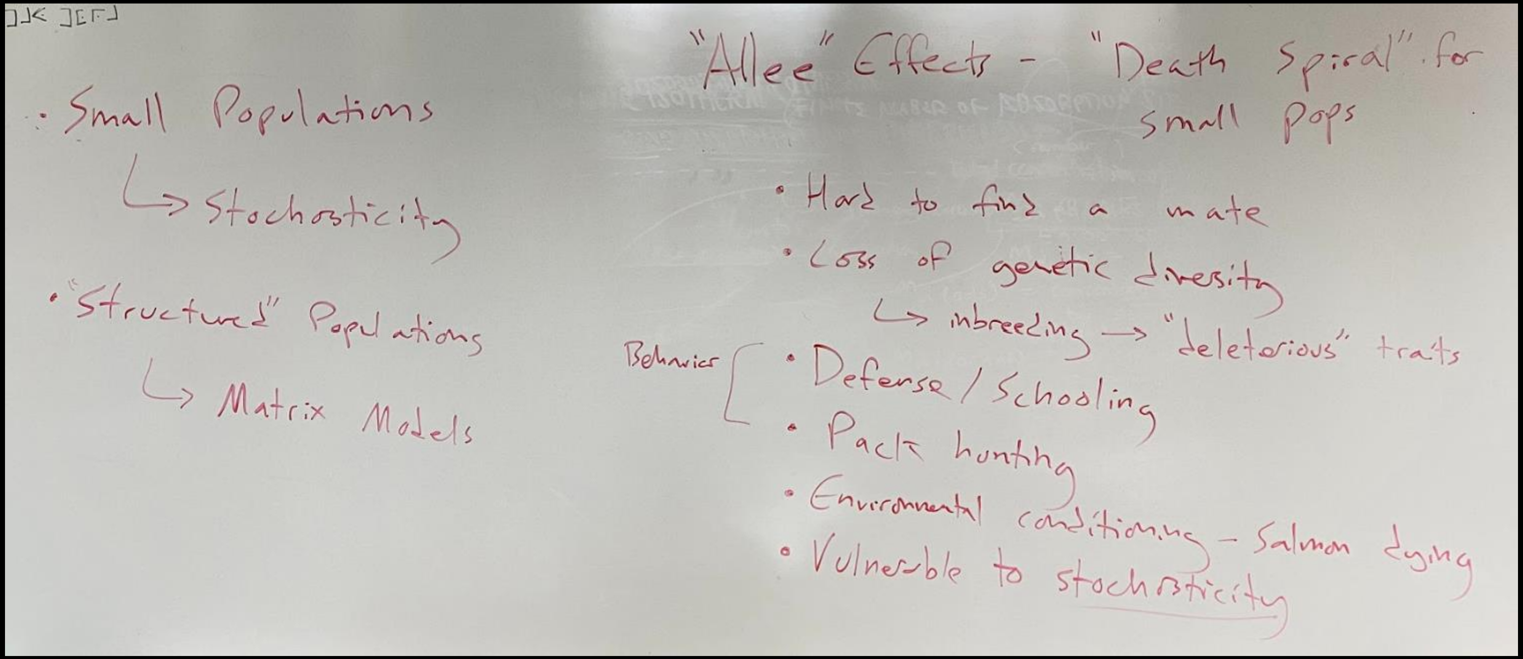
Stabilizing Outcome: A growing population will stabilize around carrying capacity



"Allee Effects" (after Wardle Allee)

- Problems for small populations that can make things worse (i.e. lead to positive density dependence)

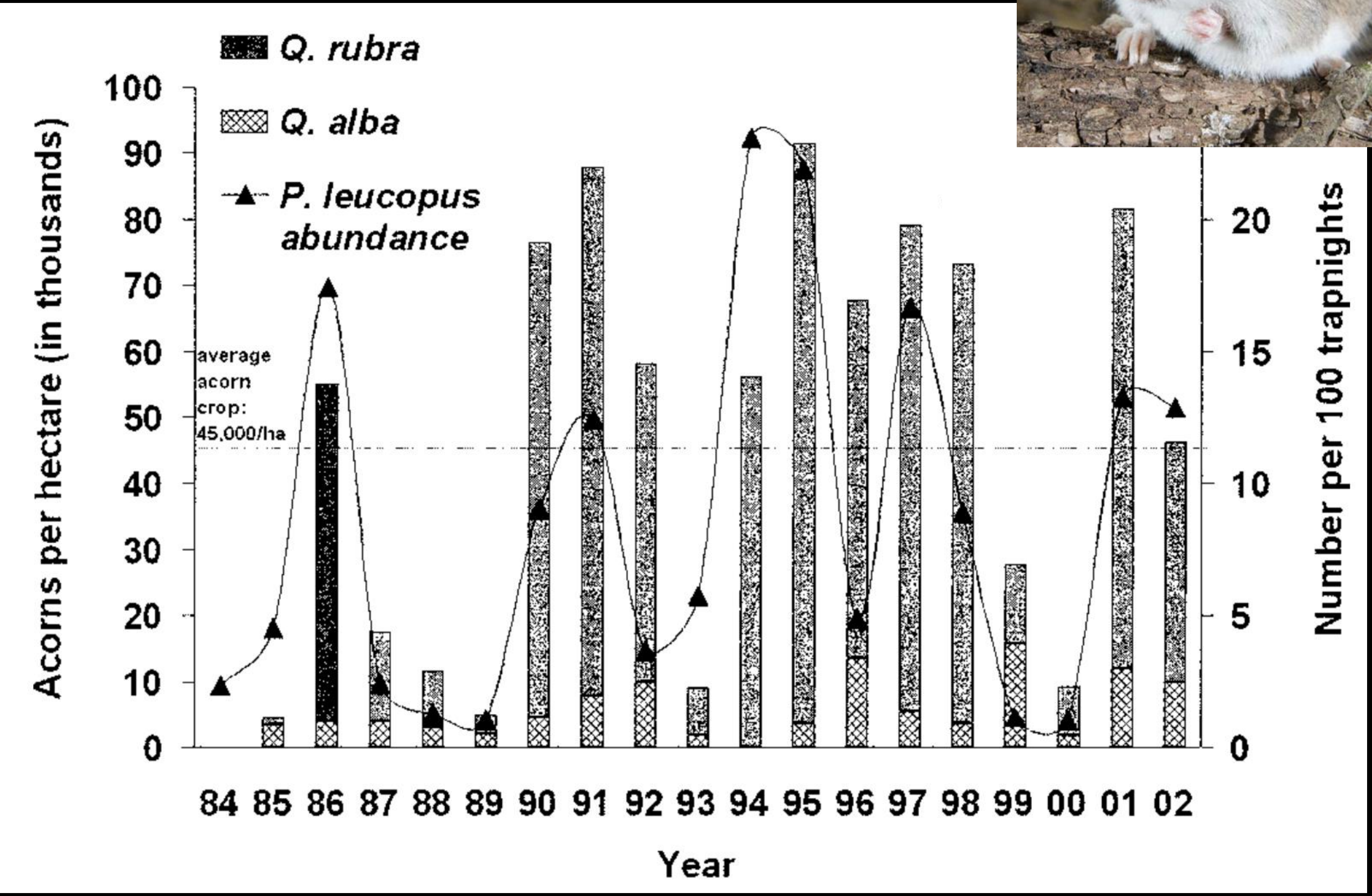
Mechanisms?



Environmental Stochasticity

Average values of survival and reproduction change through time

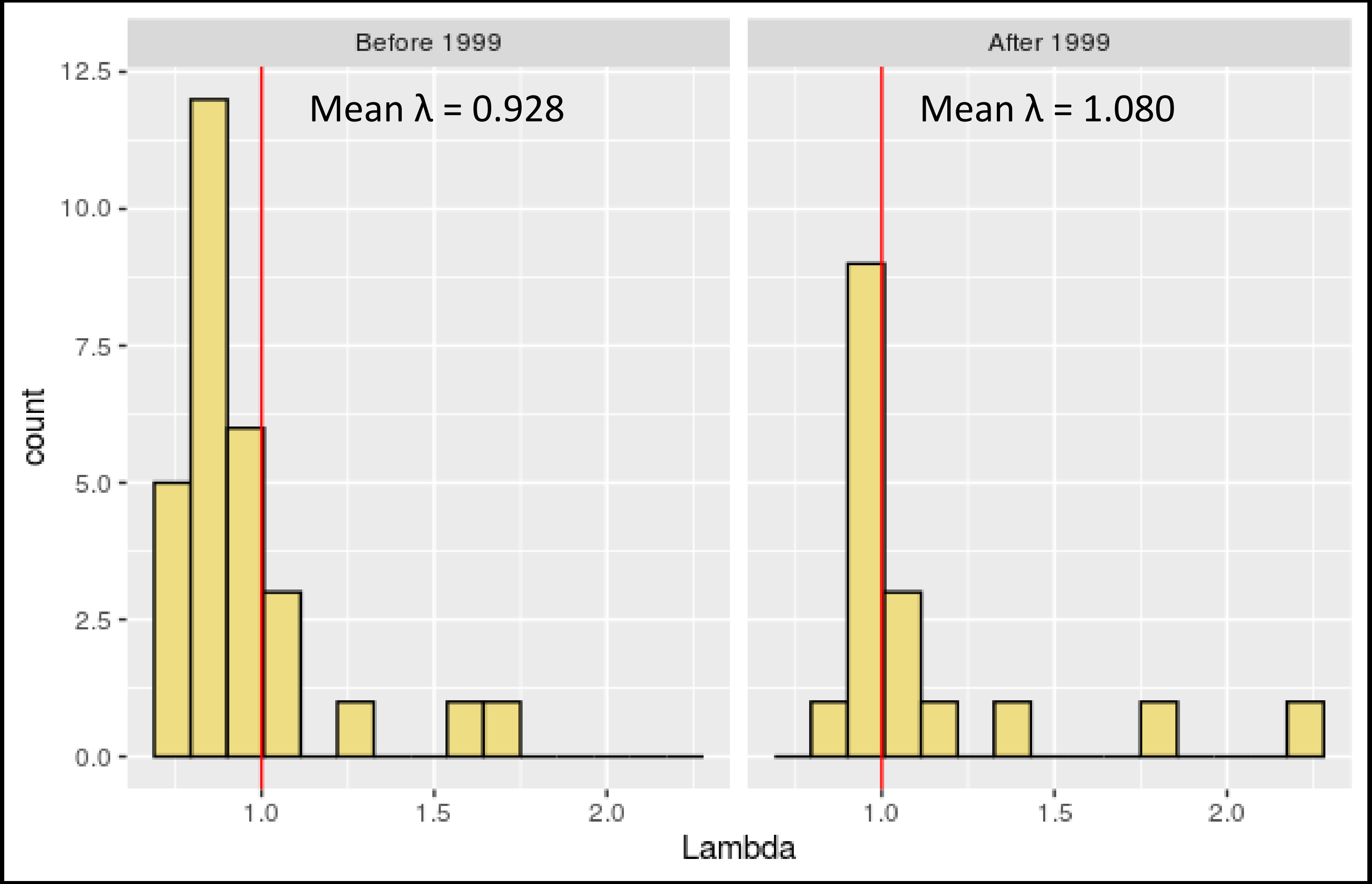
- "good years" vs. "bad years"
- Weather, disease, food shortages, etc…



(Elias et al. 2004)

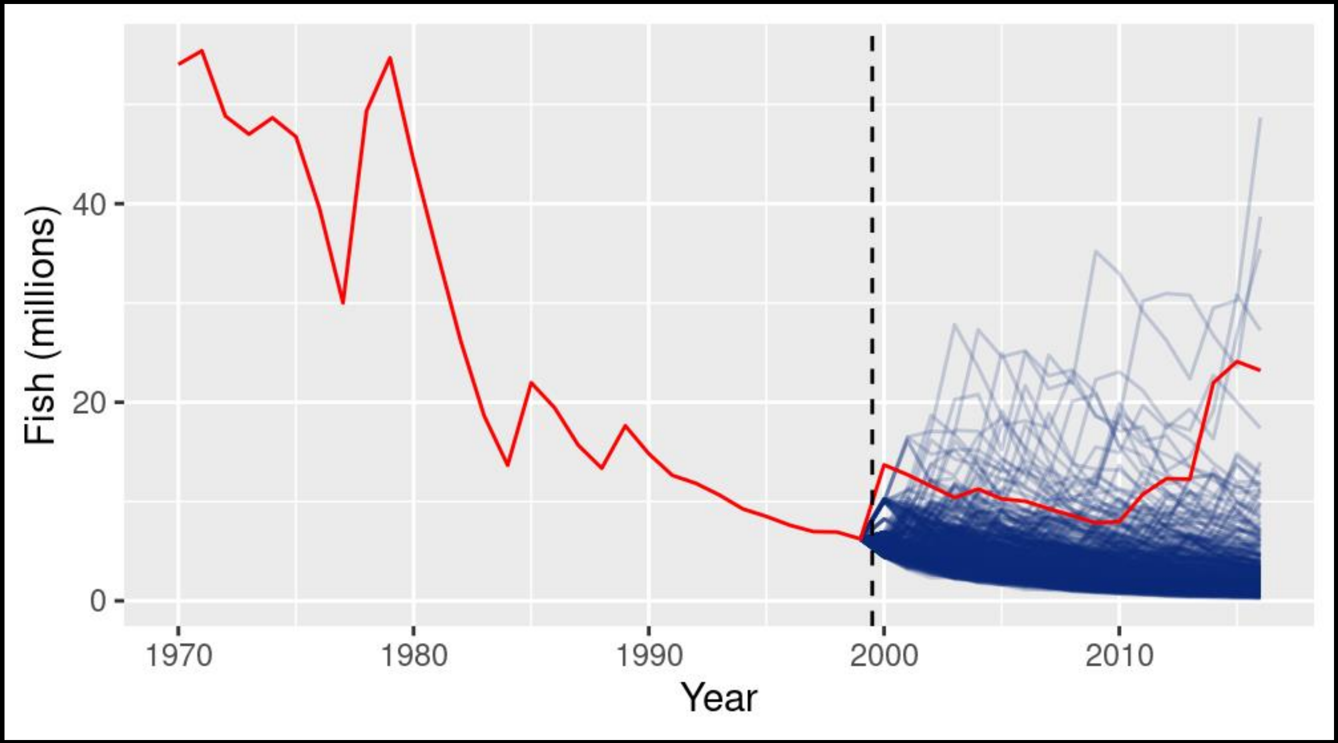
Bocaccio Data

Variability in λ



Bocaccio Data

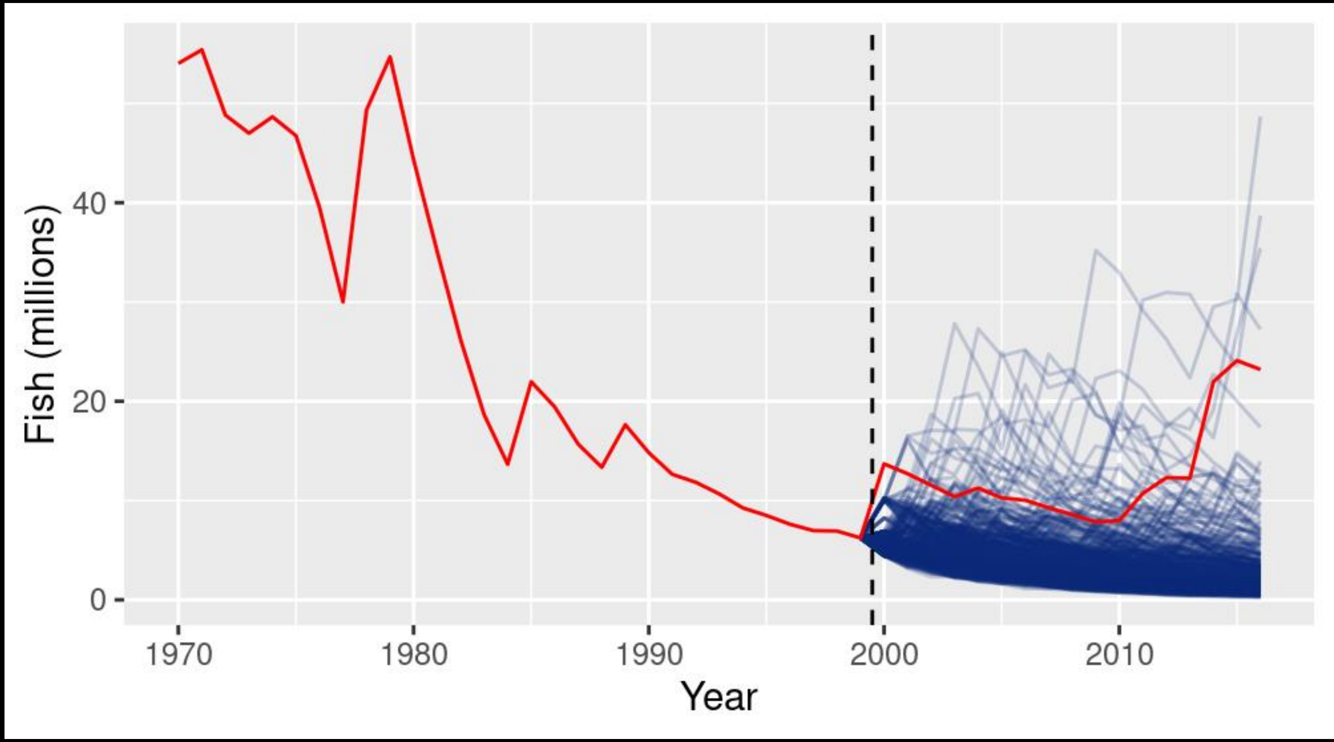
Variability in λ



Stochastic model runs based on observed variation in λ

Environmental Stochasticity

Average values of survival and reproduction change through time
- “good years” vs. “bad years”
- Weather, disease, food shortages, etc…
- Variation in human influence, e.g. fishing/hunting



Environmental Stochasticity

Average values of survival and reproduction change through time

- “good years” vs. “bad years”
- Weather, disease, food shortages, etc…

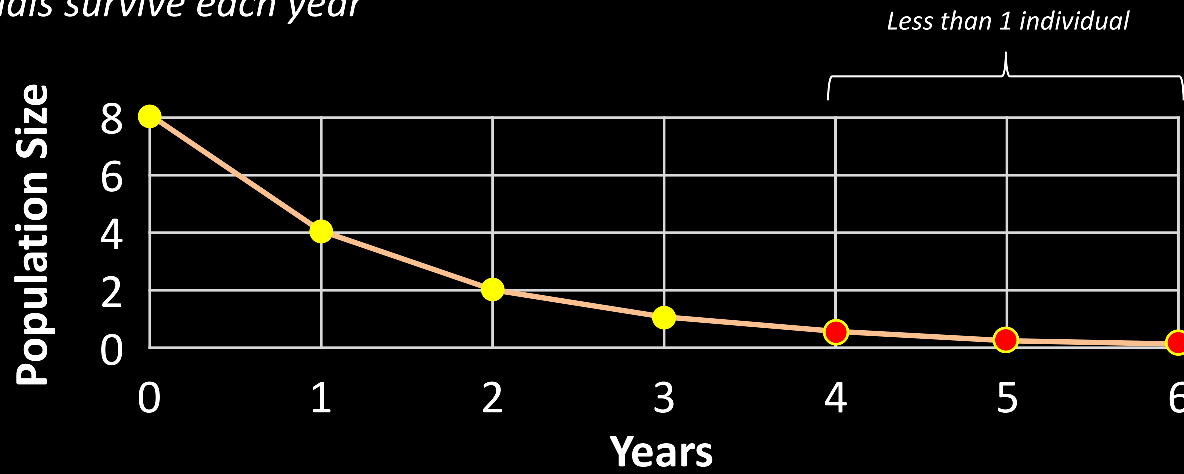
Demographic Stochasticity

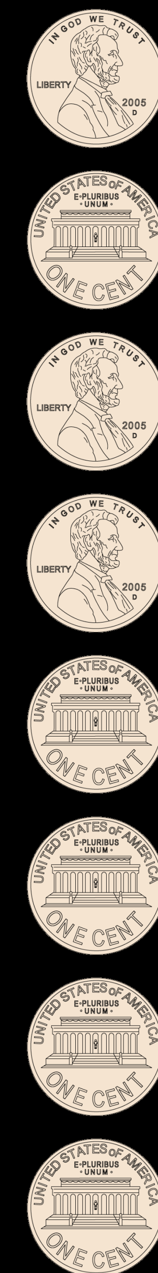
Deviations from average values of survival and reproduction by individuals due to chance.

- Average values often don’t make biological sense for individuals
    - Individuals can’t “half die”
    - Individuals can’t have 1.74 offspring

Deterministic Model: N_0 = **8**, Average Survival = **0.5**

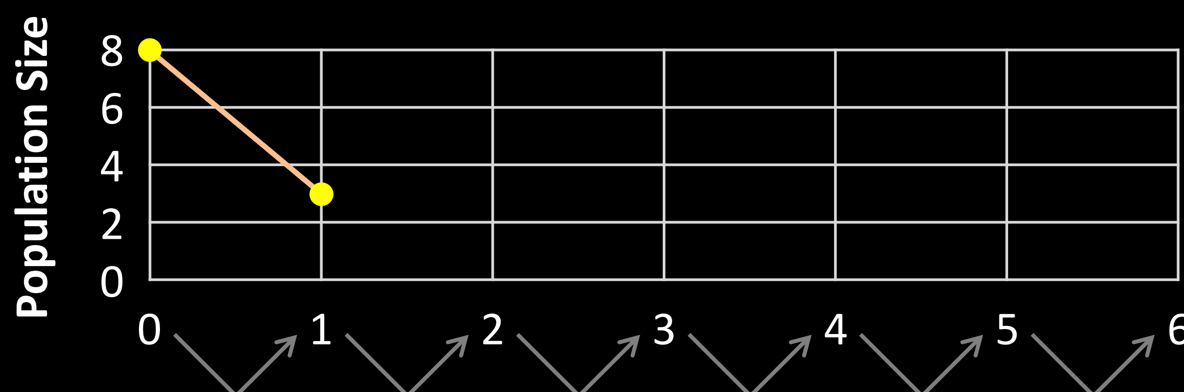
Half of individuals survive each year



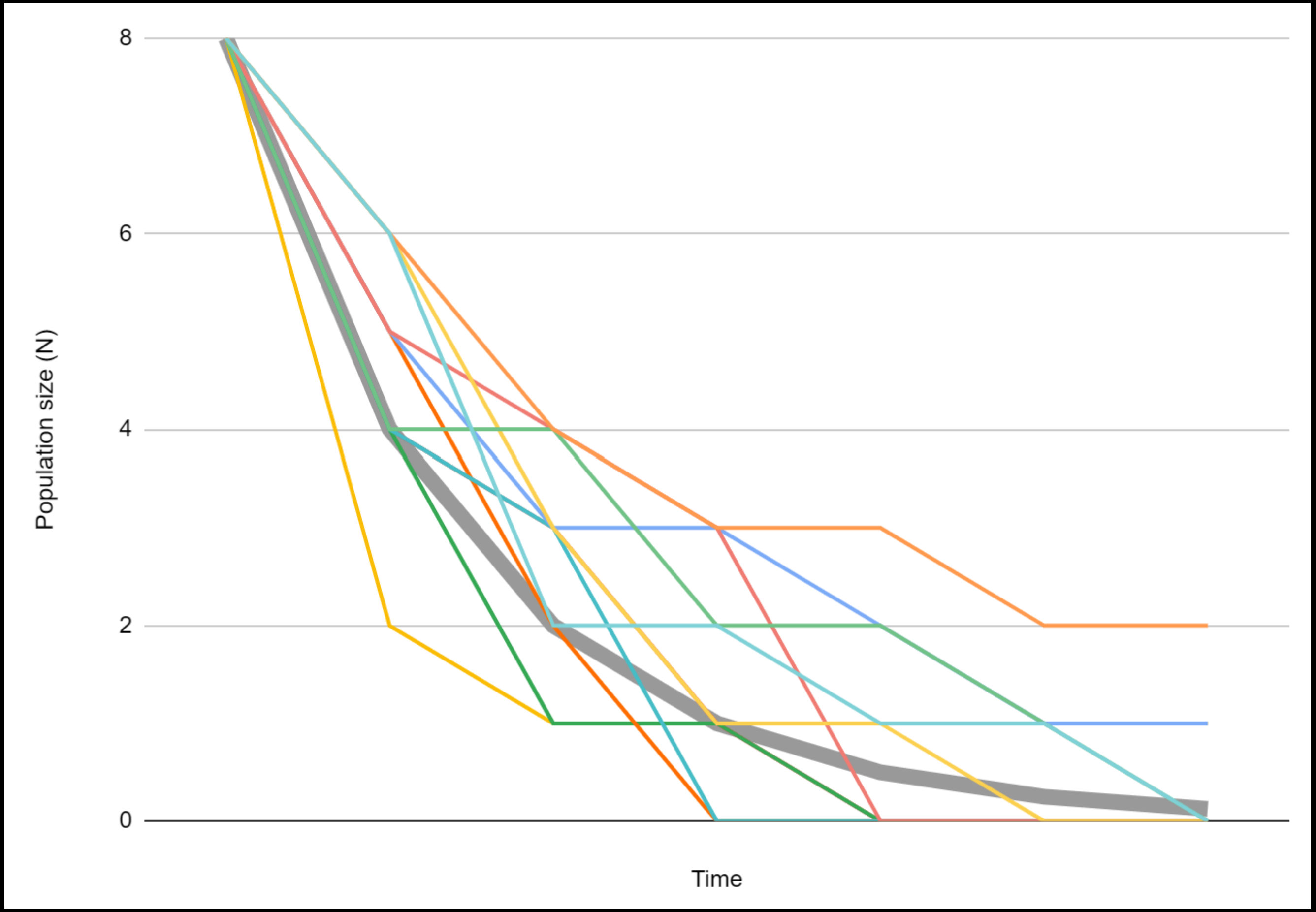


Model with <u>Demographic</u> Stochasticity: N_0 = **8**, Average Survival = **0.5**

Flip a coin <u>for each individual</u> to determine survival



Live	Die	Live	Die	Live	Die	Live	Die	Live	Die	Live	Die
3	5										

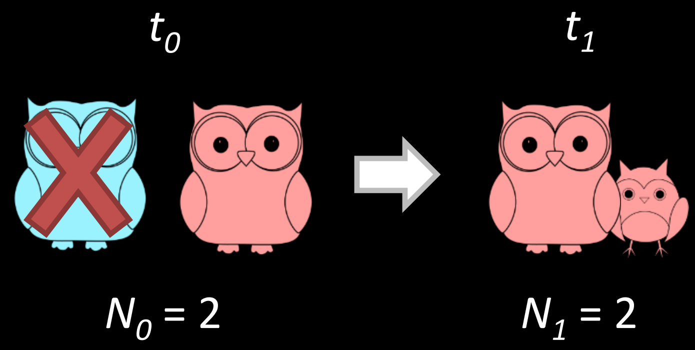


Demographic Stochasticity - Google Sheets

Is a population with λ = 1 really **stable**?

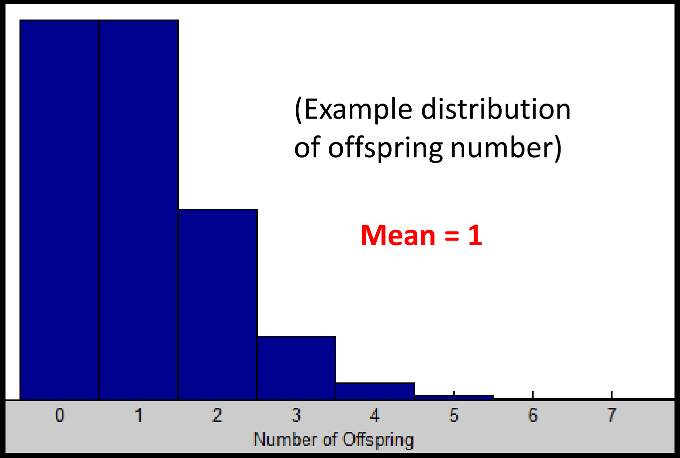
Example average values that will produce λ = 1

- Mean survival = 50%
- Mean # offspring = 1



If Mean survival = 50%...
Actual individual survival =  or 

If Mean # offspring = 1...
Actual individual # offspring =



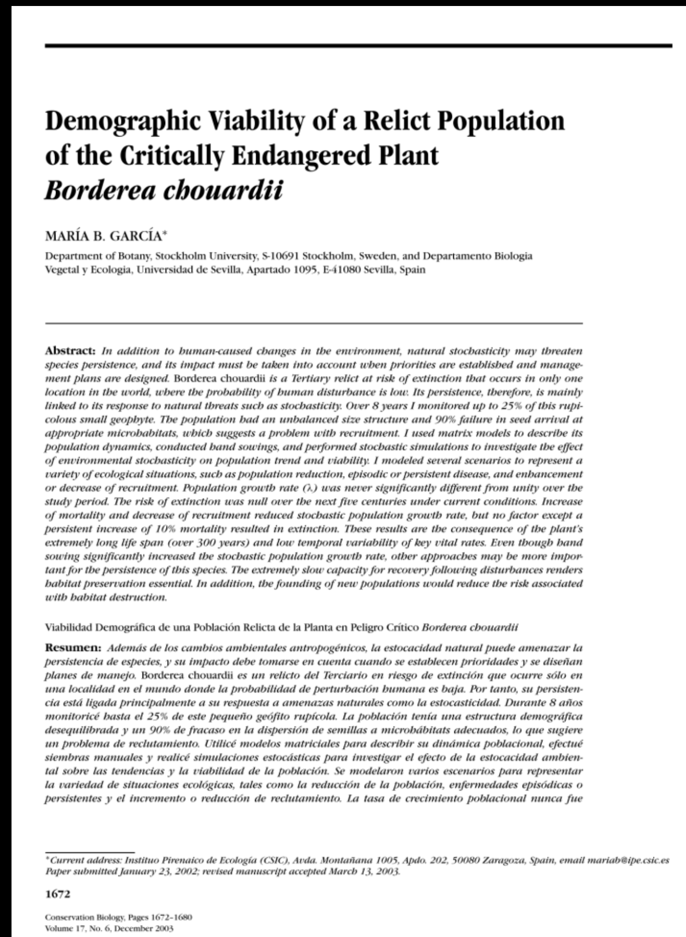
- Many individuals don't have ANY
- Some individuals have 3 or more

https://wellesley.shinyapps.io/demog-stoch/

"Quasi-Extinction" Threshold

- Pop size below which Allee may take over and management can't help

Reading for Monday



Demographic Viability of a Relict Population of the Critically Endangered Plant *Borderea chouardii*

MARÍA B. GARCÍA*

Department of Botany, Stockholm University, S-10691 Stockholm, Sweden, and Departamento Biologia Vegetal y Ecologia, Universidad de Sevilla, Apartado 1095, E-41080 Sevilla, Spain

Abstract: *In addition to human-caused changes in the environment, natural stochasticity may threaten species persistence, and its impact must be taken into account when priorities are established and management plans are designed.* Borderea chouardii *is a Tertiary relict at risk of extinction that occurs in only one location in the world, where the probability of human disturbance is low. Its persistence, therefore, is mainly linked to its response to natural threats such as stochasticity. Over 8 years I monitored up to 25% of this rupicolous small geophyte. The population had an unbalanced size structure and 90% failure in seed arrival at appropriate microhabitats, which suggests a problem with recruitment. I used matrix models to describe its population dynamics, conducted hand sowings, and performed stochastic simulations to investigate the effect of environmental stochasticity on population trend and viability. I modeled several scenarios to represent a variety of ecological situations, such as population reduction, episodic or persistent disease, and enhancement or decrease of recruitment. Population growth rate (λ) was never significantly different from unity over the study period. The risk of extinction was null over the next five centuries under current conditions. Increase of mortality and decrease of recruitment reduced stochastic population growth rate, but no factor except a persistent increase of 10% mortality resulted in extinction. These results are the consequence of the plant's extremely long life span (over 300 years) and low temporal variability of key vital rates. Even though hand sowing significantly increased the stochastic population growth rate, other approaches may be more important for the persistence of this species. The extremely slow capacity for recovery following disturbances renders habitat preservation essential. In addition, the founding of new populations would reduce the risk associated with habitat destruction.*

Viabilidad Demográfica de una Población Relicta de la Planta en Peligro Crítico *Borderea chouardii*

Resumen: *Además de los cambios ambientales antropogénicos, la estocacidad natural puede amenazar la persistencia de especies, y su impacto debe tomarse en cuenta cuando se establecen prioridades y se diseñan planes de manejo.* Borderea chouardii *es un relicto del Terciario en riesgo de extinción que ocurre sólo en una localidad en el mundo donde la probabilidad de perturbación humana es baja. Por tanto, su persistencia está ligada principalmente a su respuesta a amenazas naturales como la estocasticidad. Durante 8 años monitoricé hasta el 25% de este pequeño geófito rupícola. La población tenía una estructura demográfica desequilibrada y un 90% de fracaso en la dispersión de semillas a microhábitats adecuados, lo que sugiere un problema de reclutamiento. Utilicé modelos matriciales para describir su dinámica poblacional, efectué siembras manuales y realicé simulaciones estocásticas para investigar el efecto de la estocacidad ambiental sobre las tendencias y la viabilidad de la población. Se modelaron varios escenarios para representar la variedad de situaciones ecológicas, tales como la reducción de la población, enfermedades episódicas o persistentes y el incremento o reducción de reclutamiento. La tasa de crecimiento poblacional nunca fue*

**Current address: Instituo Pirenaico de Ecología (CSIC), Avda. Montañana 1005, Apdo. 202, 50080 Zaragoza, Spain, email mariab@ipe.csic.es*
Paper submitted January 23, 2002; revised manuscript accepted March 13, 2003.

García (2003)

Lab Projects – Choose species by Monday

Preliminary species for ES 220 project

agriffit@wellesley.edu Switch account

* Indicates required question

Email *

☐ Record **agriffit@wellesley.edu** as the email to be included with my response

Instructions
Please choose three species of interest from the available:
https://wellesley.shinyapps.io/matrix-data

You must include at least one plant or animal.

For each species, indicate the number of "Individual" matrices available. If no Individual matrices, indicate the number of other matrices. This will help me determine the amount of data that you would have to work with.

Matrix types

Type	Number
Mean	4
Pooled	0
Individual	13
Seasonal	0

Species 1: *
Please indicate whether it is threatened or invasive.

Your answer

Demography of the California Condor: Implications for Reestablishment

VICKY J. MERETSKY,* NOEL F. R. SNYDER,† STEVEN R. BEISSINGER,‡
DAVID A. CLENDENEN,§ AND JAMES W. WILEY**

*School of Public and Environmental Affairs, Indiana University, 1315 East 10th Street, Bloomington, IN 47405-1701, U.S.A., email meretsky@indiana.edu
†Wildlife Preservation Trust International, P.O. Box 16426, Portal, AZ 85632, U.S.A.
‡Department of Environmental Science, Policy & Management, 151 Hilgard Hall, University of California, Berkeley, CA 94720-3114, U.S.A.
§Wind Wolves Preserve, P.O. Box 189, Maricopa, CA 93252, U.S.A.
**Grambling Cooperative Wildlife Project, Grambling State University, P.O. Box 841, Grambling, LA 71245, U.S.A.

ON THE USE OF MATRICES IN CERTAIN POPULATION MATHEMATICS

BY P. H. LESLIE, *Bureau of Animal Population, Oxford University*

CONTENTS

1. INTRODUCTION

If we are given the age distribution of a population on a certain date, we may require to know the age distribution of the survivors and descendants of the original population at successive intervals of time, supposing that these individuals are subject to some given age-specific rates of fertility and mortality. In order to simplify the problem as much as possible, it will be assumed that the age-specific rates remain constant over a period of time, and the female population alone will be considered. The initial age distribution may be entirely arbitrary; thus, for instance, it might consist of a group of females confined to only one of the age classes.

The method of computing the female population in one unit's time, given any arbitrary age distribution at time t, may be expressed in the form of $m+1$ linear equations, where m to $m+1$ is the last age group considered in the complete life table distribution, and when the same unit of age is adopted as that of time. If

n_{xt} = the number of females alive in the age group x to $x+1$ at time t,

P_x = the probability that a female aged x to $x+1$ at time t will be alive in the age group $x+1$ to $x+2$ at time $t+1$,

F_x = the number of daughters born in the interval t to $t+1$ per female alive aged x to $x+1$ at time t, who will be alive in the age group 0–1 at time $t+1$,

then, working from an origin of time, the age distribution at the end of one unit's interval will be given by

$$\begin{aligned}
\sum_{x=0}^{m} F_x n_{x0} &= n_{01} \\
P_0 n_{00} &= n_{11} \\
P_1 n_{10} &= n_{21} \\
P_2 n_{20} &= n_{31} \\
\vdots \qquad & \quad \vdots \\
P_{m-1} n_{m-1,0} &= n_{m1}
\end{aligned}$$

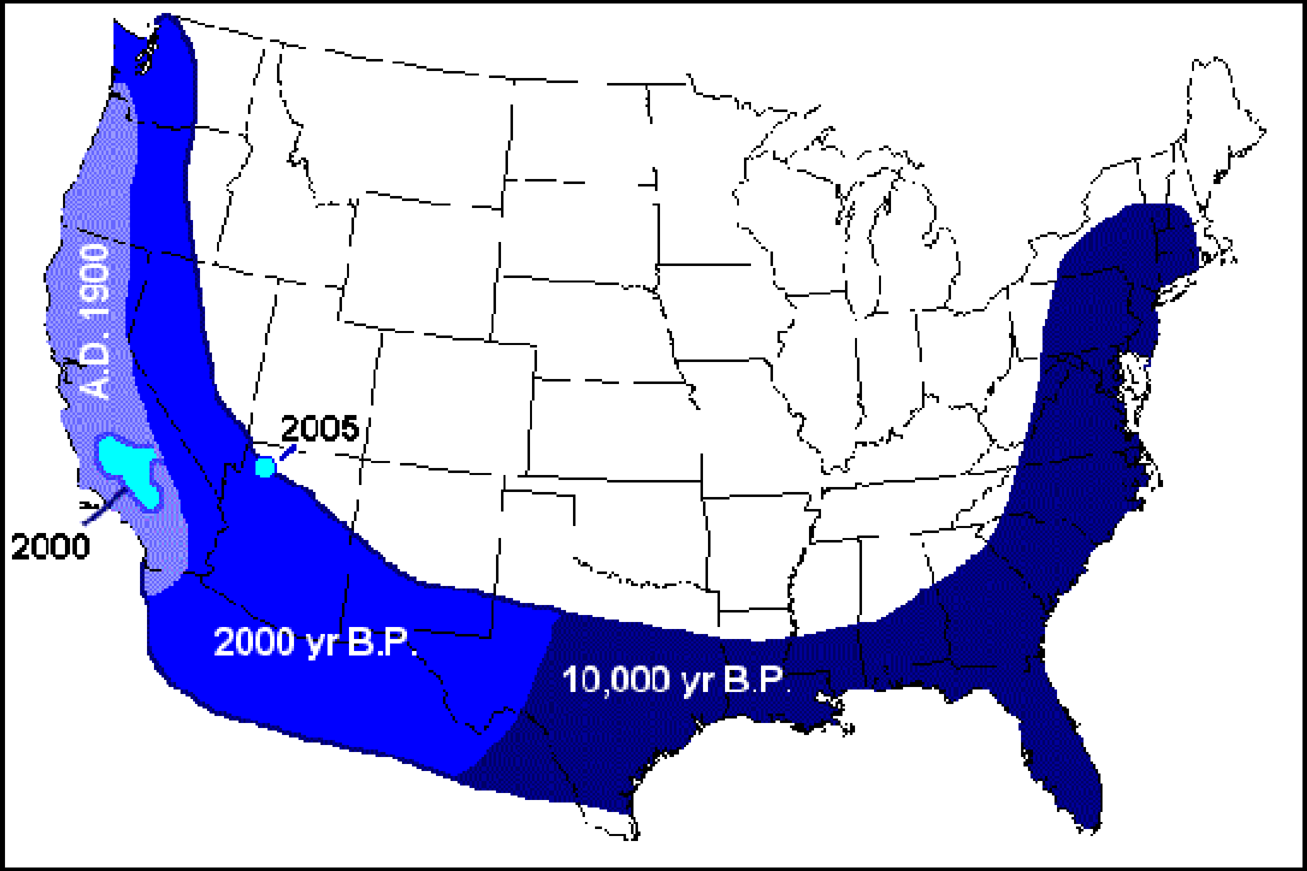
Gymnogyps californianus (California Condor)

Demography of the California Condor: Implications for Reestablishment

VICKY J. MERETSKY,* NOEL F. R. SNYDER,† STEVEN R. BEISSINGER,‡
DAVID A. CLENDENEN,§ AND JAMES W. WILEY**

Gymnogyps californianus (California Condor)

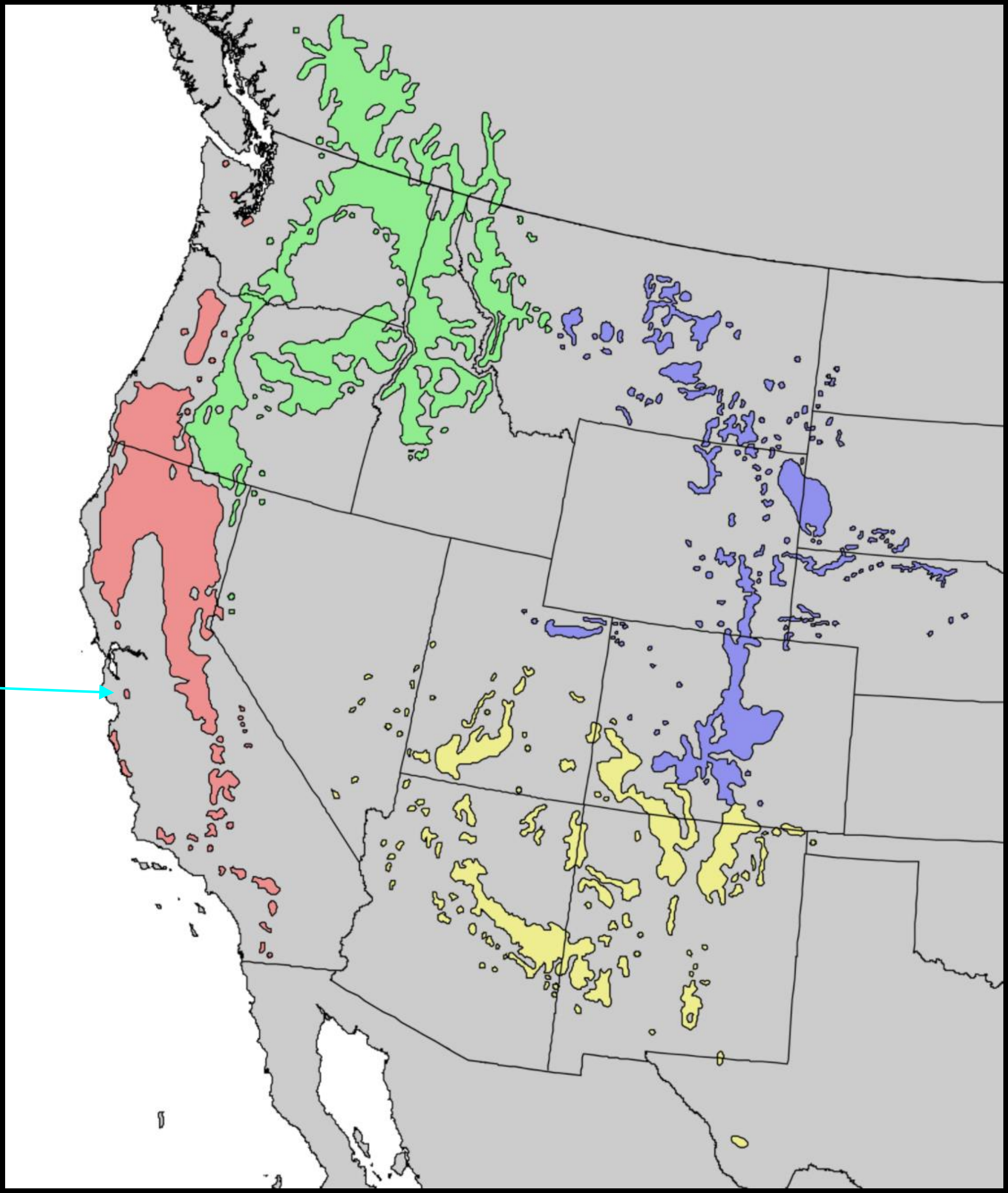
"Relict" Populations



(University of Arizona)

Distribution of Ponderosa Pine (*Pinus ponderosa*)

“Relict” Populations



Demography of the California Condor: Implications for Reestablishment

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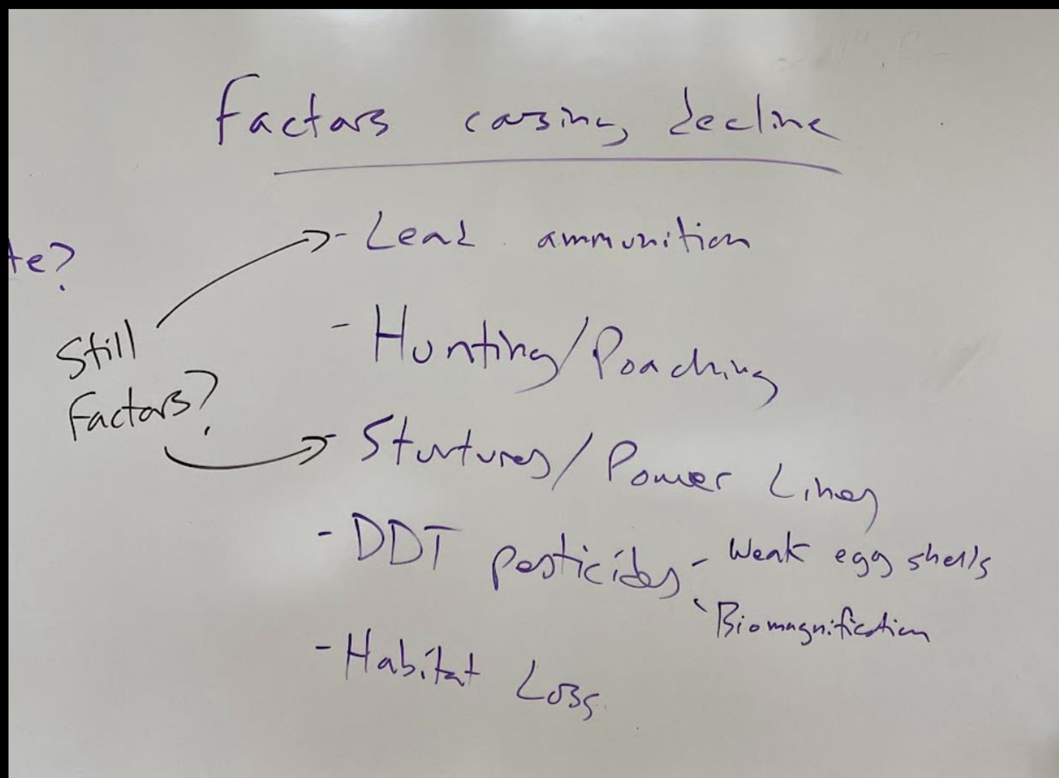
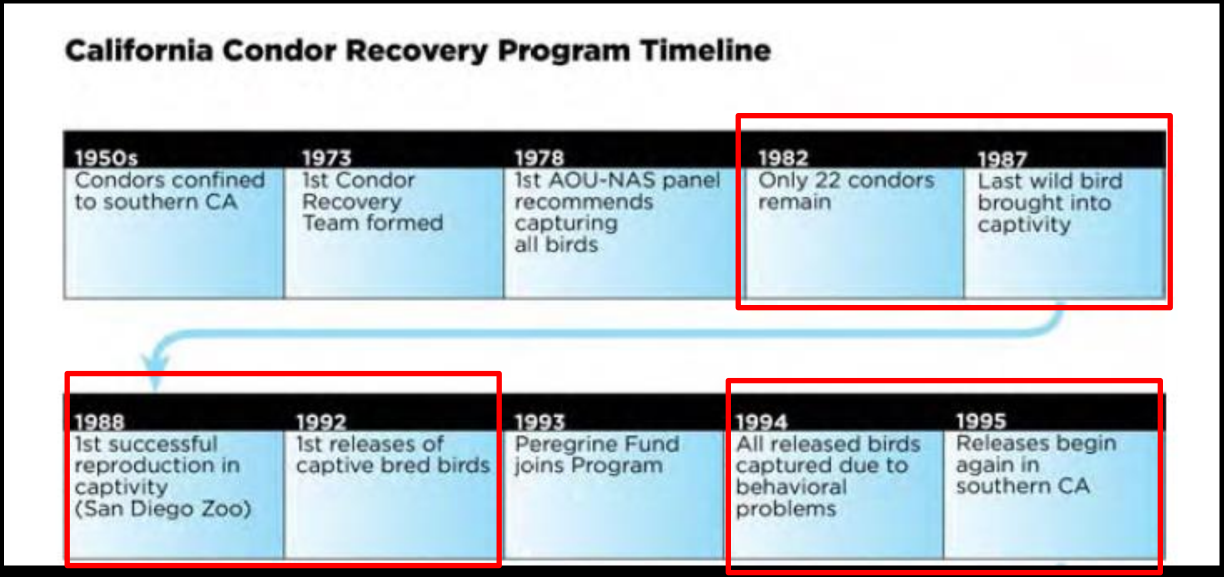
Factors causing decline?



Gymnogyps californianus (California Condor)



(Walters et al 2008)

Gymnogyps californianus (California Condor)

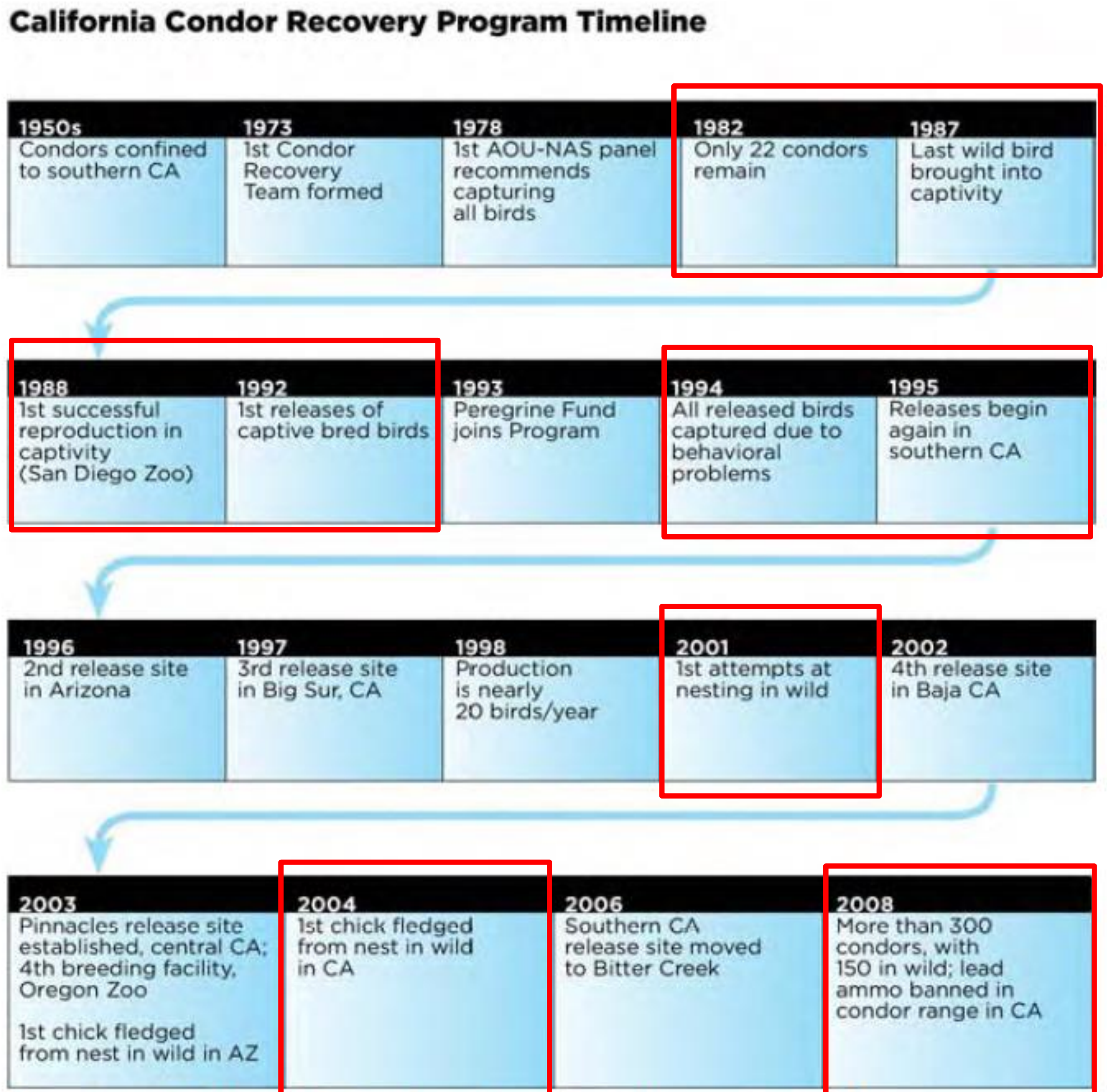


Figure 2. California Condor Recovery Program timeline.

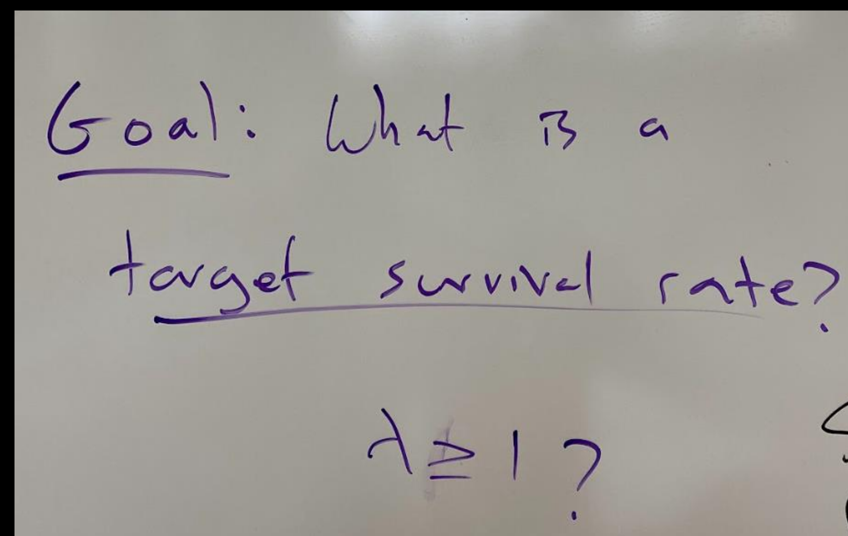
(Walters et al 2008)

Gymnogyps californianus (California Condor)

Demography of the California Condor: Implications for Reestablishment

VICKY J. MERETSKY,* NOEL F. R. SNYDER,† STEVEN R. BEISSINGER,‡
DAVID A. CLENDENEN,§ AND JAMES W. WILEY**

- What are the main goals of the study?



Model assumptions…

vs.

Biology? Lifecycle?

Biology? Life Cycle?

Survival? — Immature vs. Mature

- Time to maturity - 6-8 years
- (f) • Breeding success - 40-50%
- (r) • Prob. of renesting - 25-75%
- (c) • Clutch size (#eggs) - 1
- Final age of reproduction - 75?
- Sex ratio - 50/50
- (b) • % of Adults breeding - 50-70%

Reproduction?

We calculated the number of juveniles produced annually per adult female (J) from $J = bcf + bc(1 - f)rf$,

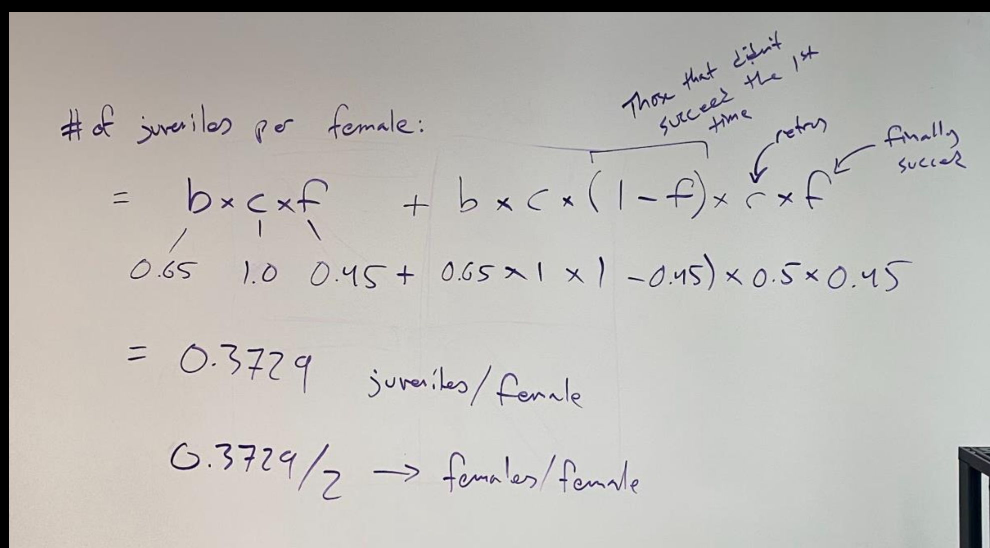
b = fraction breeding

c = clutch size (# eggs)

f = prob of success (fledged a chick)

bcf = reproductive contribution of **<u>initially successful breeders</u>**

bc(1-f)rf = those who tried and failed bc(1-f), but then **<u>tried again</u>** (**r**) and succeeded (f)



Model details…

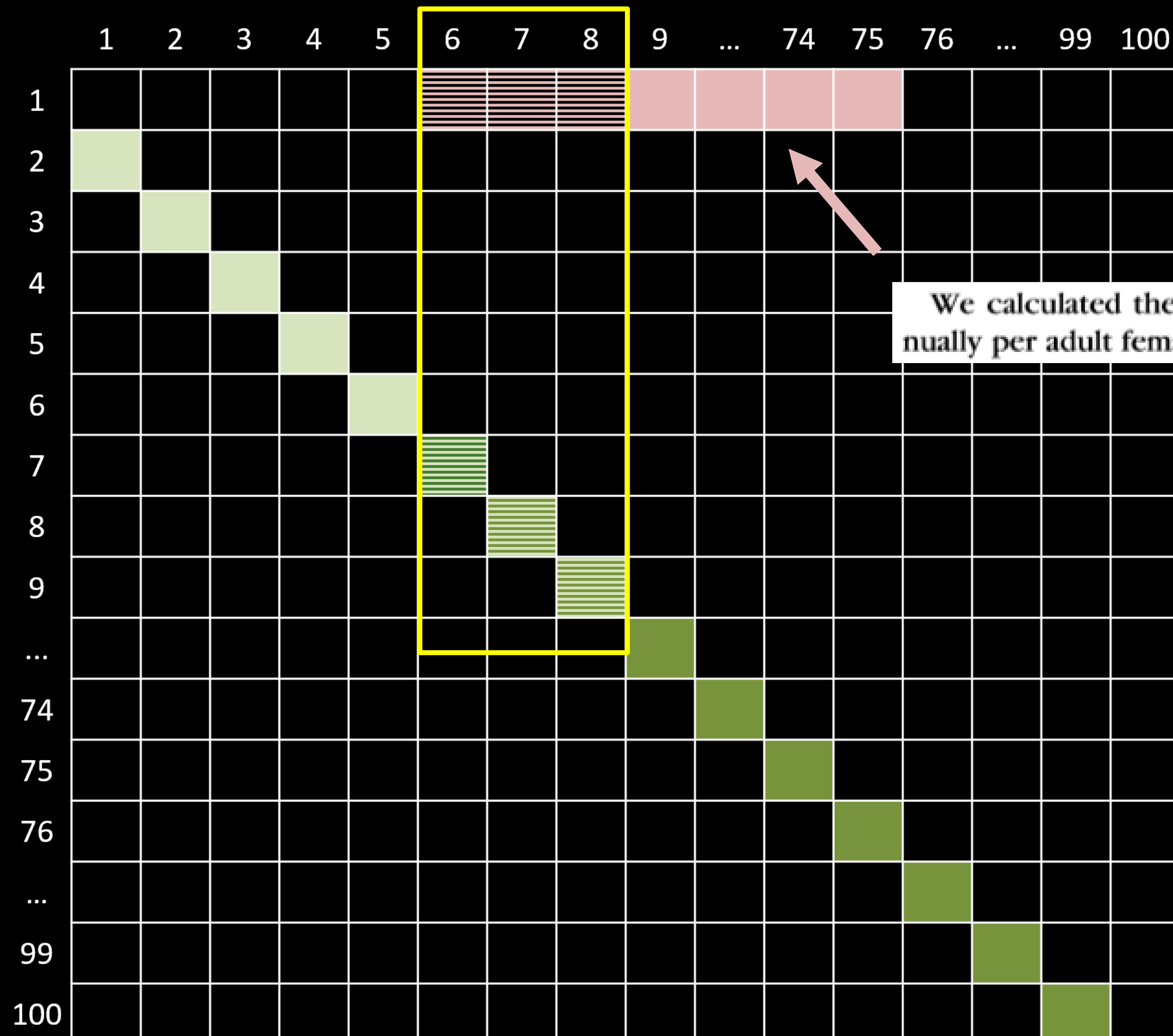
We constructed a female-based, age-based, deterministic, single-population model with a prebreeding census and a 1-year time step (Caswell 1989; Noon & Sauer 1992;

- How do they deal with lack of data?

Beissinger & Westphal 1998). We used Excel and MATLAB (1992) programs to estimate annual mortality rates that would result in stable populations ($\lambda = 1$) under varying levels of reproductive success. Although this simple model does not incorporate stochasticity or catastrophes, it provides a method to compare survival and reproductive rates to assess causes of decline (Hitchcock & Gratto Trevor 1997) and allows estimation of minimum levels of survivorship required for recovery of California Condors as a guide for reestablishment efforts.

Impossible Transition = 0 | Immature Survival | Adult Survival | Reproduction

Different matrix values used to represent variation in age of maturity



We calculated the number of juveniles produced annually per adult female (J) from $J = bcf + bc(1 - f)rf$,

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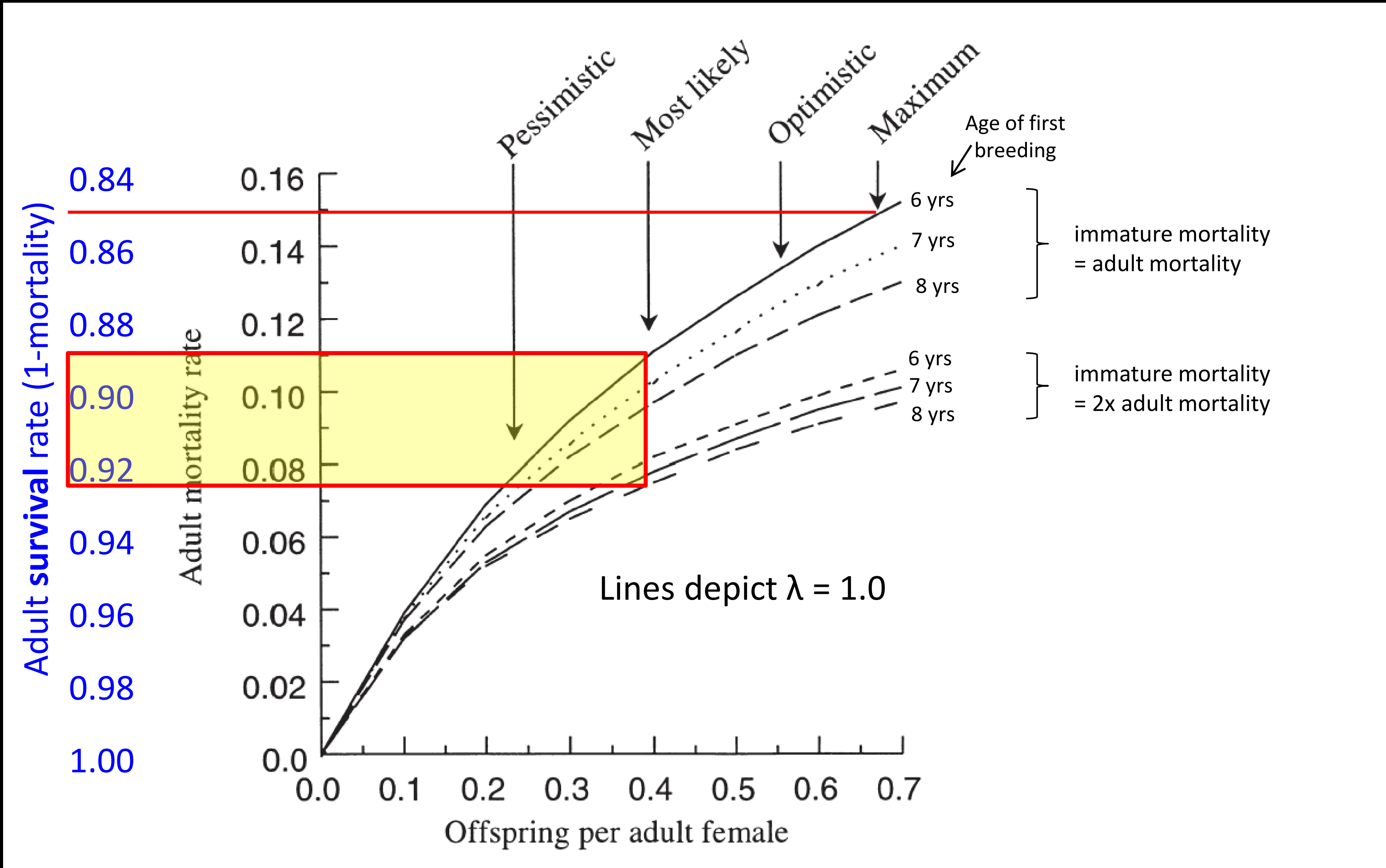
f = prob of success (fledged a chick)

bcf = reproductive contribution of initially successful breeders

bc(1-f)rf = those who tried and failed, but then tried again and succeeded

Gymnogyps californianus (California Condor)



Demographic Stochasticity?

Table 1. Estimates of mortality rates of stable California Condor populations from deterministic modeling of four reproductive scenarios.

	Model parameters				*Calculated mortality*				
Reproductive scenario	*adults breeding (%)*	*breeding success (%)*[a]	*probablility of renesting*[b]	*fledglings/ female/ year*	*age of first breeding*	*age of last breeding*	*mortality by age*[c]	*annual adult mortality*	*annual immature mortality*
Pessimistic	50	40	0.25	0.2300	8	50	I = A	0.067	0.067
	50	40	0.25	0.2300	8	50	I = 2A	0.053	0.106
Most likely	65	45	0.50	0.3729	7	75	I = A	0.099	0.099
	65	45	0.50	0.3729	7	75	I = 2A	0.075	0.150
Optimistic	80	50	0.75	0.5500	6	100	I = A	0.134	0.134
	80	50	0.75	0.5500	6	100	I = 2A	0.095	0.190
Maximum	67	100	0.0	0.6700	6	100	I = 2A	0.149	0.149
conceivable	67	100	0.0	0.6700	6	100	I = 2A	0.104	0.208

[a]*Breeding success accounts for mortality in the first year of life.*
[b]*Probability of renesting indicates chance that a pair will lay a second egg after a failed first egg in a single breeding season.*
[c]*Mortality by age shows the relationship between immature (I) and adult (A) mortality.*

Required Adult Survival = 1 – 0.099 = **0.901** (90.1%)

Fledglings:
= 0.3729 / female
= 0.3729 / 2 = **0.186** female fledglings / female

cue (Snyder & Snyder 1989). By 1987, when the last wild condor was captured, the captive population consisted of 27 individuals (14 females and 13 males). First repro-

Success of releases?

Table 3. Causes, numbers, and dates of actual and near mortalities of Andean and California Condors during releases to the wild in California and Arizona, December 1988–June 1999.

Cause	*Actual mortalities*	*Near mortalities*	*Location*	*Dates of actual and near (N) mortalities*
Collisions	7	0	California	February 1989,[a] May 1993, October 1993, June 1993, June 1994, August 1997
			Arizona	May 1997
Lead poisoning	0	5 birds, 6 incidents	California	September 1997 N (3), May 1998 N, September 1998 N (2)
Disappearances	4	1	California	April 1996 N, September 1996, November 1996, December 1996
			Arizona	July 1997
Drownings	2	0	California	July 1998 (2)
Starvation	2	2	California	April 1996 N, February 1997, June 1999
			Arizona	July 1997 N
Shooting	1 + (1)[b]	1	California	July 1992 N, June 1998
			Arizona	March 1999
Antifreeze	1	0	California	October 1992
Cancer	1	0	California	July 1994
Golden eagle	1	0	Arizona	January 1997
Coyote (?)[c]	1	0	Arizona	December 1998
Unknown injury	0	1	California	October 1990 N[c]
Found dead	1	0	Arizona	October 1998

[a] *Andean condor mortality or near mortality.*
[b] *Injured by shooting, taken to zoo to heal, cause of death unknown.*
[c] *Possibly scavenging, not predation.*

Captive Breeding Program

http://youtu.be/LhV9mNrbp9w

Reading for Thursday

Contributed Paper

Interactive Effects of Harvest and Deer Herbivory on the Population Dynamics of American Ginseng

SUSAN J. FARRINGTON,*§ ROSE-MARIE MUZIKA,* DAN DREES,†
AND TIFFANY M. KNIGHT‡

*Department of Forestry, University of Missouri-Columbia, Columbia, MO 65211, U.S.A.
†Missouri Department of Conservation, HC 1 Box 177K, Eminence, MO 65466, U.S.A.
‡Department of Biology, Washington University in St. Louis, Box 1229, St. Louis, MO 63130, U.S.A.

- What were the overall goals?
- What are the study's strengths?
- How do the authors incorporate the effects of deer and humans?
- Do deer always matter? Why or why not?
- Note: Figure 3 and the "LTRE" may be a bit confusing – we'll go over it in class

Timeline

Monday, April 1

- Choose **3** species that interest you from:
  - https://wellesley.shinyapps.io/matrix-data
- These species are included in the COMPADRE and COMADRE databases of plant and animal population matrix model data: http://www.compadre-db.org
- You must include at least one plant or animal.
- It's best to choose species that have multiple years, populations, and/or treatments.
- Submit your species via the form: https://forms.gle/xRJEYNhyxrV3uGn56

Wednesday, April 3

- I will briefly meet with you during lab to help narrow in on your species and help you locate the publication that the dataset comes from.

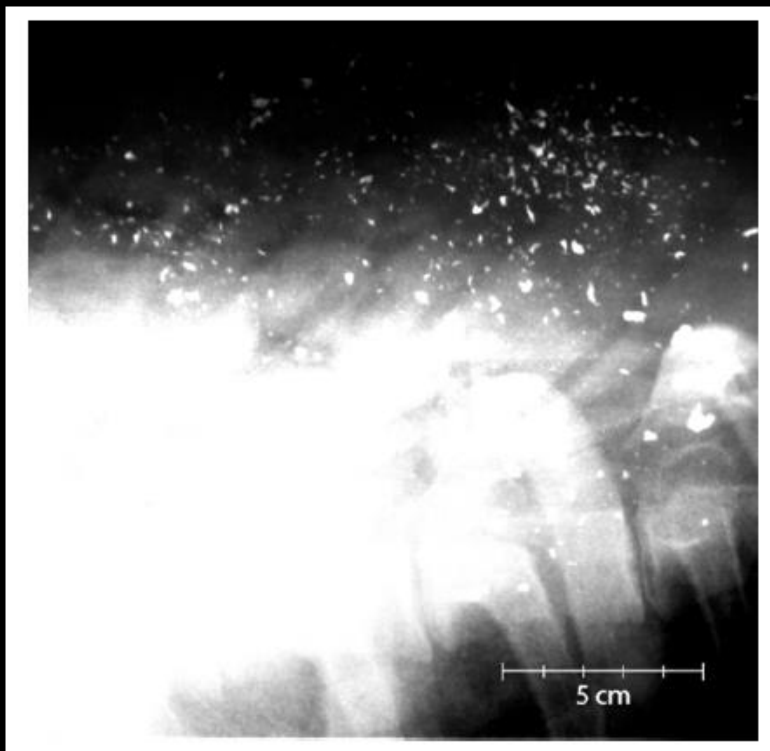
Monday, April 8

- Turn in a one page "proposal" that includes preliminary research (at least two identified sources) and **clearly specifies your main questions to address**.
- You must include a brief rationale for why you are addressing these questions and how they will help inform the management of this species.

Wednesday, April 10

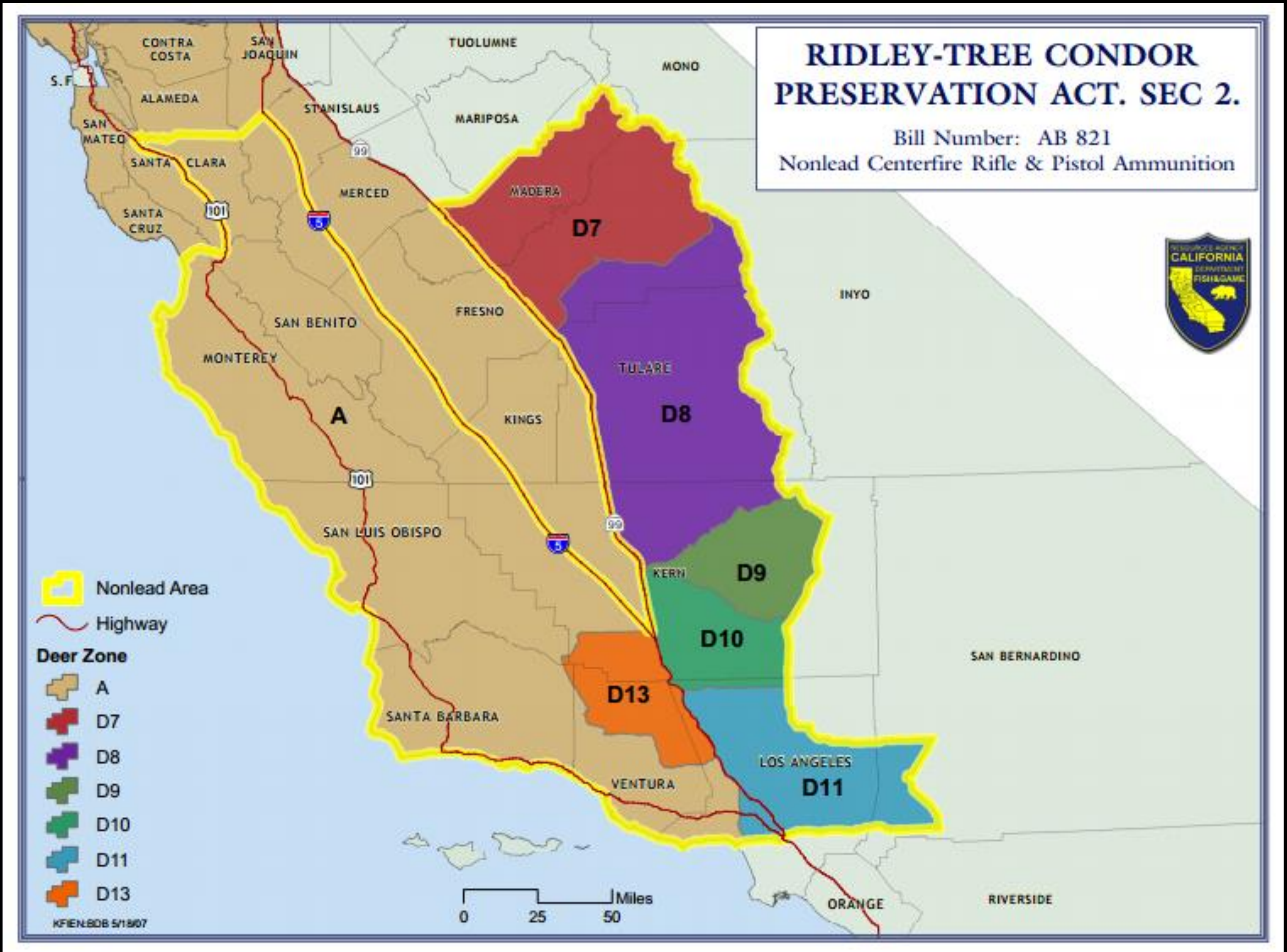
- We will be smelting copper in lab, but there will be time for me to talk with you about your ideas and give feedback on your proposal.

Lead Ammunition



Human Infrastructure

(Walters et al 2008)



(enacted in 2008)

Nonlead Ammunition in California

Effective July 1, 2019, nonlead ammunition is required when taking any wildlife with a firearm anywhere in California.

In October 2013, Assembly Bill 711 was signed into law requiring the use of nonlead ammunition when taking any wildlife with a firearm in California. This law required the California Fish and Game Commission to adopt regulations that phased-in the statute's requirements by July 1, 2019.

THE HILL

Just In...

Interior secretary repeals ban on lead bullets

BY TIMOTHY CAMA - 03/02/17 03:03 PM EST

642 COMMENTS

55,498 SHARES

SHARE (55.5K) TWEET PLUS ONE

© Getty Images

Interior Secretary Ryan Zinke signed an order Thursday overturning a ban on using lead ammunition on wildlife refuges.

Zinke signed the order on his first day in office, overturning a policy implemented by former Fish and Wildlife Service (FWS) Director Dan Ashe on Jan. 19, the Obama administration's last full day in office.

Ashe's policy banned the use of lead ammunition and fishing tackle on all FWS wildlife refuges that allow hunting or fishing, as well as in all other hunting or fishing regulated by the agency elsewhere.

It was meant to help prevent plants and animals from being poisoned by lead left on the ground or in the water.

"After reviewing the order and the process by which it was promulgated, I have determined that the order is not mandated by any existing statutory or regulatory requirement and was issued without significant communication, consultation or coordination with affected stakeholders," Zinke wrote in his order.

(2017)

StarTribune (Minnesota)

Bills would ban lead in fishing gear, a bird killer

It only takes a piece of lead the size of a grain of rice to kill a bird.

By Jim Williams Special to the Star Tribune | MARCH 16, 2021 — 10:41AM

JIM WILLIAMS

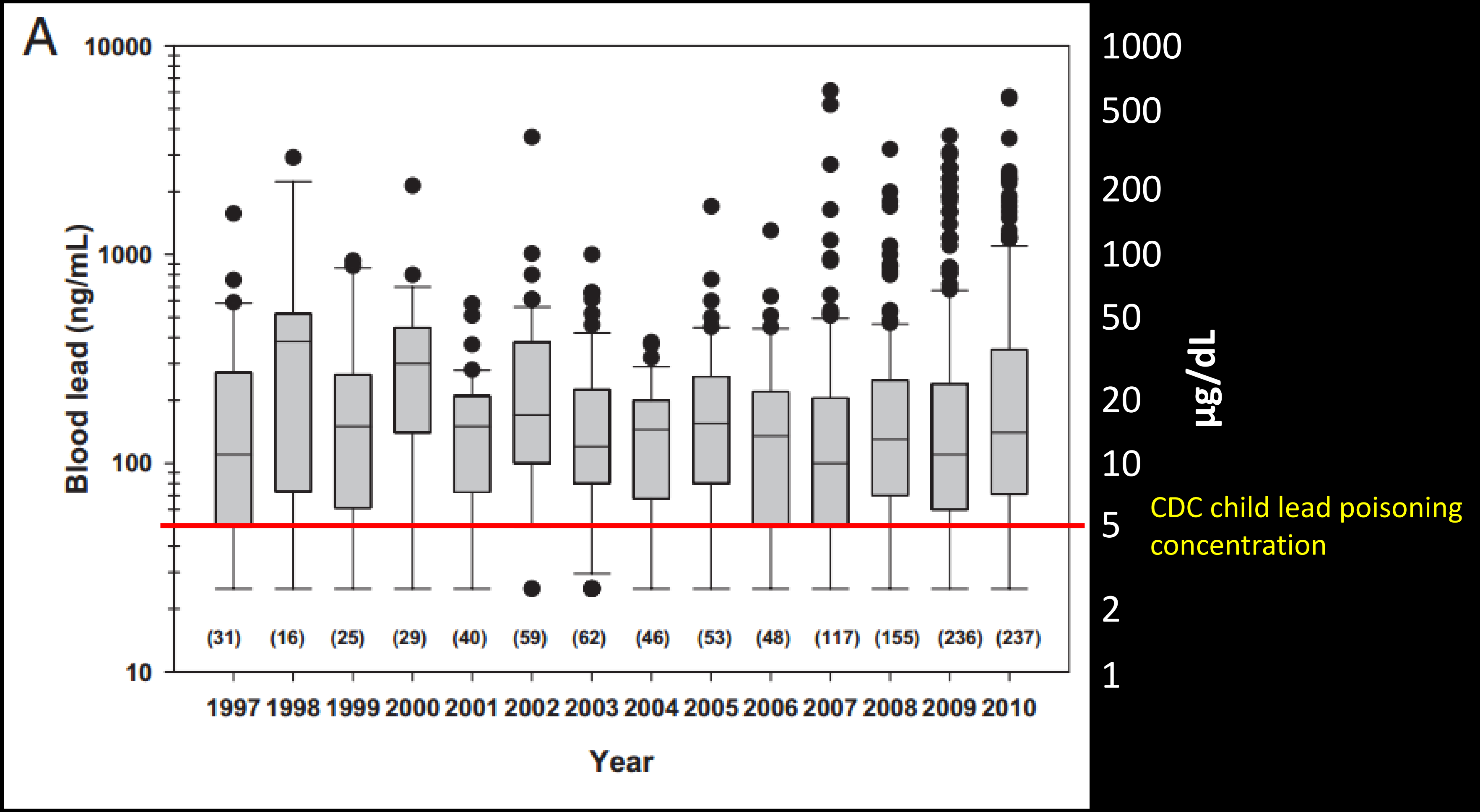
Common loons swallow old lead pellets while searching for small stones they use to aid digestion.

A ban on lead used in fishing equipment — sinkers and jigs — is again being discussed at the Legislature.

Lead poisons any animal that ingests it. The impetus this year was discovery of dead trumpeter swans that were believed to have swallowed lost lead fishing gear while feeding.

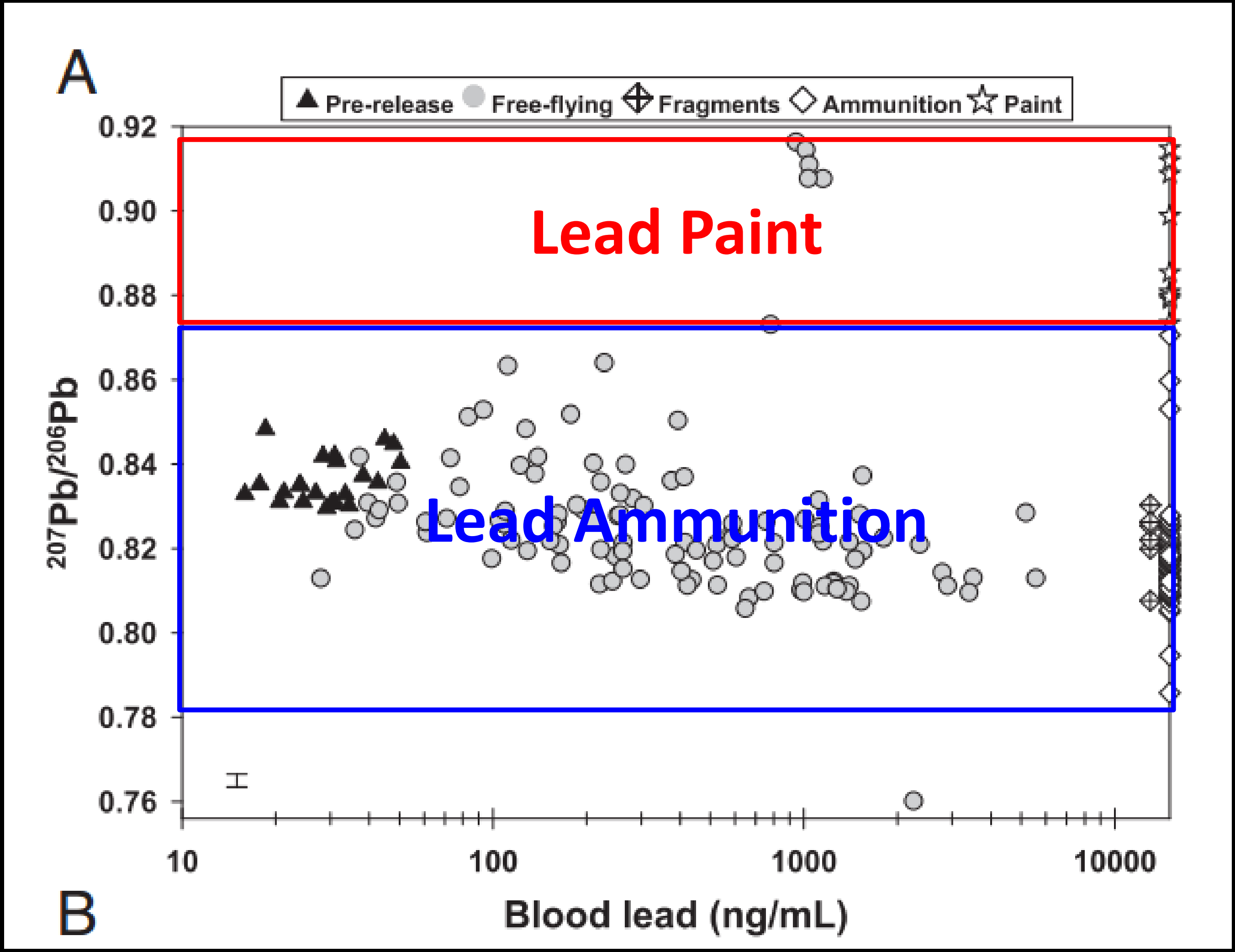
Lead poisoning and the deceptive recovery of the critically endangered California condor

Myra E. Finkelstein[a,1], Daniel F. Doak[b], Daniel George[c], Joe Burnett[d], Joseph Brandt[e], Molly Church[f], Jesse Grantham[e], and Donald R. Smith[a]



(Finkelstein, Doak, et al 2012)

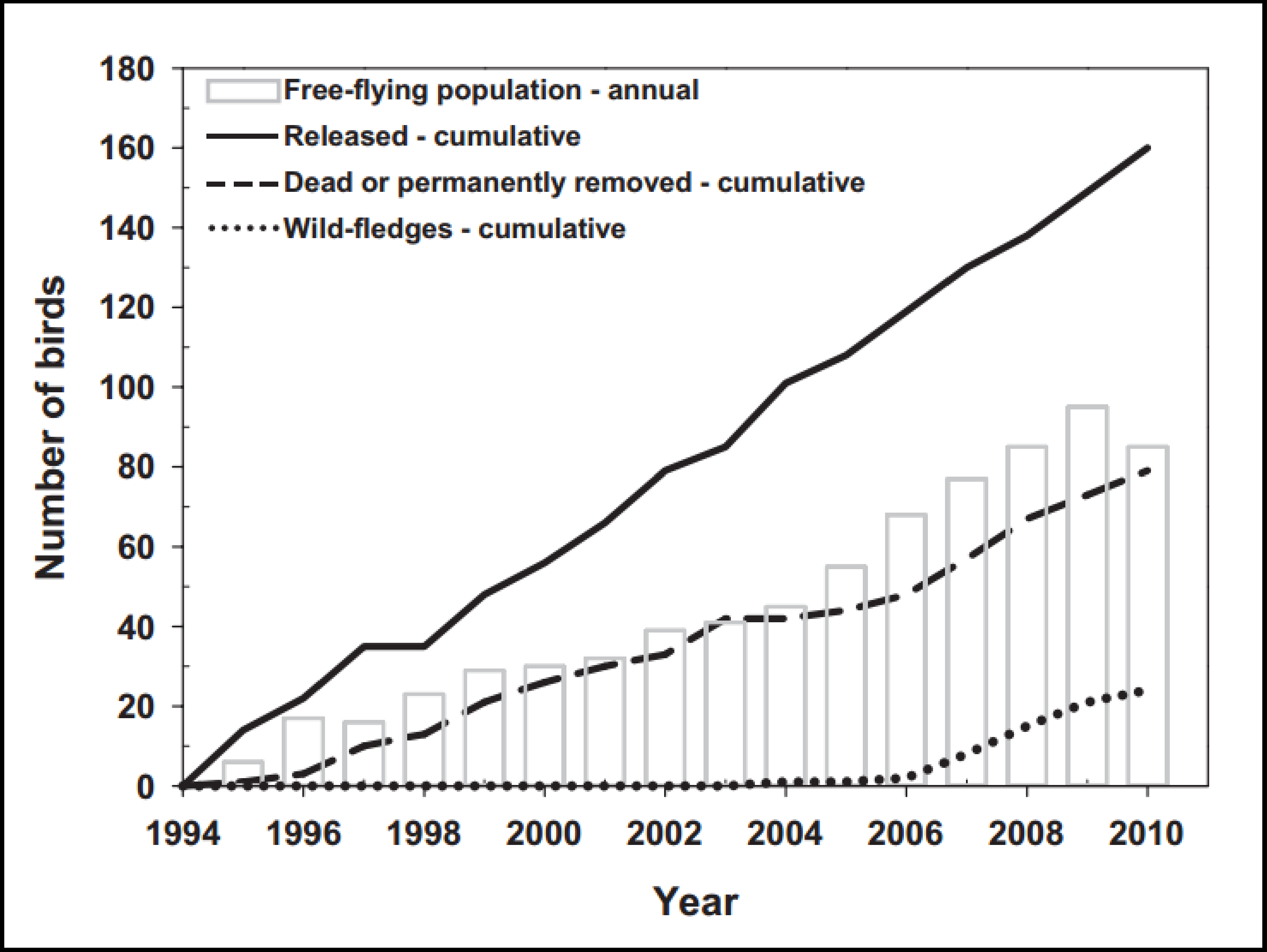
Isotopic Analysis – source attribution



(Finkelstein, Doak, et al 2012)

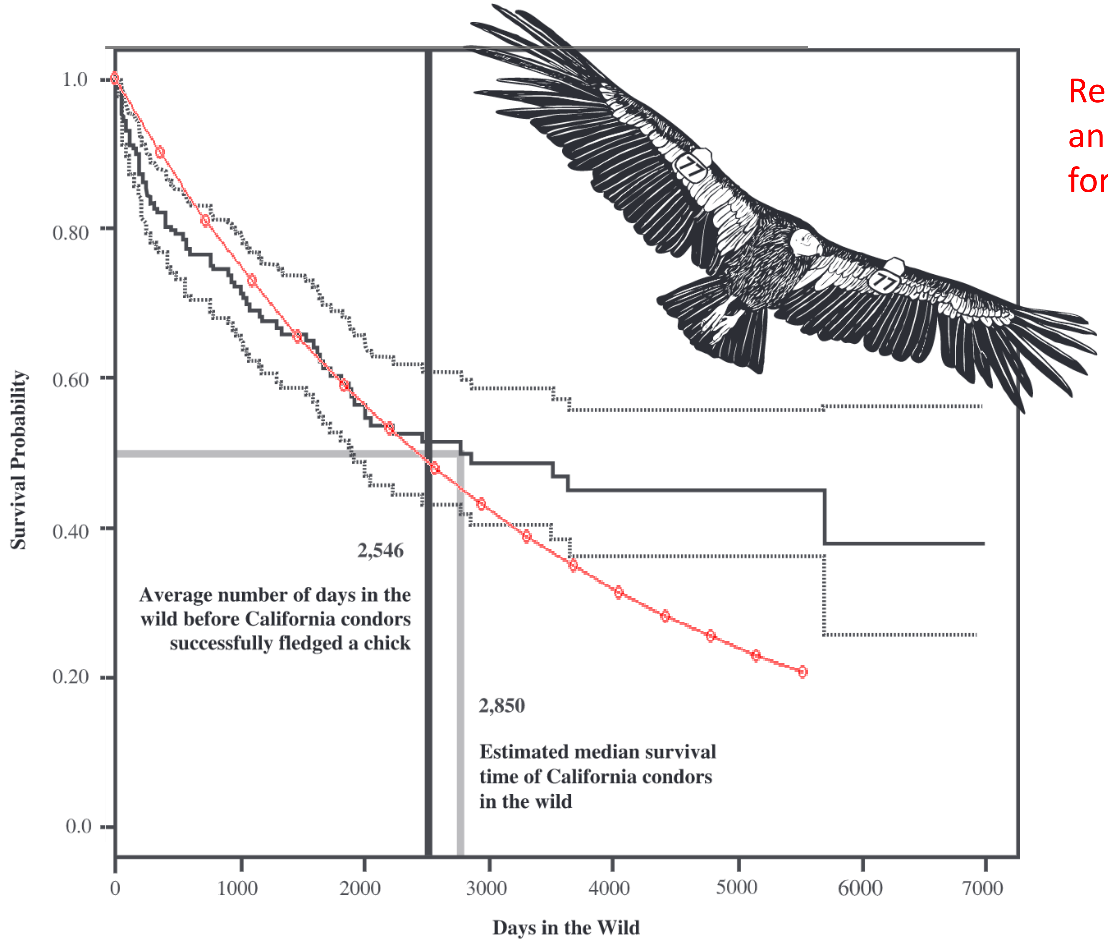
Success of releases?

(California Only)



(Finkelstein, Doak, et al 2012)

Success of releases?



Red line is 90% annual survival for reference

Fig. 1. The estimated unadjusted median survival time for California condors in the wild was 7.8 years (2850 days, 95% CI: 1886 days, NA; light gray line) during the two decades of reintroductions. Because California condors were free-flying in the wild for 7 years on average before they successfully fledged a chick (black line), findings suggest that 50% of condors released or fledged within the 20 year period would be expected to survive until the average time in which they successfully fledge their first chick, illustrating low recruitment to the breeding population.

(Kelly et al. 2015)

ARTICLE

World CA Condor Update – 2022 Population Status

TOTAL WORLD POPULATION = 561

Number of wild-fledged chicks = 9

Number of birds newly released into the wild from captivity = 31

Note: the Pacific Northwest Flock was newly established as a wild flock in 2022!!

Number of mortalities in the free-flying population = 20

TOTAL CAPTIVE POPULATION = 214

Captive Breeding is conducted at the Peregrine Fund's World Center for Birds of Prey, Los Angeles Zoo, San Diego Zoo and Safari Park and Oregon Zoo in the U.S. and Chapultepec Zoo in Mexico City, Mexico.

Number of captive breeding pairs = 43

Number of captive hatched chicks = 44

Number of captive adult deaths = 0

Chicks held for release in 2023 = 39

Demographic Viability of a Relict Population of the Critically Endangered Plant *Borderea chouardii*

MARÍA B. GARCÍA*

Department of Botany, Stockholm University, S-10691 Stockholm, Sweden, and Departamento Biologia Vegetal y Ecologia, Universidad de Sevilla, Apartado 1095, E-41080 Sevilla, Spain

Borderea chouardii

(Garcia et al 2012)

Table 1. Finite growth rates (λ) as predicted by deterministic matrix models, with 95% confidence interval (CI).

Transition years	λ	*CI*	G[a]	λhs[b]
1995–1996	0.997	0.941–1.053	12.64*	
1996–1997	1.021	0.923–1.12	11.81*	1.025
1997–1998	0.989	0.934–1.043	3.35 ns	0.991
1998–1999	1.009	0.931–1.088	2.68 ns	1.014
1999–2000	0.999	0.921–1.078	5.52 ns	1.007
2000–2001	0.982	0.936–1.028	1.82 ns	0.985
2001–2001	1.009	0.903–1.115	3.24 ns	1.013

[a] *Comparisons between observed population structures and those expected in stable-stage distribution (ns, $p > 0.05$; *, $0.01 < p < 0.05$).*
[b] *The λhs are the result, at the population level, of increased fertility after fruits are collected and sowed in the monitoring area.*

```
> geomean(c(0.997, 1.021, 0.989, 1.009, 0.999, 0.982, 1.009))
[1] 1.000782
```

Table 2. Lefkovitch mean matrix for *Borderia chouardii* calculated for 1995–2002 ($\lambda = 1.001$).*

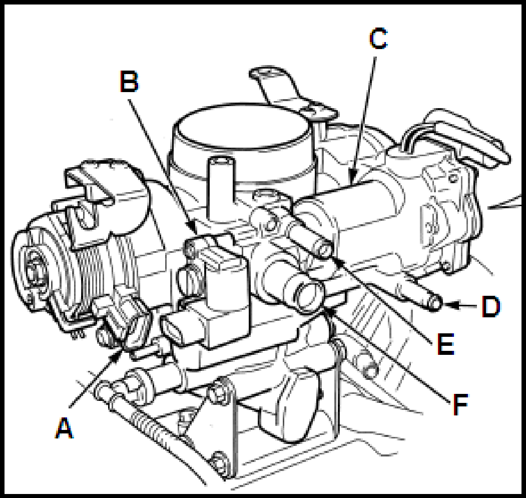
	S	*F0*	*F1*	*F2*	*F3*	*F4*
S	0.500			0.032	0.220	0.528
F0	0.030			0.002	0.011	0.026
F1		0.772	0.856	0.046	0.002	
F2		0.019	0.095	0.759	0.079	
F3				0.179	0.838	0.151
F4				0.003	0.074	0.845

**Abbreviations: S, seeds in the seed bank; F0, plants younger than 1 year; F1, juveniles; F2, small females; F3, medium females; F4, large females.*

Population
Growth Rate (λ)

Projection
Matrix

Vital Rates



Vital Rates for *Borderea chouardii*

Dormant seed survival and/or germination

Table 2. Lefkovitch mean matrix for *Borderia chouardii* calculated for 1995–2002 ($\lambda = 1.001$).*

	S	*F0*	*F1*	*F2*	*F3*	*F4*
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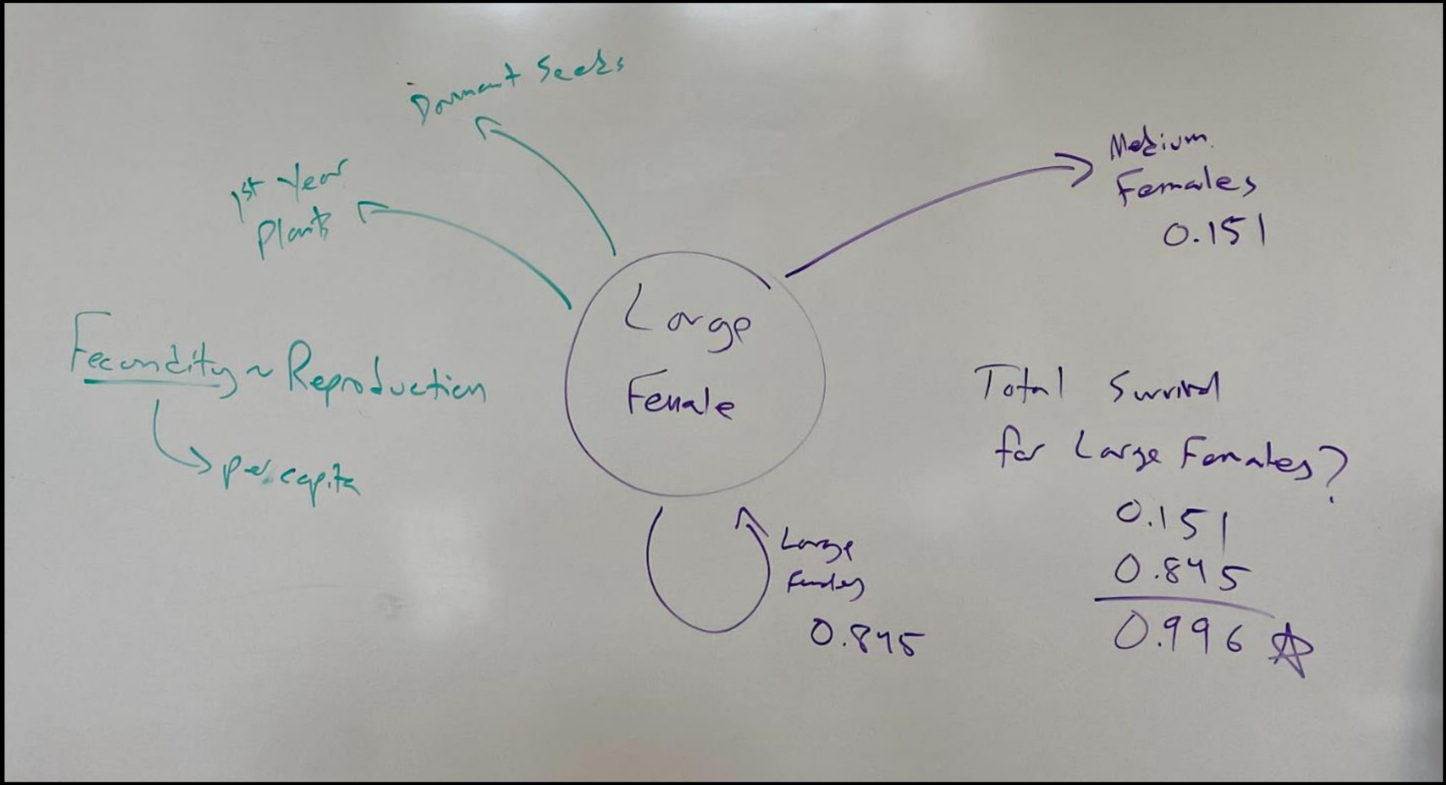
Production of dormant seeds

Production of new plants

Probability of surviving
<u>AND</u> changing sizes


Dormant Seeds
1st Year Plants
Medium Females
0.151
Large Female
Fecundity ~ Reproduction
per capita
Large Females
0.845
Total Survival for Large Females?
0.151
0.845
0.996

**Abbreviations: S, seeds in the seed bank; F0, plants younger than 1 year; F1, juveniles; F2, small females; F3, medium females; F4, large females.*

	S	F0	F1	F2	F3	F4
S						
F0						
F1						
F2						
F3						
F4						

S = Survival of different stage classes

P = Probability of transitioning from one size class to another (<u>for survivors only</u>)

**Abbreviations: S, seeds in the seed bank; F0, plants younger than 1 year; F1, juveniles; F2, small females; F3, medium females; F4, large females.*

	S	F0	F1	F2	F3	F4
S						
F0						
F1		$S_{F0} \times P_{F0 \rightarrow F1}$	$S_{F1} \times P_{F1 \rightarrow F1}$	$S_{F2} \times P_{F2 \rightarrow F1}$	$S_{F3} \times P_{F3 \rightarrow F1}$	0
F2		$S_{F0} \times P_{F0 \rightarrow F2}$	$S_{F1} \times P_{F1 \rightarrow F2}$	$S_{F2} \times P_{F2 \rightarrow F2}$	$S_{F3} \times P_{F3 \rightarrow F2}$	0
F3		0	0	$S_{F2} \times P_{F2 \rightarrow F3}$	$S_{F3} \times P_{F3 \rightarrow F3}$	$S_{F4} \times P_{F4 \rightarrow F3}$
F4		0	0	$S_{F2} \times P_{F3 \rightarrow F4}$	$S_{F3} \times P_{F3 \rightarrow F4}$	$S_{F4} \times P_{F4 \rightarrow F4}$

S = Survival of different stage classes

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**Abbreviations: S, seeds in the seed bank; F0, plants younger than 1 year; F1, juveniles; F2, small females; F3, medium females; F4, large females.*

	S	F0	F1	F2	F3	F4
S						
F0						
F1		$S_{F0} \times P_{F0 \rightarrow F1}$	$S_{F1} \times P_{F1 \rightarrow F1}$	$S_{F2} \times P_{F2 \rightarrow F1}$	$S_{F3} \times P_{F3 \rightarrow F1}$	0
F2		$S_{F0} \times P_{F0 \rightarrow F2}$	$S_{F1} \times P_{F1 \rightarrow F2}$	$S_{F2} \times P_{F2 \rightarrow F2}$	$S_{F3} \times P_{F3 \rightarrow F2}$	0
F3		0	0	$S_{F2} \times P_{F2 \rightarrow F3}$	$S_{F3} \times P_{F3 \rightarrow F3}$	$S_{F4} \times P_{F4 \rightarrow F3}$
F4		0	0	$S_{F2} \times P_{F3 \rightarrow F4}$	$S_{F3} \times P_{F3 \rightarrow F4}$	$S_{F4} \times P_{F4 \rightarrow F4}$

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Abbreviations: S, seeds in the seed bank; F0, plants younger than 1 year; F1, juveniles; F2, small females; F3, medium females; F4, large females.

F = Probability of flowering

R = # seeds per flowering plant

G_{new} = Germination rate of new seeds

E = Establishment/survival of seedlings

	S	F0	F1	F2	F3	F4
S						
F0				$F_{F2} \times R_{F2} \times G_{new} \times E$	$F_{F3} \times R_{F3} \times G_{new} \times E$	$F_{F4} \times R_{F4} \times G_{new} \times E$
F1		$S_{F0} \times P_{F0 \to F1}$	$S_{F1} \times P_{F1 \to F1}$	$S_{F2} \times P_{F2 \to F1}$	$S_{F3} \times P_{F3 \to F1}$	0
F2		$S_{F0} \times P_{F0 \to F2}$	$S_{F1} \times P_{F1 \to F2}$	$S_{F2} \times P_{F2 \to F2}$	$S_{F3} \times P_{F3 \to F2}$	0
F3		0	0	$S_{F2} \times P_{F2 \to F3}$	$S_{F3} \times P_{F3 \to F3}$	$S_{F4} \times P_{F4 \to F3}$
F4		0	0	$S_{F2} \times P_{F3 \to F4}$	$S_{F3} \times P_{F3 \to F4}$	$S_{F4} \times P_{F4 \to F4}$

S = Survival of different stage classes

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Abbreviations: S, seeds in the seed bank; F0, plants younger than 1 year; F1, juveniles; F2, small females; F3, medium females; F4, large females.

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	S	F0	F1	F2	F3	F4
S				$F_{F2}\times R_{F2}\times(1-G_{new})$	$F_{F3}\times R_{F3}\times(1-G_{new})$	$F_{F4}\times R_{F4}\times(1-G_{new})$
F0				$F_{F2}\times \mathrm{R}_{F2}\times G_{new}\times E$	$F_{F3}\times R_{F3}\times G_{new}\times E$	$F_{F4}\times R_{F4}\times G_{new}\times E$
F1		$S_{F0}\times P_{F0\rightarrow F1}$	$S_{F1}\times P_{F1\rightarrow F1}$	$S_{F2}\times P_{F2\rightarrow F1}$	$S_{F3}\times P_{F3\rightarrow F1}$	0
F2		$S_{F0}\times P_{F0\rightarrow F2}$	$S_{F1}\times P_{F1\rightarrow F2}$	$S_{F2}\times P_{F2\rightarrow F2}$	$S_{F3}\times P_{F3\rightarrow F2}$	0
F3		0	0	$S_{F2}\times P_{F2\rightarrow F3}$	$S_{F3}\times P_{F3\rightarrow F3}$	$S_{F4}\times P_{F4\rightarrow F3}$
F4		0	0	$S_{F2}\times P_{F3\rightarrow F4}$	$S_{F3}\times P_{F3\rightarrow F4}$	$S_{F4}\times P_{F4\rightarrow F4}$

S = Survival of different stage classes

P = Probability of transitioning from one size class to another (<u>for survivors only</u>)

**Abbreviations: S, seeds in the seed bank; F0, plants younger than 1 year; F1, juveniles; F2, small females; F3, medium females; F4, large females.*

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	S	F0	F1	F2	F3	F4
S				$F_{F2}\times R_{F2}\times(1-G_{new})$	$F_{F3}\times R_{F3}\times(1-G_{new})$	$F_{F4}\times R_{F4}\times(1-G_{new})$
F0				$F_{F2}\times \mathrm{R}_{F2}\times G_{new}\times E$	$F_{F3}\times R_{F3}\times G_{new}\times E$	$F_{F4}\times R_{F4}\times G_{new}\times E$
F1		$S_{F0}\times P_{F0\rightarrow F1}$	$S_{F1}\times P_{F1\rightarrow F1}$	$S_{F2}\times P_{F2\rightarrow F1}$	$S_{F3}\times P_{F3\rightarrow F1}$	0
F2		$S_{F0}\times P_{F0\rightarrow F2}$	$S_{F1}\times P_{F1\rightarrow F2}$	$S_{F2}\times P_{F2\rightarrow F2}$	$S_{F3}\times P_{F3\rightarrow F2}$	0
F3		0	0	$S_{F2}\times P_{F2\rightarrow F3}$	$S_{F3}\times P_{F3\rightarrow F3}$	$S_{F4}\times P_{F4\rightarrow F3}$
F4		0	0	$S_{F2}\times P_{F3\rightarrow F4}$	$S_{F3}\times P_{F3\rightarrow F4}$	$S_{F4}\times P_{F4\rightarrow F4}$

S = Survival of different stage classes

P = Probability of transitioning from one size class to another (<u>for survivors only</u>)

**Abbreviations: S, seeds in the seed bank; F0, plants younger than 1 year; F1, juveniles; F2, small females; F3, medium females; F4, large females.*

F = Probability of flowering

R = # seeds per flowering plant

G_{new} = Germination rate of new seeds

E = Establishment/survival of seedlings

G_{dorm} = Germination rate of dormant seeds

	S	F0	F1	F2	F3	F4
S	$S_S\times(1-G_{dorm})$			$F_{F2}\times R_{F2}\times(1-G_{new})$	$F_{F3}\times R_{F3}\times(1-G_{new})$	$F_{F4}\times R_{F4}\times(1-G_{new})$
F0	$S_S\times G_{dorm}\times E$			$F_{F2}\times R_{F2}\times G_{new}\times E$	$F_{F3}\times R_{F3}\times G_{new}\times E$	$F_{F4}\times R_{F4}\times G_{new}\times E$
F1		$S_{F0}\times P_{F0\to F1}$	$S_{F1}\times P_{F1\to F1}$	$S_{F2}\times P_{F2\to F1}$	$S_{F3}\times P_{F3\to F1}$	0
F2		$S_{F0}\times P_{F0\to F2}$	$S_{F1}\times P_{F1\to F2}$	$S_{F2}\times P_{F2\to F2}$	$S_{F3}\times P_{F3\to F2}$	0
F3		0	0	$S_{F2}\times P_{F2\to F3}$	$S_{F3}\times P_{F3\to F3}$	$S_{F4}\times P_{F4\to F3}$
F4		0	0	$S_{F2}\times P_{F3\to F4}$	$S_{F3}\times P_{F3\to F4}$	$S_{F4}\times P_{F4\to F4}$

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**Abbreviations: S, seeds in the seed bank; F0, plants younger than 1 year; F1, juveniles; F2, small females; F3, medium females; F4, large females.*

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	S	F0	F1	F2	F3	F4
S	$S_S\times(1-G_{dorm})$			$F_{F2}\times R_{F2}\times(1-G_{new})$	$F_{F3}\times R_{F3}\times(1-G_{new})$	$F_{F4}\times R_{F4}\times(1-G_{new})$
F0	$S_S\times G_{dorm}\times E$			$F_{F2}\times R_{F2}\times G_{new}\times E$	$F_{F3}\times R_{F3}\times G_{new}\times E$	$F_{F4}\times R_{F4}\times G_{new}\times E$
F1		$S_{F0}\times P_{F0\to F1}$	$S_{F1}\times P_{F1\to F1}$	$S_{F2}\times P_{F2\to F1}$	$S_{F3}\times P_{F3\to F1}$	0
F2		$S_{F0}\times P_{F0\to F2}$	$S_{F1}\times P_{F1\to F2}$	$S_{F2}\times P_{F2\to F2}$	$S_{F3}\times P_{F3\to F2}$	0
F3		0	0	$S_{F2}\times P_{F2\to F3}$	$S_{F3}\times P_{F3\to F3}$	$S_{F4}\times P_{F4\to F3}$
F4		0	0	$S_{F2}\times P_{F3\to F4}$	$S_{F3}\times P_{F3\to F4}$	$S_{F4}\times P_{F4\to F4}$

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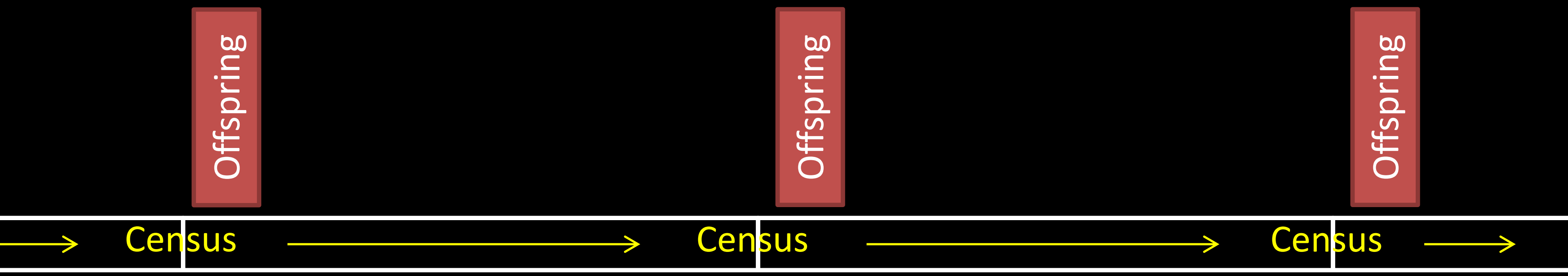
E = Establishment/survival of seedlings

G_{dorm} = Germination rate of dormant seeds

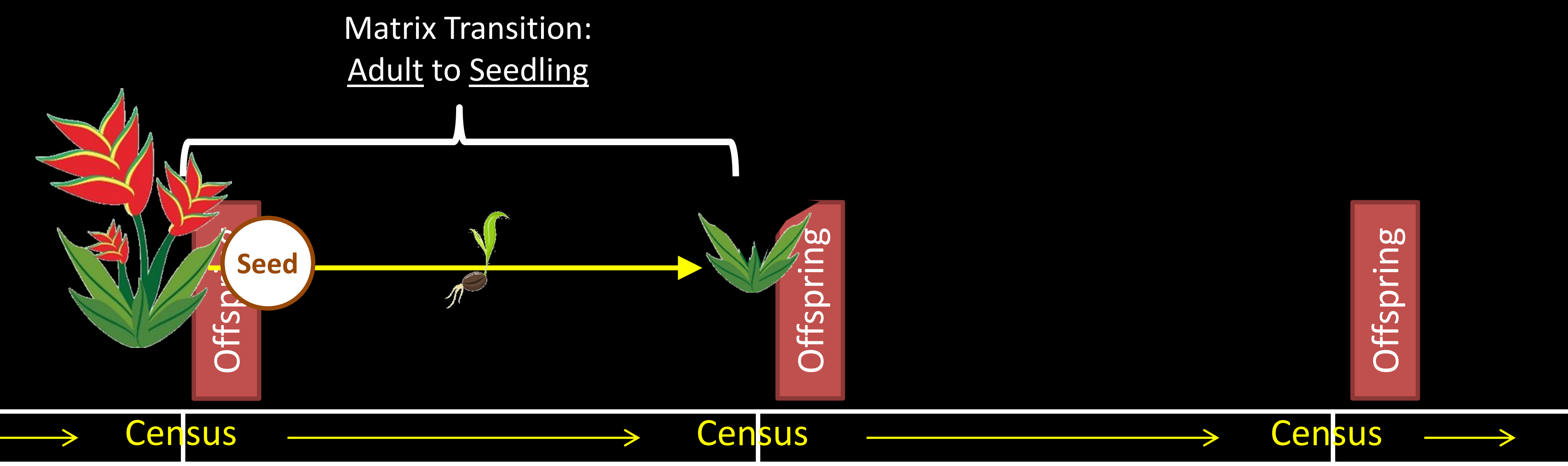
	S	F0	F1	F2	F3	F4
S	$S_S \times (1-G_{dorm})$	0	0	$F_{F2} \times R_{F2} \times (1-G_{new})$	$F_{F3} \times R_{F3} \times (1-G_{new})$	$F_{F4} \times R_{F4} \times (1-G_{new})$
F0	$S_S \times G_{dorm} \times E$	0	0	$F_{F2} \times R_{F2} \times G_{new} \times E$	$F_{F3} \times R_{F3} \times G_{new} \times E$	$F_{F4} \times R_{F4} \times G_{new} \times E$
F1	0	$S_{F0} \times P_{F0 \to F1}$	$S_{F1} \times P_{F1 \to F1}$	$S_{F2} \times P_{F2 \to F1}$	$S_{F3} \times P_{F3 \to F1}$	0
F2	0	$S_{F0} \times P_{F0 \to F2}$	$S_{F1} \times P_{F1 \to F2}$	$S_{F2} \times P_{F2 \to F2}$	$S_{F3} \times P_{F3 \to F2}$	0
F3	0	0	0	$S_{F2} \times P_{F2 \to F3}$	$S_{F3} \times P_{F3 \to F3}$	$S_{F4} \times P_{F4 \to F3}$
F4	0	0	0	$S_{F2} \times P_{F3 \to F4}$	$S_{F3} \times P_{F3 \to F4}$	$S_{F4} \times P_{F4 \to F4}$

Census Timing

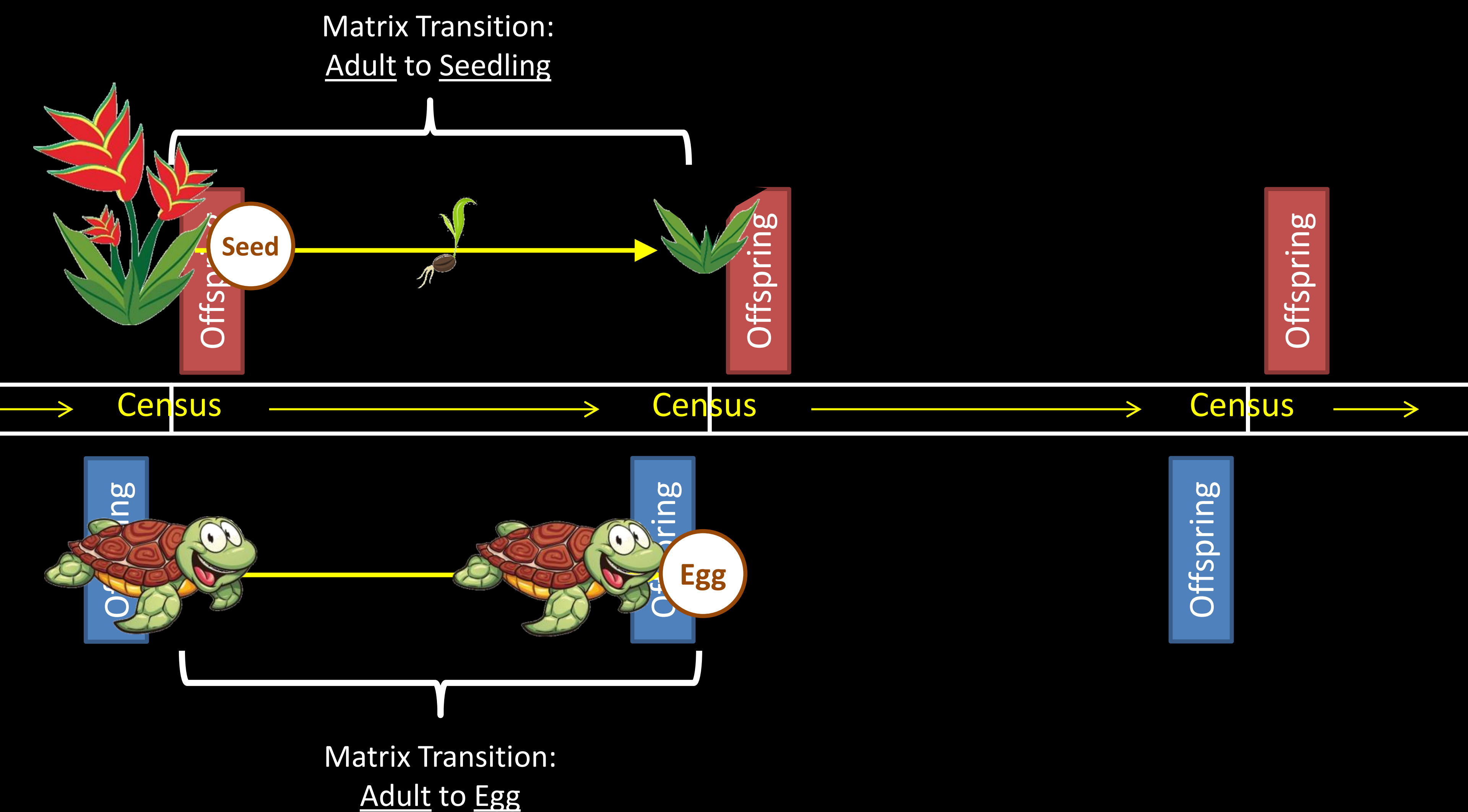
"Census" = Date when transitions begin/end
Date of data collection



“Pre-breeding Census”: Fecundity values must include offspring survival

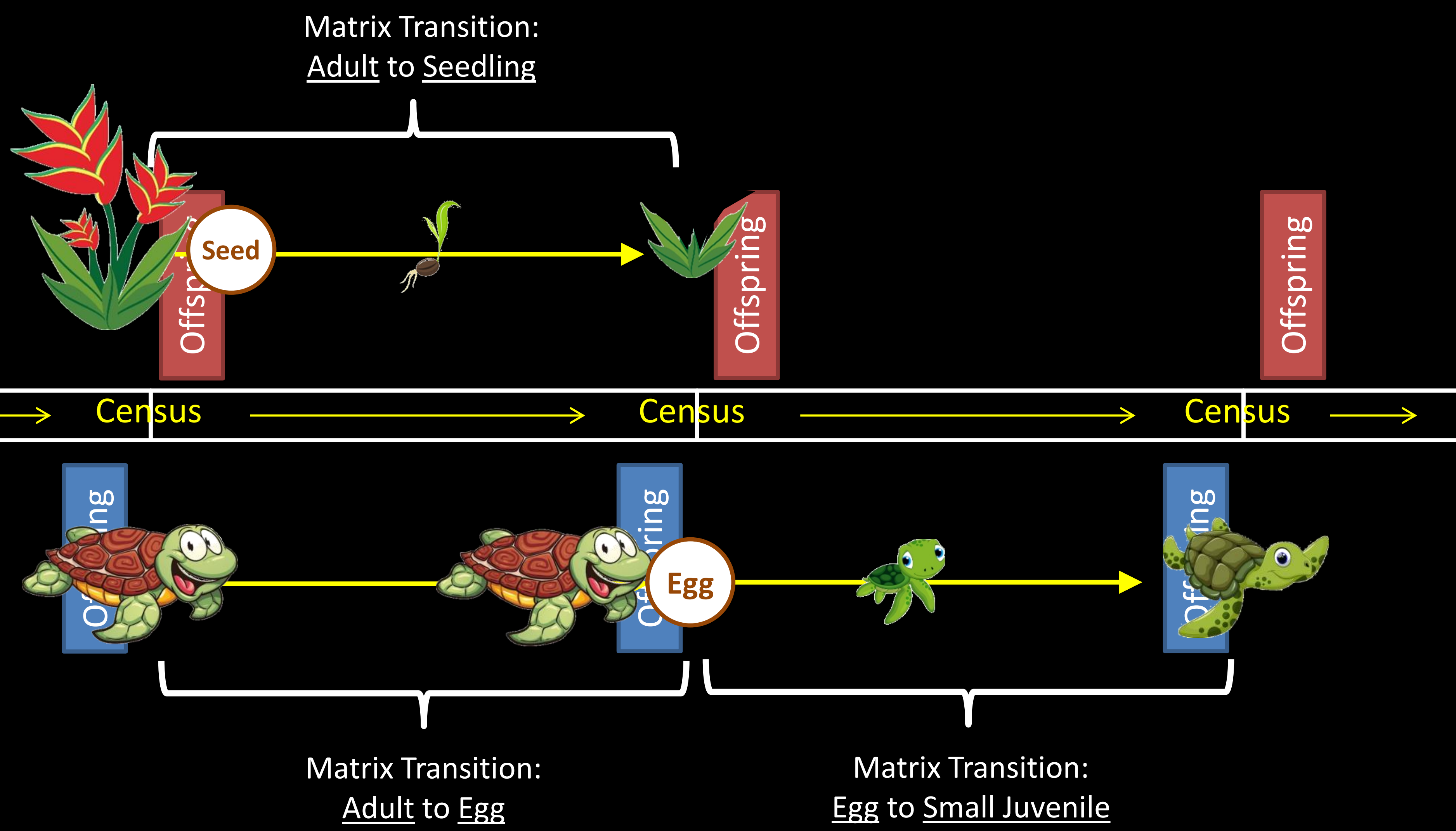


"Pre-breeding Census": Fecundity values must include offspring survival



"Post-breeding Census": Fecundity values must include parent survival

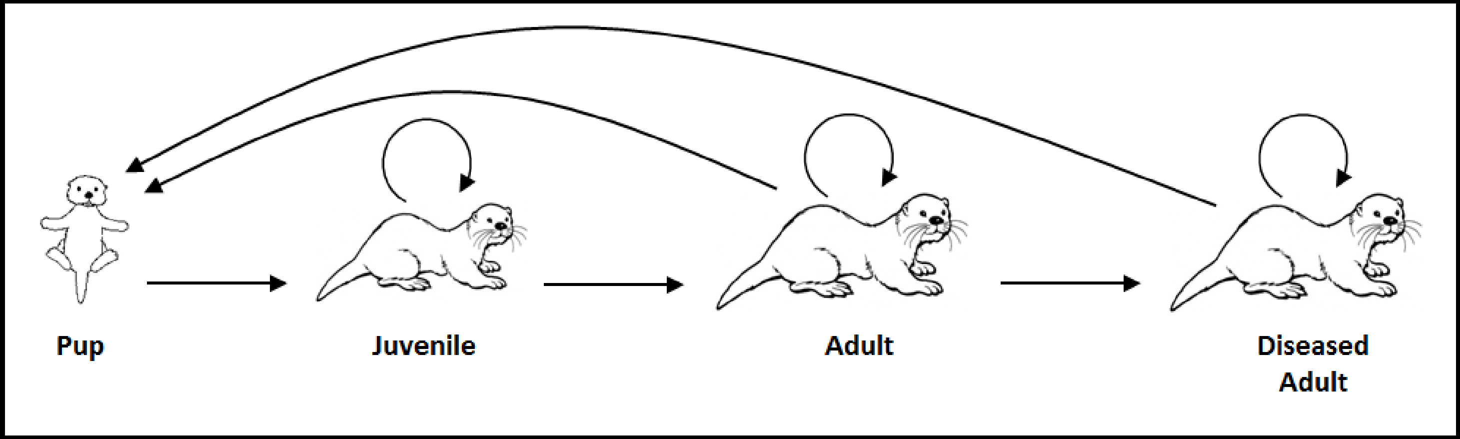
"Pre-breeding Census": Fecundity values must include offspring survival



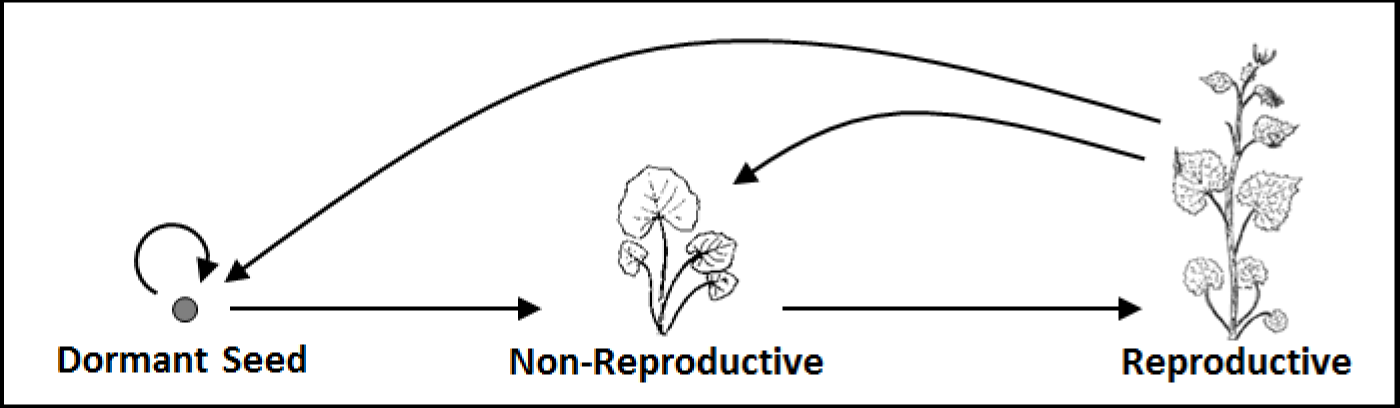
"Post-breeding Census": Fecundity values must include parent survival

Considering Time and Underlying Vital Rates

Sea Otter (*Enhydra lutris*)

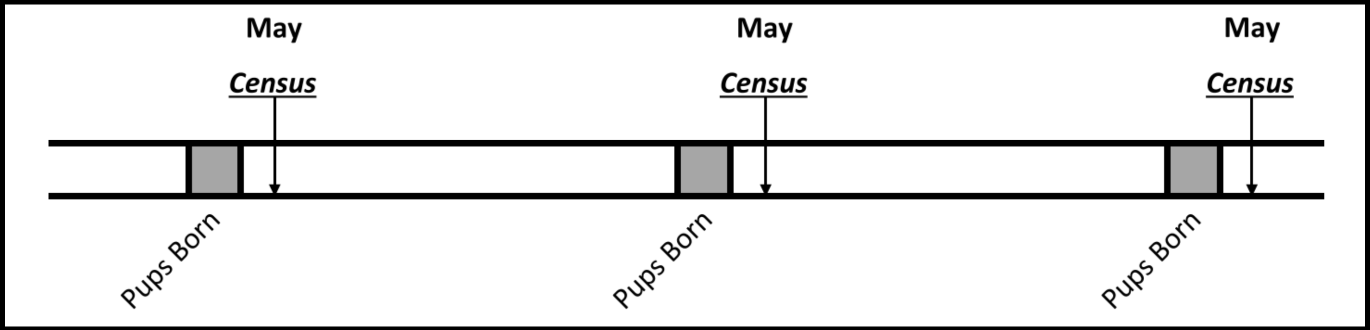


Garlic Mustard (*Alliaria petiolata*)

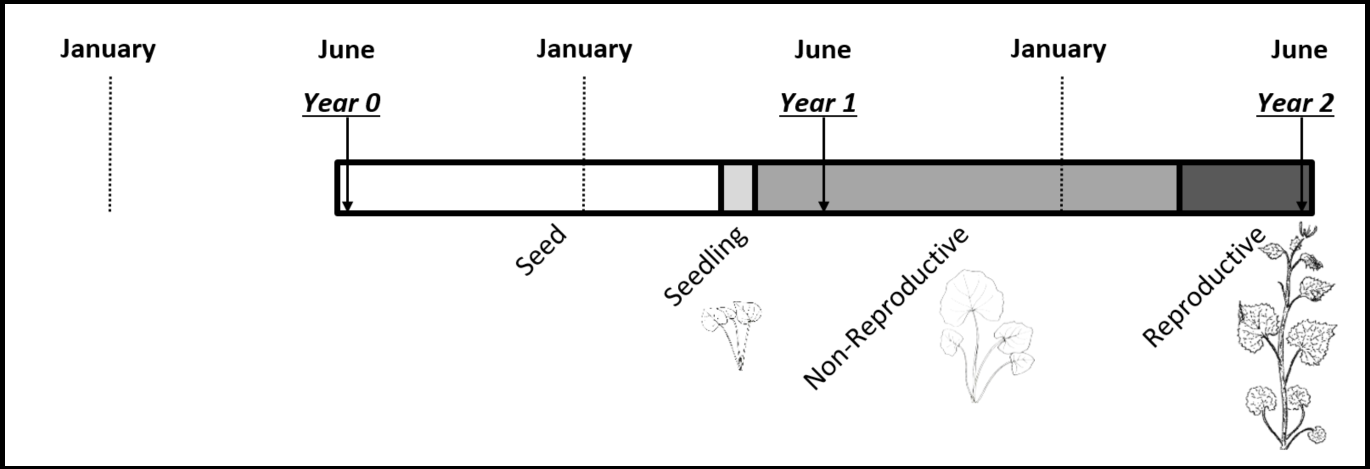


Considering Time and Underlying Vital Rates

Sea Otter (*Enhydra lutris*)



Garlic Mustard (*Alliaria petiolata*)



Considering Time and Underlying Vital Rates

1. Read through the handout to get a sense of
    - The life cycle
    - Considerations of time
    - Difference between matrix elements and vital rates

2. Construct the matrix using Vital Rates

Tips:

- Read through the handout
- Carefully consider and go back to the life cycle diagram and timeline
- Fill in impossible transitions first (zeros)
- The probability of something *NOT* happening is <u>1 minus</u> the probability of it happening.

Garlic Mustard (*Alliaria petiolata*)

Vital Rates:

- S_{DS} Dormant seed survival
- E Seedling establishment and survival (becomes a non-reproductive plant)
- S_{Sum} Survival of non-reproductive plants over summer
- S_{Win} Survival of non-reproductive plants over winter
- G_{DS} Fraction germination of dormant seeds
- G_{NS} Fraction germination of newly produced seeds
- F Per capita seed production of reproductive plants ("fecundity")

	Dormant Seed	**Non-Reproductive**	**Reproductive**
Dormant Seed			
Non-Reproductive			$(F)(G_{NS})(E)$
Reproductive			

Sea Otter (*Enhydra lutris*)

Vital Rates:

- S_P Pup survival
- S_J Juvenile survival
- M Fraction of surviving juveniles that mature into adults
- S_A Adult survival (from causes other than disease)
- D Fraction of adults newly infected with disease (*Toxoplasma gondii*)
- S_{DA} Survival of infected adults (due to disease only)
- F Number of pups born per adult ("fecundity")

	Pup	**Juvenile**	**Adult**	**Diseased Adult**
Pup				
Juvenile				
Adult		$(S_J)(M)$		
Diseased Adult				

Garlic Mustard (*Alliaria petiolata*)

Vital Rates:

S_{DS}	Dormant seed survival
E	Seedling establishment and survival (becomes a non-reproductive plant)
S_{Sum}	Survival of non-reproductive plants over summer
S_{Win}	Survival of non-reproductive plants over winter
G_{DS}	Fraction germination of dormant seeds
G_{NS}	Fraction germination of newly produced seeds
F	Per capita seed production of reproductive plants ("fecundity")

	Dormant Seed	Non-Reproductive	Reproductive
Dormant Seed	$(S_{DS})(1\text{-}G_{DS})$	0	$(F)(1\text{-}G_{NS})(S_{DS})$
Non-Reproductive	$(S_{DS})(G_{DS})(E)$	0	$(F)(G_{NS})(E)$
Reproductive	0	$(S_{Sum})(S_{Win})$	0

	Pup	Juv	Adult	Diseased
Pup	0	0	$(S_A)F$	? $(S_A)(S_{DA})F$
Juv	S_P	$(S_J)(1-M)$	0	0
Adult	0	$(S_J)(M)$	$(S_A)(1-D)$	0
Diseased	0	0	$(S_A)D$	? $(S_A)(S_{DA})$

Sea Otter (*Enhydra lutris*)

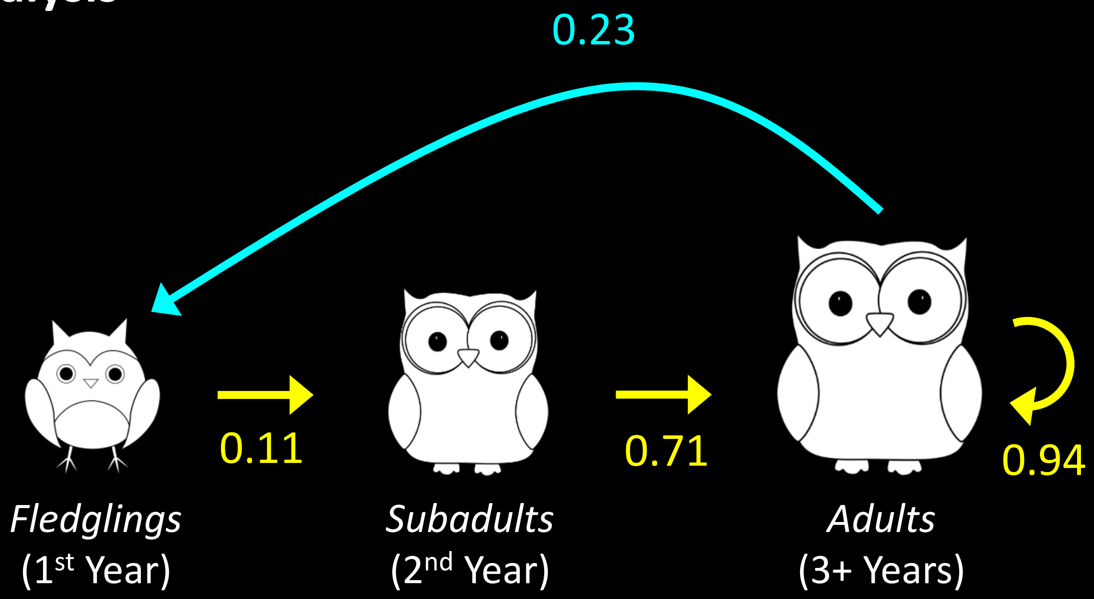
Vital Rates:

S_P	Pup survival
S_J	Juvenile survival
M	Fraction of surviving juveniles that mature into adults
S_A	Adult survival (from causes other than disease)
D	Fraction of adults newly infected with disease (*Toxoplasma gondii*)
S_{DA}	Survival of infected adults (due to disease only)
F	Number of pups born per adult ("fecundity")

	Pup	Juvenile	Adult	Diseased Adult
Pup	0	0	$(S_A)(F)$	$(S_A)(S_{DA})(F)$
Juvenile	S_P	$(S_J)(1-M)$	0	0
Adult	0	$(S_J)(M)$	$(S_A)(1-D)$	0
Diseased Adult	0	0	$(S_A)(D)$	$(S_A)(S_{DA})$

	Dormant Seed	Non-Repro	Repro
Dormant Seed	$S_{DS} \times (1-G_{DS})$	0	$F \times (1-G_{NS}) \times S_{DS}$?
Non-Repro	$S_{DS} \times E \times G_{DS}$?	0	$F \times G_{NS} \times E$ surv
Repro	0	$S_{sum} \times S_{win}$	0

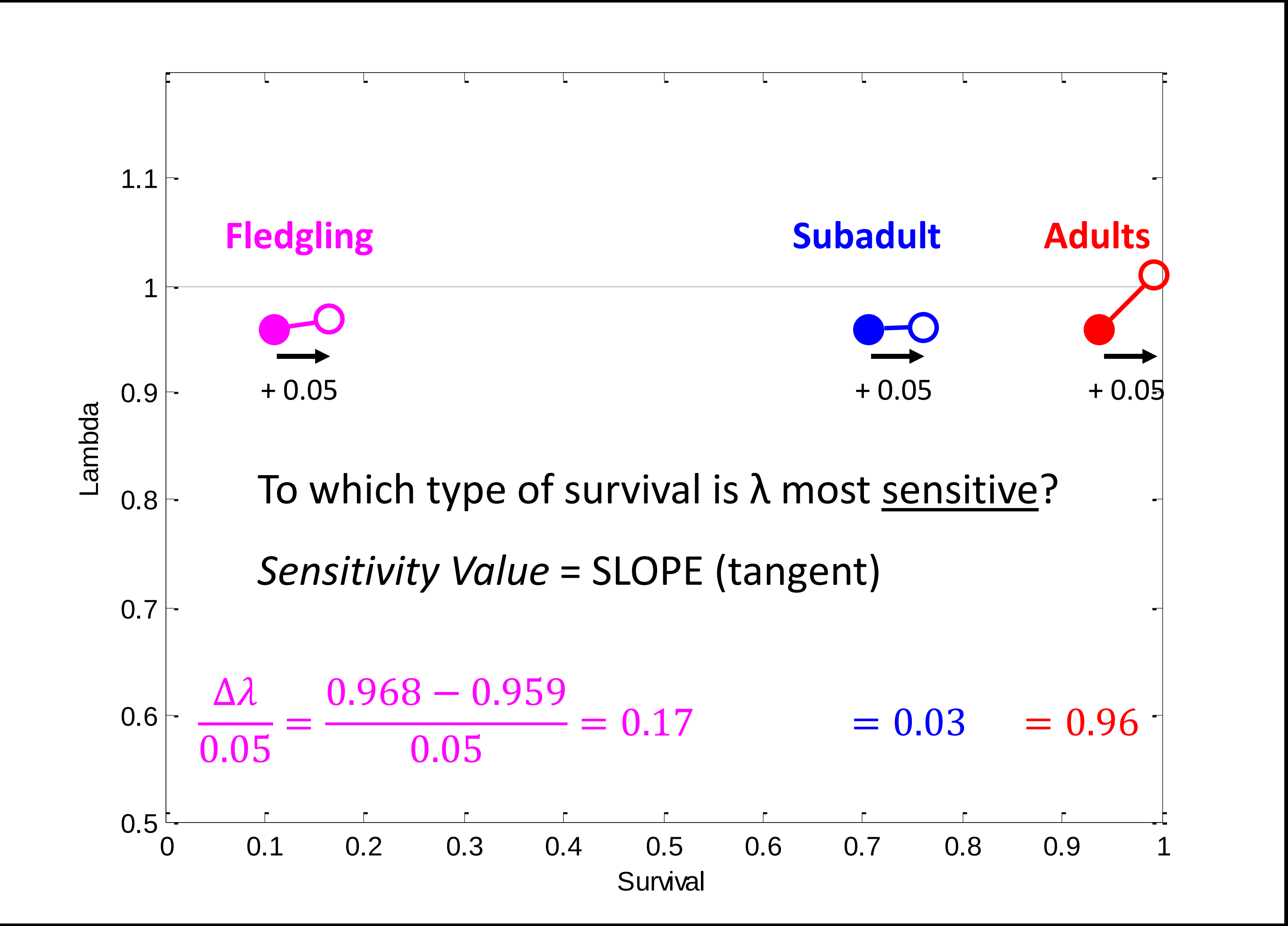
Perturbation Analysis



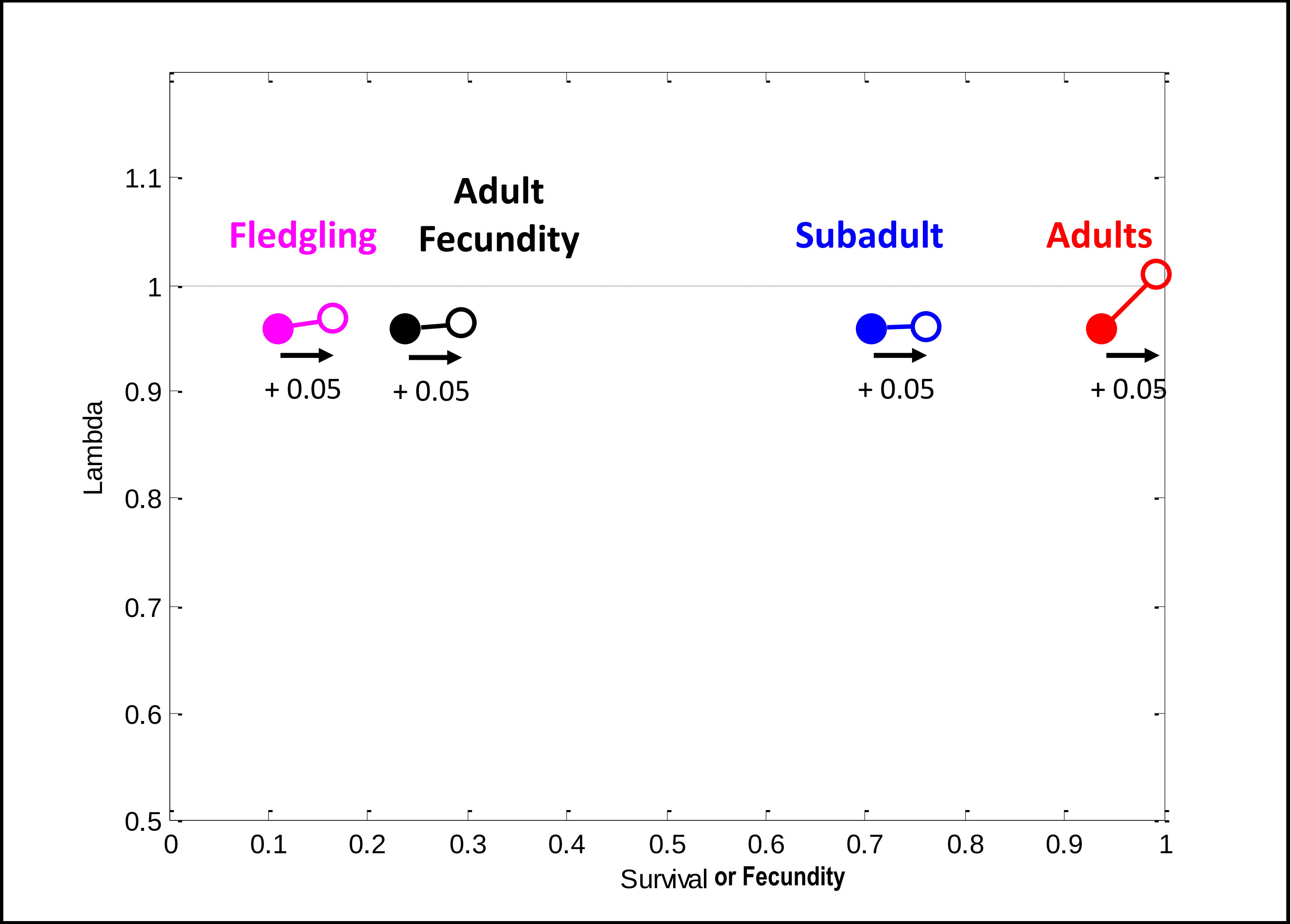
Projection Matrix:

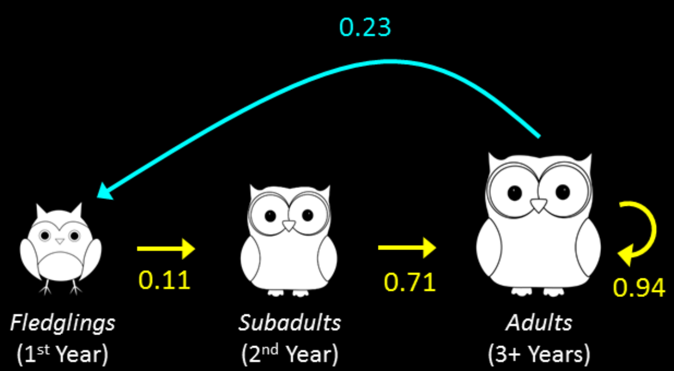
$$
\begin{array}{cc}
 & \underline{\textit{This Year}} \\
 & \begin{array}{ccc} \textbf{Fledgling} & \textbf{Subadult} & \textbf{Adult} \end{array} \\
\underline{\textit{Next Year}} \begin{array}{c} \textbf{Fledgling} \\ \textbf{Subadult} \\ \textbf{Adult} \end{array} & \begin{pmatrix} 0 & 0 & 0.23 \\ 0.11 & 0 & 0 \\ 0 & 0.71 & 0.94 \end{pmatrix}
\end{array}
$$

What if we increase <u>survival</u> by 0.05 for each life stage?
(one at a time, *while holding everything else constant*)



What if we increase <u>fecundity</u> by 0.05?



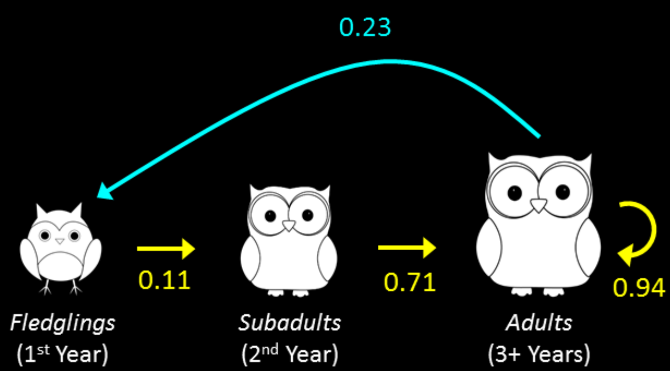


Projection Matrix:

$$
\begin{array}{r c}
 & \begin{array}{ccc} \text{Fledgling} & \text{Subadult} & \text{Adult} \end{array} \\
\begin{array}{r} \text{Fledgling} \\ \text{Subadult} \\ \text{Adult} \end{array} & \begin{pmatrix} 0 & 0 & 0.23 \\ 0.11 & 0 & 0 \\ 0 & 0.71 & 0.94 \end{pmatrix}
\end{array}
$$

Sensitivity Values:

$$
\begin{array}{r c}
 & \begin{array}{ccc} \text{Fledgling} & \text{Subadult} & \text{Adult} \end{array} \\
\begin{array}{r} \text{Fledgling} \\ \text{Subadult} \\ \text{Adult} \end{array} & \begin{pmatrix} & & 0.08 \\ 0.17 & & \\ & 0.03 & 0.96 \end{pmatrix}
\end{array}
$$



Projection Matrix:

	Fledgling	Subadult	Adult
Fledgling	0	0	0.23
Subadult	0.11	0	0
Adult	0	0.71	0.94

Sensitivity Values:

	Fledgling	Subadult	Adult
Fledgling	0.02	0.01	0.08
Subadult	0.17	0.02	0.71
Adult	0.23	0.03	0.96

Sensitivity Values

- Absolute influence of life cycle transition values on λ

$$\frac{Absolute\ change\ in\ \lambda}{Absolute\ change\ in\ Matrix\ Element}$$

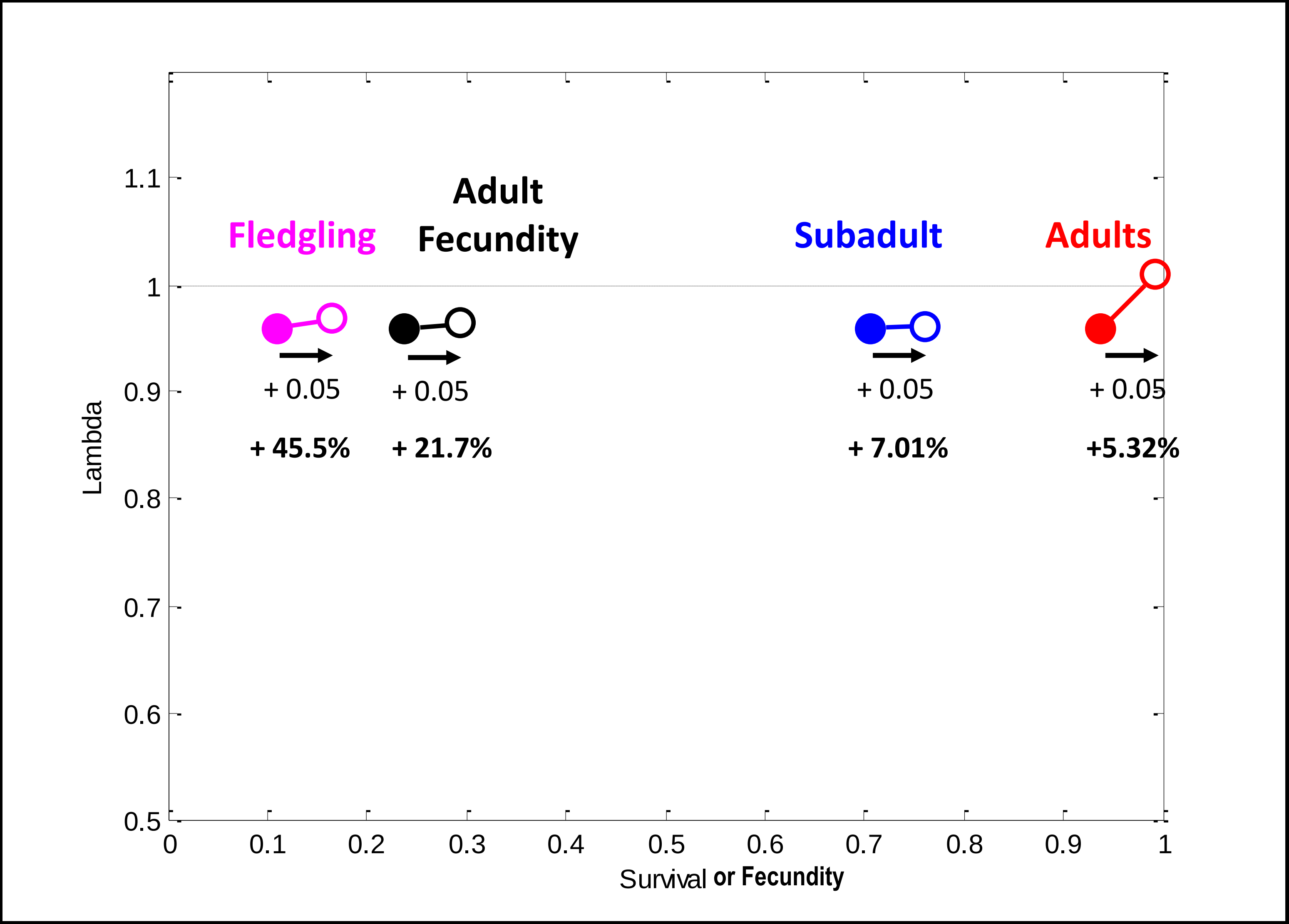
$$Sensitivity = \frac{\lambda_{New} - \lambda_{Orig}}{a_{New} - a_{Orig}} = \frac{\Delta\lambda}{\Delta a}$$

Elasticity Values

- Relative influence of life cycle transition values on λ

$$\frac{Proportional\ change\ in\ \lambda}{Proportional\ change\ in\ Matrix\ Element}$$

What if we increase values on a relative (i.e. percentage) scale?
(one at a time, *while holding everything else constant*)



What if we increase values on a relative (i.e. percentage) scale?
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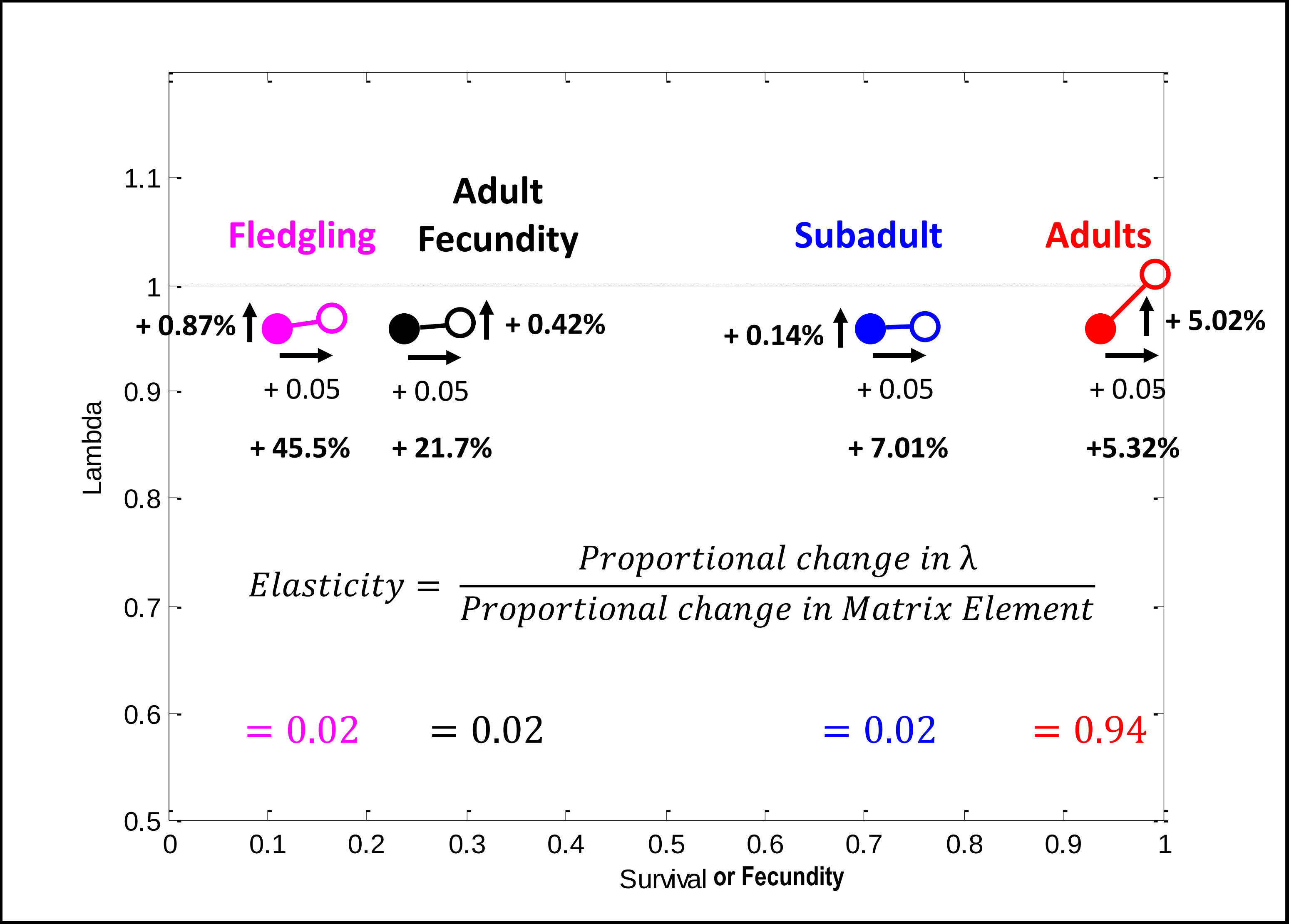


Sensitivity Values

- Absolute influence of life cycle transition values on λ

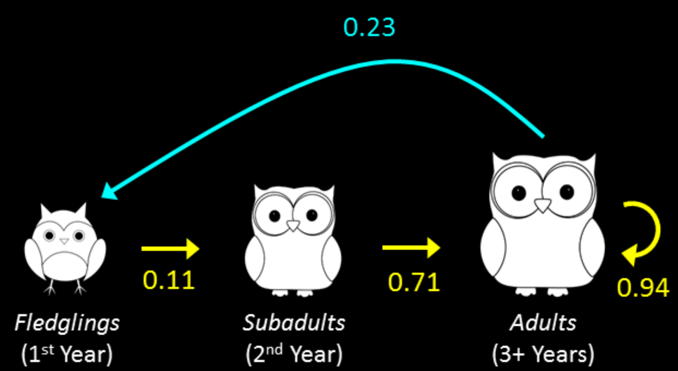
$$Sensitivity = \frac{\lambda_{New} - \lambda_{Orig}}{a_{New} - a_{Orig}} = \frac{\Delta\lambda}{\Delta a}$$

Elasticity Values

- Relative influence of life cycle transition values on λ

$$\frac{Proportional\ change\ in\ \lambda}{Proportional\ change\ in\ Matrix\ Element}$$

$$Elasticity = \frac{\Delta\lambda/\lambda_{Orig}}{\Delta a/a_{Orig}} = \left(\frac{a_{Orig}}{\lambda_{Orig}}\right)\left(\frac{\Delta\lambda}{\Delta a}\right) = \left(\frac{a_{Orig}}{\lambda_{Orig}}\right) \times Sensitivity$$



Projection Matrix:

$$\begin{array}{r c}
 & \begin{array}{ccc} \text{Fledgling} & \text{Subadult} & \text{Adult} \end{array} \\
\begin{array}{r} \text{Fledgling} \\ \text{Subadult} \\ \text{Adult} \end{array} & \begin{pmatrix} 0 & 0 & 0.23 \\ 0.11 & 0 & 0 \\ 0 & 0.71 & 0.94 \end{pmatrix}
\end{array}$$

Elasticity Values:

$$\begin{array}{r c}
 & \begin{array}{ccc} \text{Fledgling} & \text{Subadult} & \text{Adult} \end{array} \\
\begin{array}{r} \text{Fledgling} \\ \text{Subadult} \\ \text{Adult} \end{array} & \begin{pmatrix} 0 & 0 & 0.02 \\ 0.02 & 0 & 0 \\ 0 & 0.02 & 0.94 \end{pmatrix}
\end{array}$$

Reading for Monday (Reading Response Due)

Conservation Biology

Editorial

The "New Conservation"

A powerful but chimeric movement is rapidly gaining recognition and supporters. Christened the "new conservation," it promotes economic development, poverty alleviation, and corporate partnerships as surrogates or substitutes for endangered species listings, protected areas, and other mainstream conservation tools. Its proponents claim that helping economically disadvantaged people to achieve a higher standard of living will kindle their sympathy and affection for nature. Because its goal is to supplant the biological diversity–based model of traditional conservation with something entirely dif-

the characters of older conservation icons, such as Henry David Thoreau, John Muir, and Edward Abbey, are defamed as hypocrites and misanthropes and contemporary conservation leaders and writers are ignored entirely (Lalasz et al. 2011).

The new conservationists assume biological diversity conservation is out of touch with the economic realities of ordinary people, even though this is manifestly false. Since its inception, the Society for Conservation Biology has included scores of progressive social scientists among its editors and authors (see also letters in BioScience,

Soulé (2013)

Conservation Biology

Editorial

New Conservation Is True Conservation

As conservation scientists, we all work to stem the tide of extinction and to protect abundant areas of natural beauty, both for people and the many species that share this planet. But Soule (2013) describes some of the work of my colleagues and I as belonging to a "chimeric movement" that "does not deserve to be labeled conservation." Attempts to marginalize a group of dedicated individuals and discredit new approaches to conservation are troubling, especially within a movement that appears to be

demic first became apparent. Certainly, hospital beds were needed, but they were not sufficient. Instead, governments around the world turned to university and industry research laboratories for game-changing solutions based on understanding of the causative virus and designing one antiviral agent after another. Analogously, conservation absolutely needs protected areas, but it also needs new solutions that tackle the systemic root causes of planetary degradation. In light of this, my colleagues

Marvier (2013)

Timeline

Monday, April 1

- Choose **3** species that interest you from:
  - https://wellesley.shinyapps.io/matrix-data
- These species are included in the COMPADRE and COMADRE databases of plant and animal population matrix model data: http://www.compadre-db.org
- You must include at least one plant or animal.
- It's best to choose species that have multiple years, populations, and/or treatments.
- Submit your species via the form: https://forms.gle/xRJEYNhyxrV3uGn56

Wednesday, April 3

- I will briefly meet with you during lab to help narrow in on your species and help you locate the publication that the dataset comes from.

Monday, April 8

- Turn in a one page "proposal" that includes preliminary research (at least two identified sources) and **clearly specifies your main questions to address**.
- You must include a brief rationale for why you are addressing these questions and how they will help inform the management of this species.

Wednesday, April 10

- We will be smelting copper in lab, but there will be time for me to talk with you about your ideas and give feedback on your proposal.

First North Atlantic right whale mother and calf of season observed near Cape Cod Bay

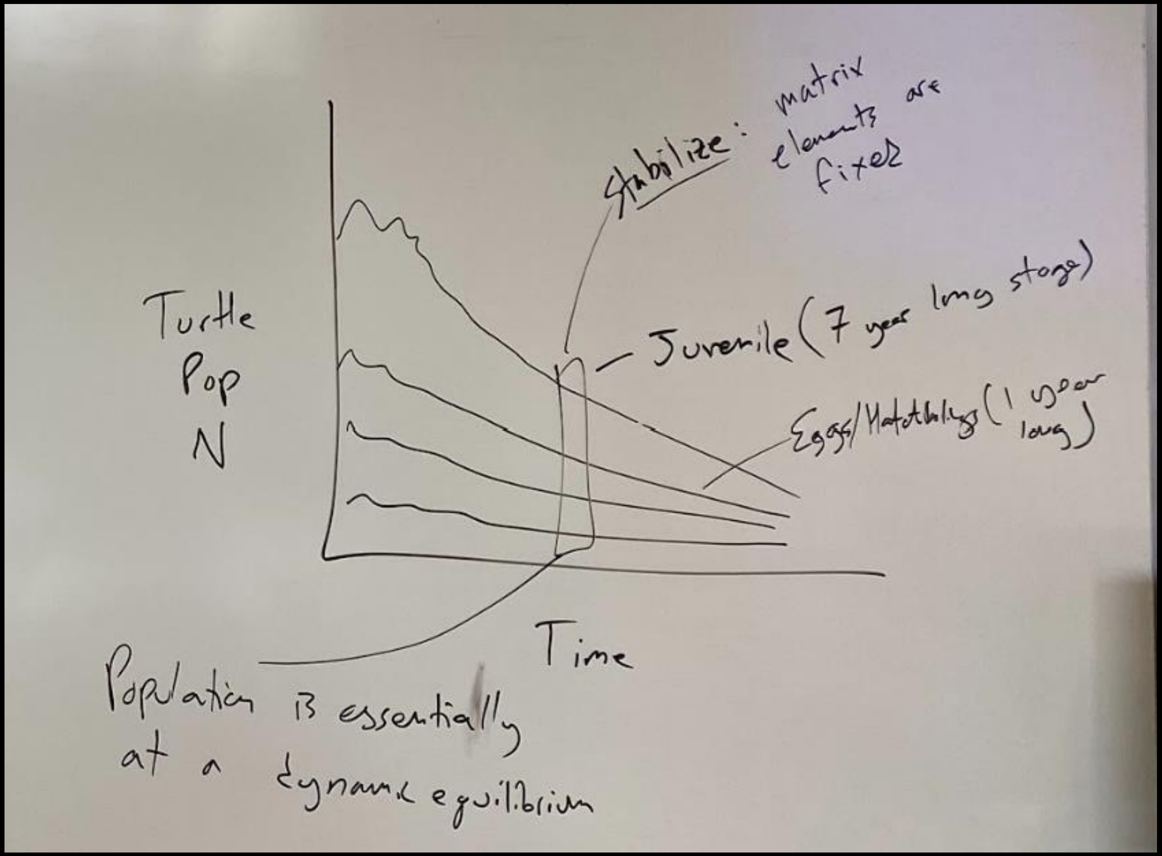
Apr 2, 2024 | PRESS

Aerial observers from the Center for Coastal Studies spotted a North Atlantic right whale mother with her calf just north of Marshfield yesterday. This is the first such sighting of a right whale calf in Massachusetts waters in the 2024 season.

The right whale mother was identified as Legato (EgNo 1802). Legato is 36 years old and the daughter of Staccato (EgNo 1014). Legato gave birth to her calf in December, and the two whales were first sighted together by Florida's Fish and Wildlife Research Institute on New Year's Eve.

North Atlantic Right Whale Calving Season 2024 | NOAA Fisheries

What's up with the "wiggles" that smooth out during matrix model projections?



Conservation Biology

Contributed Paper

Interactive Effects of Harvest and Deer Herbivory on the Population Dynamics of American Ginseng

SUSAN J. FARRINGTON,*§ ROSE-MARIE MUZIKA,* DAN DREES,†
AND TIFFANY M. KNIGHT‡

*Department of Forestry, University of Missouri-Columbia, Columbia, MO 65211, U.S.A.
†Missouri Department of Conservation, HC 1 Box 177K, Eminence, MO 65466, U.S.A.
‡Department of Biology, Washington University in St. Louis, Box 1229, St. Louis, MO 63130, U.S.A.

Interactive Effect:

The effect one one variable depends on another

https://www.youtube.com/watch?v=I3ej7VQy1EM

Ginseng Regulations

Ginseng is a legally protected plant in North Carolina and is subject to certain regulations.

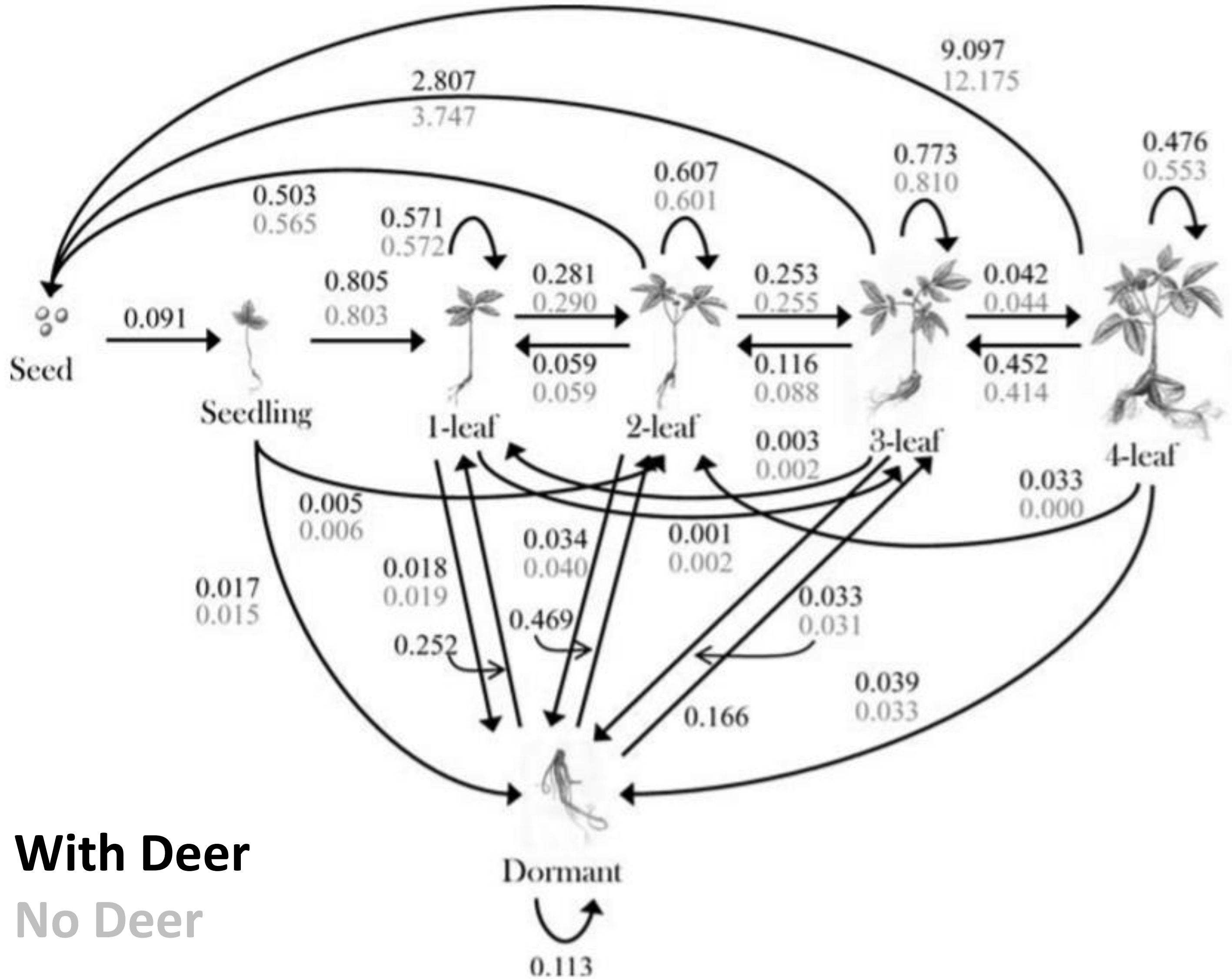
- Wild ginseng collection in the state is prohibited from Jan. 1 through Aug. 31. This allows the plants to set seed. During the harvest season Sept. 1-Dec. 31, collectors should replant any ginseng seeds from collected plants in the place where the roots are dug. It is unlawful to possess ginseng roots and ginseng berries(seeds) simultaneously.

- To collect ginseng from another's land the collector must have written permission from the landowner, signed, dated and valid for no more than 180 days. The document must be on the collector's person when digging ginseng on that land. This requirement applies to both public and private lands. In National Forests, district offices are responsible for such permits. State and national parks, including the Blue Ridge Parkway and the Great Smoky Mountains National Park, state forests and state game lands do not allow ginseng collection.

- No state permit is needed to dig ginseng on private property, only the landowner's written permission. The season of Sept. 1 - Dec. 31 applies to private and public lands.

- Taking ginseng from another's land with intent to steal (without written permission) is a felony.

- Diggers should collect only 3-prong plants or larger. Only roots 5 years old or older can be sold. Plants with three prongs are usually at least 5 years old; 1- or 2-prong plants are too young and should not be dug. This applies to wild and "wild-simulated" ginseng. Diggers need to check about current restrictions each season before digging wild roots, as rules may change.



With Deer

No Deer

Role of Deer and Humans

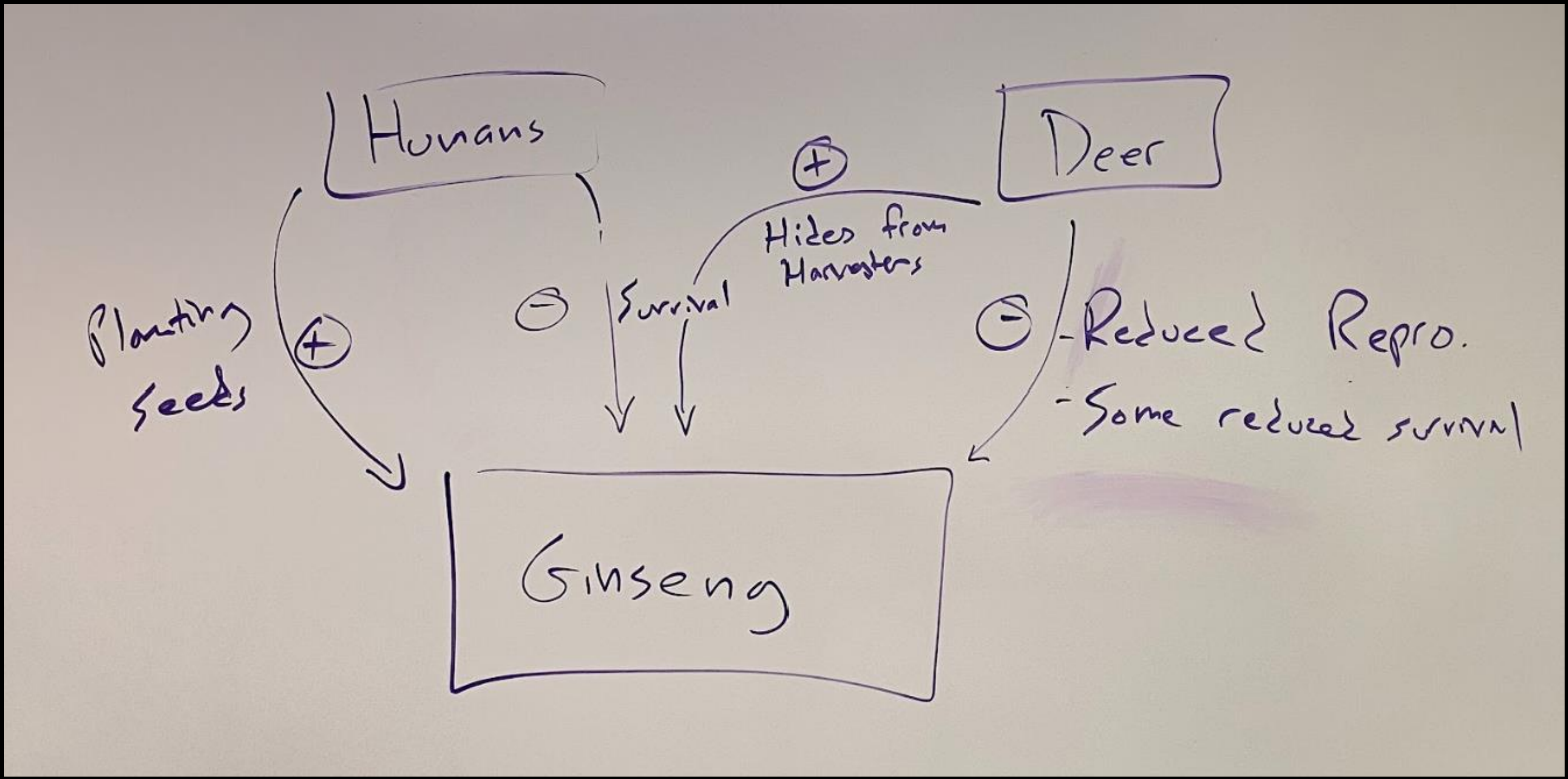


Table 1. Matrix calculations for the harvested populations of ginseng in the presence of ambient levels of deer browse (values are averages across years).

Time t+1	*Time* t							
	seed (natural)[a]	*seed (planted)*[b]	*seedling*	*1 leaf*	*2 leaves*	*3 leaves*[c]	*4 leaves*[c]	*dormant*
Seed (natural)	0	0	0	0	0.5033	$(1\text{-}b_3)*f_3*n$	$(1\text{-}b_4)*f_4*n$	0
Seed (planted)	0	0	0	0	0	$(1\text{-}b_3)*f_3*s$	$(1\text{-}b_4)*f_4*s$	0
Seedling	0.091	0.745	0	0	0	0	0	0
1 leaf	0	0	0.8031	0.5708	0.0580	b_3*p_i	0	0.2458
2 leaves	0	0	0.0049	0.2813	0.6081	b_3*p_r	0	0.4667
3 leaves	0	0	0	0.0014	0.2520	b_3*p_s	b_4*t_r	0.1632
4 leaves	0	0	0	0	0	b_3*p_a	b_4*t_s	0
Dormant	0	0	0.0175	0.0175	0.0376	b_3*p_d	b_4*t_d	0.1243

b_i = probability of being browsed by deer

f_i = # seeds produced

n = fraction of seeds that fall naturally (before harvest)

s = fraction of seeds planted by harvester

p_i, t_i, = survival and growth

Table 2. Matrix calculations for the harvested populations of ginseng in the absence of deer browse (values are averages across years).

Time t+1	*Time* t							
	seed (natural)[a]	*seed (planted)*[b]	*seedling*	*1 leaf*	*2 leaves*	*3 leaves*[c]	*4 leaves*[c]	*dormant*
Seed (natural)	0	0	0	0	0.5652	f_3*n	f_4*n	0
Seed (planted)	0	0	0	0	0	f_3*s	f_4*s	0
seedling	0.091	0.745	0	0	0	0	0	0
1 leaf	0	0	0.8026	0.5723	0.0586	0	0	0.2458
2 leaves	0	0	0.0056	0.2897	0.6014	0	0	0.4667
3 leaves	0	0	0	0.0017	0.2546	0	0	0.1632
4 leaves	0	0	0	0	0	0	0	0
Dormant	0	0	0.0152	0.0186	0.0400	0	0	0.1243

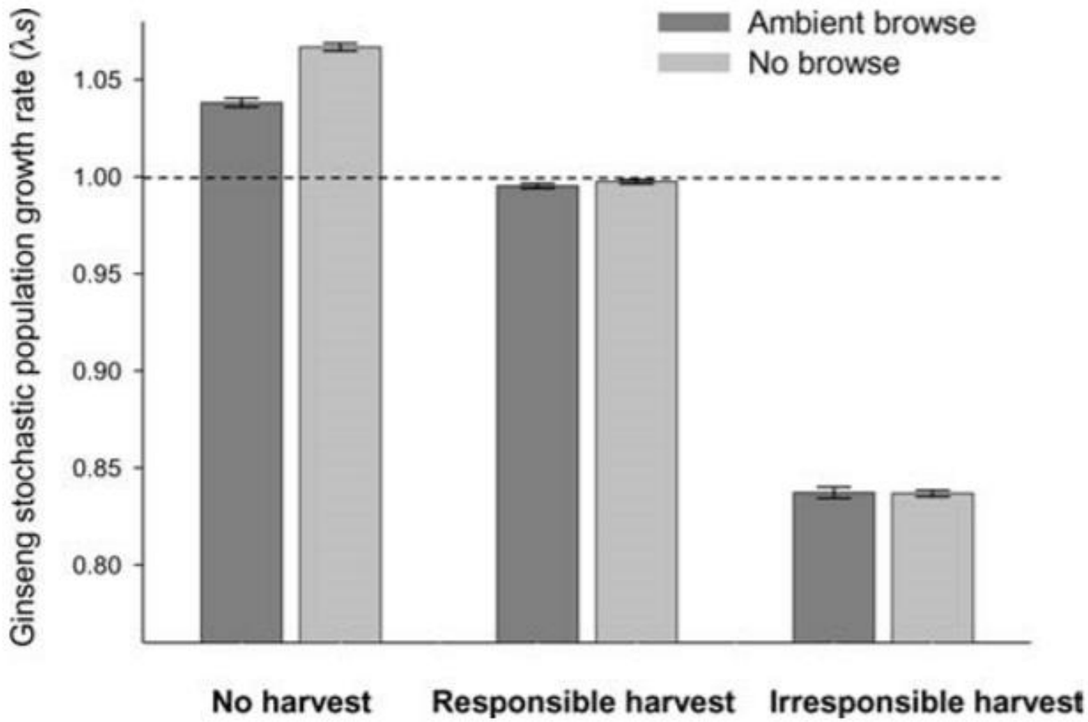
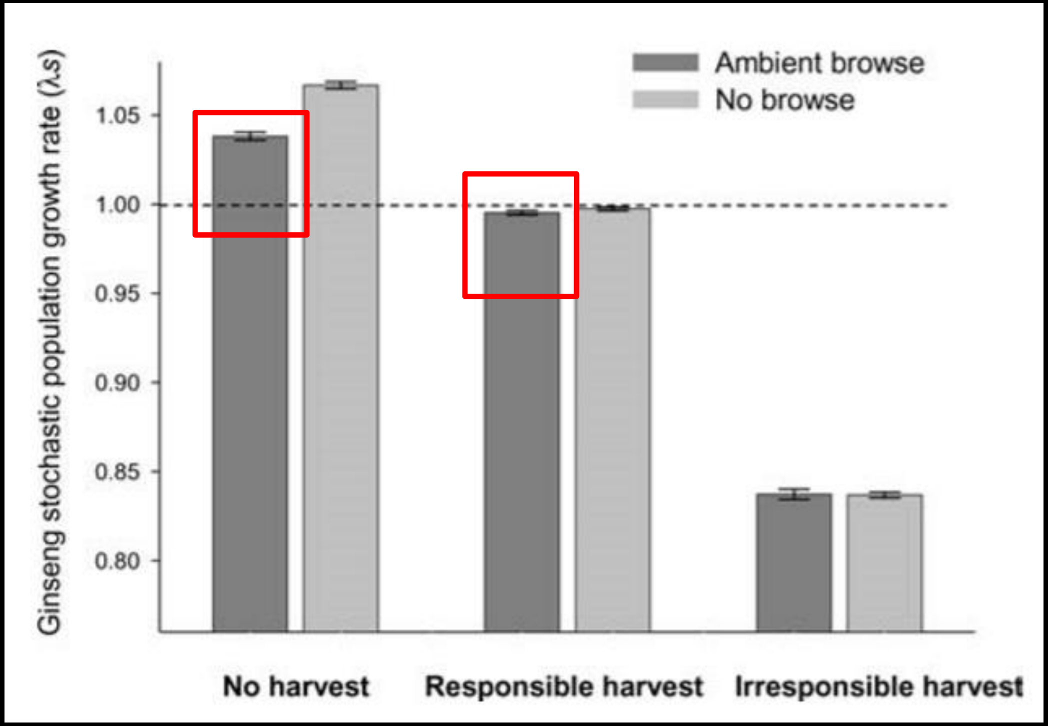
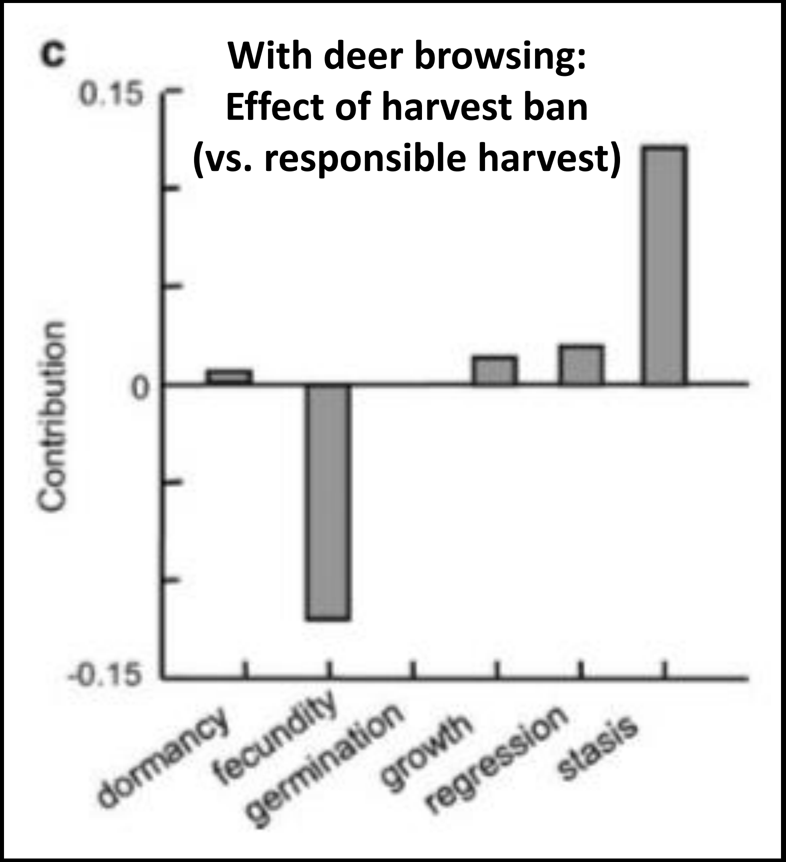


Figure 2. Stochastic population growth rate (and 95% CIs from 50,000 estimates) of 6 pooled populations of American ginseng under 6 conditions in which harvest and herbivory varied. When $\lambda_s > 1$, the populations are projected to grow.

LTRE: *Life Table Response Experiment*

How did differences in vital rates contribute to differences in λ ?

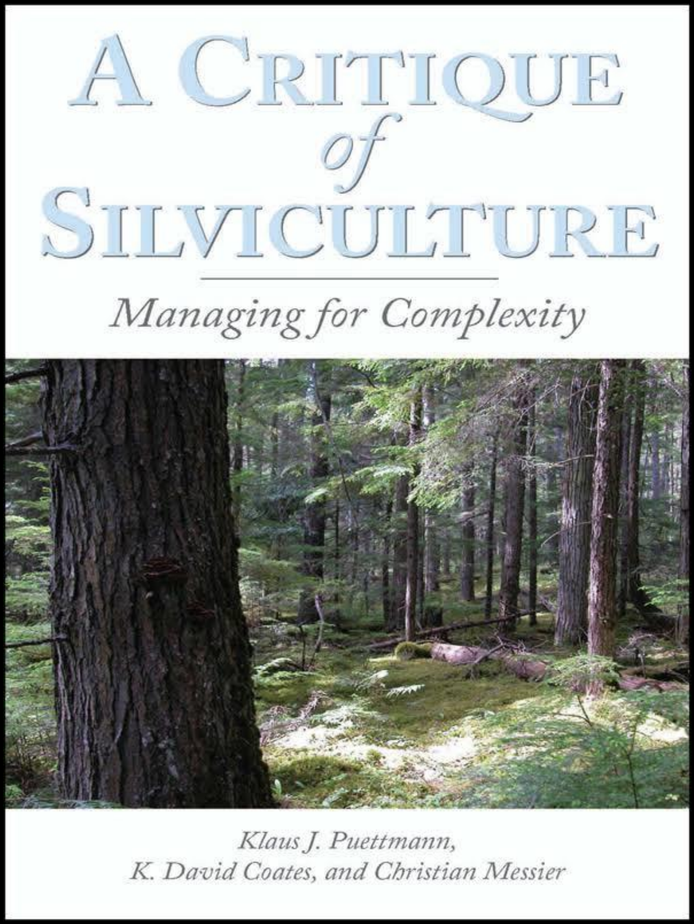




A harvest ban (with deer browsing):

- Increases survival (better to be eaten than to be harvested)
- Decreases fecundity (because plants are eaten)

Reading for NEXT Thursday (no class on Thursday or Monday)



Chapter 1

- Consider the motivations behind forestry / silviculture
- What are different possible goals / outcomes that influence management?

Lab this Week: Copper Smelting in the Botanic Gardens!

- Meet in the classroom as usual
- Dress for a chilly morning (mid 40s but warming to 60)
  - You will likely smell a bit like a campfire afterwards
- I'll be able to spend some time discussing your species and project ideas
- Feel free to bring anything you might want to have at a picnic: fold up chair, blanket, etc.

Key Tools:

- Population Viability (projections)
  - Deterministic
  - ☆ Stochastic
- Scenario Testing
  - Perturbation analysis: general "what if?"
  - Management scenarios: specific "what if?"
- Management Targets
  - Required survival rates?

Conservation Biology

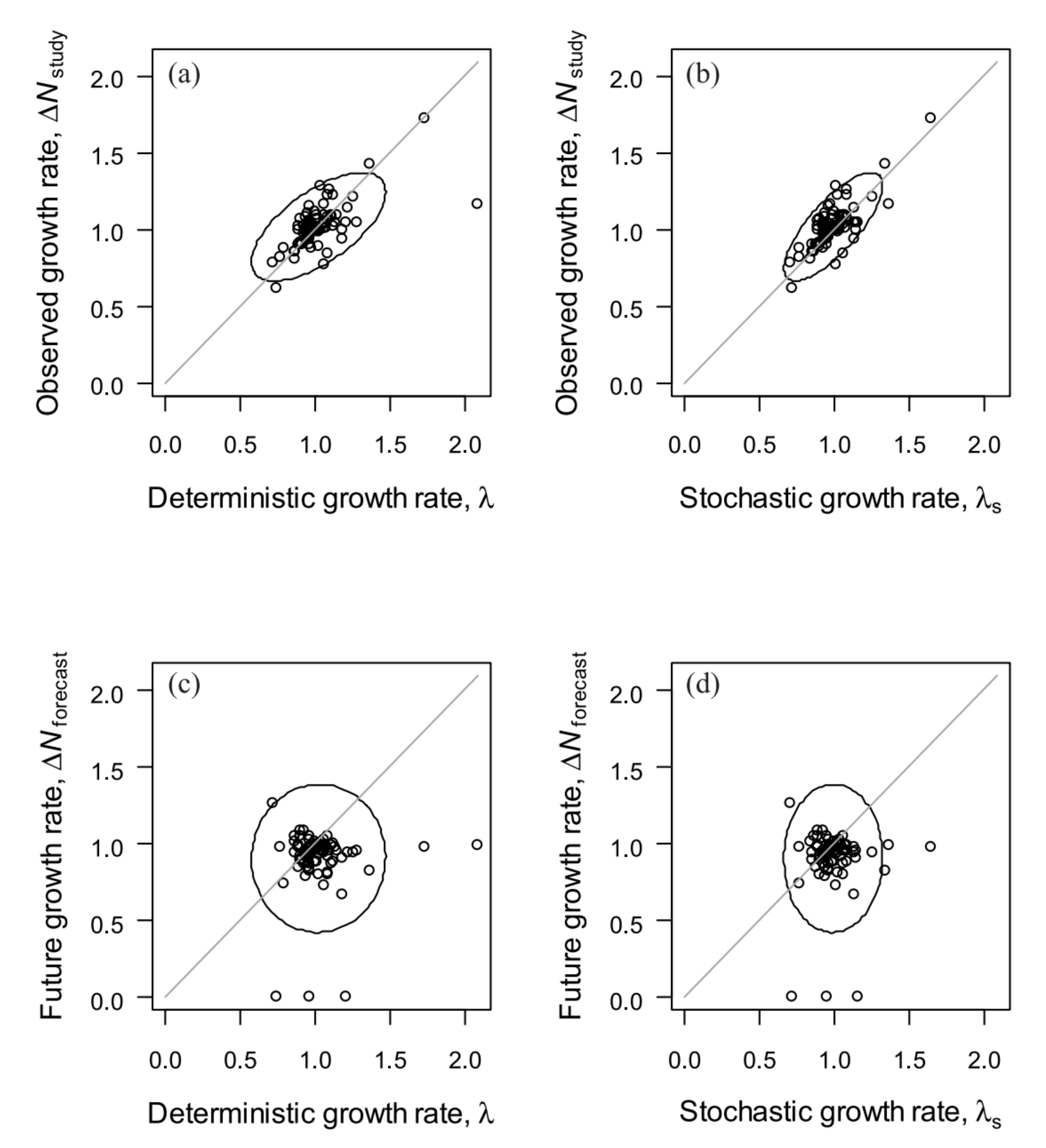
Contributed Paper

Ability of Matrix Models to Explain the Past and Predict the Future of Plant Populations

ELIZABETH E. CRONE,[*] MARTHA M. ELLIS,[†] WILLIAM F. MORRIS,[‡] AMANDA STANLEY,[§] TIMOTHY BELL,[**] PAULETTE BIERZYCHUDEK,[††] JOHAN EHRLÉN,[‡‡] THOMAS N. KAYE,[§] TIFFANY M. KNIGHT,[§§] PETER LESICA,[***] GERARD OOSTERMEIJER,[†††] PEDRO F. QUINTANA-ASCENCIO,[‡‡‡] TAMARA TICKTIN,[§§§] TERESA VALVERDE,[****] JENNIFER L. WILLIAMS,[††††] DANIEL F. DOAK,[‡‡‡‡] RENGAIAN GANESAN,[§§§§] KATHYRN MCEACHERN,[*****] ANDREA S. THORPE,[§] AND ERIC S. MENGES[†††††]

- 82 populations of 20 plant species
- Population models successfully predict population growth rates (λ) during study period
- Models fail to predict future growth rates (5+ years after study)

(Crone et al. 2013)



ECOLOGY LETTERS

Ecology Letters, (2015) **18**: 303–314 doi: 10.1111/ele.12410

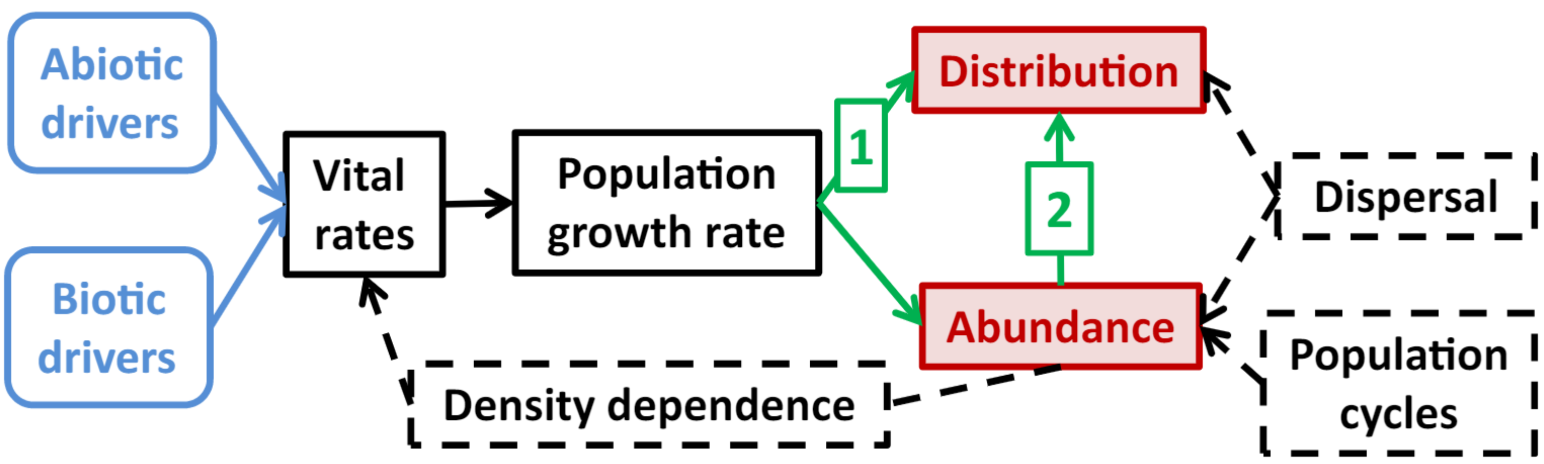
REVIEW AND SYNTHESIS

Predicting changes in the distribution and abundance of species under environmental change

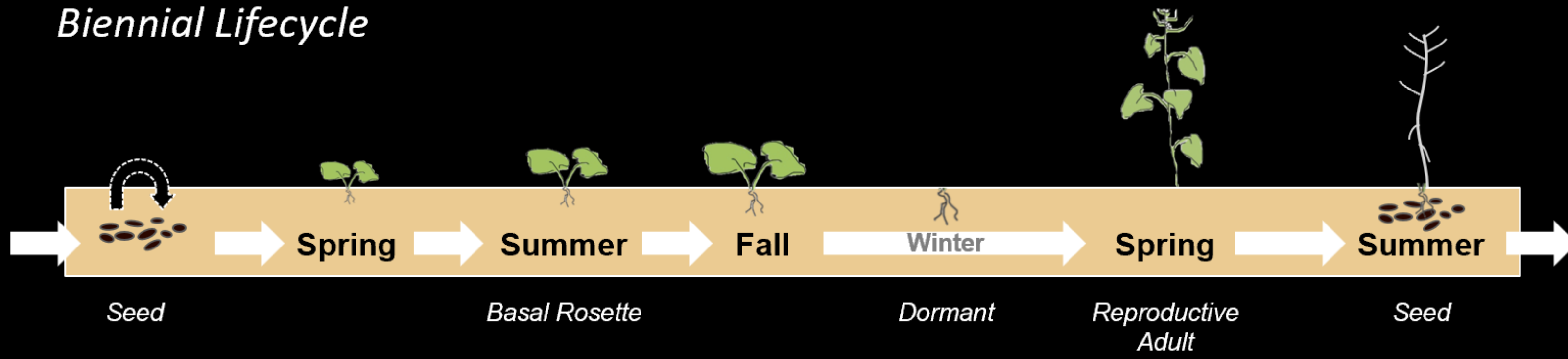
Johan Ehrlén[1,†] and
William F. Morris[2,3,†*]

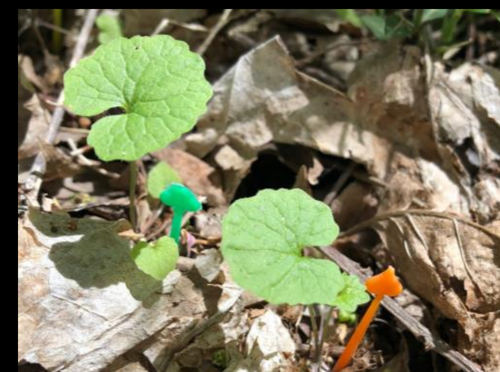
Abstract

Environmental changes are expected to alter both the distribution and the abundance of organisms. A disproportionate amount of past work has focused on distribution only, either documenting historical range shifts or predicting future occurrence patterns. However, simultaneous

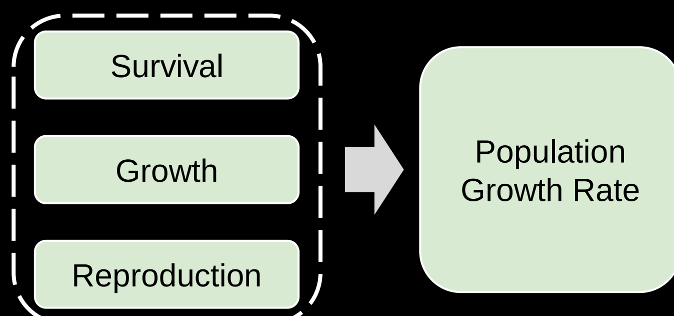


Biennial Lifecycle



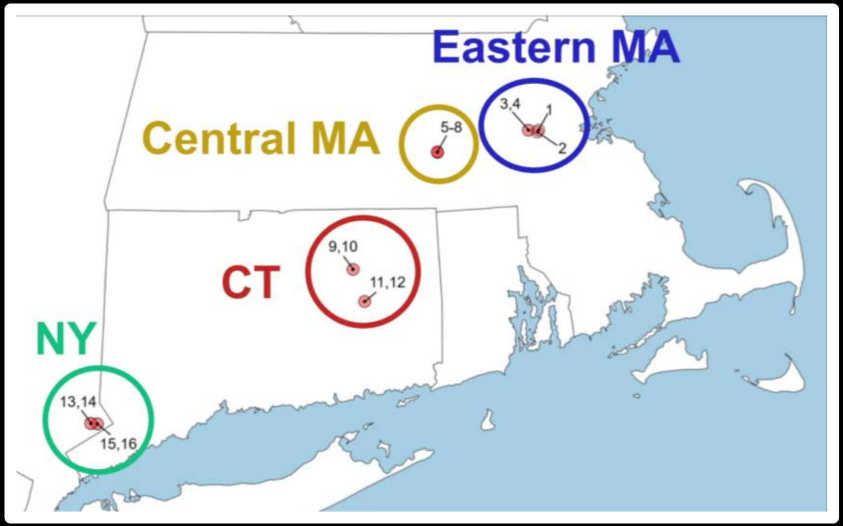


Demography



Demographic Variables

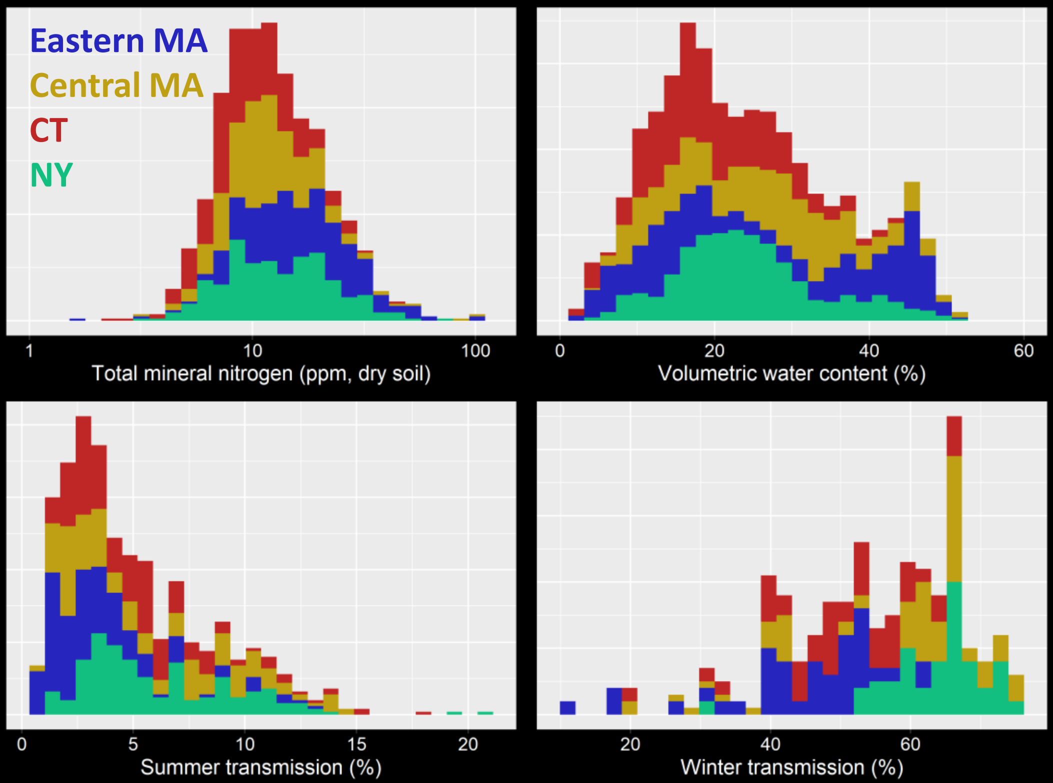
- Establishment
- Survival
- Size (biomass ~ leaf #, leaf length)
- Fruit Production
- 4,515 total individuals



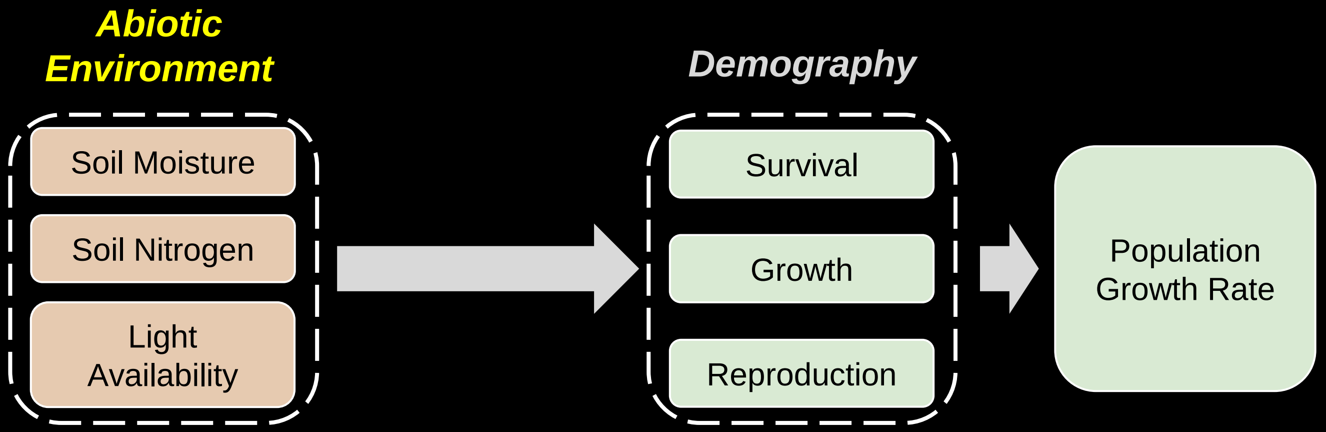
4 Regions

4 Sampling Sites (16 Total)

10 Plots (160 Total)



Eastern MA
Central MA
CT
NY
1
10
100
Total mineral nitrogen (ppm, dry soil)
0
20
40
60
Volumetric water content (%)
0
5
10
15
20
Summer transmission (%)
20
40
60
Winter transmission (%)

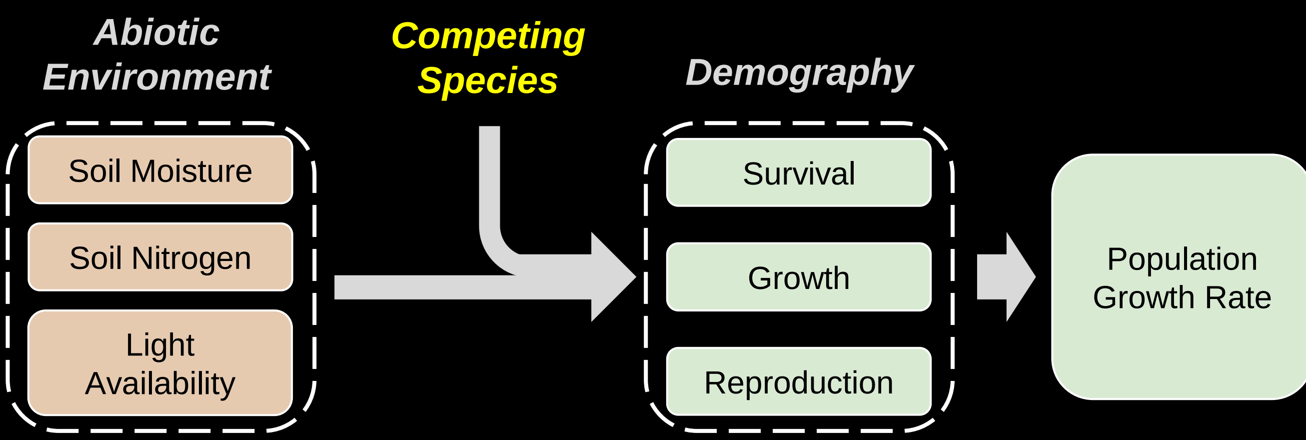


Abiotic Environment
Soil Moisture
Soil Nitrogen
Light Availability
Demography
Survival
Growth
Reproduction
Population Growth Rate

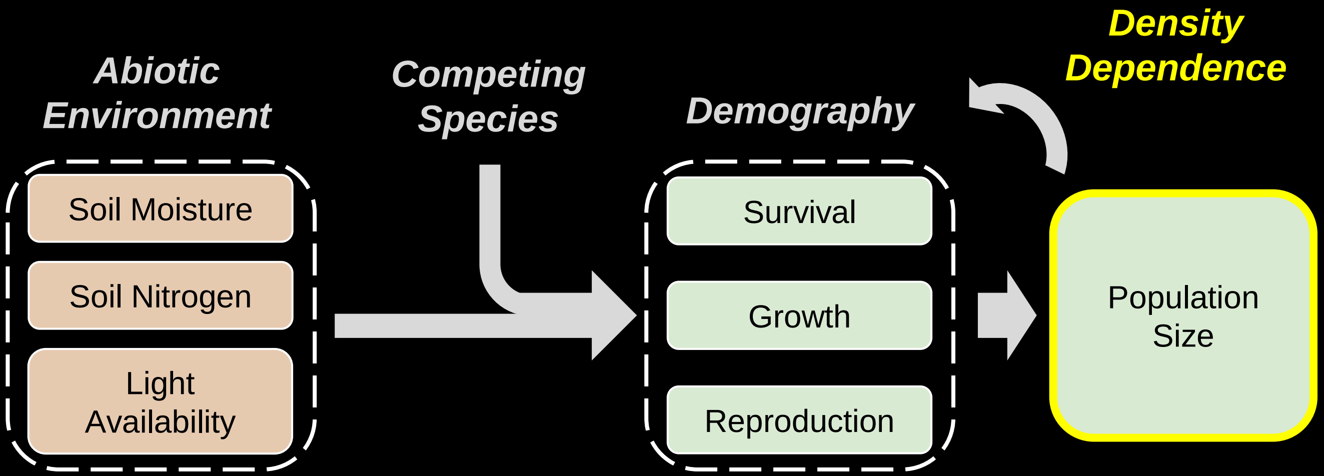
Manual clipping of understory competitors

With Competition

Without Competition

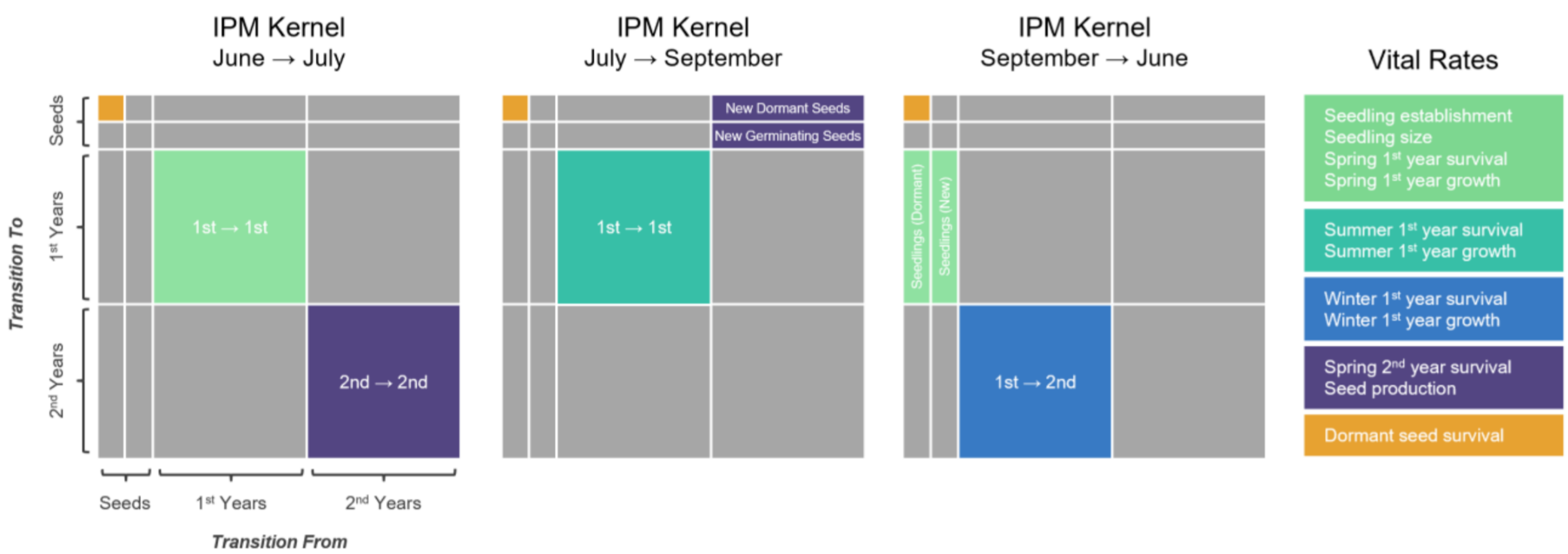


Competition ***within*** garlic mustard



Integral Projection Model (IPM)

- Essentially high-resolution matrix models where stage classes span a continuous range of plant sizes



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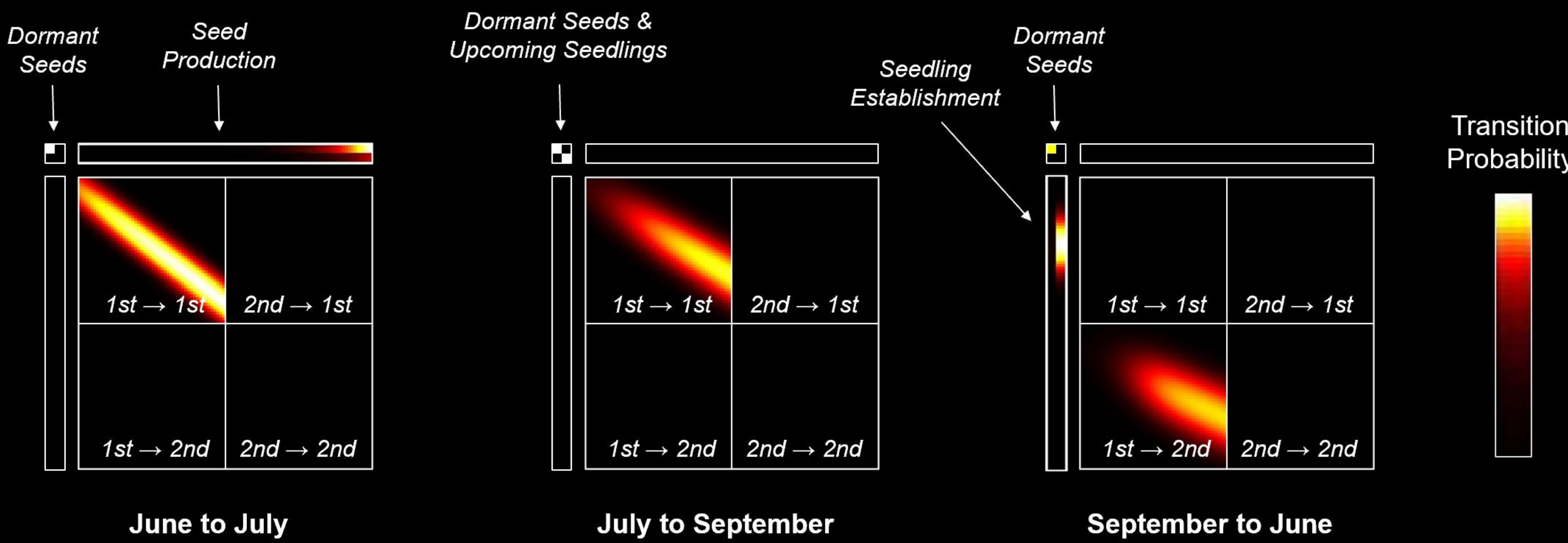
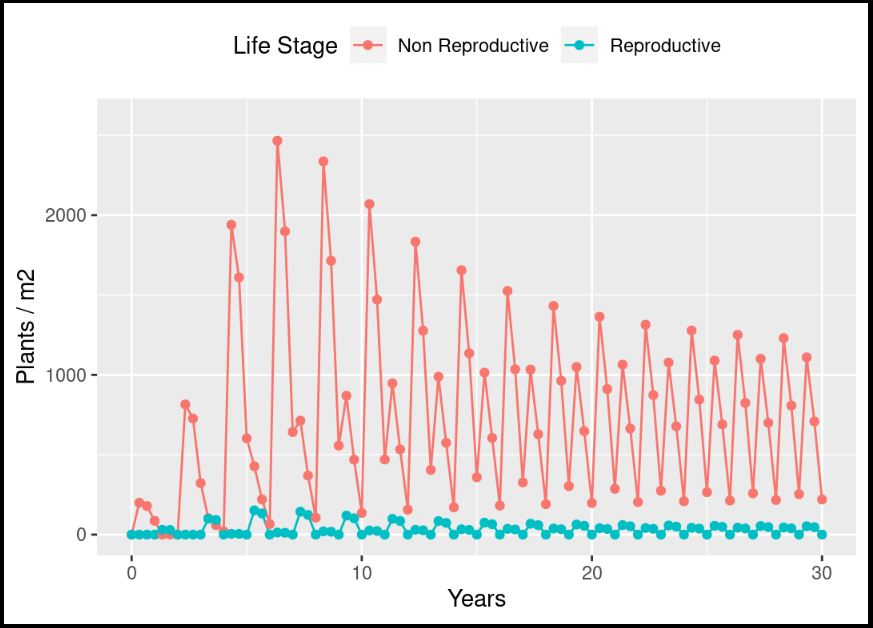


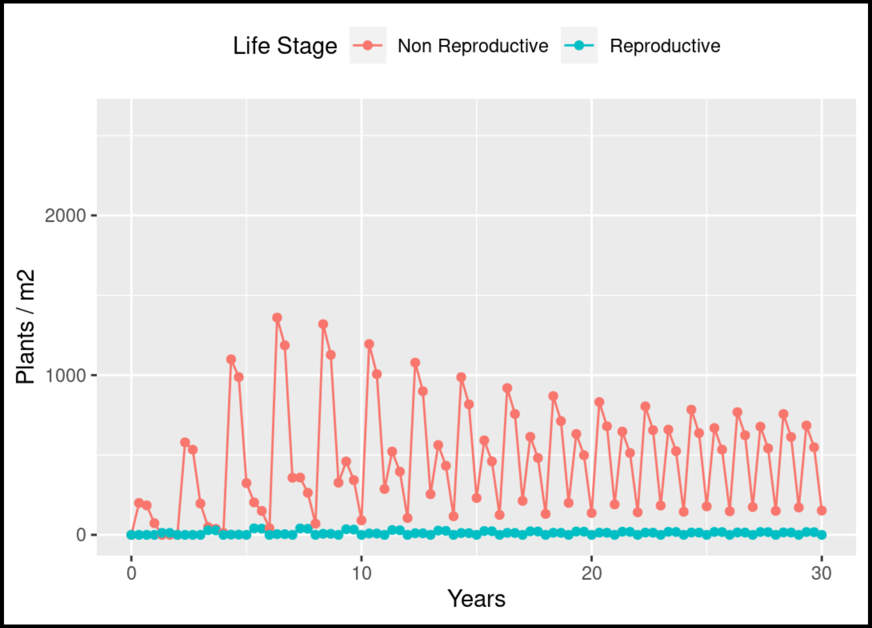
(Note these images are from an older version of the model and don't fully align with the previous slide)

Model Projections (in the presence of other species)

Average Light

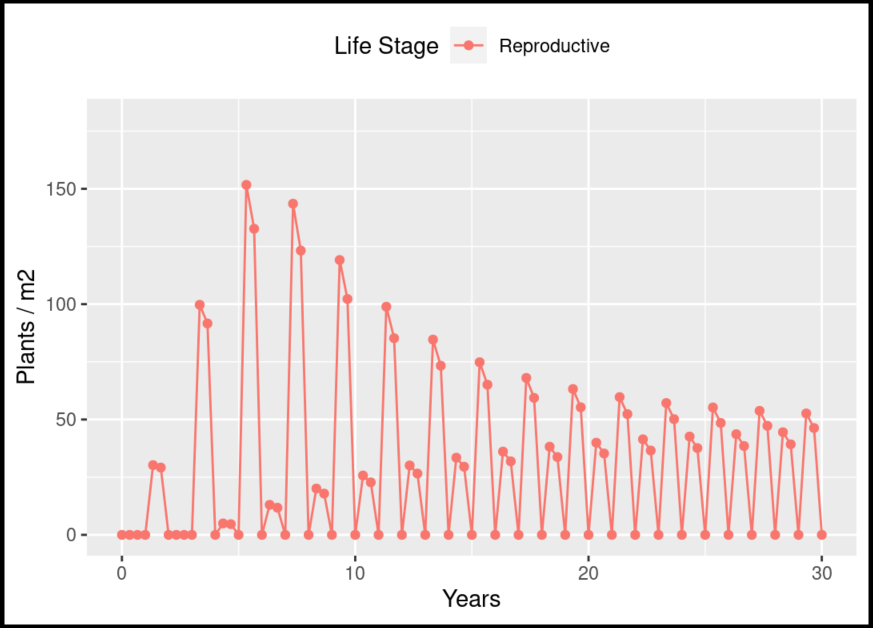


Low Light (-1.5 SD)

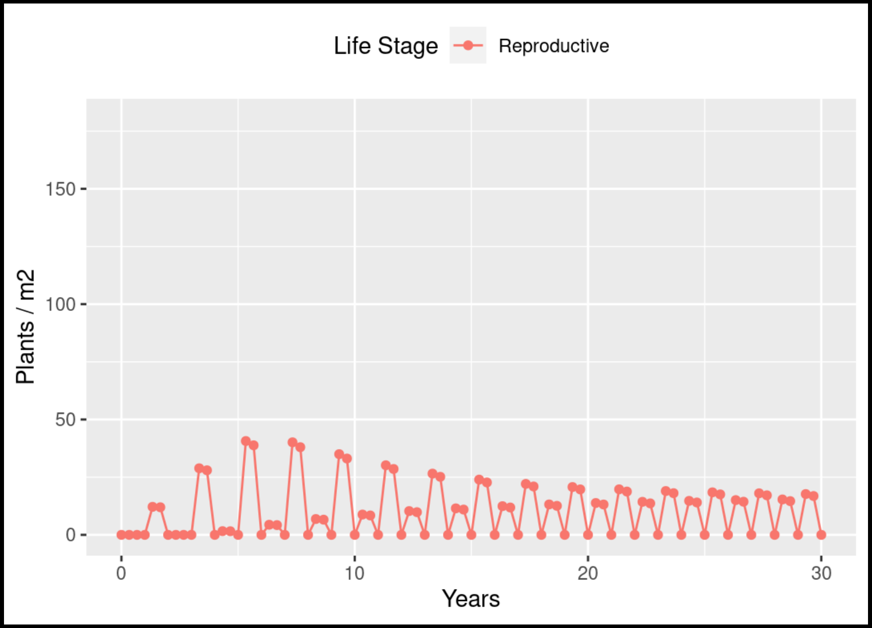


Model Projections (in the presence of other species)

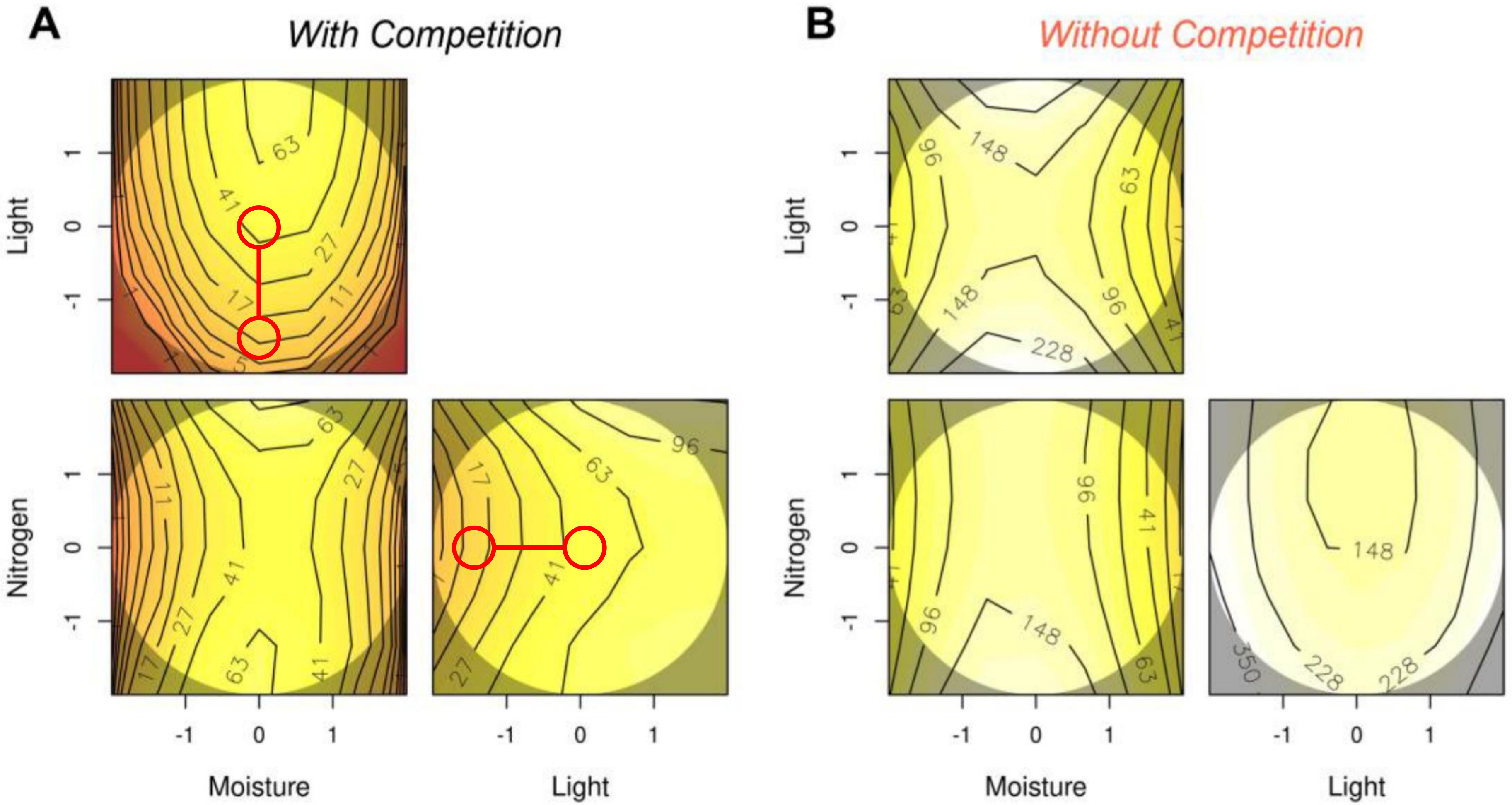
Average Light



Low Light (-1.5 SD)



Contour lines represent the density of reproductive plants



Conservation Biology

Editorial

The "New Conservation"

A powerful but chimeric movement is rapidly gaining recognition and supporters. Christened the "new conservation," it promotes economic development, poverty alleviation, and corporate partnerships as surrogates or substitutes for endangered species listings, protected areas, and other mainstream conservation tools. Its proponents claim that helping economically disadvantaged people to achieve a higher standard of living will kindle their sympathy and affection for nature. Because its goal is to supplant the biological diversity–based model of traditional conservation with something entirely dif-

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Conservation Biology

Editorial

New Conservation Is True Conservation

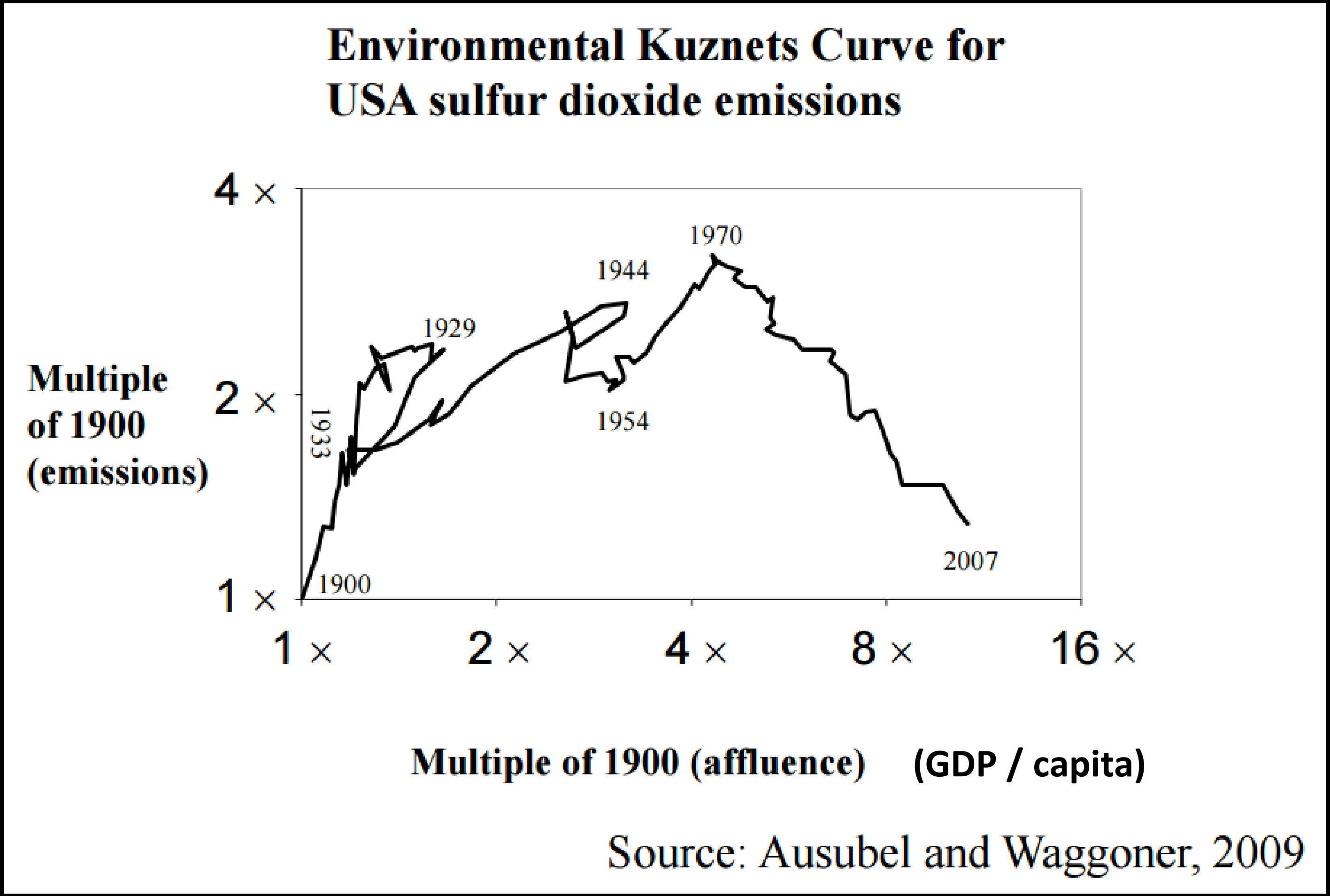
As conservation scientists, we all work to stem the tide of extinction and to protect abundant areas of natural beauty, both for people and the many species that share this planet. But Soule (2013) describes some of the work of my colleagues and I as belonging to a "chimeric movement" that "does not deserve to be labeled conservation." Attempts to marginalize a group of dedicated individuals and discredit new approaches to conservation are troubling, especially within a movement that appears to be suffering waning support. Public opinion surveys show

demic first became apparent. Certainly, hospital beds were needed, but they were not sufficient. Instead, governments around the world turned to university and industry research laboratories for game-changing solutions based on understanding of the causative virus and designing one antiviral agent after another. Analogously, conservation absolutely needs protected areas, but it also needs new solutions that tackle the systemic root causes of planetary degradation. In light of this, my colleagues and I advocate that conservation must expand its toolbox

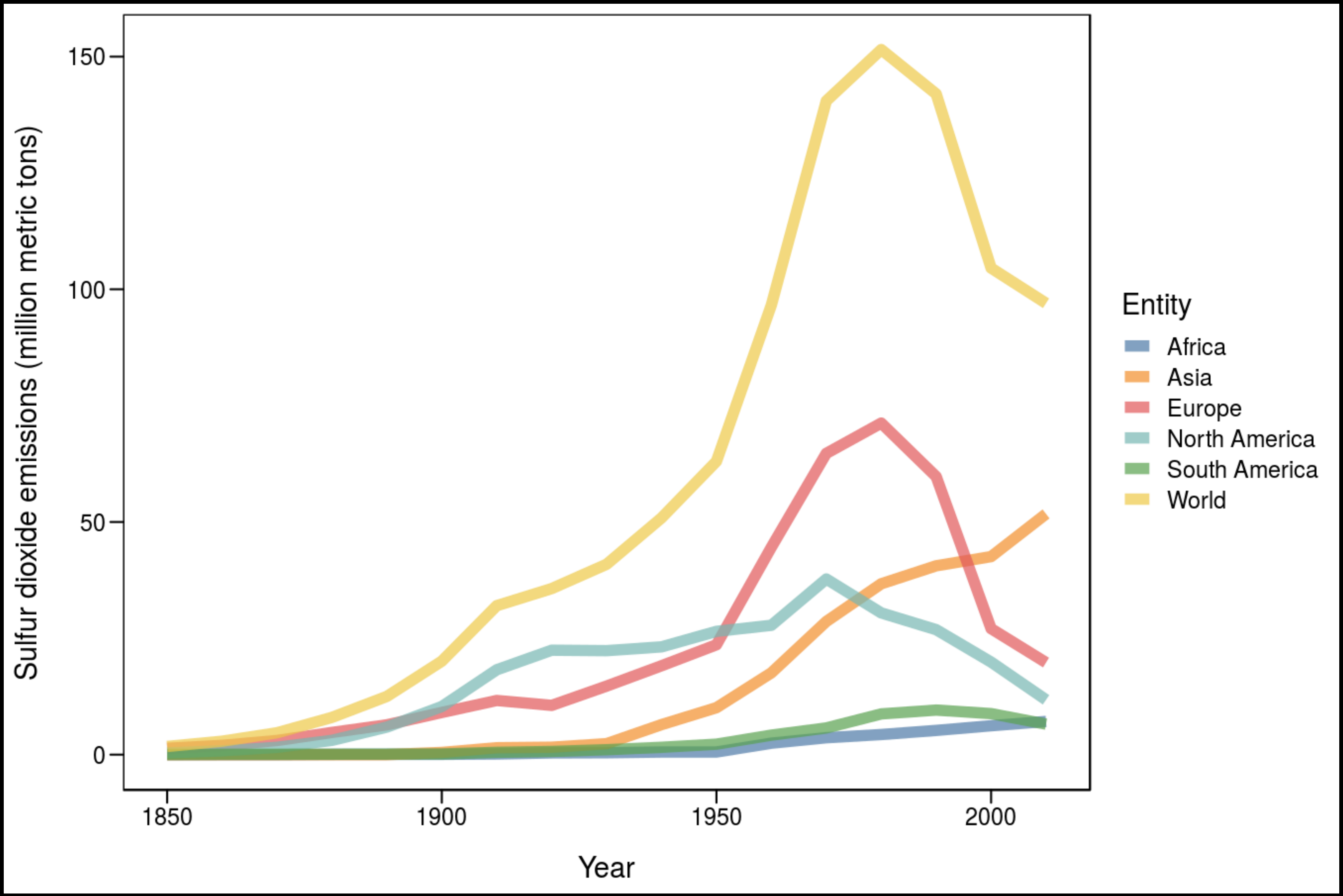
Soulé:

The key assertion of the new conservation is that affection for nature will grow in step with income growth. The problem is that evidence for this theory is lacking. In fact, the evidence points in the opposite direction, in part because increasing incomes affect growth in per capita ecological footprint (Soulé 1995; Oates 1999).

Environmental Kuznets Curve



Environmental Kuznets Curve



Environmental Kuznets Curve for <u>Conservation / Biodiversity</u>?

???

“Affluence”

Ecological Economics 68 (2009) 2087–2095

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Economic prosperity, biodiversity conservation, and the environmental Kuznets curve

Julianne H. Mills *, Thomas A. Waite

Department of Evolution, Ecology and Organismal Biology, Ohio State University, 300 Aronoff Laboratory, 318 W. 12th Ave., Columbus, OH, 43210, USA

variables eliminated or even reversed much of this support. A closer examination of conservation practices and environmental indicators within the countries, particularly those countries that drove our initial support, suggests that wealth is not a reliable indicator of improved conservation practice. Our findings indicate that an EKC for biodiversity is overly simplistic and further exploration is required to fully understand the mechanisms by which income affects biodiversity.

For Monday 4/22 (Reading Response Due)

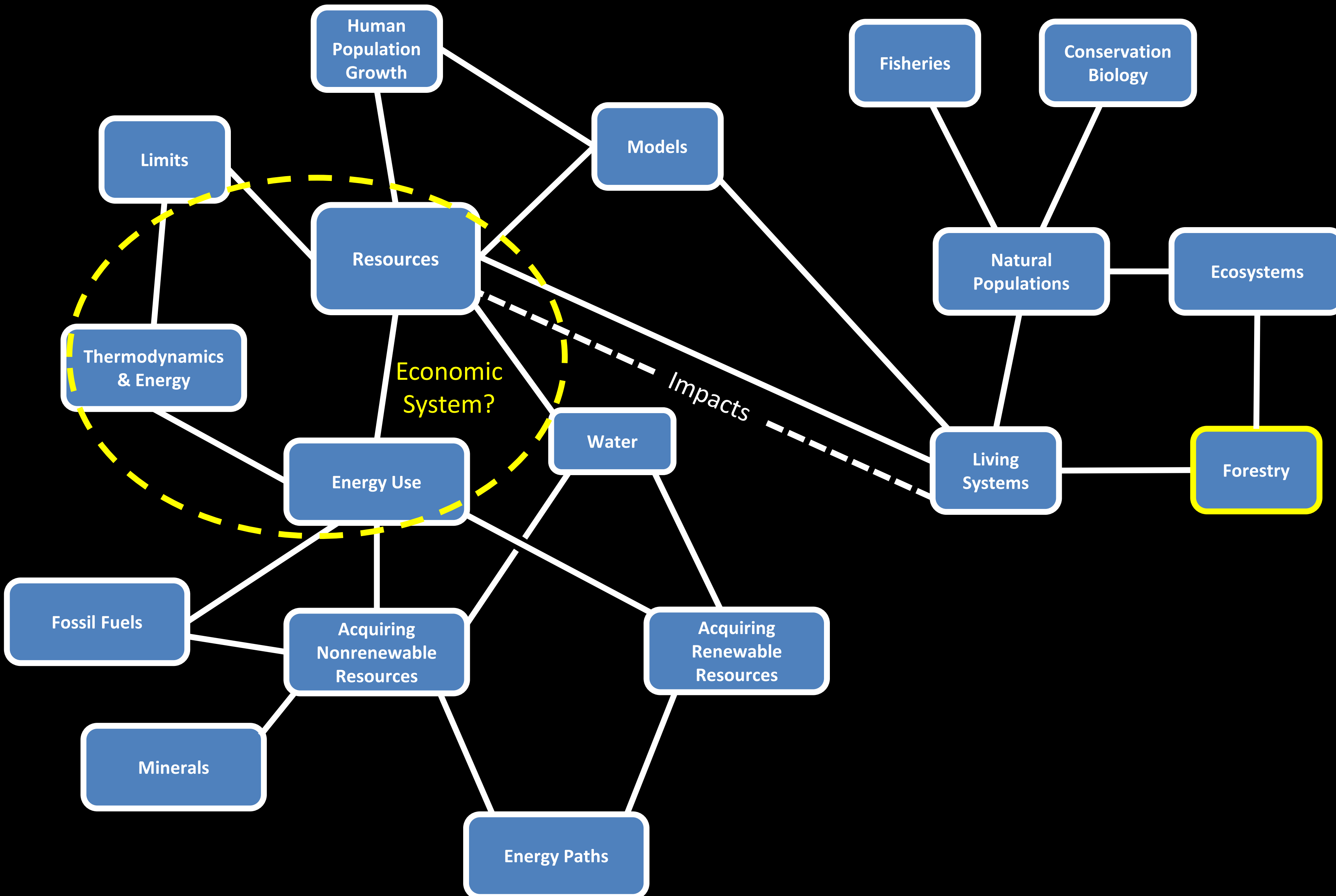
Use Web of Science / Web of Knowledge to look for a recent peer-reviewed journal article about forestry. Let's collectively broaden our geographic and conceptual scope!

www.webofscience.com

Be prepared to briefly share with your table:

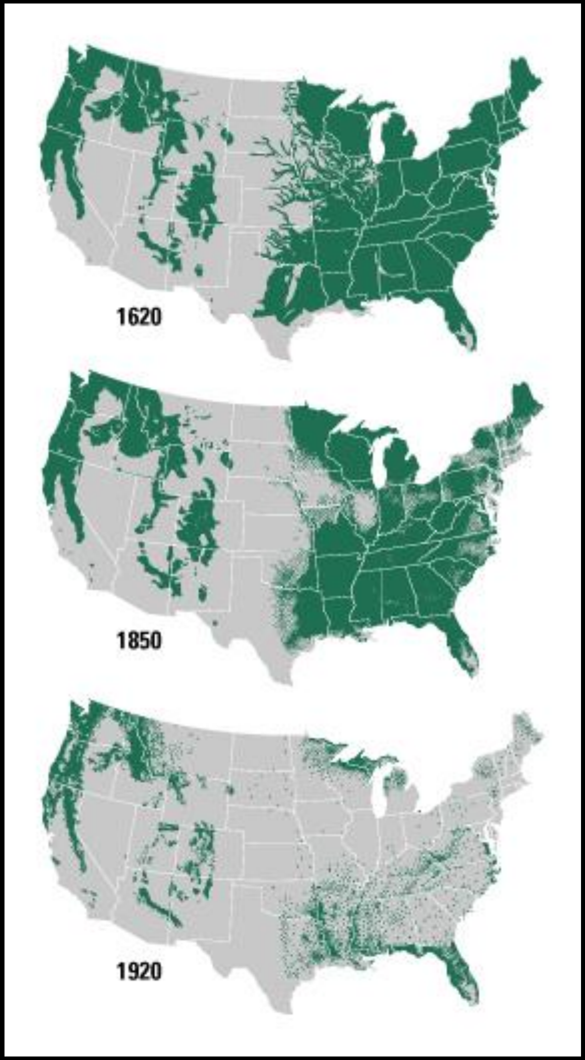
- Details of paper: Lead Author (do a quick search for info) and Journal
- Main motivation / questions of the study
- Most important takehome point

Course Map



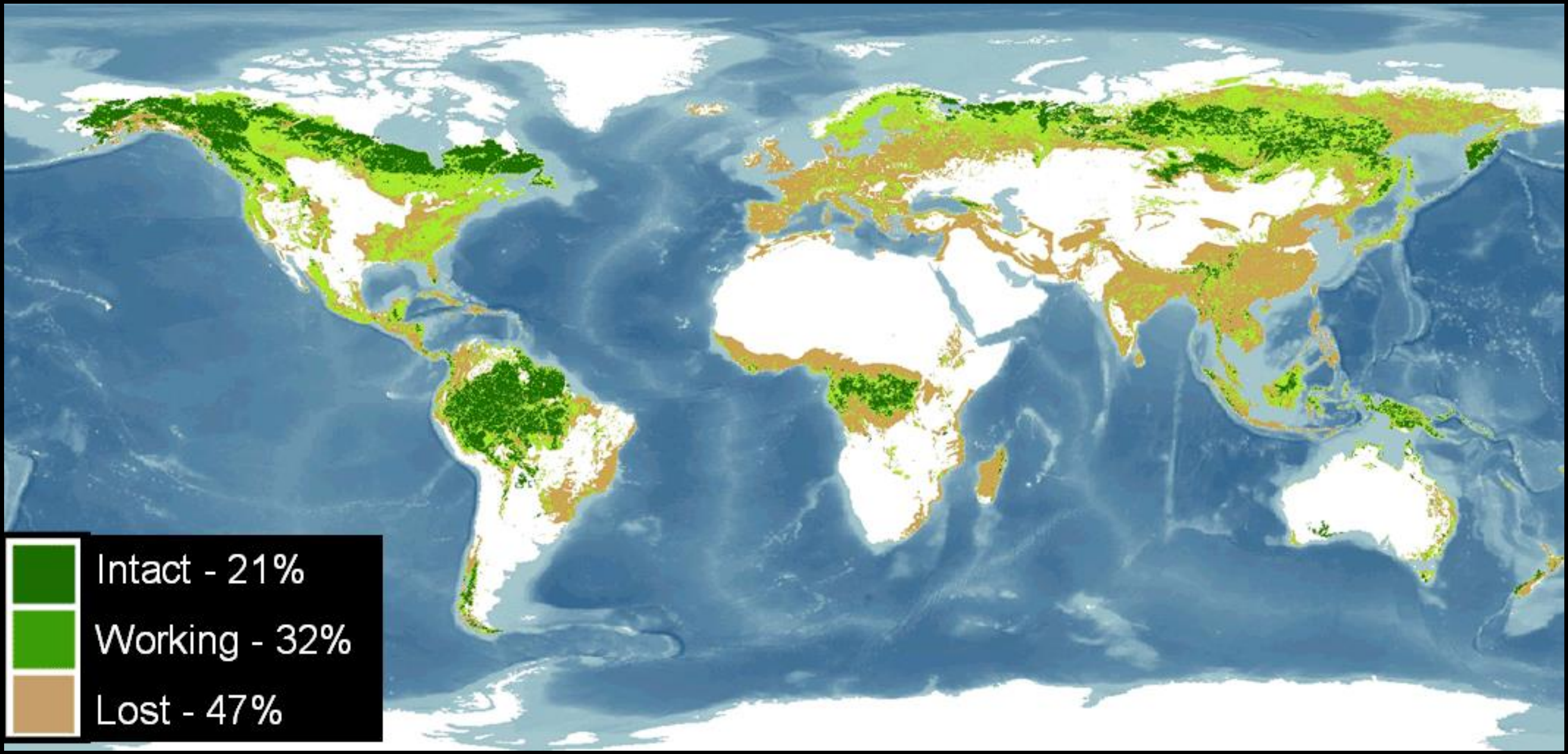
Human Population Growth
Models
Limits
Resources
Thermodynamics & Energy
Economic System?
Impacts
Energy Use
Water
Fossil Fuels
Acquiring Nonrenewable Resources
Acquiring Renewable Resources
Minerals
Energy Paths
Fisheries
Conservation Biology
Natural Populations
Ecosystems
Living Systems
Forestry

Primary Forests in US



Current Forest Cover in US

Forests Worldwide

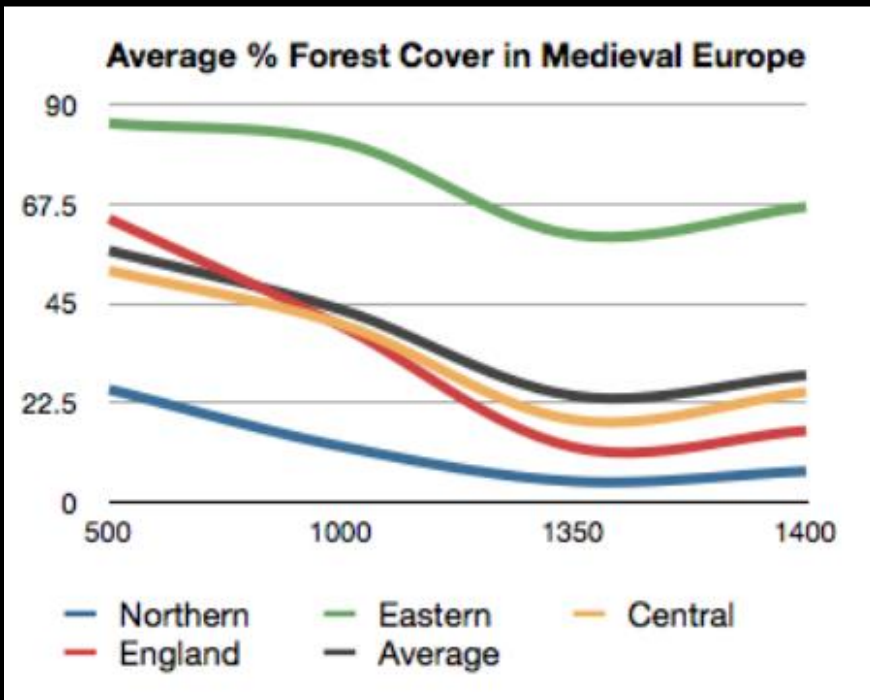


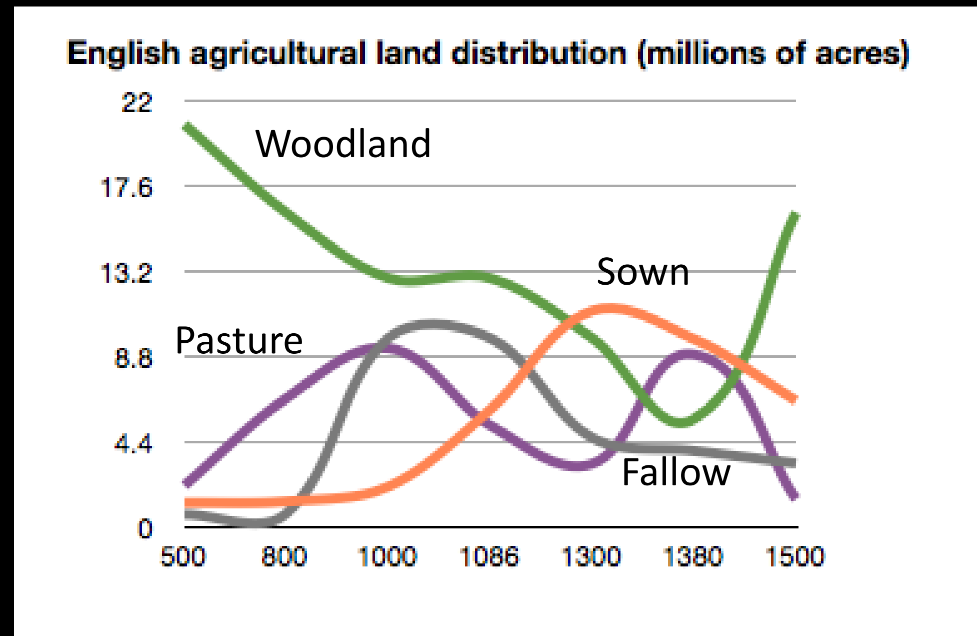
“Intact” = Primary forest
“Working” = Secondary forest or managed forest

WRI

Humans and Trees: Cedars of Lebanon

Humans and Trees: Land Use in Medieval Europe



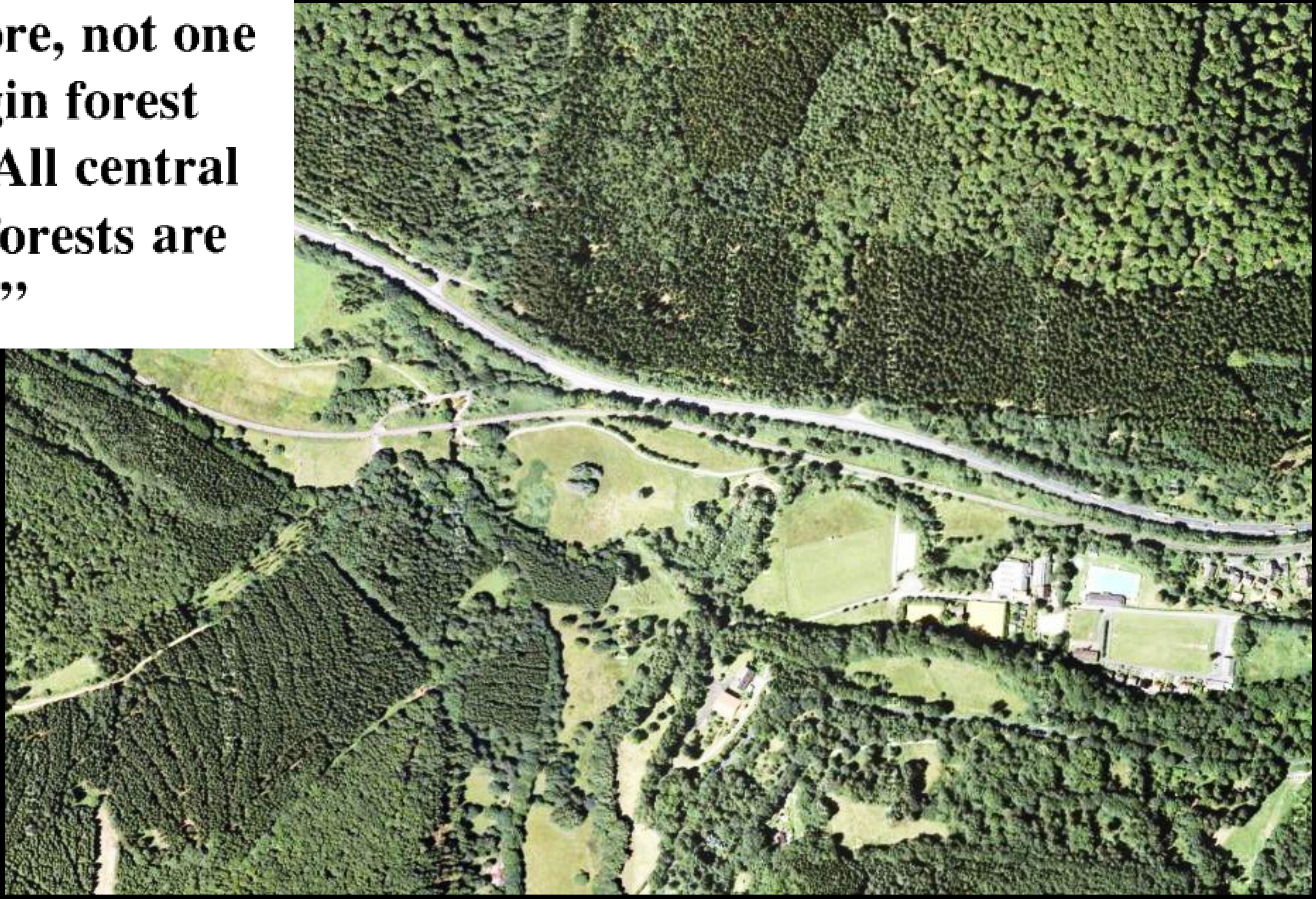


(Jenny Goldleaf '12)

Humans and Trees: Legacy of Deforestation / Reforestation

"Not one acre of forest was left untouched, and therefore, not one acre of virgin forest still exists. All central European forests are man-made."

-Richard Plochmann



Humans and Trees: Patches of Primary Forest

Białowieża Forest (Poland and Belarus)

Humans and Trees: Environmental Justice

The Trillion Tree Campaign

The Trillion Tree Campaign app aims to bring transparency to tree-planting projects around the world and make it as easy as possible for anyone to support them.
Global reforestation could capture 25% of global annual carbon emissions and create wealth in the global south.

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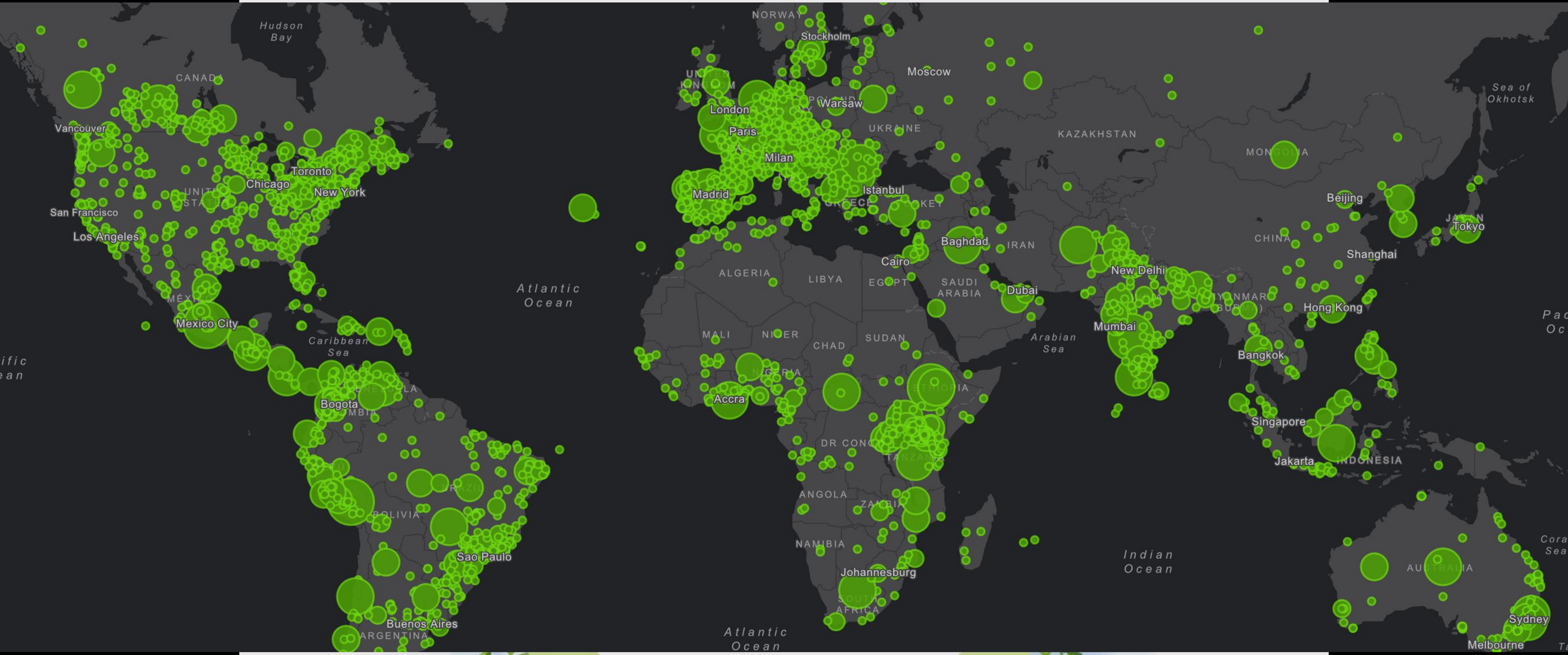


Forestry and Resources?

Silviculture

- Forests as agriculture
- Highly managed systems

Forest Resources

- Renewable, but slow
  - → what is being renewed?
    - Wood?
    - Ecosystem?

Physical Resource

  - → Land productivity? Erosion, desertification

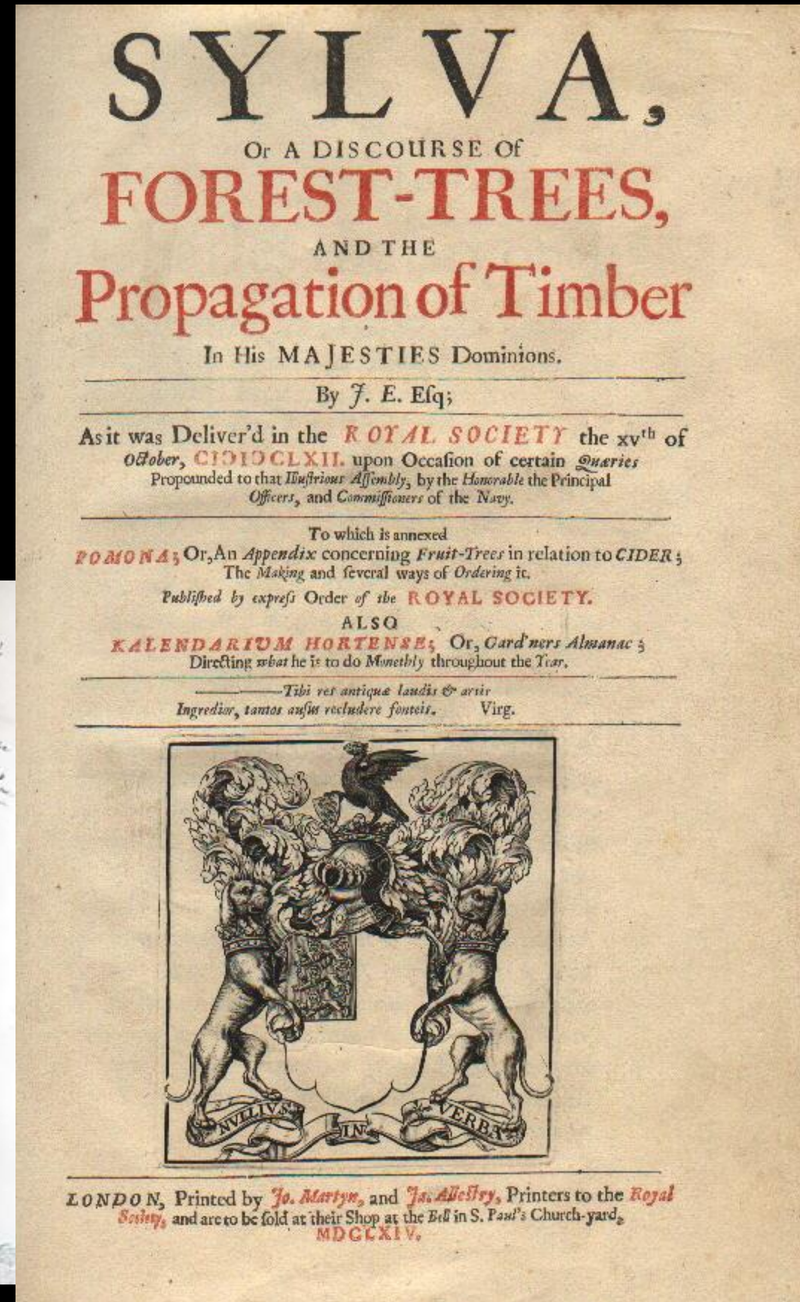
Resources?

Functional - wood: material, energy, paper

- Ecosystem services: Carbon Sequestration

1660: John Evelyn's *Sylva*

- Restoration of forests in England



SYLVA,

Or A DISCOURSE Of

FOREST-TREES,

AND THE

Propagation of Timber

In His MAJESTIES Dominions.

By *J. E.* Esq;

As it was Deliver'd in the *ROYAL SOCIETY* the xv[th] of *October*, CIƆIƆCLXII. upon Occasion of certain *Quæries* Propounded to that *Illustrious Assembly*, by the *Honorable* the Principal *Officers*, and *Commissioners* of the *Navy*.

To which is annexed

POMONA; Or, An *Appendix* concerning *Fruit-Trees* in relation to *CIDER*; The *Making* and several ways of *Ordering* it.

Published by express Order of the ROYAL SOCIETY.

ALSO

KALENDARIUM HORTENSE; Or, *Gard'ners Almanac*; Directing *what* he is to do *Monethly* throughout the *Year*.

——*Tibi res antiquæ laudis & artis*
Ingredior, tantos ausus recludere fonteis. Virg.

LONDON, Printed by *Jo. Martyn*, and *Ja. Allestry*, Printers to the *Royal Society*, and are to be sold at their Shop at the *Bell* in S. *Paul's* Church-yard, MDCLXIV.

I need not Aquaint Your Majesty, *how many* Millions *of* Timber-Trees *(beside infinite* others*) have been* Propagated *and* Planted *throughout Your vast* Dominions, *at the* Instigation, *and by the sole* Direction *of this* Work*; because Your* Gracious Majesty, *has been pleas'd to* own *it* Publickly, *for my* Encouragement, *who, in all that I here pretend to say, deliver only those* Precepts *which Your* Majesty *has put into* Practice*; as having (like another* Cyrus*) by Your own* Royal Example, *exceeded all your* Predecessors *in the* Plantations *You have made, beyond (I dare assert it) all the* Monarchs *of this* Nation, *since the* Conquest *of it. And, indeed what*

'Tis now some Years *past that Your* Majesty *was pleas'd to declare Your Favourable Acceptance of a* Treatise *of* Architecture *which I then presented to* You, *with many* Gracious Expressions, *and that it was a most* useful *Piece.* Sir, *that* Encouragement *(together with the* Success *of the* Book *it self, and of the former* Editions *of* this*) has animated me still to continue my* Oblation *to Your* Majesty *of these* Improvements*: Nor was it certainly without some* Provident *Conduct, that we have been thus solicitous to begin, as it were, with* Materials *for Building, and* Directions *to* Builders*; if due Reflection be made on that Deplorable* Calamity, *the* Conflagration *of Your* Imperial City*; which nevertheless, by the Blessing of* God, *and Your* Majesty's *Gracious* Influence, *we have seen* Rise *again, a* New, *and much more* Glorious *PHOENIX.*

Gracious Sir,

Your *Majesty's*

Ever *Loyal*, most *Obedient* and

Faithful Subject and *Servant*,

J. Evelyn.

Economic Shifts

- Evolution of capitalism, economic liberalism
    - Free markets, profit seeking
    - Property rights: who owns land

"Land Rent", "Soil Rent"

↳ profits and value from land

“Land Rent”

As soon as the land of any country has all become private property, the landlords, like all other men, love to reap where they never sowed, and demand a rent even for its natural produce. The wood of the forest, the grass of the field, and all the natural fruits of the earth, which, when land was in common, cost the labourer only the trouble of gathering them, come, even to him, to have an additional price fixed upon them. He must then pay for the licence to gather them; and must give up to the landlord a portion of what his labour either collects or produces. This portion, or, what comes to the same thing, the price of this portion, constitutes the rent of land ....

Adam Smith (*The Wealth of Nations*, 1776)

Incentives for land owners?

Good Outcomes
For Forests:

- Motivation to keep it productive
- Avoids "tragedy of the commons"

Bad Outcomes
For Forests:

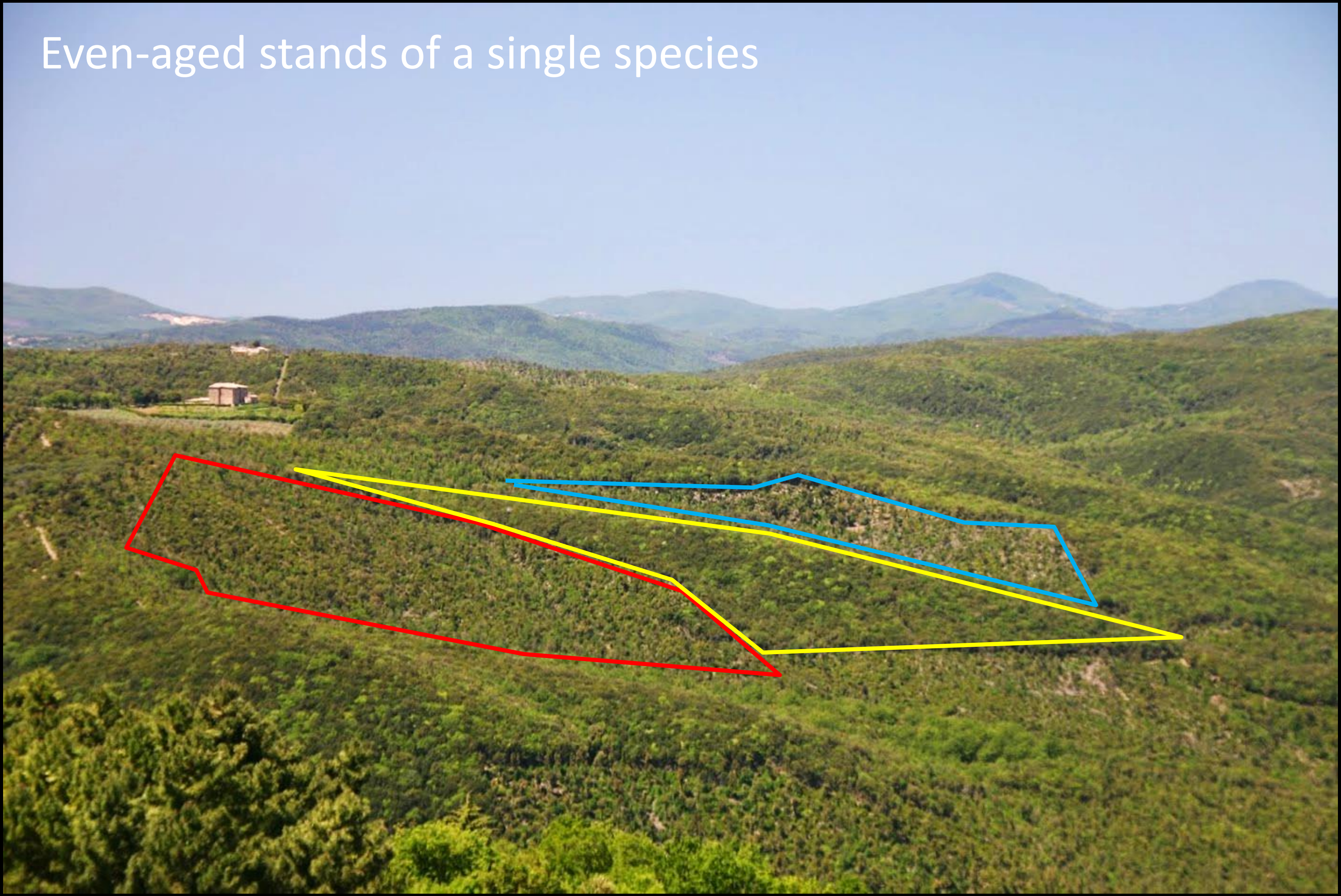
- Focus is on economic/monetary value
minimizes other types of value
↳ short term focus

Highly managed
Forests → Silviculture

Coppice (trunk regrowth, e.g. firewood)

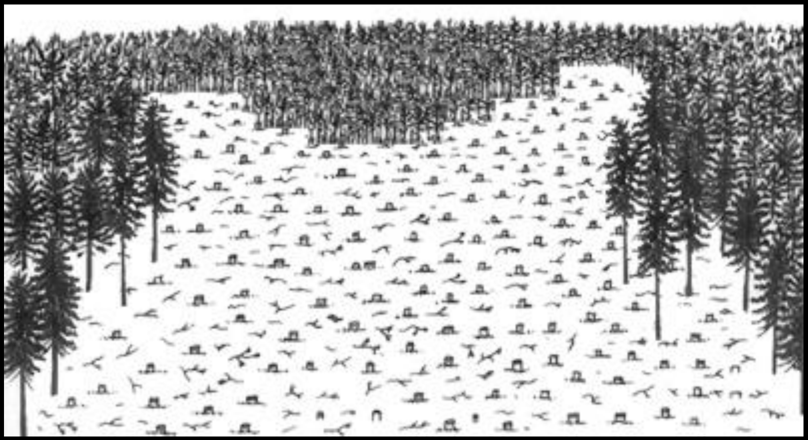
Clearcut

“Normal Forest”, Stands, and Rotation

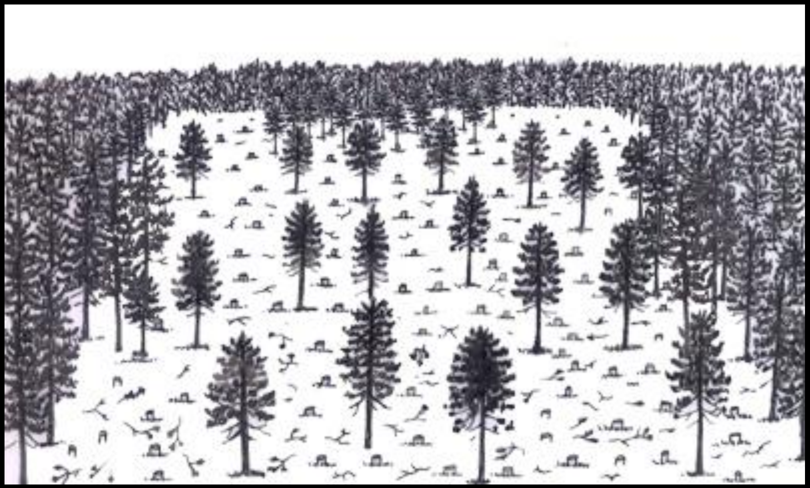


“Normal Forest”, Stands, and Rotation

Clearcut



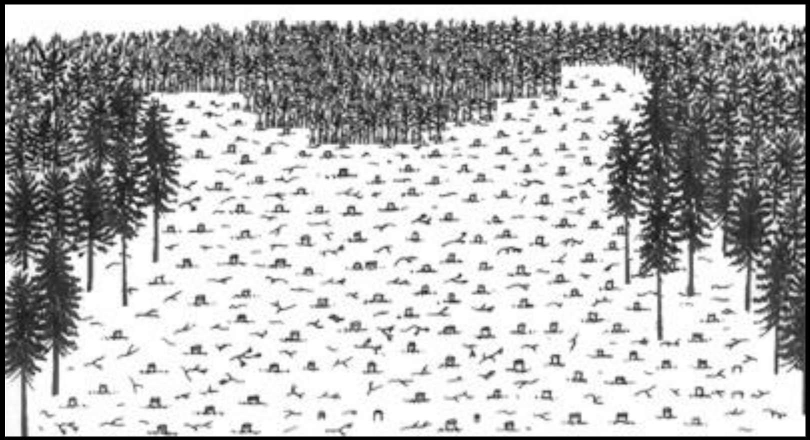
Clearcut with “seed trees”



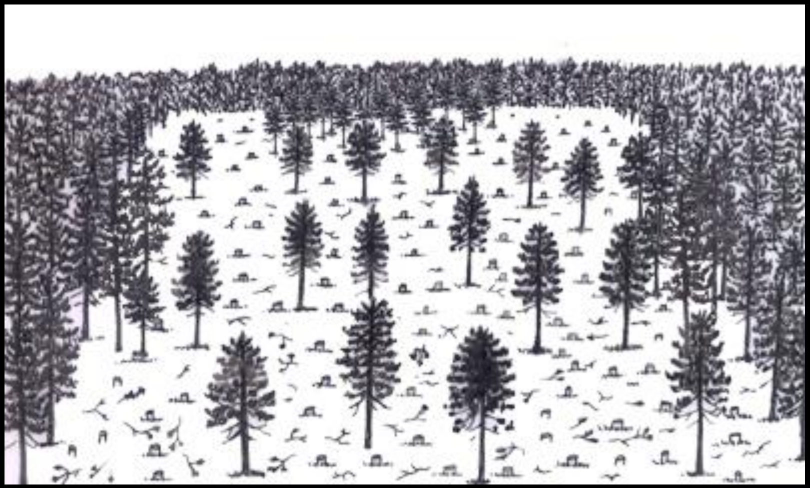
(USFS)

Shelterwood

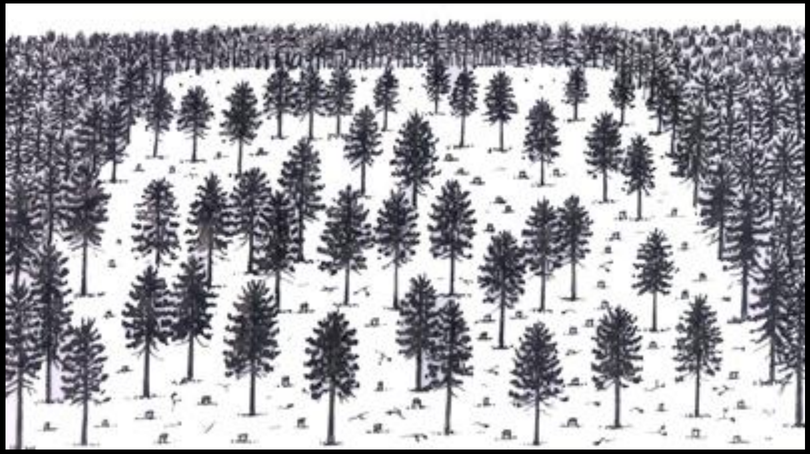
Clearcut



Clearcut with “seed trees”



Shelterwood



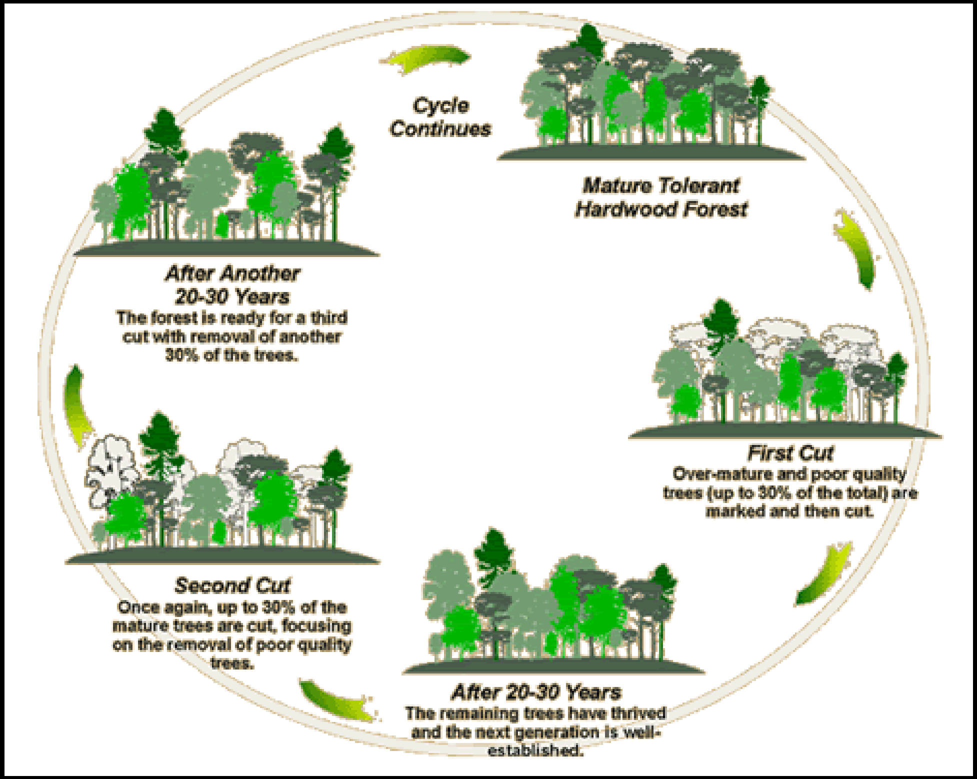
(USFS)

Multi-aged and/or multi-species management

"Selection Cutting"

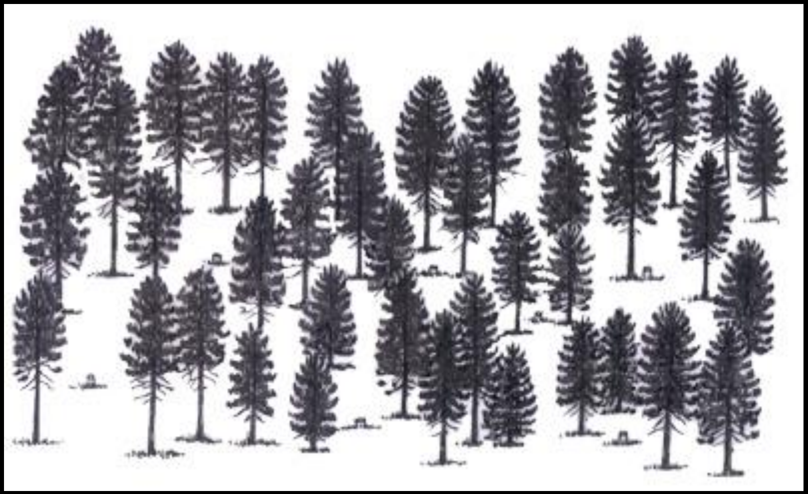
- Opens gaps for seedling regeneration
- Removes older trees to promote tree growth
- Can maintain complex forest structure

"Group Selection" with open gaps

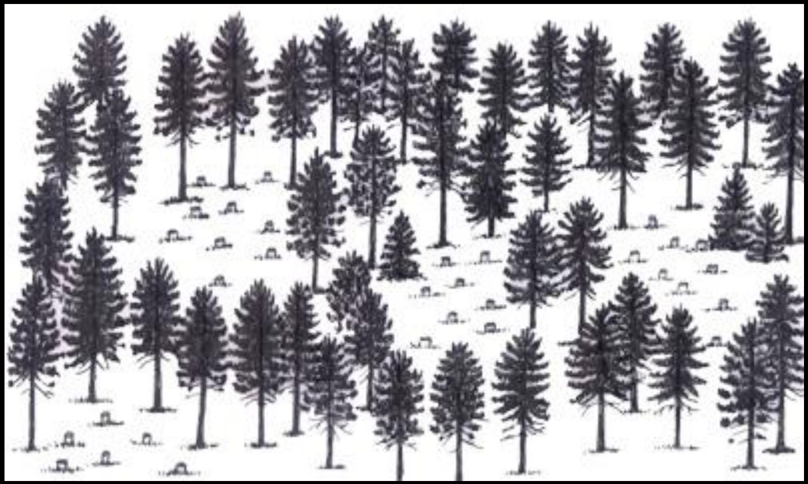


(Nipissing Forest Resource Management)

Single Tree Selection



Group Selection

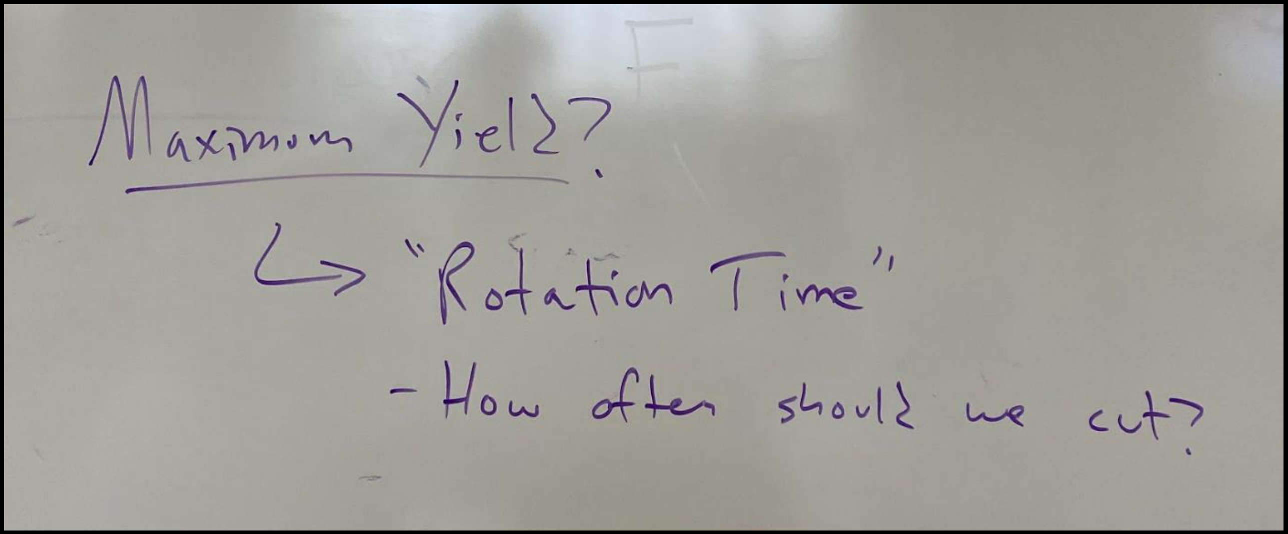


(USFS)

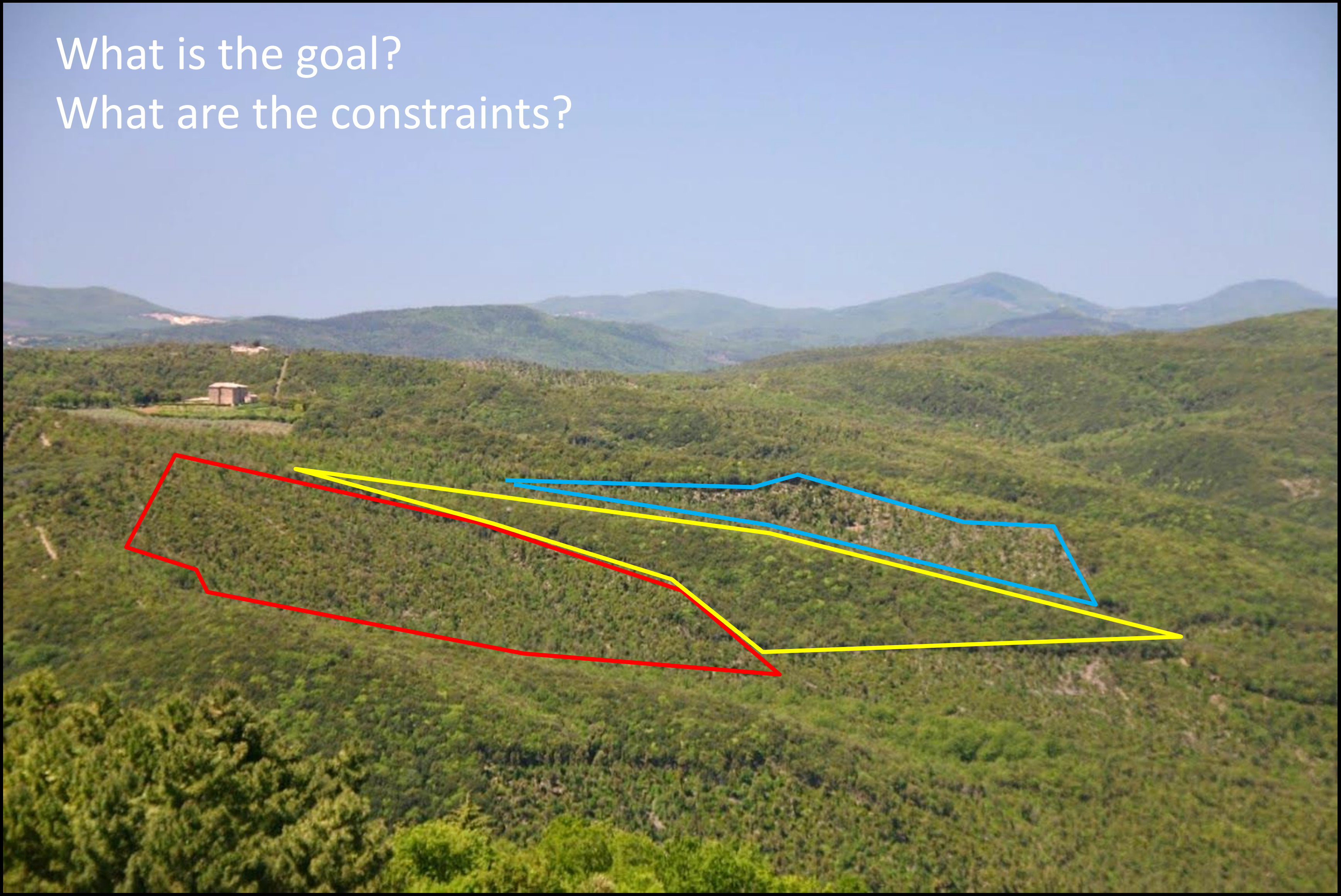
Thinning (reducing density of trees)

- Multiple harvests as a stand grows
- Can apply to any type of overall management strategy

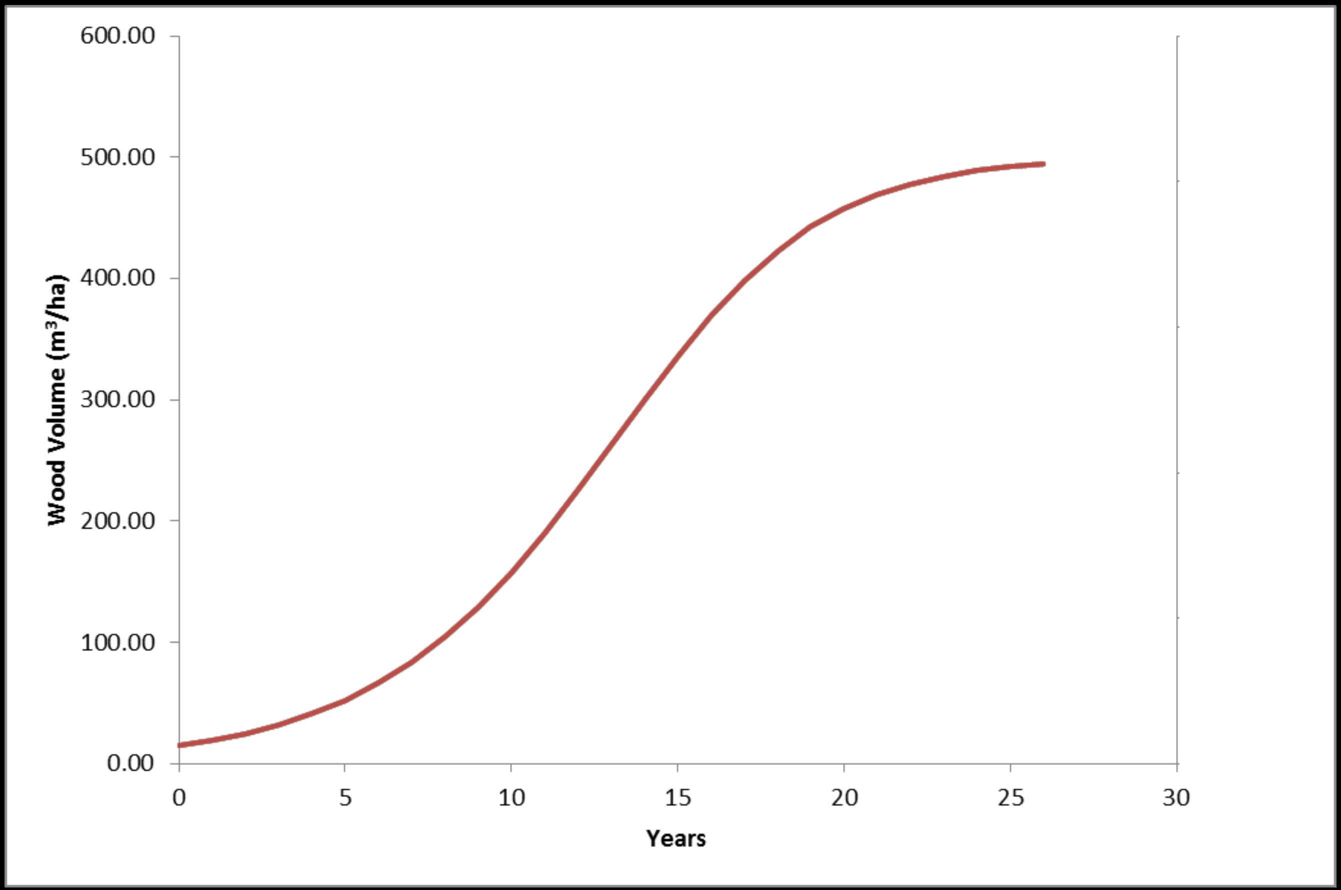
Maximum Yield?



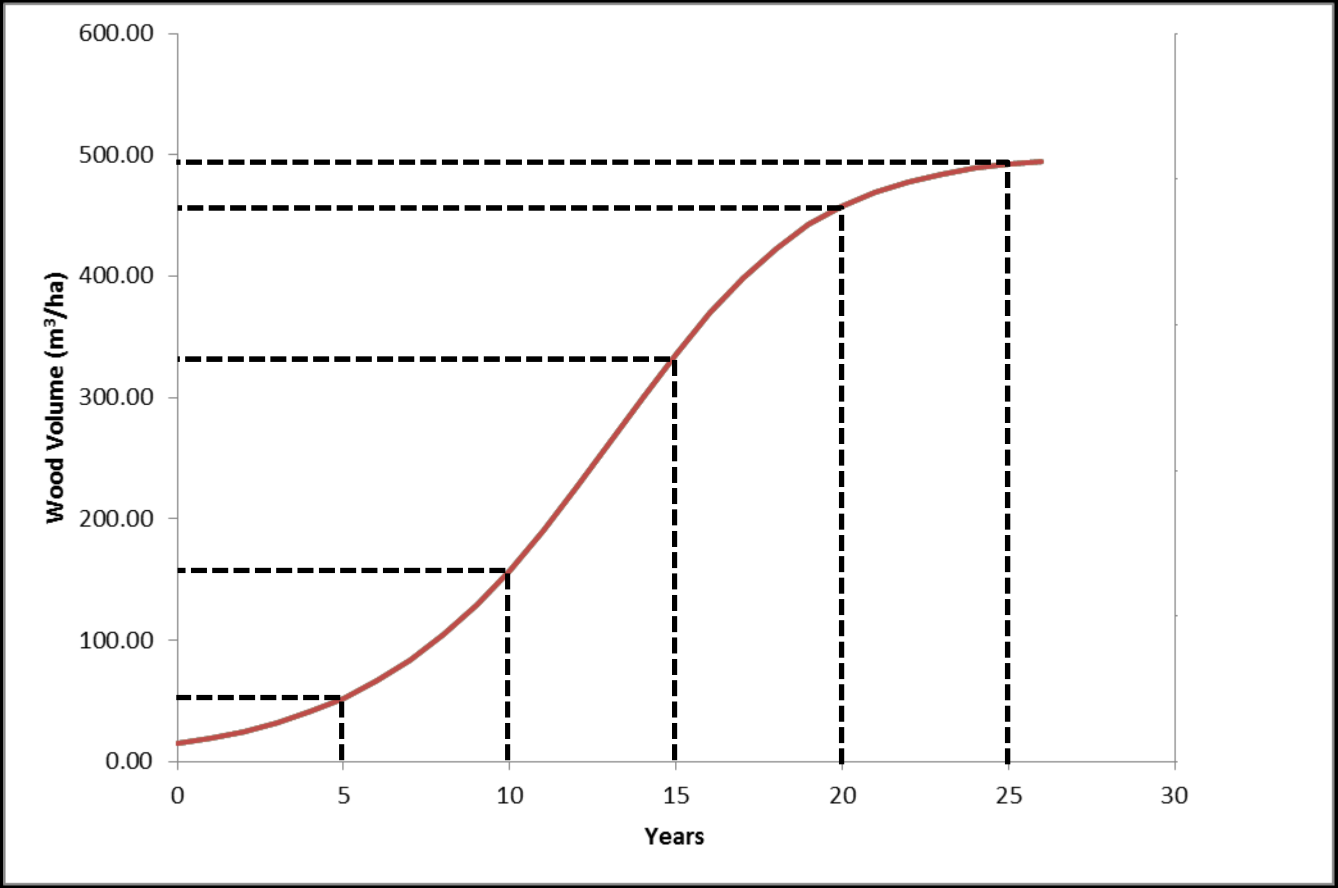
“Normal Forest”: when to cut an even-aged stand?



Maximizing Timber – Normal Forest / Clear Cut



Maximizing Timber – Normal Forest / Clear Cut



Maximizing Timber – Normal Forest / Clear Cut

(Ab) "Normal Forest"

- Highly managed
- Single species
- Even-aged: planted at the same time

→ In patches with different ages

- Cut / Clear-cut at different times, same age
- Rotation of cutting

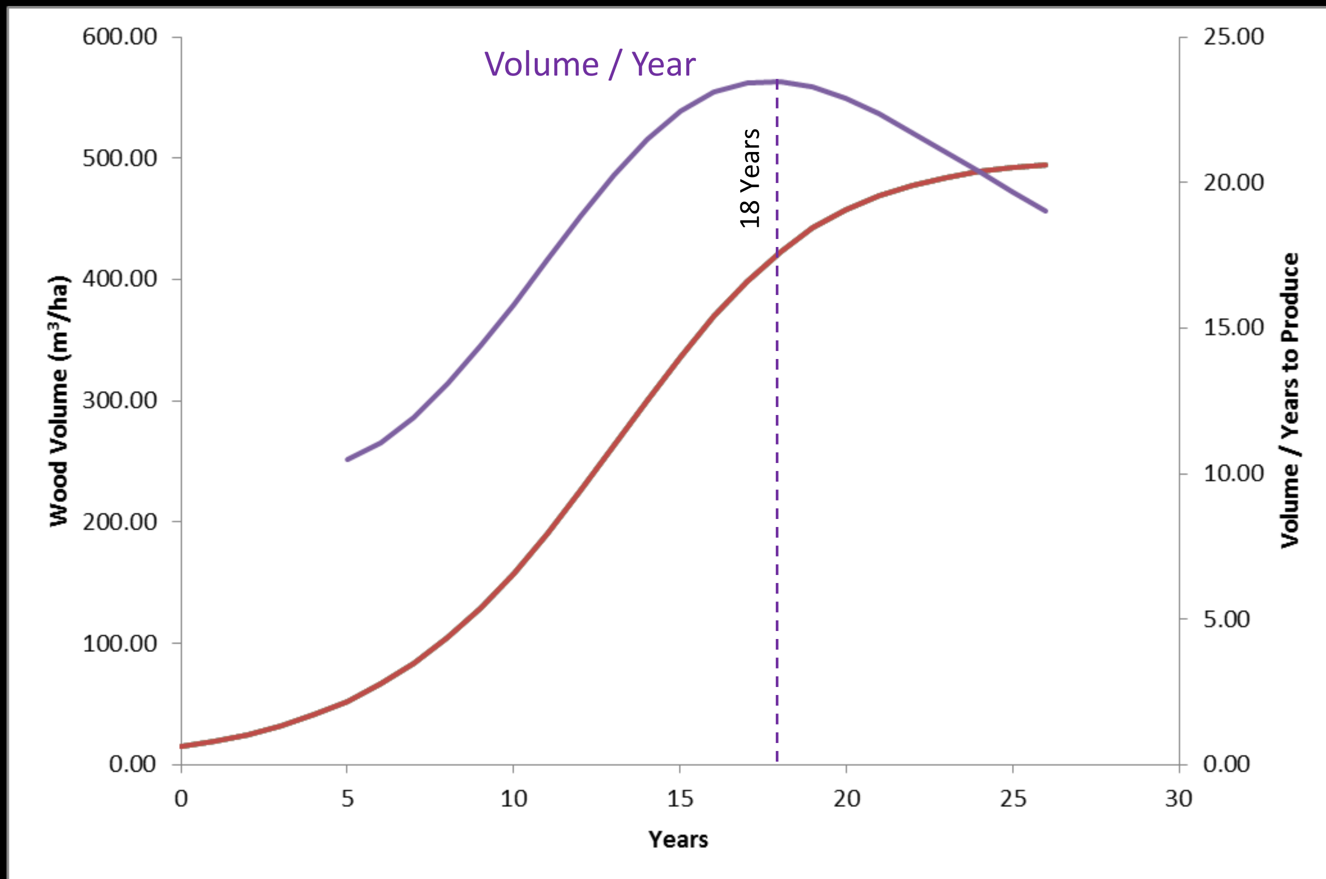
Age:

0 yr	15 yr	5 yr	10 yr

$\frac{\text{Volume}}{\text{years to produce}}$ ← want to maximize

Years	Volume	Volume/Years
5	52.3	10.5 vol/year
10	158	15.8
15	337	22.5
18	423	23.5
20	458	22.9
25	492	19.7

Maximizing Timber – Normal Forest / Clear Cut



Reading for Thursday

Forest Ecology and Management 261 (2011) 1558–1563

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/foreco

When and where to actively restore ecosystems?

K.D. Holl[a,*], T.M. Aide[b]

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[b] Department of Biology, University of Puerto Rico-Rio Piedras, P.O. Box 23360, San Juan, PR 00931-3360, USA

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Passive restoration
Succession
Tropical forest

ABSTRACT

Given the extent of land use and land cover change by humans on a global scale, conservation efforts have increasingly focused on restoring degraded ecosystems to provide ecosystem services and biodiversity. Many examples in the tropics and elsewhere, however, show that some ecosystems recover rapidly without human intervention which begs the question of in which cases and to what extent humans should actively work to facilitate ecosystem recovery. We recommend that all land managers consider a suite of ecological and human factors before selecting a restoration approach. Land managers should first consider what the likely outcome of a passive restoration (natural regeneration) approach would be based on the natural ecosystem resilience, past land-use history, and the surrounding landscape matrix. They should also identify the specific goals of the project and assess the resources available. Conducting these analyses prior to selecting restoration approaches should result in a more efficient use of restoration resources both within and among projects and should maximize the success of restoration efforts.

1. Introduction

Conservation efforts have traditionally focused on protecting areas where the land cover has not been heavily altered by humans and such efforts must remain a priority. Given the extent of land use and land cover change by humans on a global scale, conservation efforts have increasingly focused on natural recovery and actively manipulating disturbance regimes such as fire and flooding (Perrow and Davy, 2002; Van Andel and Aronson, 2006).

There is considerable debate, however, regarding whether active restoration is always necessary (Prach and Hobbs, 2008; Clewell and McDonald, 2009; Rey Benayas et al., 2009), given the numerous examples of ecosystems recovering over a period of decades without human intervention (Jones and Schmitz, 2009).

Holl and Aide 2011

Wednesday Lab

- **Starts at 9:30!**
- Breakfast provided!
- Share your digital poster with me
- Be prepared to briefly walk us through your modeling and findings

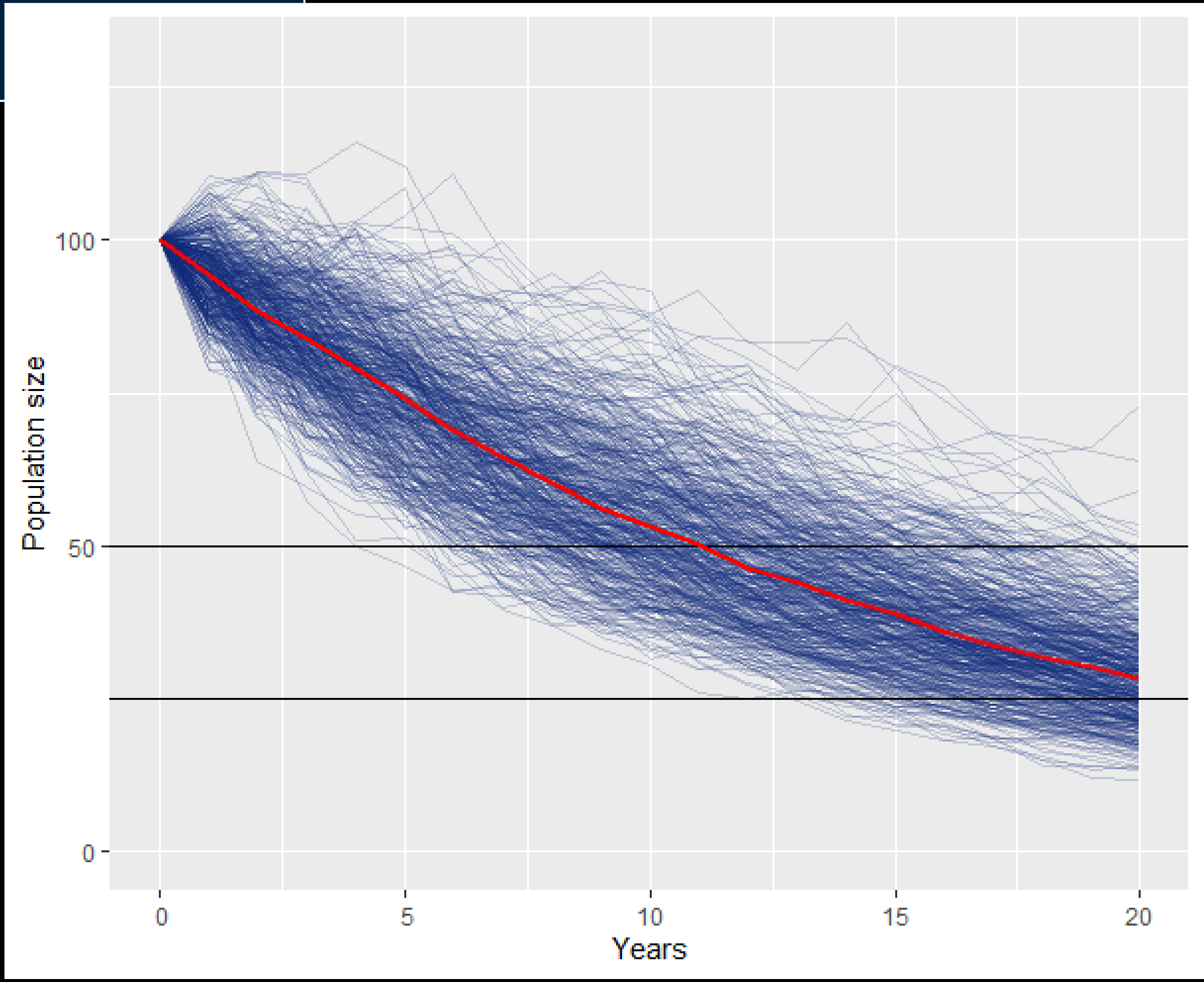
Office Hours Tomorrow:

9:00 – 12:00

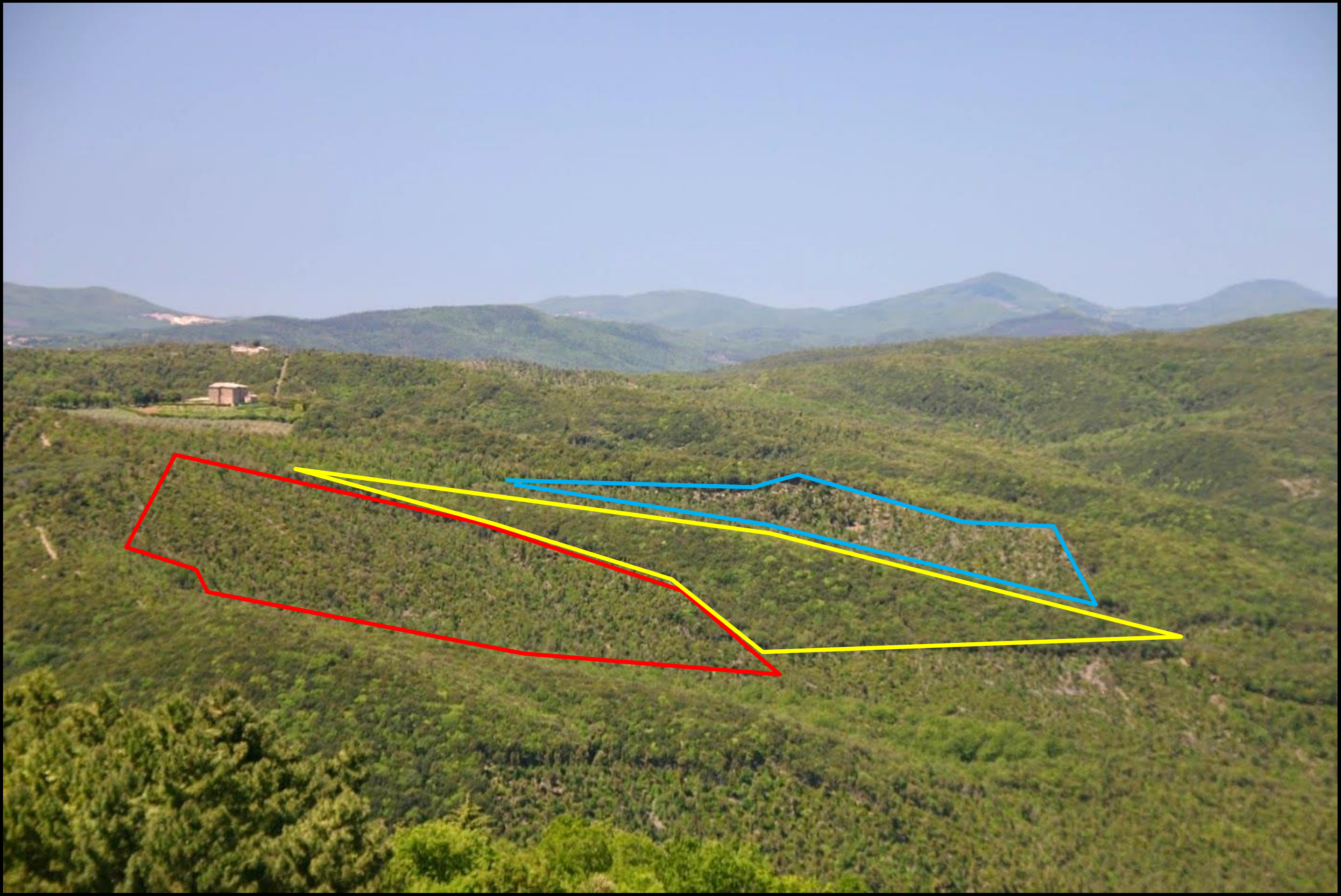
1:00 – 5:00

```r
Med <- median.N(N)

weplot(x = 0:Time, y = N, transparency = 0.8,
       xlab = "Years", ylab = "Population size",
       ylim = c(0, 130)) +
  geom_hline(yintercept = 50) +
  geom_hline(yintercept = 25) +
  add.weplot(x = 0:Time, y = Med, color = "red",
             size = 2, type = "line")

extinct.prob(N, 50)
extinct.prob(N, 25)
```

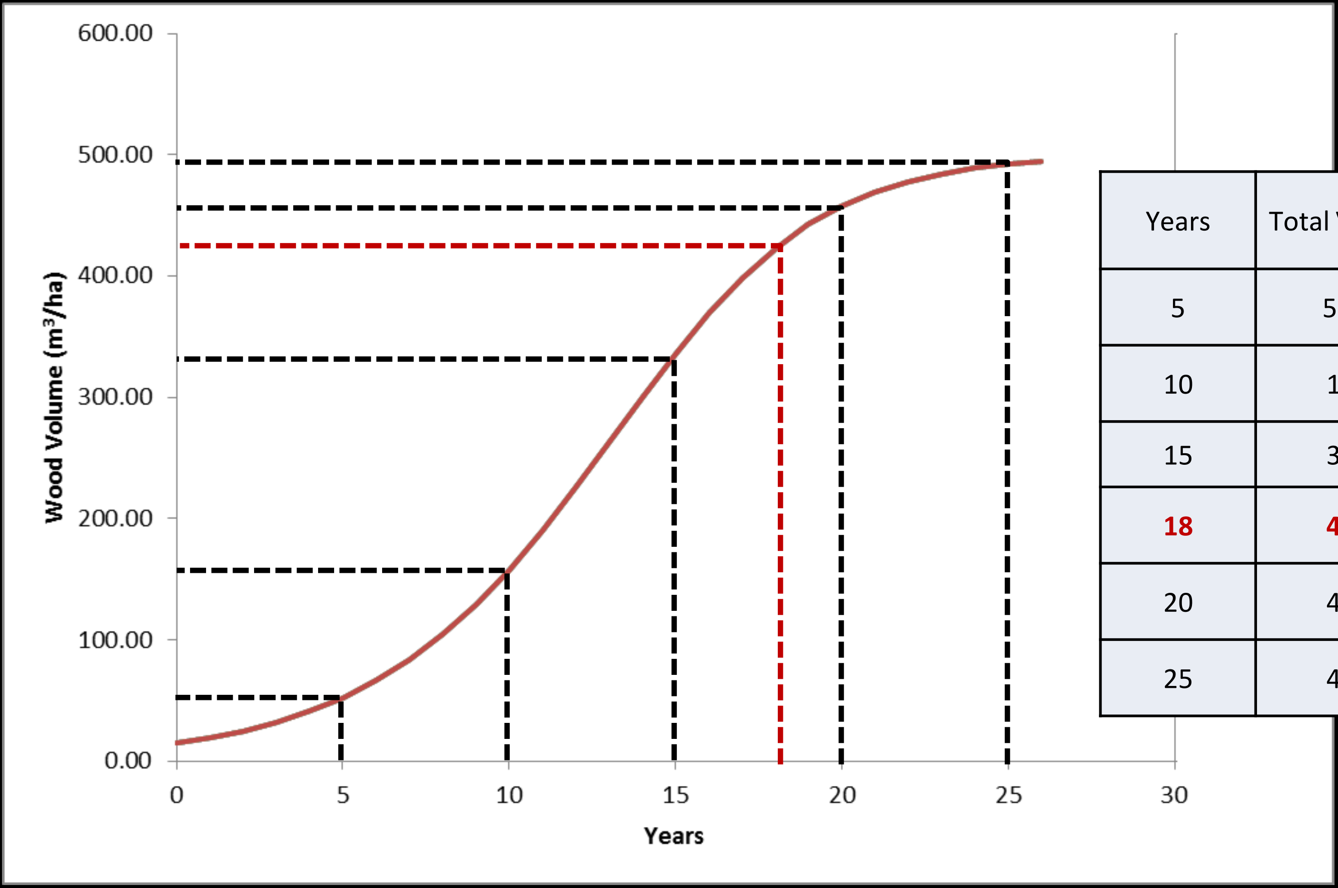
```
> extinct.prob(N, 50)
[1] 0.988
> extinct.prob(N, 25)
[1] 0.346
```



“Normal Forest”: when to cut an even-aged stand?

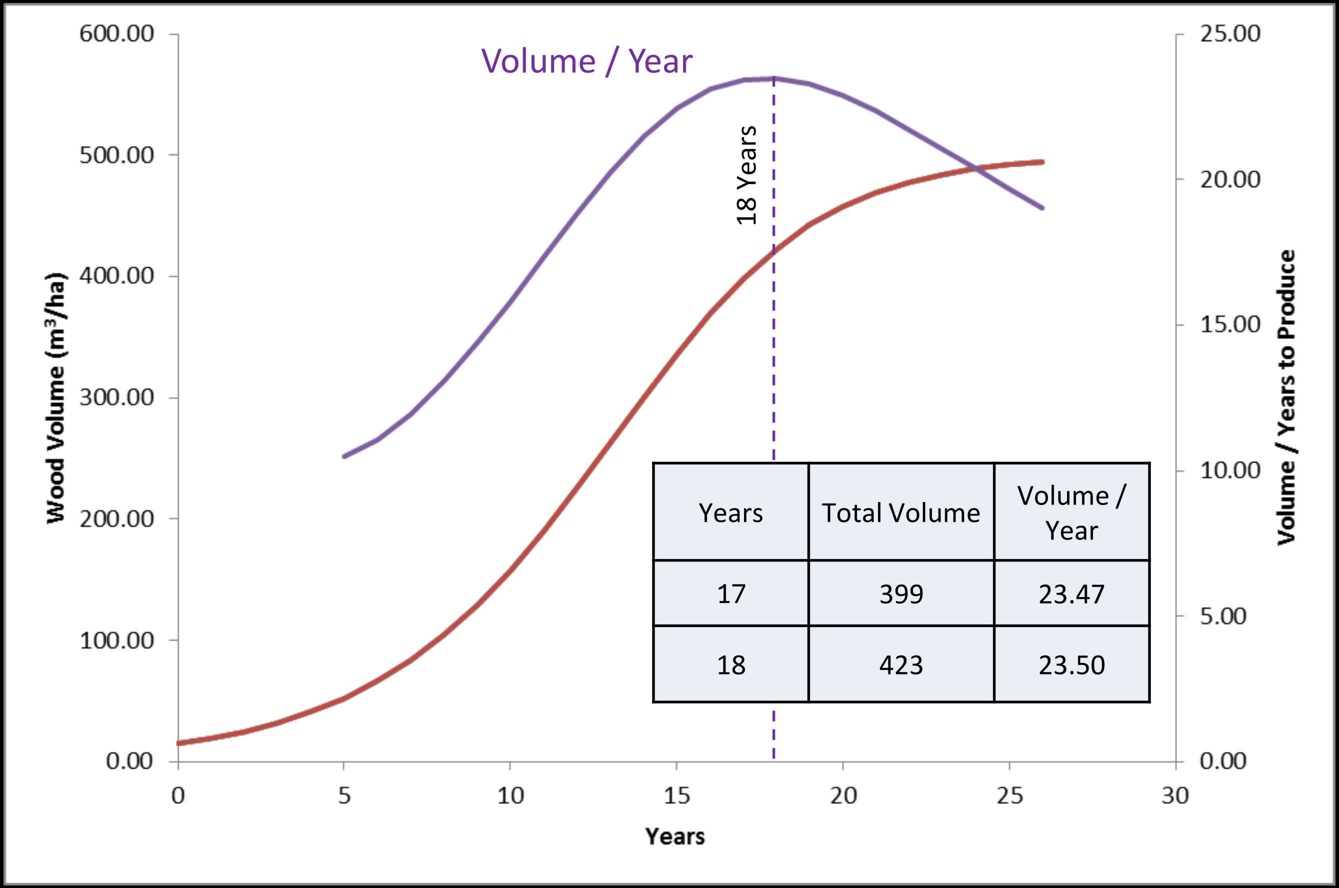


Maximizing Timber – Normal Forest / Clear Cut



Years	Total Volume	Volume / Year
5	52.3	10.5
10	158	15.8
15	337	22.5
18	**423**	**23.5**
20	458	22.9
25	492	19.7

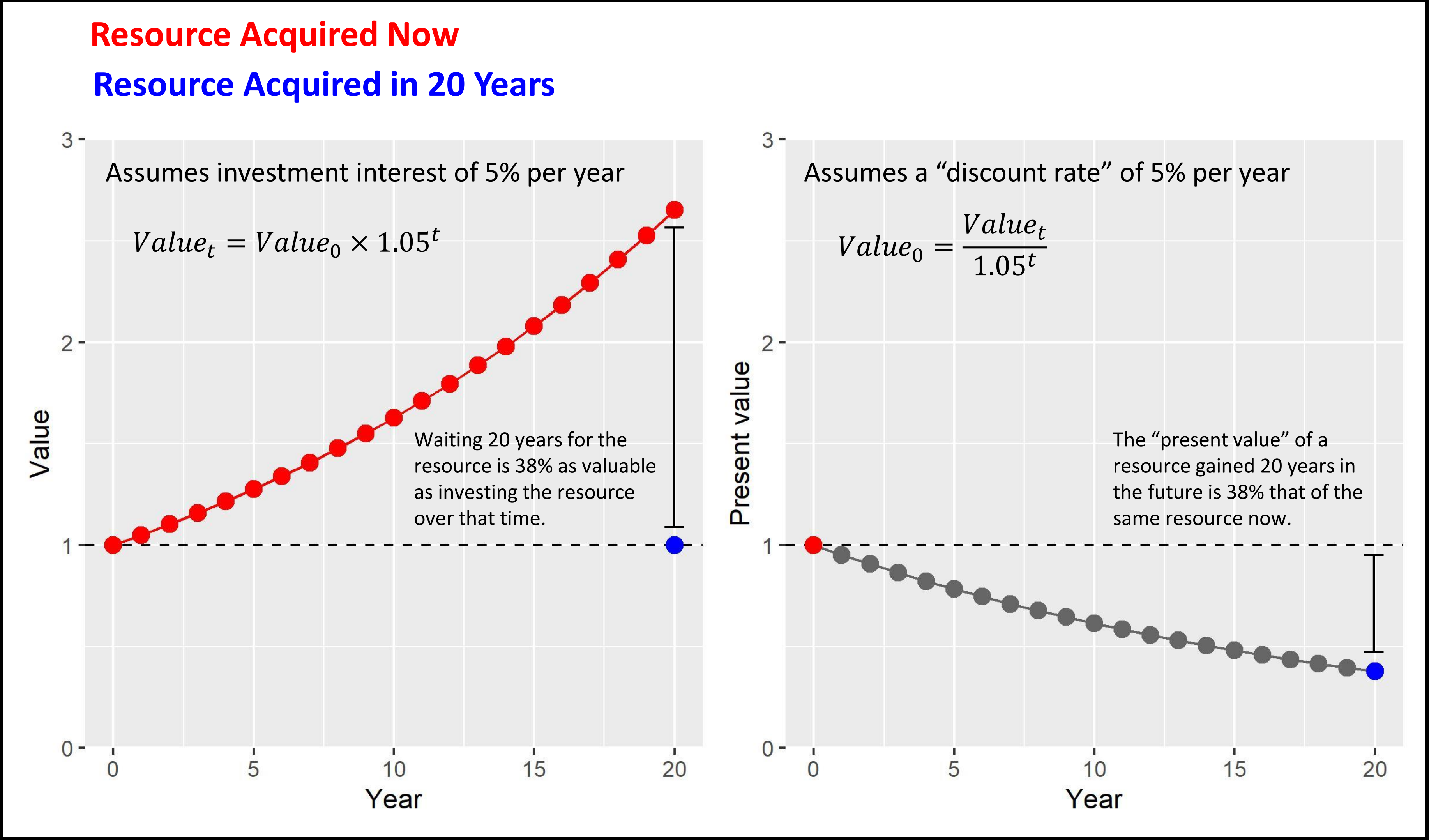
Maximizing Timber – Normal Forest / Clear Cut



Years	Total Volume	Volume / Year
17	399	23.47
18	423	23.50

Economic Discounting

The same resource is worth more now than in the future



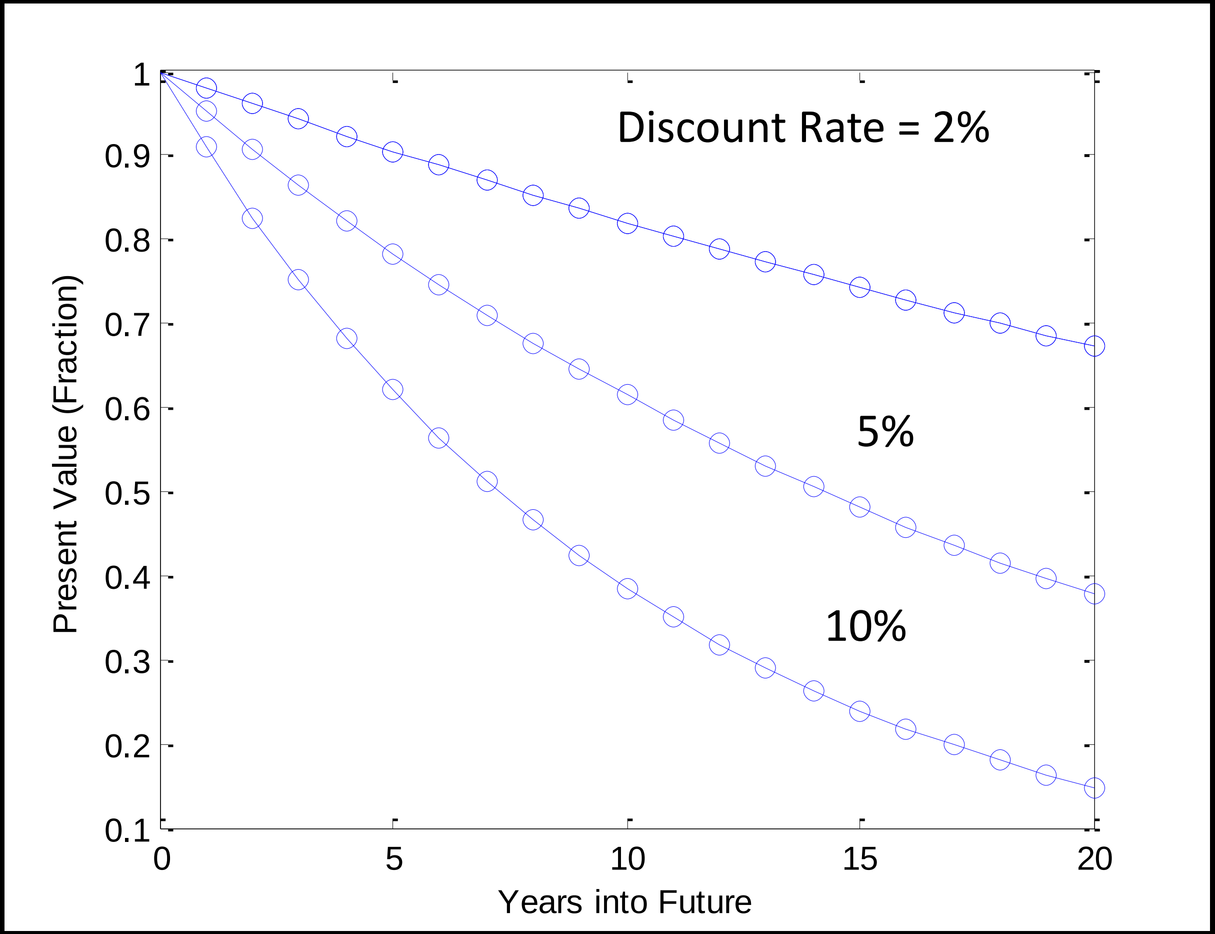
Maximizing Land Value (Faustmann model) "Soil Rent" "Land Rent"

$$\text{Present Value} = \frac{\text{Value of forest at time T}}{(1 + r)^T}$$

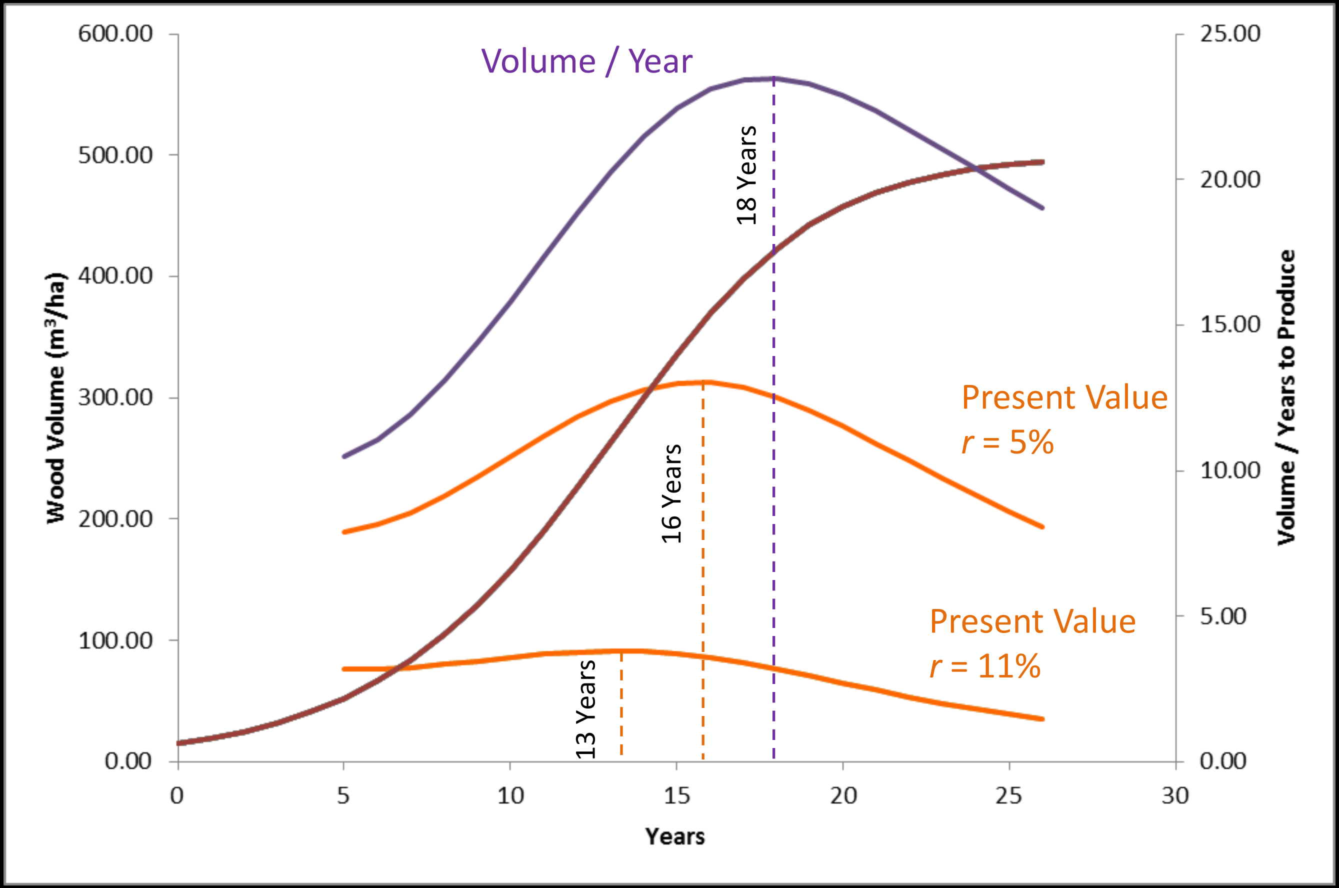
$$= \frac{\text{Value of forest at time T}}{\lambda^T}$$

r = fractional discount rate
= $\lambda - 1$ (1.05 - 1 = 0.05)

(λ as an economic rate, <u>not</u> a population rate)



Maximizing Land Value (Faustmann model) “Soil Rent” “Land Rent”



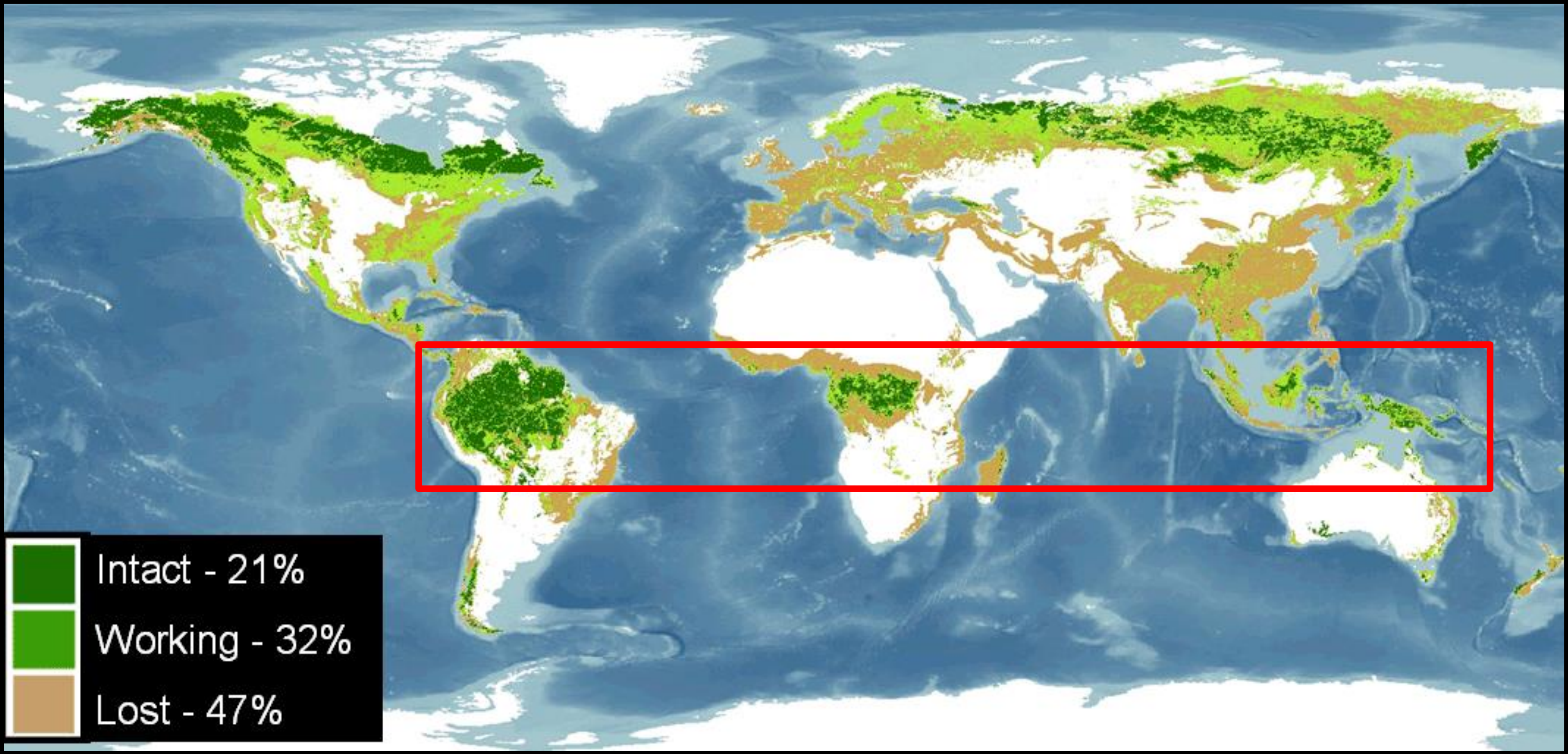
Shorter Rotation Times

- Sustainability → erosion
  nutrients
- limit board width (less value)

Soft Woods: pine → fast growing, cheap

Hard Woods: Oaks, maple, hickory → slow growing, expensive

Forests Worldwide



"Intact" = Primary forest
"Working" = Secondary forest or managed forest

WRI

Timber harvesting in Bolivia

CENTURIES-OLD MAHOGANY log awaits cutting at a Bolivian sawmill. Logging of mahogany (*Swietenia macrophylla* King), one of the most valuable tropical woods, occurs in many parts of Central and South America, including Guatemala, Belize, Bolivia, Peru and Brazil.

Differences among tree species

- Mahogany: very valuable and slow growing

Can Sustainable Management Save Tropical Forests?

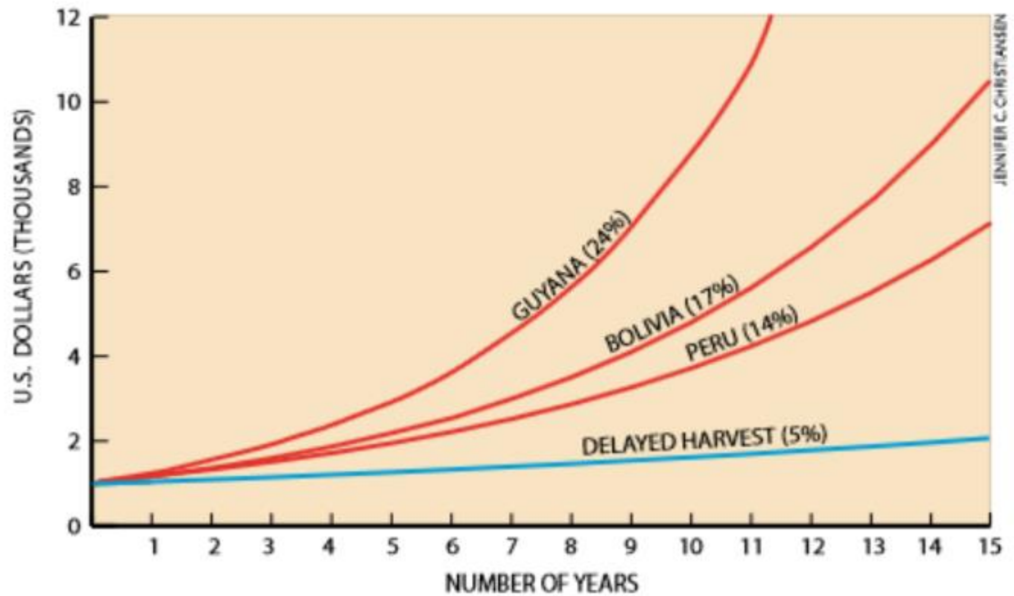
Sustainability proves surprisingly problematic in the quest to reconcile conservation with the production of tropical timber

by Richard E. Rice, Raymond E. Gullison and John W. Reid

To those of us who have dedicated careers to conserving the biodiversity and natural splendor of the earth's woodlands, the ongoing destruction of tropical rain forest is

ternational aid agencies had a very slim chance for success. Although our concerns about the effectiveness of sustainable forestry have since mounted, our initial disillusionment sprang from our

turn to Washington, D.C., after working with the Smithsonian Institution at the Beni Biosphere Reserve, located next to the Chimanes Permanent Timber Production Forest, a tract of half a million



FINANCIAL REWARDS that can be earned by harvesting trees worth US$1,000 and investing the proceeds at the real interest rates available locally (*red*) outstrip the return attained by letting the trees grow in size and value before cutting them down (*blue*).

Articles on forestry

Add your paper's location(s) to the map on the board

In groups:

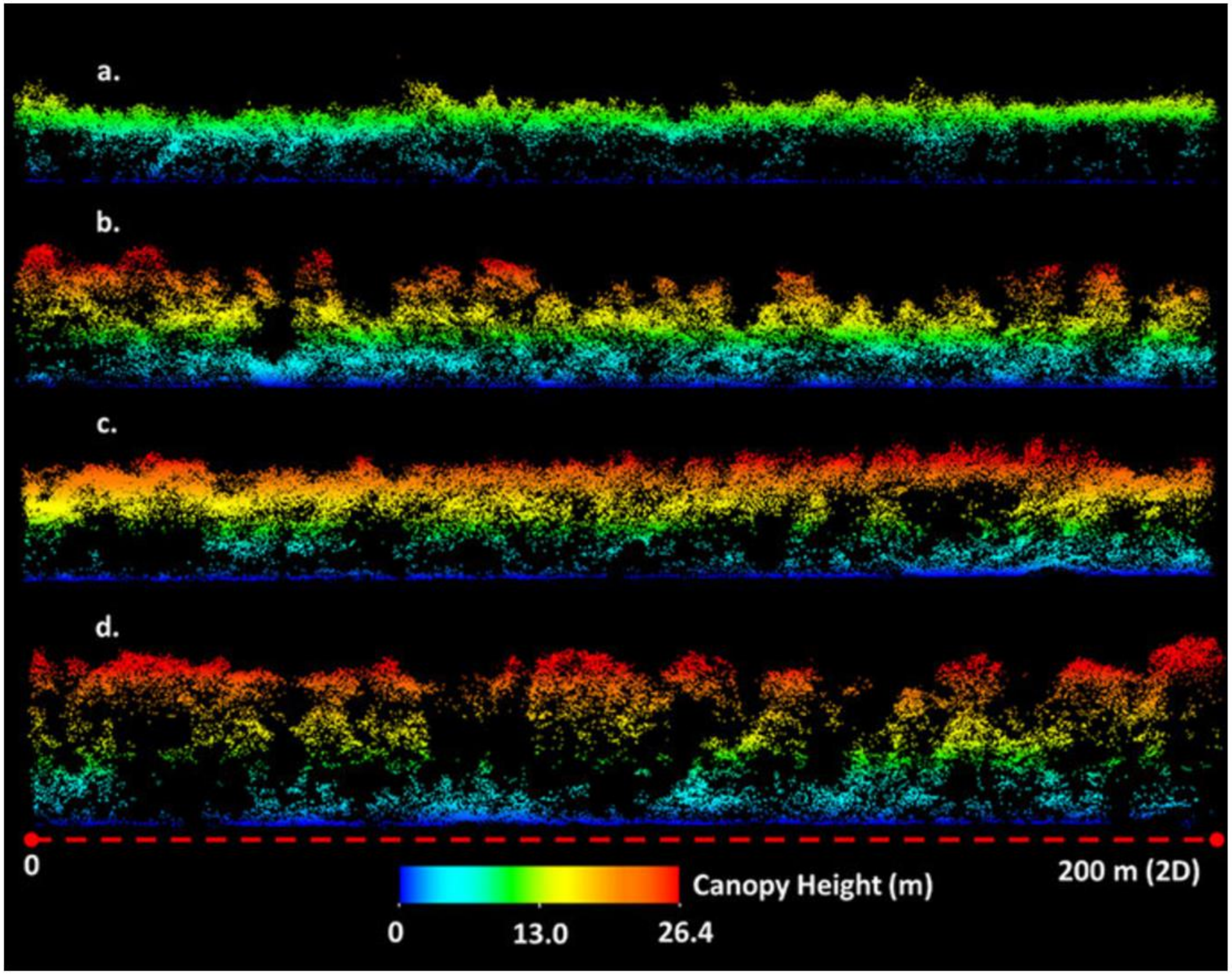
Briefly share the main motivation and takehome points from your article.

Brief report out to the class:

- Highlights
- Similarities, differences
- How does this help us understand / expand our framework on forestry?

Managing complexity…

Monitoring forest volume and structure using Lidar (lasers from above!)

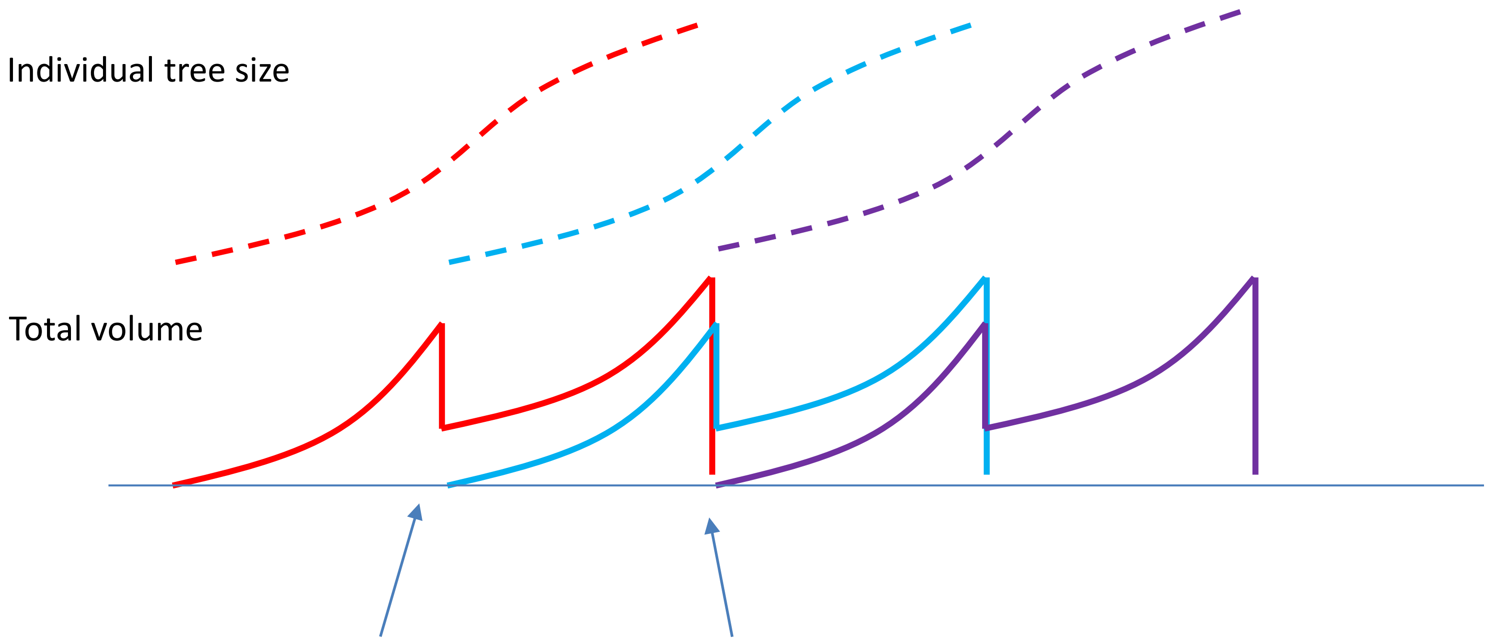


(**a**) Short even aged stand with little understory vegetation. (**b**) Uneven aged stand composed of tall trees and dense midstory vegetation. (**c**) Even aged stand with some mid and understory growth. (**d**) Tall open stand with distinct understory vegetation.

(Swatantran et al. 2016)

Uneven-aged stand
Selection cutting

https://wellesley.shinyapps.io/forestry



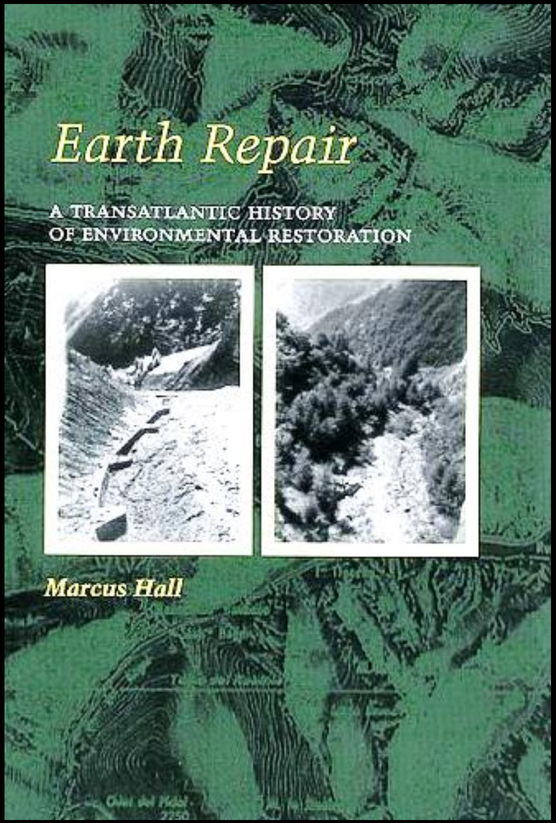
Thin small trees

- Firewood, small boards
- Reduce competition – promote large tree growth
- Plant new trees

Harvest large trees

- Valuable $$
- Thin small trees
- Plant new trees

For Monday 4/29 – "Earth Repair" by Marcus Hall



How do humans consider "nature"?
What is *Preservation*? *Conservation*? *Restoration*?

- Everybody read the Introduction
- Chapter Four:
  - Last names A-I
- Chapter Six:
  - Last names K-Z

1. Come prepared to help introduce your chapter to the other group
2. What are Hall's main points? What frameworks does he introduce? What do they contribute?
3. How do you think about conservation / restoration / stewardship and does Hall change anything for you?

Final Synthesis

- Similar format to midterm synthesis
- Focused more (but not entirely) on material since midterm
- There will be *some* coding required, but not much

<u>Review Session</u>: Thursday (5/2) 2:00 – 3:00

<u>Synthesis Available</u>: Friday 5/3

<u>Synthesis Due</u>: Thursday 5/9 at 4:00pm (college deadline)

Tropical deforestation (Sumatra)

Tar sands (Canada)

Abandoned field (China)

Desertification (Burkina Faso)

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When and where to actively restore ecosystems?

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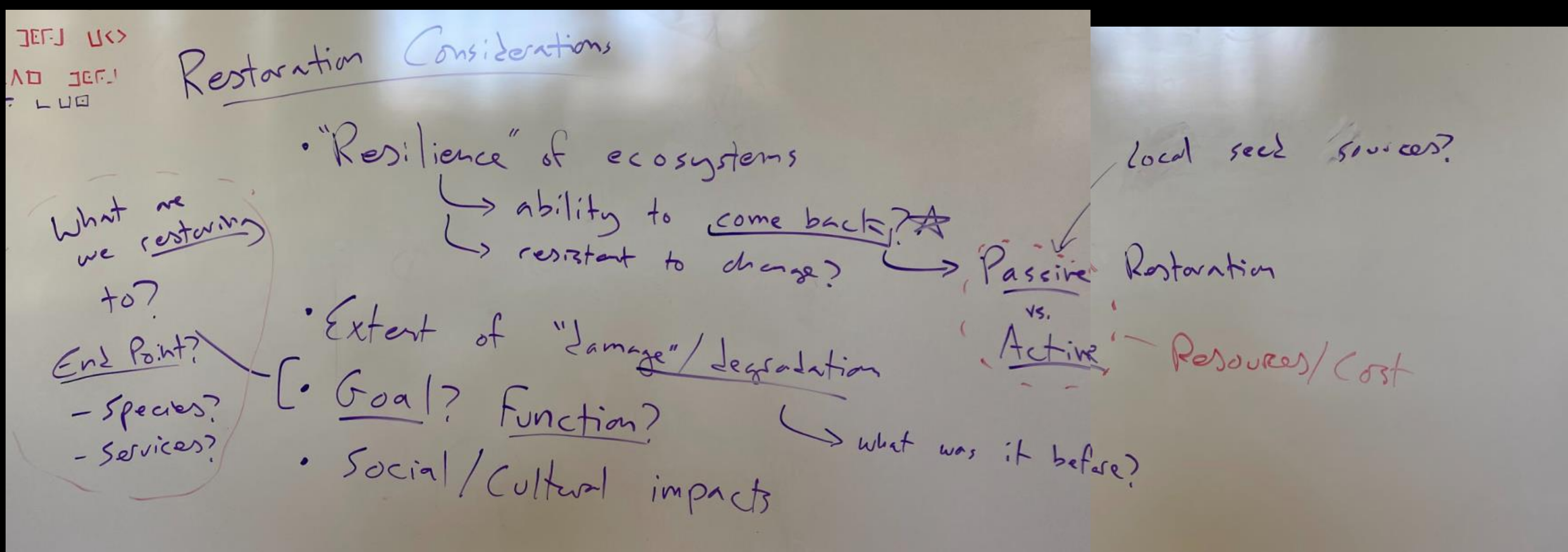
[a] Environmental Studies Department, University of California, Santa Cruz, CA 95064, USA
[b] Department of Biology, University of Puerto Rico-Rio Piedras, P.O. Box 23360, San Juan, PR 00931-3360, USA

What do we need to consider when restoring an ecosystem?

What do we need to consider when restoring an ecosystem?



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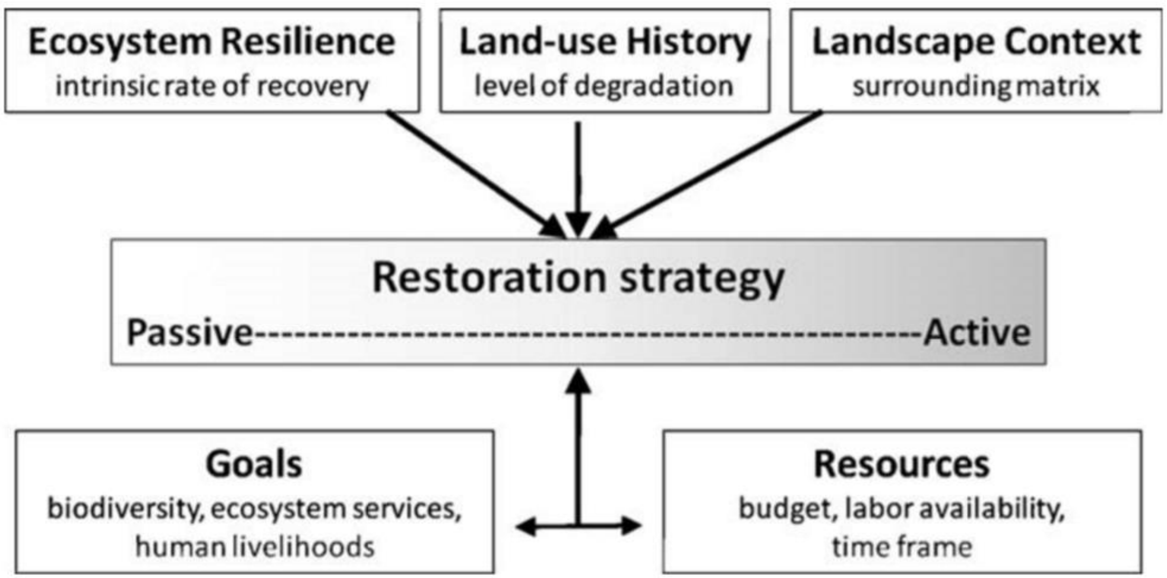
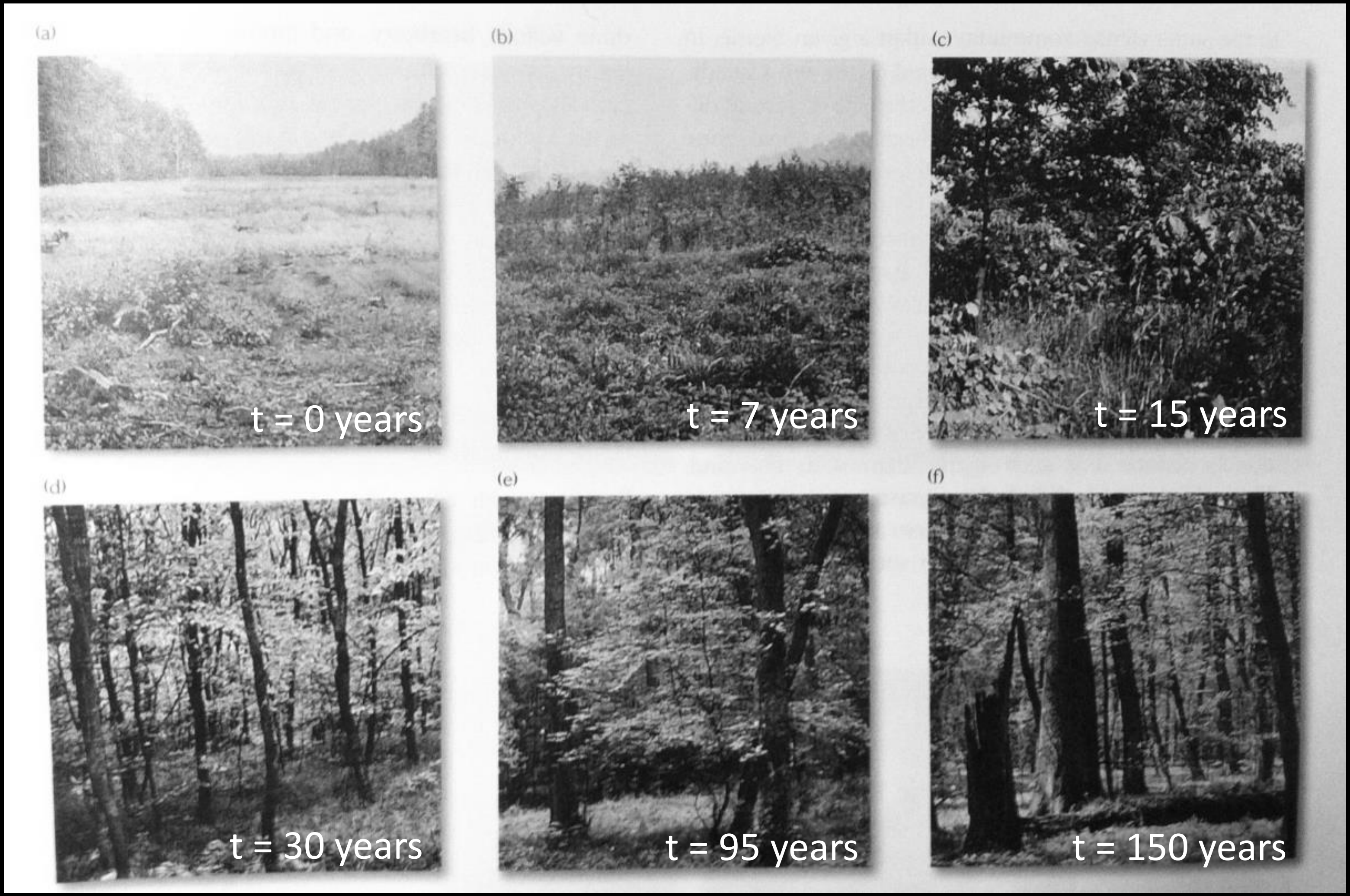


Fig. 1. Factors that should be considered when planning the management strategies for recovering/restoring degraded lands.

Forest succession in Southern Poland - Passive Restoration



(Z. Glowacinski)

Active Restoration

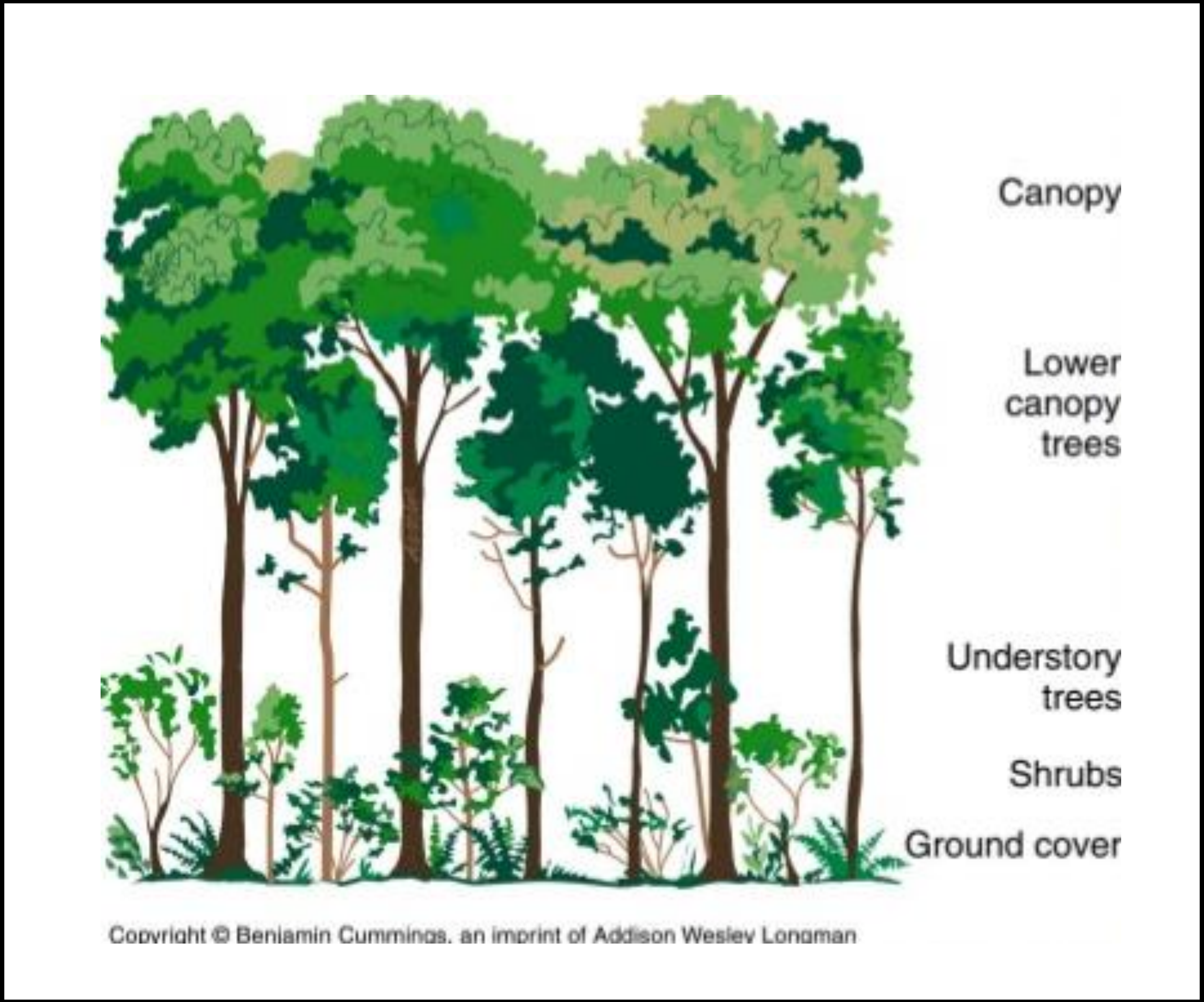
How can we characterize ecosystems?

Characterizing Ecosystems?

Quantifying the "state" of an ecosystem

- Density/ #'s of individuals (trees, herbs, birds)
- Soil type/ Quality
- Types of species, composition
    - total species or types of species
- Function: carbon sequestion/photosynthesis
- Microclimate
- Age structure, canopy structure

Recovery of forest understories?



Do Appalachian Herbaceous Understories Ever Recover from Clearcutting?

DAVID CAMERON DUFFY

Institute of Ecology
University of Georgia
Athens, GA 30602, U.S.A.

ALBERT J. MEIER

Institute of Ecology
University of Georgia
Athens, GA 30602, U.S.A.

(Southern Appalachian Timber, Inc.)

Primary = Never Logged *Secondary* = Logged within past 90 years

Table 1. Means and standard errors for species richness of primary and matching secondary sites.

Site	*Primary*	*Secondary*	*DF*	*P*	*Age of second growth*
Cumberland Plateau	11.20 ± 0.67	7.25 ± 0.49	38	<0.0001	10,70*
Lilley Cornett	9.00 ± 0.43	7.35 ± 0.42	37	0.0047	45
Ramsay Cascade	9.95 ± 0.30	8.75 ± 0.63	38	0.0475	51
Kilmer Memorial	14.53 ± 0.67	6.04 ± 0.59	37	<0.0001	52
Walker Cove	10.40 ± 0.53	7.30 ± 0.50	38	<0.0001	58
Porter's Flat	11.60 ± 0.43	4.94 ± 0.51	36	<0.0001	64
Upper Porter's Creek	11.36 ± 1.12	2.50 ± 0.67	19	<0.0001	64
Ramp Cove	10.65 ± 0.39	7.45 ± 0.31	38	<0.0001	68
Sosebee Cove	9.55 ± 0.41	7.55 ± 0.36	38	0.0003	87

* *See text for details.*

"Reference" Ecosystem

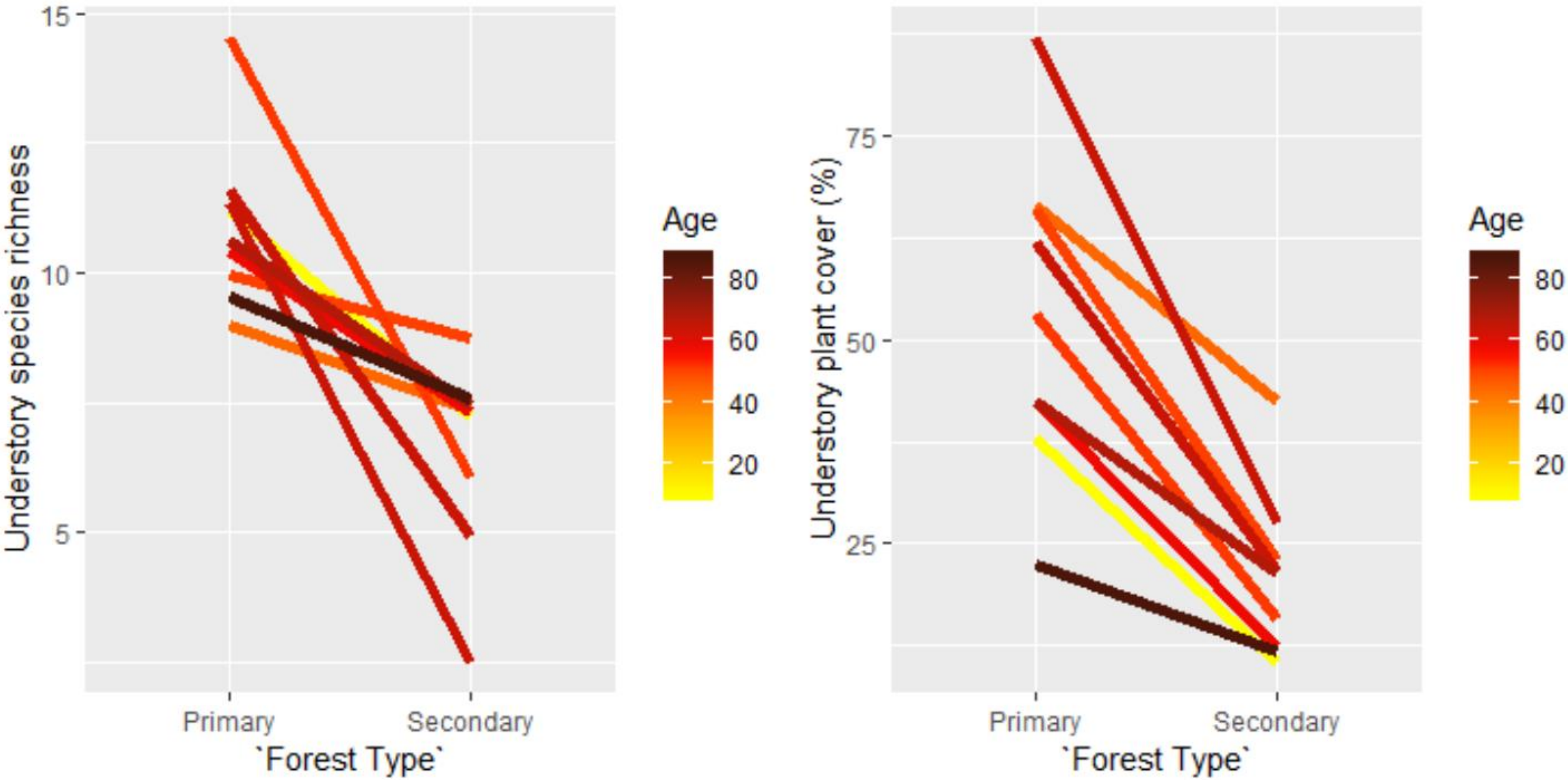
"Space for Time" substitution

Table 2. Means and standard errors for cover of primary and matching secondary sites.*

	Primary	*Secondary*	*P*
Cumberland Plateau	38.0 ± 3.2	10.5 ± 1.7	<0.0001
Lilley Cornett	66.6 ± 3.8	42.5 ± 2.9	<0.0001
Ramsay Cascade	66.0 ± 3.9	23.0 ± 3.1	<0.0001
Kilmer Memorial	53.0 ± 4.2	15.7 ± 2.6	<0.0001
Walker Cove	42.5 ± 3.5	12.25 ± 3.5	<0.0001
Porter's Flat	87.0 ± 1.9	27.6 ± 5.0	<0.0001
Upper Porter's Creek	62.0 ± 7.8	21.5 ± 7.7	0.0008
Ramp Cove	42.5 ± 2.9	21.3 ± 2.4	<0.0001
Sosebee Cove	22.5 ± 1.9	11.7 ± 1.2	<0.0001

* *Sites are arranged by increasing age of the secondary sites (Table 1).*

(Duffy and Meier)



15
10
5
Understory species richness
Primary
Secondary
`Forest Type`
Age
80
60
40
20
75
50
25
Understory plant cover (%)
Primary
Secondary
`Forest Type`
Age
80
60
40
20

Recovery Patterns of Understory Herbs and Their Use as Indicators of Deciduous Forest Regeneration

STEPHANE M. McLACHLAN* AND DAWN R. BAZELY
Department of Biology, York University, North York, Ontario M3J 1P3, Canada

Point Pelee National Park (Canada)

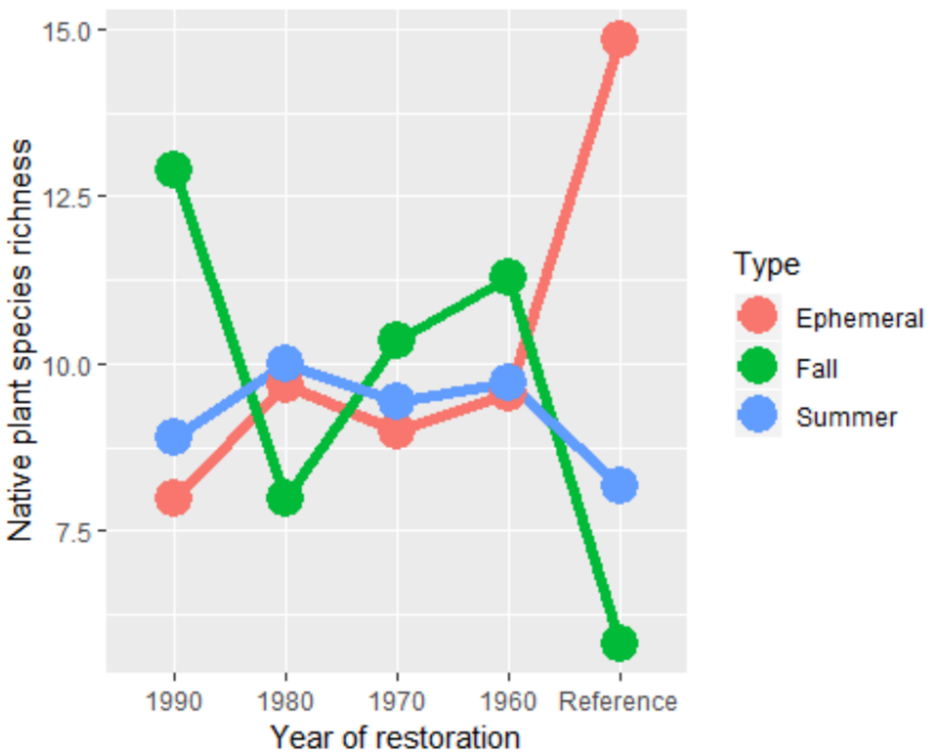
Table 4. Relationship between restoration history of sites and flowering phenology types for the native plant communities of restored sites at Point Pelée National Park and relatively undisturbed reference sites at Point Pelée National Park and Fish Point Nature Preserve, Ontario, Canada.*

		Ephemeral		*Summer*		*Fall*	
Decade of restoration	*No. of sites*	*percent cover (SE)*	*spp. no. (SE)*	*percent cover (SE)*	*spp. no. (SE)*	*percent cover (SE)*	*spp. no. (SE)*
1990	6	4.54 (1.27)*a*	8.00 (1.09)*a*	7.69 (3.69)*a*	8.89 (1.53)*a*	65.14 (23.21)*a*	12.89 (1.70)*a*
1980	7	28.25 (17.73)*bc*	9.67 (0.33)*a*	18.75 (10.57)*a*	10.00 (2.89)*a*	46.15 (29.40)*ab*	8.00 (3.61)*bc*
1970	8	12.93 (2.86)*c*	9.00 (0.37)*a*	16.18 (4.20)*a*	9.44 (0.73)*a*	44.16 (9.20)*a*	10.33 (0.96)*ab*
1960	7	31.95 (13.25)*c*	9.57 (1.04)*a*	21.39 (4.21)*a*	9.71 (1.04)*a*	20.69 (5.07)*ab*	11.29 (1.32)*ab*
Reference site	6	69.27 (16.09)*b*	14.83 (0.65)*b*	16.29 (4.55)*a*	8.17 (0.75)*a*	7.29 (1.61)*b*	5.83 (1.17)*c*

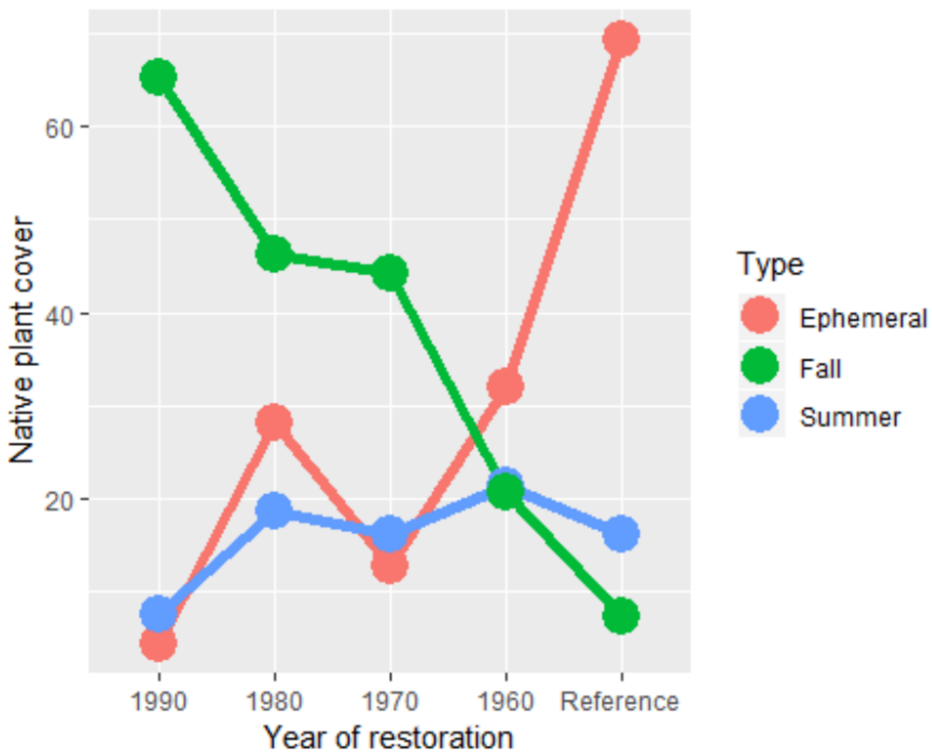
**Ephemeral herbs flower April–June (ephemeral); summer herbs flower June–August (summer); fall herbs flower after August (fall). Data are square-root transformed; untransformed means are presented. Percent cover is the mean percent cover per site for each age class. Spp. no. is the mean species richness per site for each age class. Means followed by different letters are significantly different at* $p < 0.05$ *according to Duncan's multiple means test.*

(McLachlan and Bazeley)

Diversity



Cover



<u>Ephemeral</u>: Flowers in early spring, then goes dormant
<u>Summer</u>: Grows all season and flowers in the summer
<u>Fall</u>: Grows all season and flowers in the fall

How can <u>quantify</u> ecosystem similarity / dissimilarity?

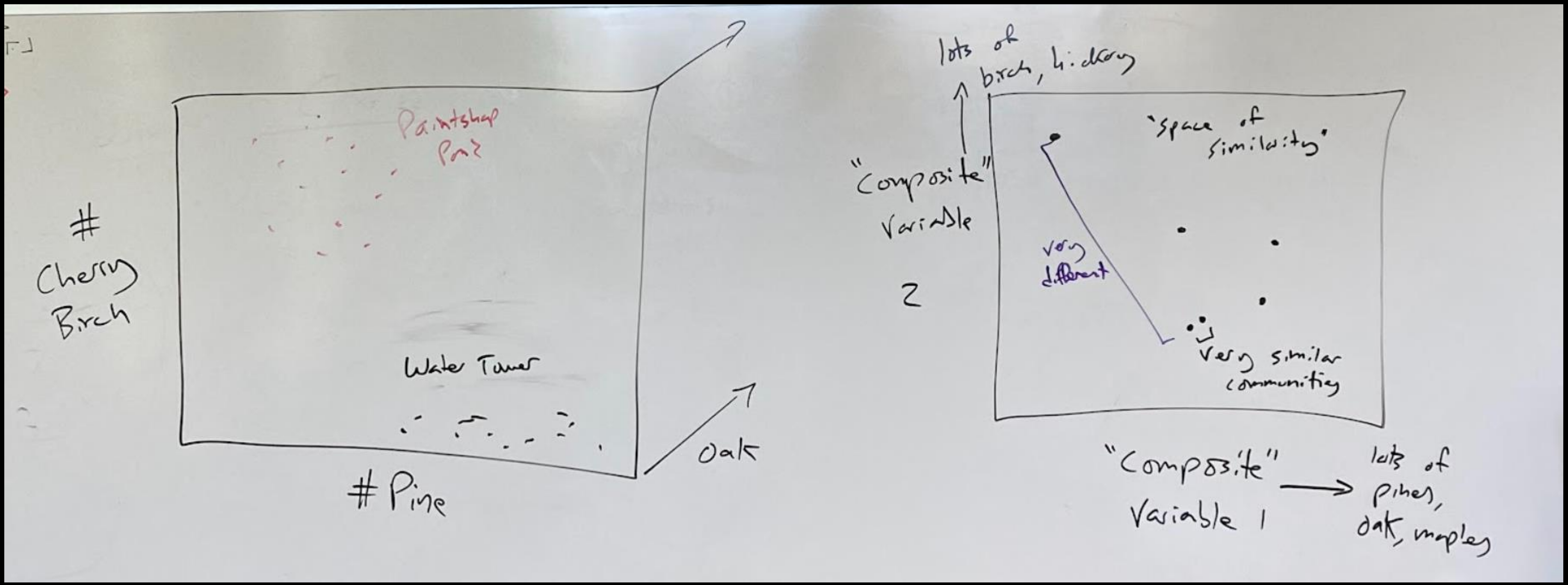
"Community Matrix"

- The number of individuals of each species found in each sampling plot
- NOT a projection matrix

Location	Plot	Cherry birch	Red oak	White pine	Pignut hickory	Red maple	Black oak	Eastern hemlock	Scarlet oak	White oak	American beech	Black cherry	Mockernut hickory	Norway maple	Shagbark hickory	Flowering dogwood	Paper birch	Yellow birch	European beech	Choke cherry	Norway spruce	American chestnut	Malus sp.	Sugar maple
Paintshop Pond Esker	PPE 2017 - 1	8	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 2	16	6	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 3	6	0	2	0	0	2	6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 4	0	0	0	0	0	1	6	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 5	3	3	9	1	1	4	6	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 1	5	3	2	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 2	3	4	1	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 3	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 4	9	3	3	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 1	0	0	4	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 10	0	0	1	0	0	1	0	0	1	0	1	1	1	4	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 11	0	0	3	0	1	3	0	1	1	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 4	0	0	8	0	0	1	0	1	0	0	0	0	0	0	1	6	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 6	1	0	10	0	0	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 8	0	0	3	0	0	0	1	2	4	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2017 - 1	0	0	4	0	6	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Water Tower Hill	WTH 2017 - 2	0	0	8	0	6	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2017 - 3	0	0	2	1	2	2	0	0	1	0	0	0	3	0	0	0	0	1	0	0	0	0	0
Water Tower Hill	WTH 2018 - 1	0	0	2	0	0	0	0	2	2	1	0	0	3	4	0	0	0	0	1	0	0	0	0
Water Tower Hill	WTH 2018 - 2	0	0	6	0	0	0	1	0	1	0	0	0	1	4	0	0	0	0	0	1	0	0	0
Water Tower Hill	WTH 2019 - 1	0	0	5	0	1	3	0	0	5	0	1	2	0	1	1	0	0	0	0	0	1	1	1
Water Tower Hill	WTH 2019 - 2	0	0	4	0	2	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Ordination

- A "family" of analyses that aims to simplify datasets with many variables into simpler representations that describe similarities/differences among samples.



Ordination ("Multidimensional Scaling")

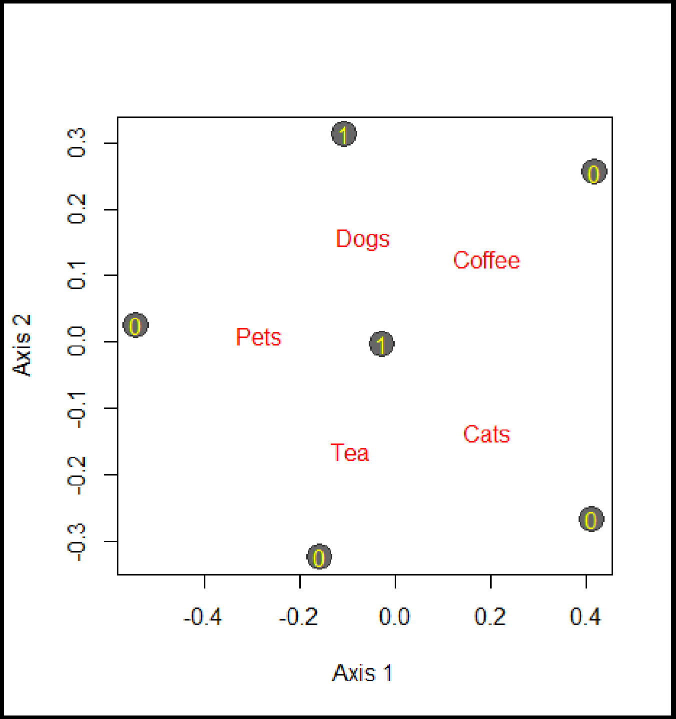
Example Data

- One person has a 1 for all variables
- Everyone else has a 1 in a unique variable

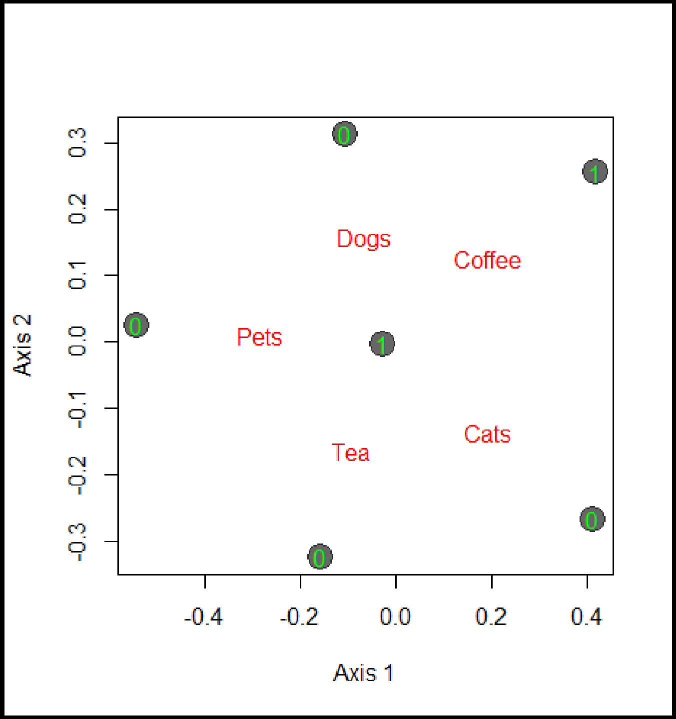
Cats	Dogs	Pets	Coffee	Tea
1	1	1	1	1
1	0	0	0	0
0	1	0	0	0
0	0	1	0	0
0	0	0	1	0
0	0	0	0	1

Red labels indicate average values

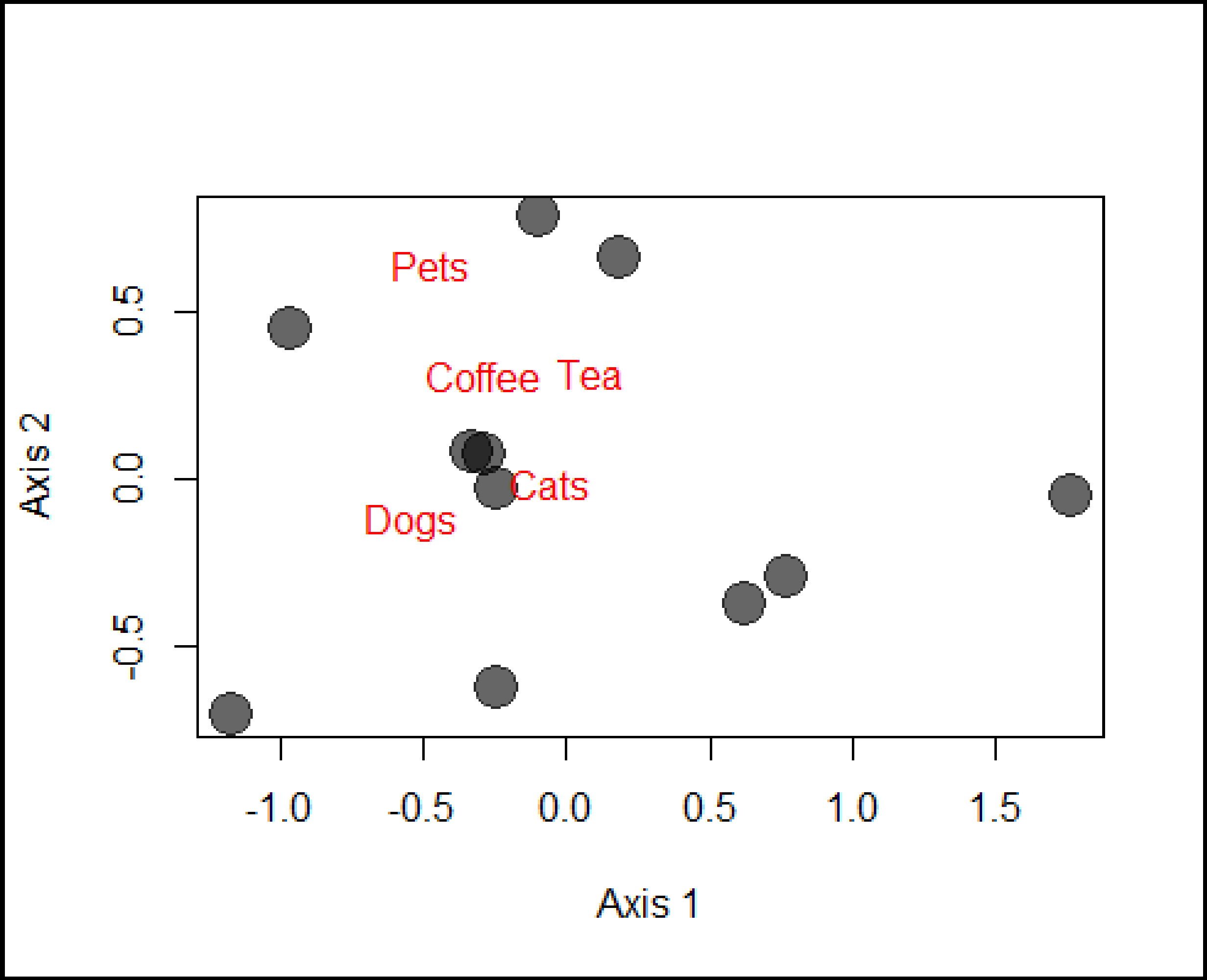
Yellow = Number of Dogs



Green = Cups of Coffee



ES 220 – Ordination of Similarities



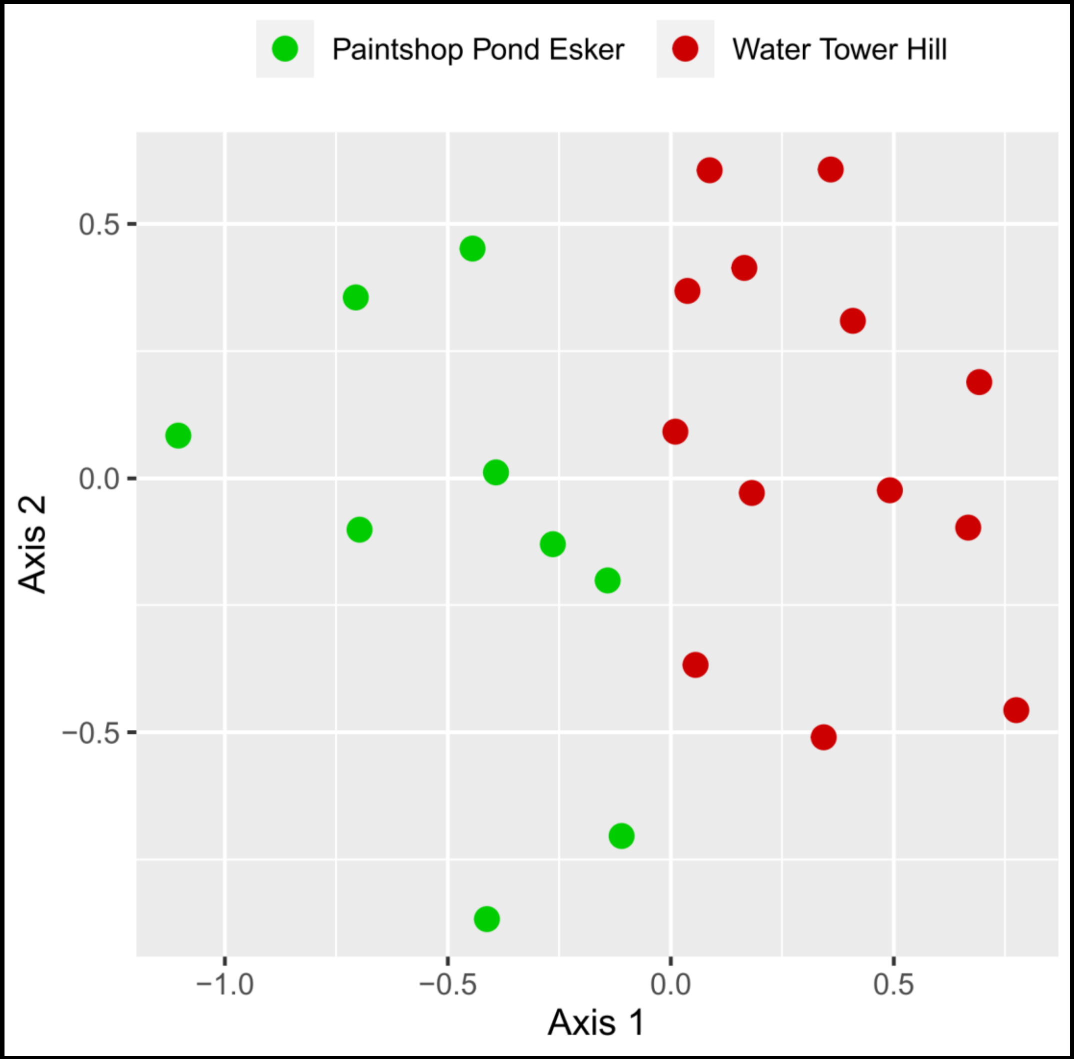
"Community Matrix"

- The <u>number of individuals</u> of each species found in each sampling plot
- NOT a projection matrix

Location	Plot	Cherry birch	Red oak	White pine	Pignut hickory	Red maple	Black oak	Eastern hemlock	Scarlet oak	White oak	American beech	Black cherry	Mockernut hickory	Norway maple	Shagbark hickory	Flowering dogwood	Paper birch	Yellow birch	European beech	Choke cherry	Norway spruce	American chestnut	Malus sp.	Sugar maple
Paintshop Pond Esker	PPE 2017 - 1	8	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 2	16	6	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 3	6	0	2	0	0	2	6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 4	0	0	0	0	0	1	6	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 5	3	3	9	1	1	4	6	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 1	5	3	2	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 2	3	4	1	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 3	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 4	9	3	3	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 1	0	0	4	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 10	0	0	1	0	0	1	0	0	1	0	1	1	1	4	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 11	0	0	3	0	1	3	0	1	1	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 4	0	0	8	0	0	1	0	1	0	0	0	0	0	0	1	6	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 6	1	0	10	0	0	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 8	0	0	3	0	0	0	1	2	4	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2017 - 1	0	0	4	0	6	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Water Tower Hill	WTH 2017 - 2	0	0	8	0	6	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2017 - 3	0	0	2	1	2	2	0	0	1	0	0	0	3	0	0	0	0	1	0	0	0	0	0
Water Tower Hill	WTH 2018 - 1	0	0	2	0	0	0	0	2	2	1	0	0	3	4	0	0	0	0	1	0	0	0	0
Water Tower Hill	WTH 2018 - 2	0	0	6	0	0	0	1	0	1	0	0	0	1	4	0	0	0	0	0	1	0	0	0
Water Tower Hill	WTH 2019 - 1	0	0	5	0	1	3	0	0	5	0	1	2	0	1	1	0	0	0	0	0	1	1	1
Water Tower Hill	WTH 2019 - 2	0	0	4	0	2	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Ordination of Tree Communities on Campus

- "Nonmetric multidimensional scaling" analysis
- Points close together are similar in terms of the types and number of trees



Ordination of Tree Communities on Campus

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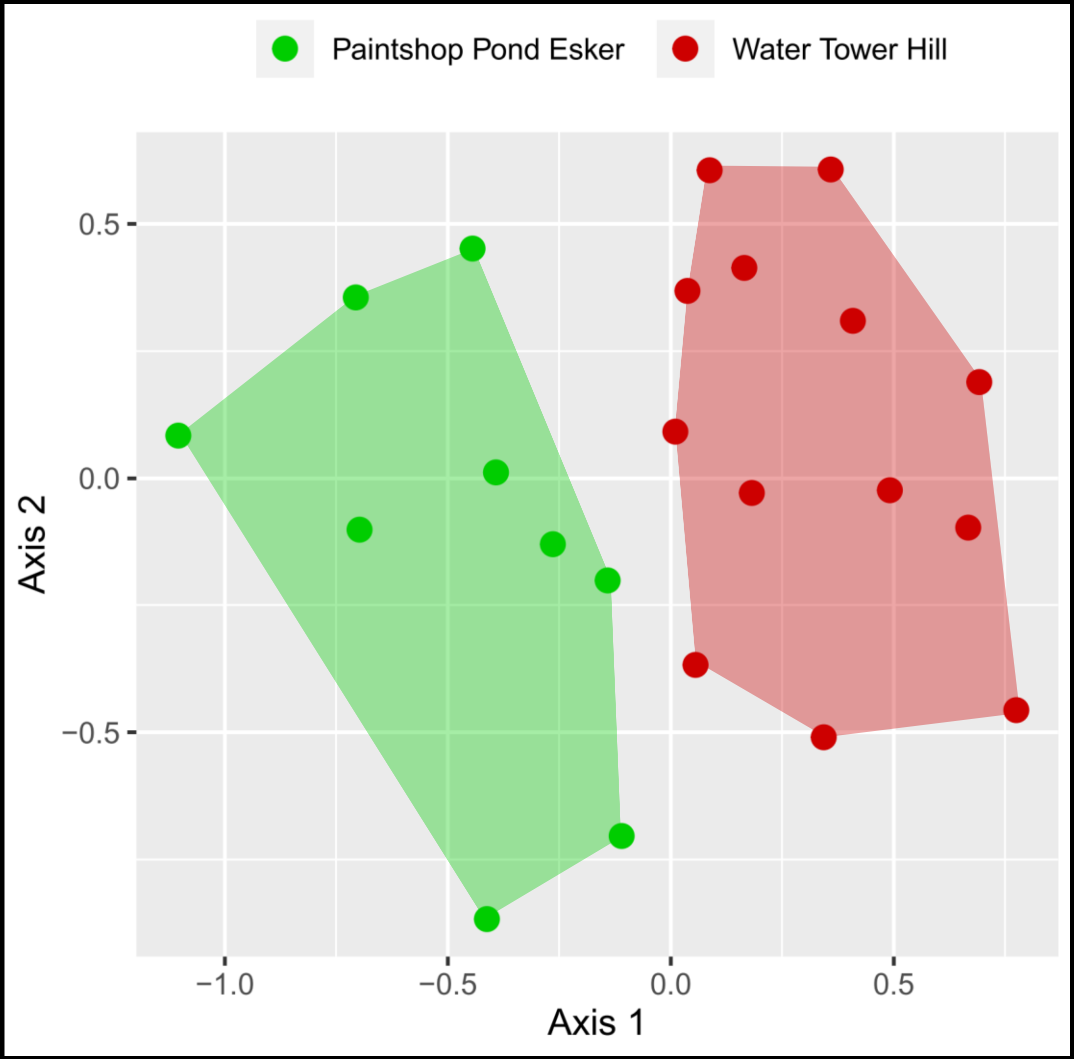


Reading for Wednesday (Reading Response Due)

The Planet of No Return

Human Resilience on an Artificial Earth

Erle Ellis

Final Synthesis

- Similar format to midterm synthesis
- Focused more (but not entirely) on material since midterm
- There will be *some* coding required, but not much

<u>Review Session</u>: Thursday (5/2) 2:00 – 3:00 (in Obs 123)

<u>Synthesis Available</u>: Friday 5/3

<u>Synthesis Due</u>: Thursday 5/9 at 4:00pm (college deadline)

Ordination ("Multidimensional Scaling")

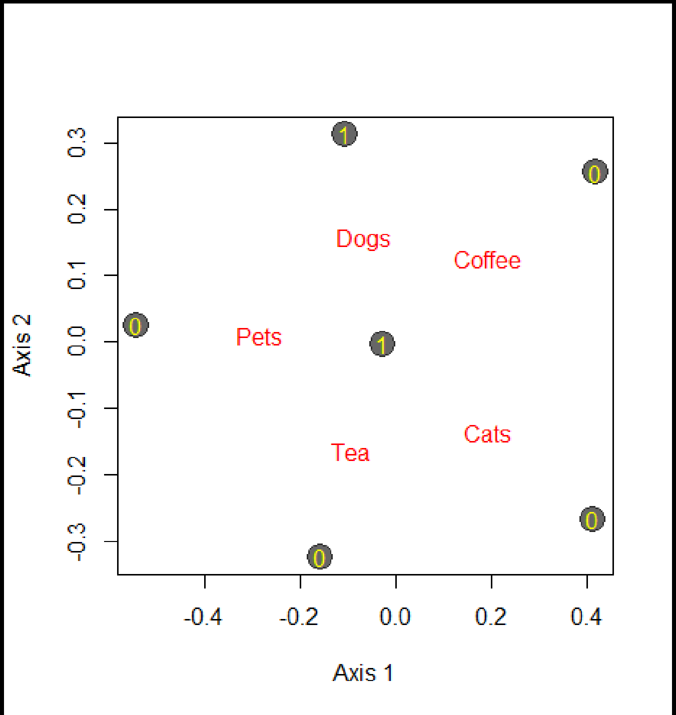
Example Data

- One person has a 1 for all variables
- Everyone else has a 1 in a unique variable

Cats	Dogs	Pets	Coffee	Tea
1	1	1	1	1
1	0	0	0	0
0	1	0	0	0
0	0	1	0	0
0	0	0	1	0
0	0	0	0	1

Red labels indicate average values

Yellow = Number of Dogs



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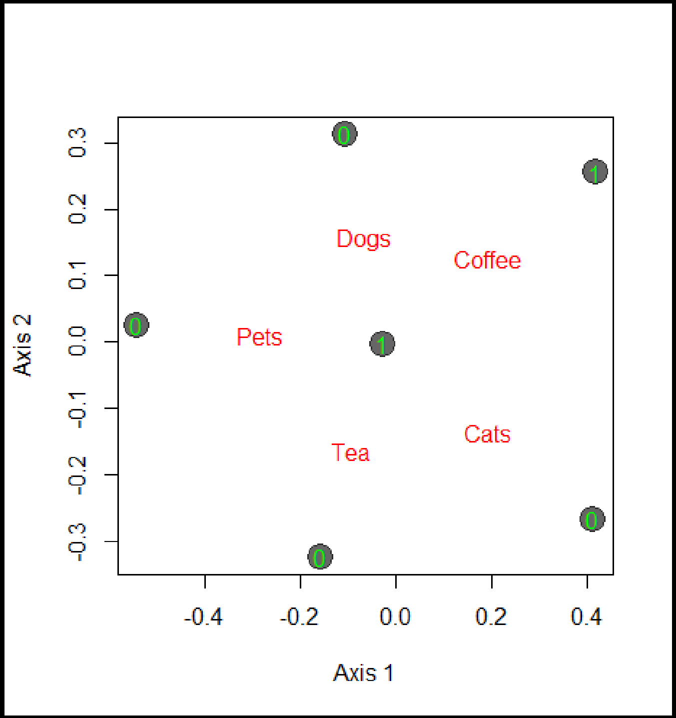
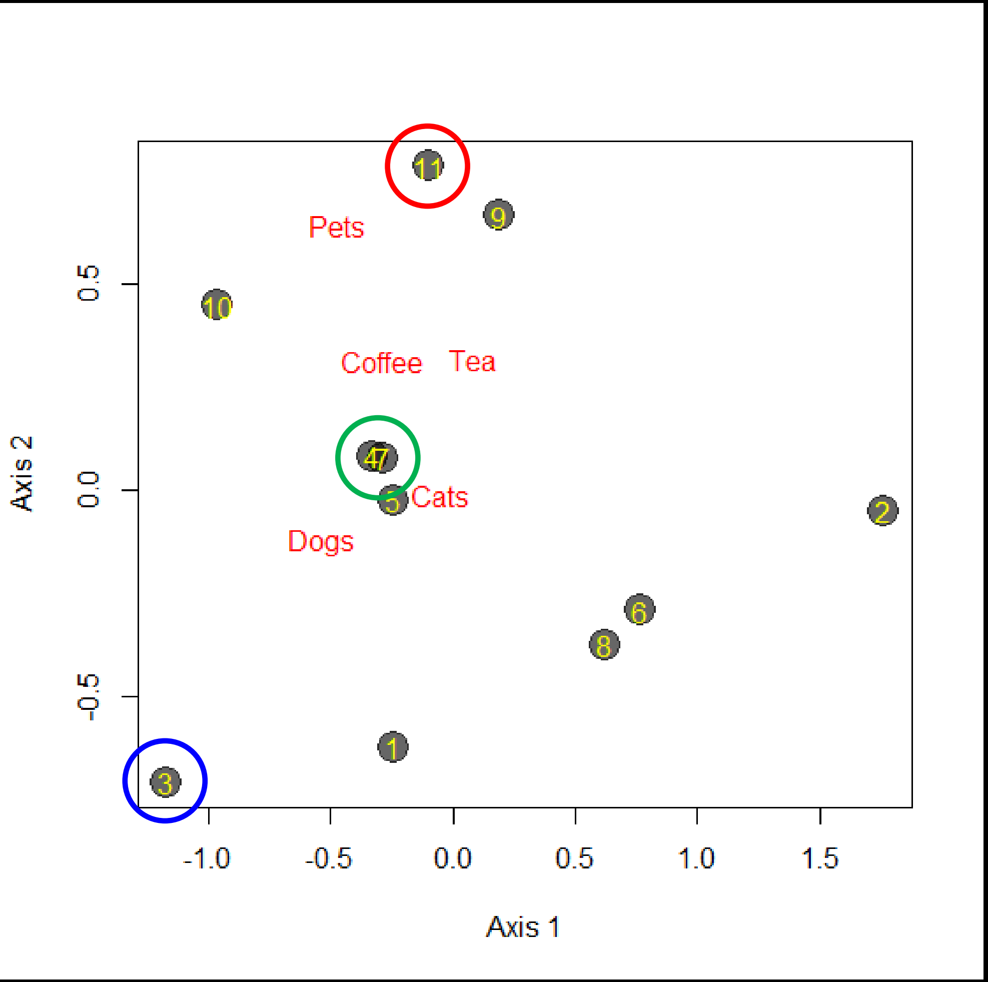


ES 220 – Ordination of Similarities

Individual	Cats	Dogs	Pets	Coffee	Tea
1	2	1	0	0	0.5
2	0	0	0	0	0.1
3	0	1	0	0	0
4	0	1	0	3	1
5	1	1	0	2	1
6	0	0	0	0	1
7	0	1	0	2	1
8	1	0	0	0.1	1.2
9	0	0	0	2	4
10	0	1	3	2	0
11	2	0	4	2	3

Yellow = Individual



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Paintshop Pond Esker	PPE 2017 - 1	8	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 2	16	6	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 3	6	0	2	0	0	2	6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 4	0	0	0	0	0	1	6	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2017 - 5	3	3	9	1	1	4	6	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 1	5	3	2	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 2	3	4	1	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 3	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paintshop Pond Esker	PPE 2019 - 4	9	3	3	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 1	0	0	4	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 10	0	0	1	0	0	1	0	0	1	0	1	1	1	4	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 11	0	0	3	0	1	3	0	1	1	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 4	0	0	8	0	0	1	0	1	0	0	0	0	0	0	1	6	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 6	1	0	10	0	0	1	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2016 - 8	0	0	3	0	0	0	1	2	4	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2017 - 1	0	0	4	0	6	1	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Water Tower Hill	WTH 2017 - 2	0	0	8	0	6	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Tower Hill	WTH 2017 - 3	0	0	2	1	2	2	0	0	1	0	0	0	3	0	0	0	0	1	0	0	0	0	0
Water Tower Hill	WTH 2018 - 1	0	0	2	0	0	0	0	2	2	1	0	0	3	4	0	0	0	0	1	0	0	0	0
Water Tower Hill	WTH 2018 - 2	0	0	6	0	0	0	1	0	1	0	0	0	1	4	0	0	0	0	0	1	0	0	0
Water Tower Hill	WTH 2019 - 1	0	0	5	0	1	3	0	0	5	0	1	2	0	1	1	0	0	0	0	0	1	1	1
Water Tower Hill	WTH 2019 - 2	0	0	4	0	2	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Ordination of Tree Communities on Campus

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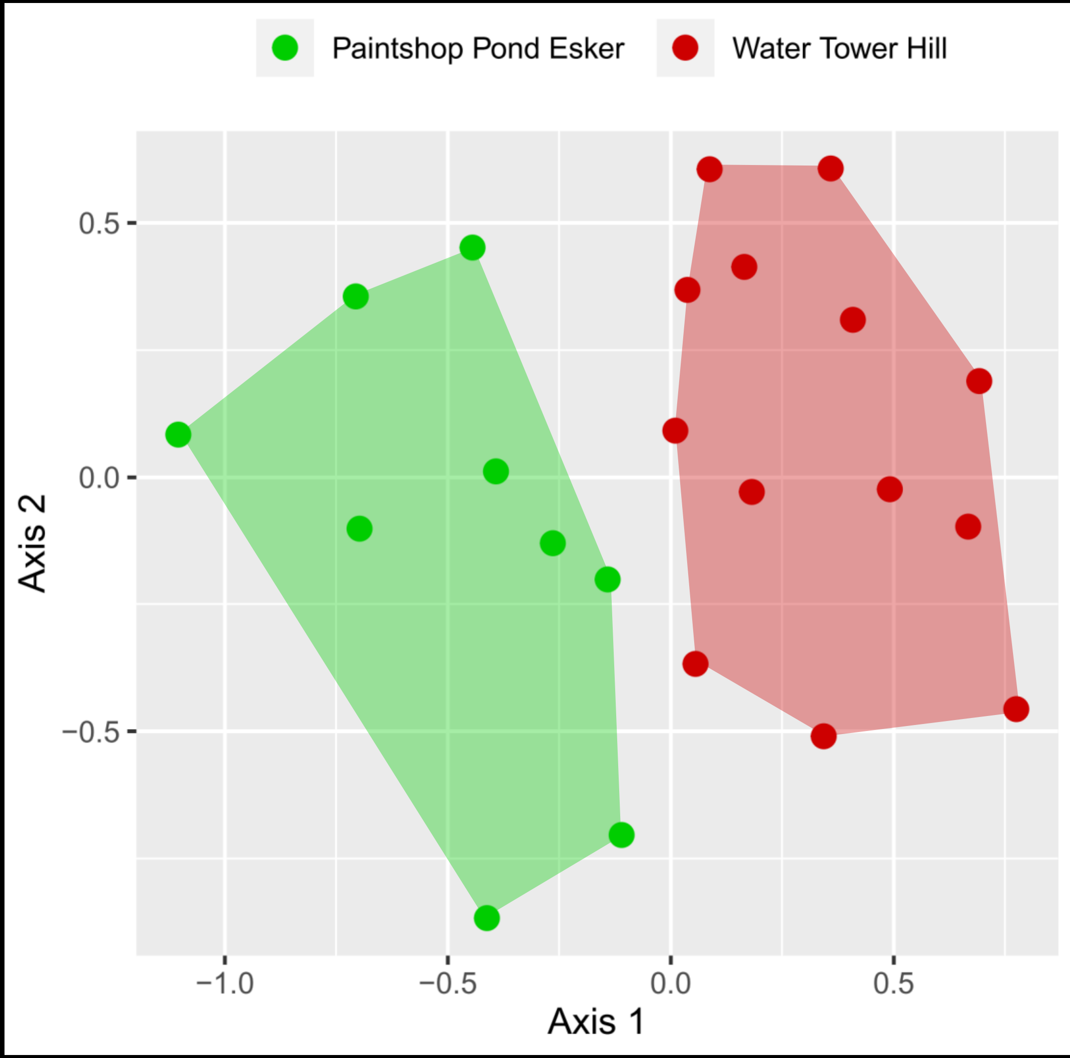


Journal of Applied Ecology 2002
39, 960–970

Long-term vegetation recovery on reclaimed coal surface mines in the eastern USA

KAREN D. HOLL
Department of Environmental Studies, University of California, Santa Cruz, CA 95064, USA

Comparison of abandoned coal mines, relaimed at different times:

Journal of Applied Ecology 2002
39, 960–970

Long-term vegetation recovery on reclaimed coal surface mines in the eastern USA

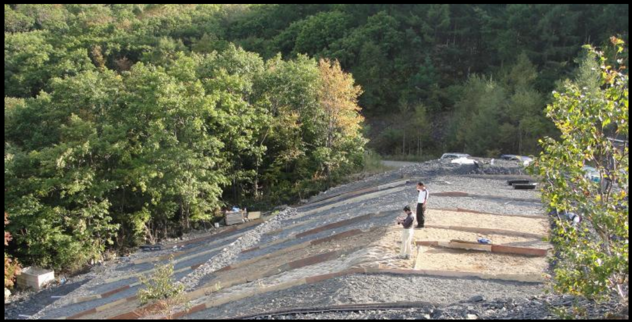
KAREN D. HOLL
Department of Environmental Studies, University of California, Santa Cruz, CA 95064, USA

Comparison of abandoned coal mines, relaimed at different times:

1962-1967
- hand seeded with nonnative grasses / legumes and one native tree
- no soil or site restorations

1972-1977
- mechanically seeded (hydroseeded)
  - mostly nonnative species
- pines planted on slopes

1980-1987 (legal requirements)
- restore original contour
- 1000 pines / ha
- mechanically seeded
  - mostly nonnative species



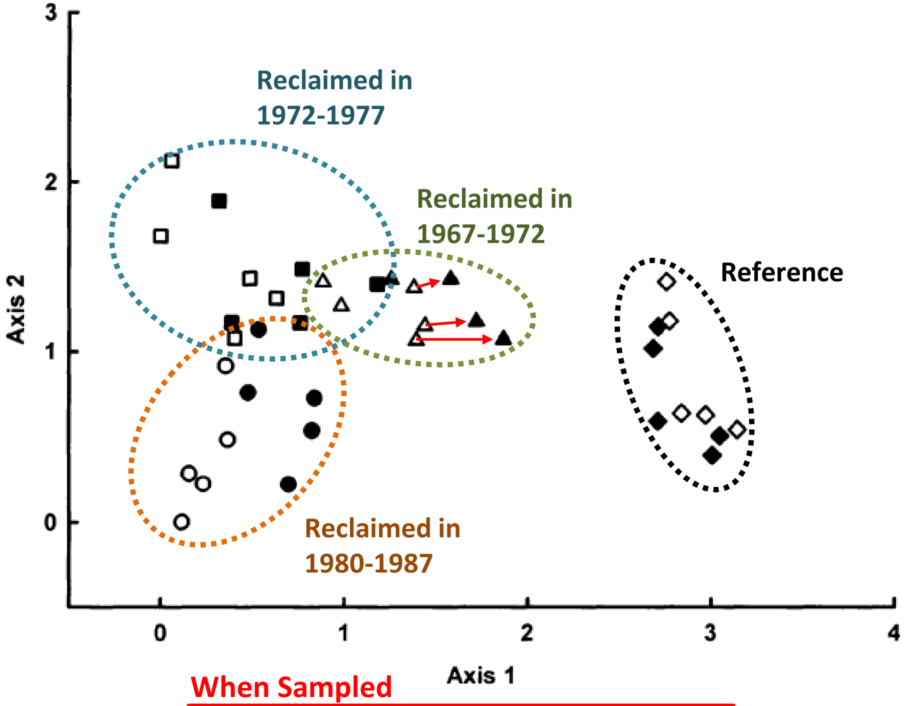
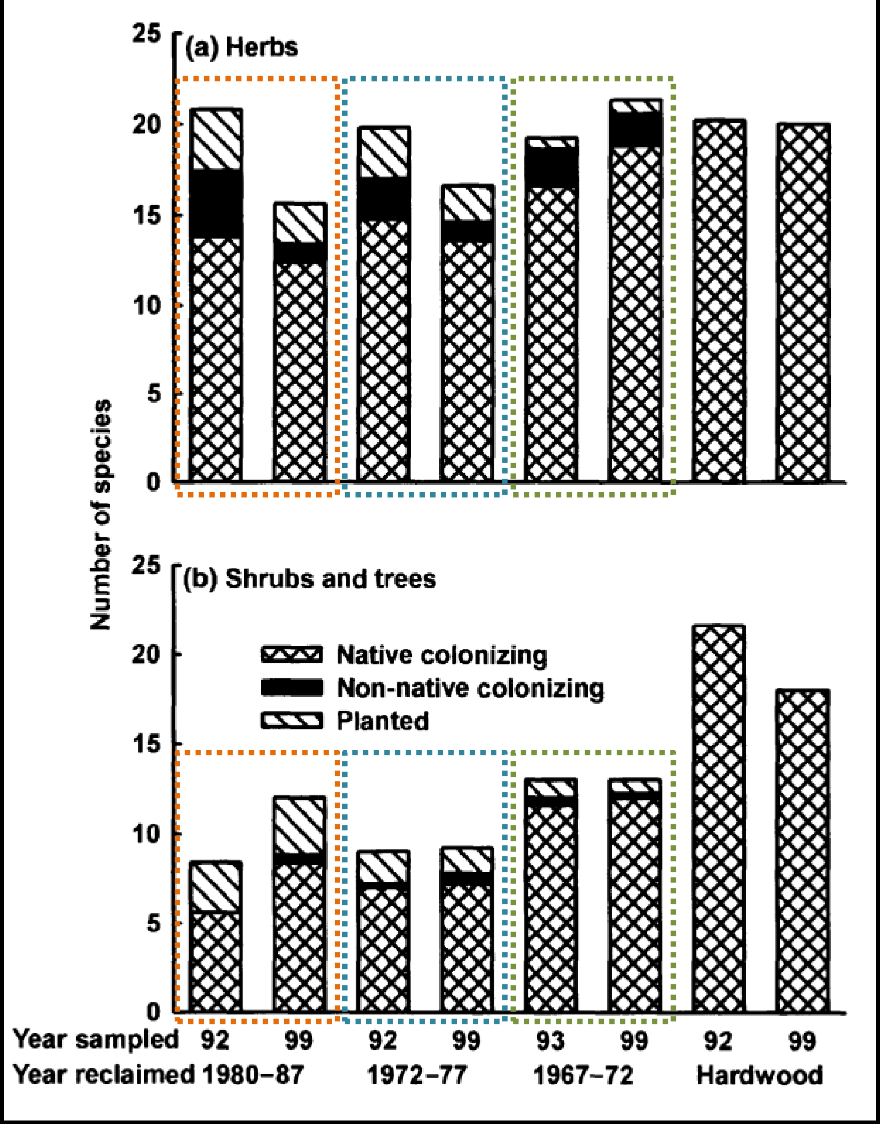
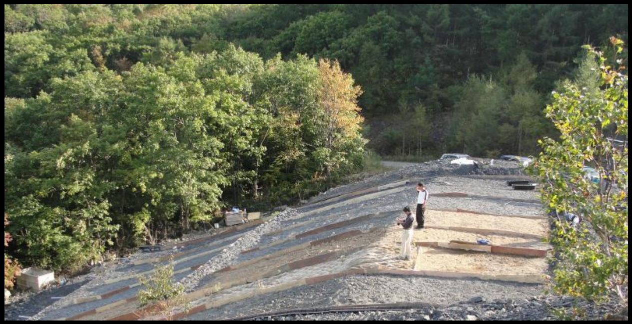


Fig. 2. Vegetation site DCA scores in 1992–93 (open symbols) and 1999 (solid symbols). Site type indicated by symbol shape: reclaimed 1980–87, circles; 1972–77, squares; 1967–72, triangles; forest, diamonds. Eigenvalues: axis 1 = 0·524, axis 2 = 0·198.

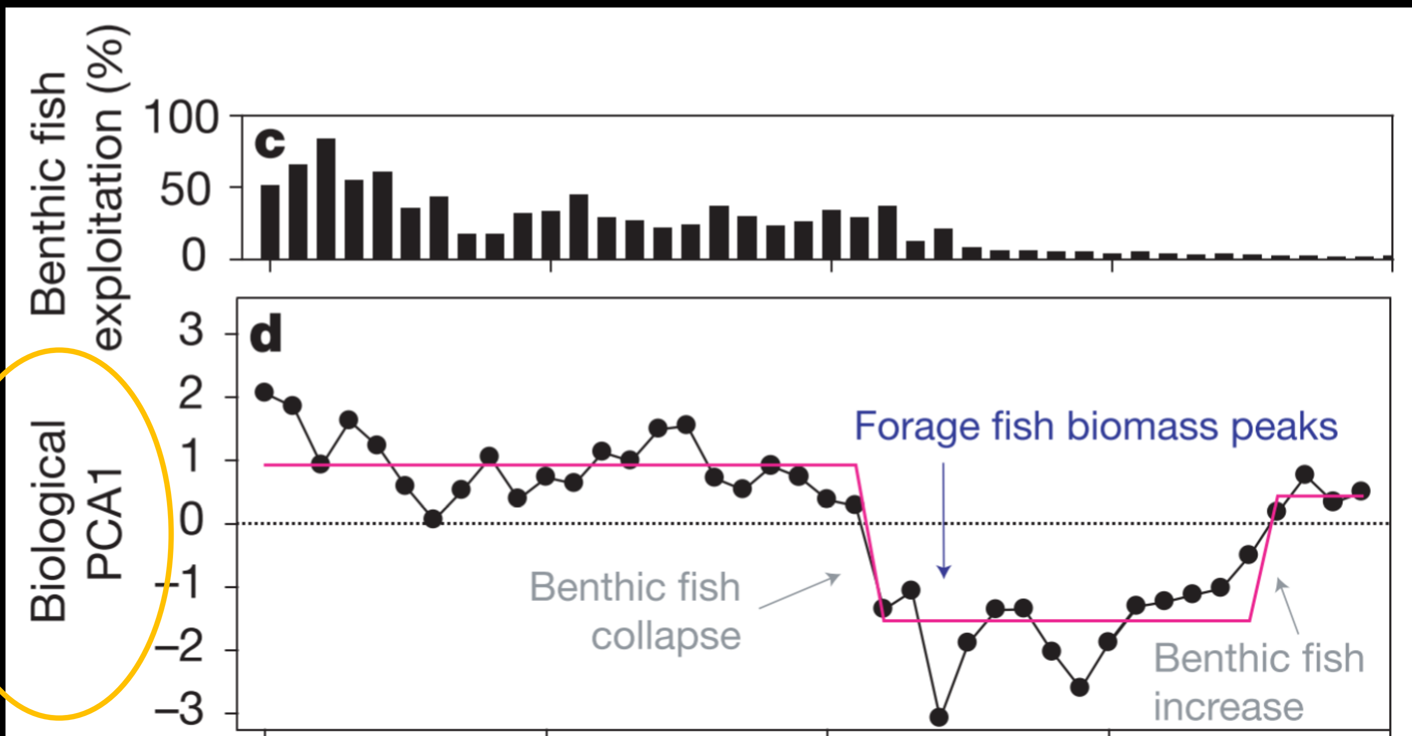
“Detrended Correspondence Analysis” – a type of ordination analysis

(Holl 2002)


(a) Herbs
(b) Shrubs and trees
Number of species
0
5
10
15
20
25
Native colonizing
Non-native colonizing
Planted
Year sampled 92 99 92 99 93 99 92 99
Year reclaimed 1980–87 1972–77 1967–72 Hardwood

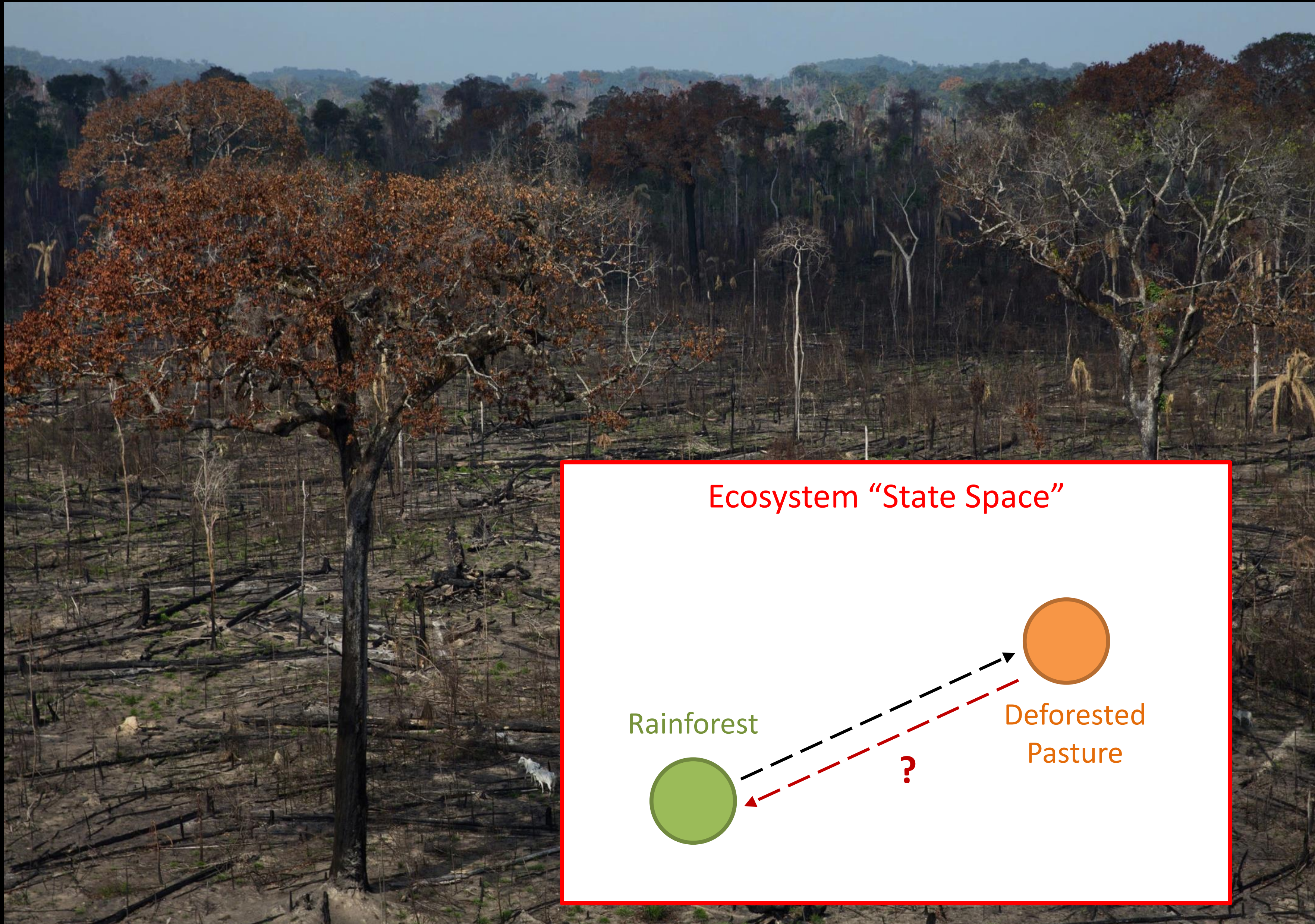


(Holl 2002)



Values for one axis of an ordination of ecosystem similarity / “state space”

(Frank et al.)

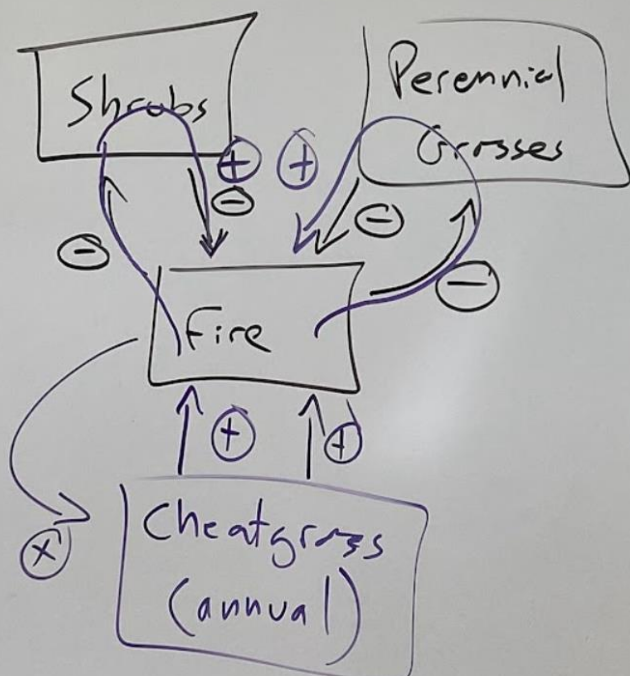


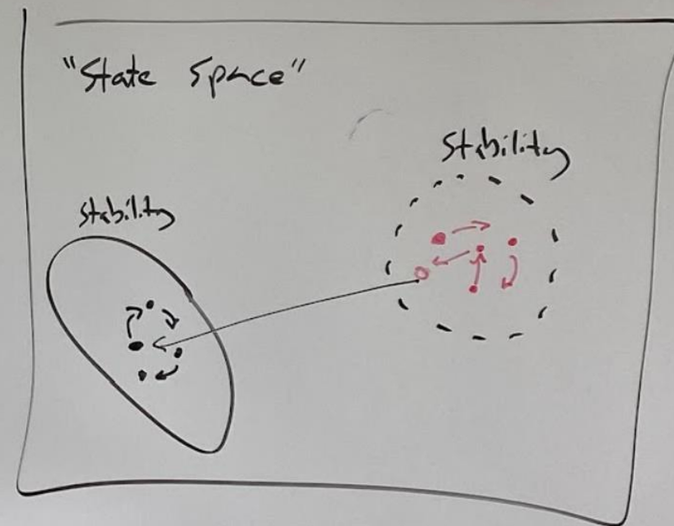
Cattle grazing on a tract of illegally cleared Amazon forest in Pará state, Brazil. In most major land habitats, the average abundance of native plant and animal life has fallen by 20 percent or more, mainly over the past century. Lalo de Almeida for The New York Times

Bromus tectorum – 'cheatgrass'

A 'Transformer Species'…

Alternative Ecosystem "States"





Bromus tectorum – ‘cheatgrass’

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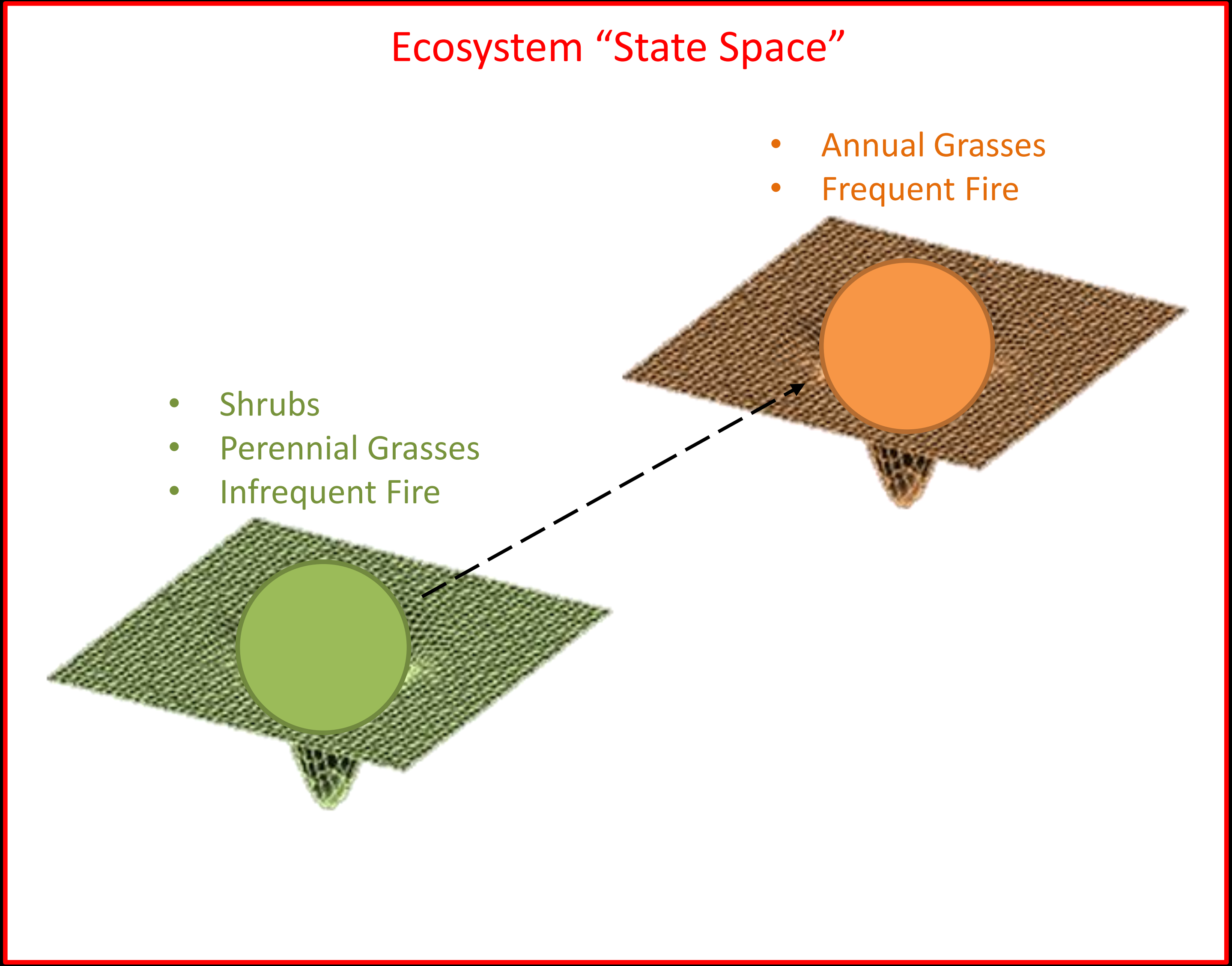
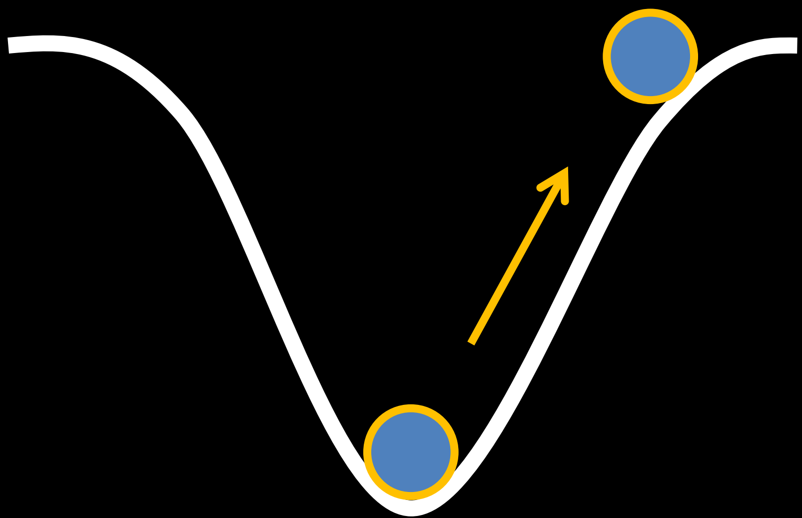
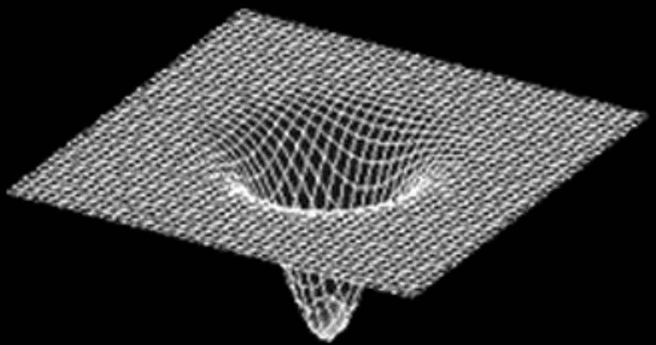
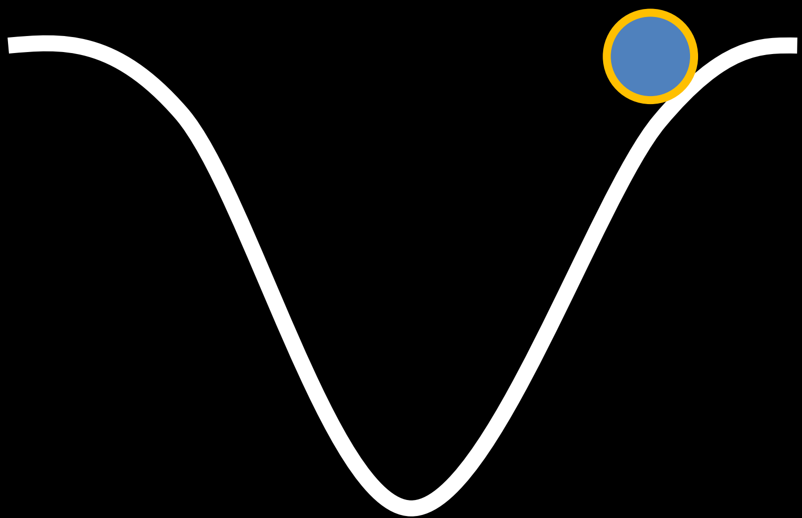


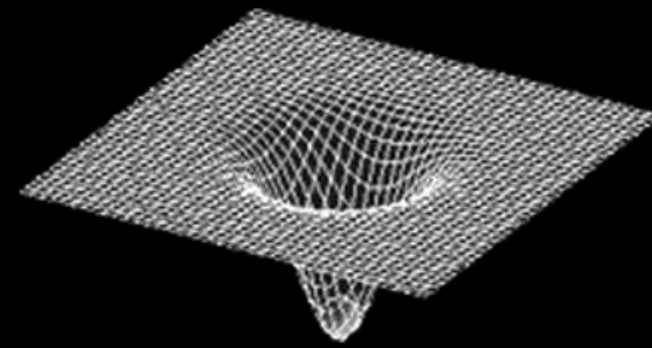
Ecosystem states, stability, and resilience



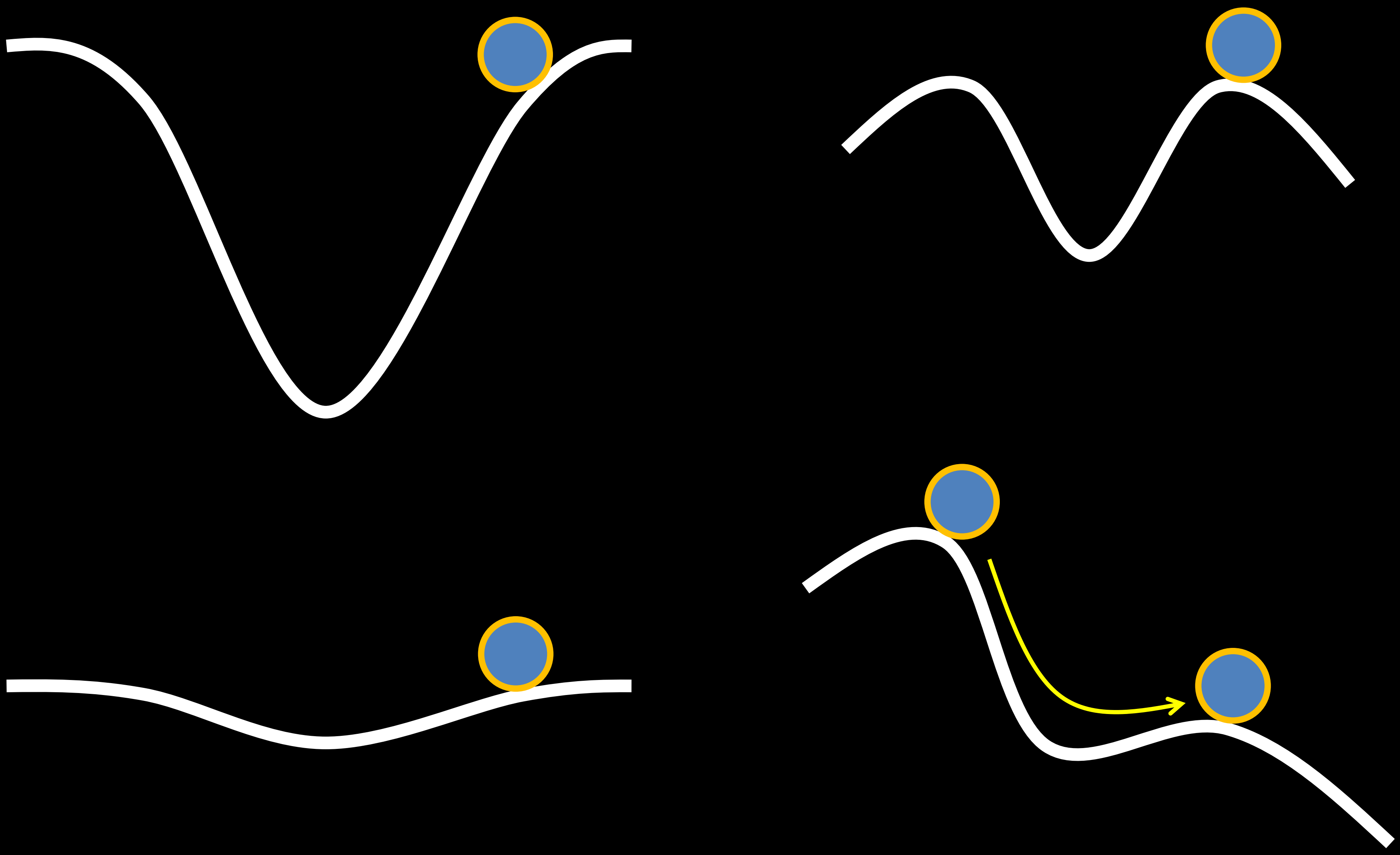


Ecosystem states, stability, and resilience

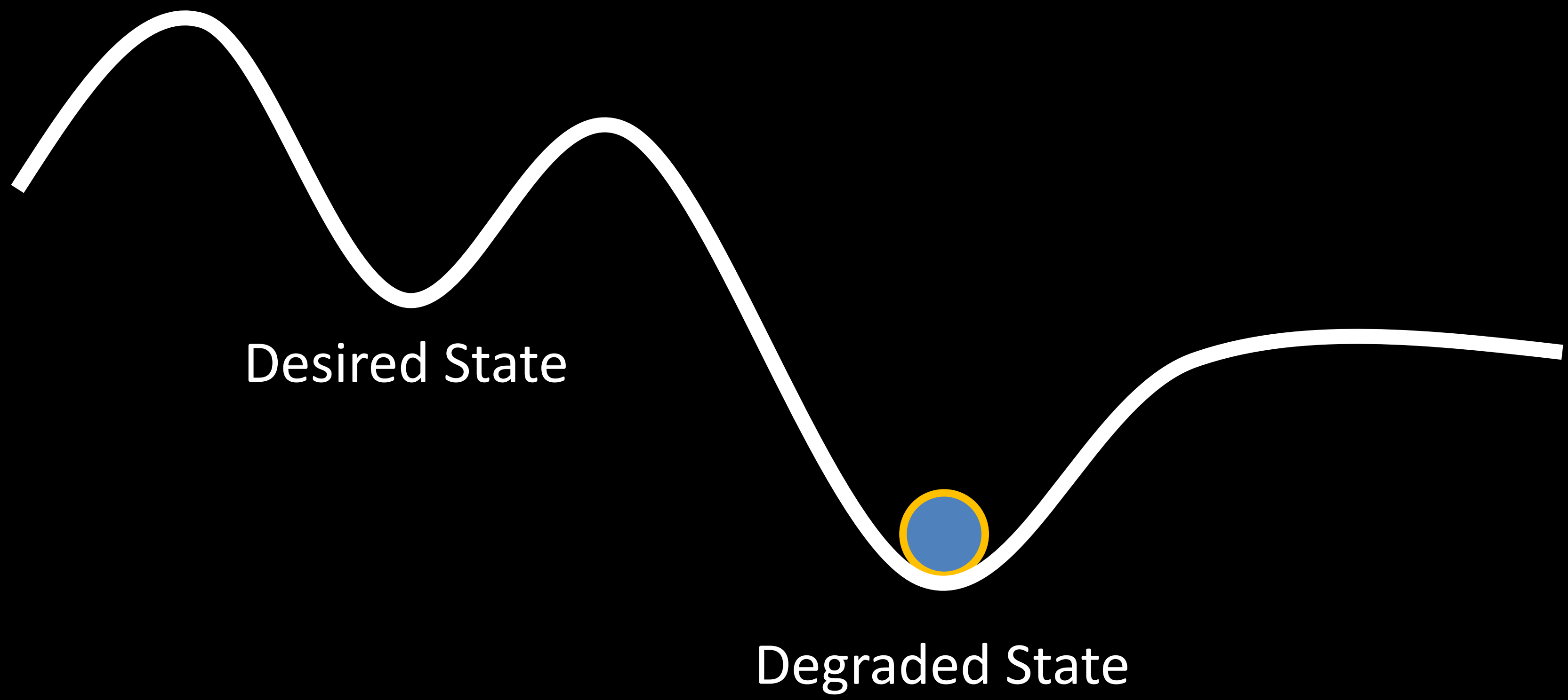




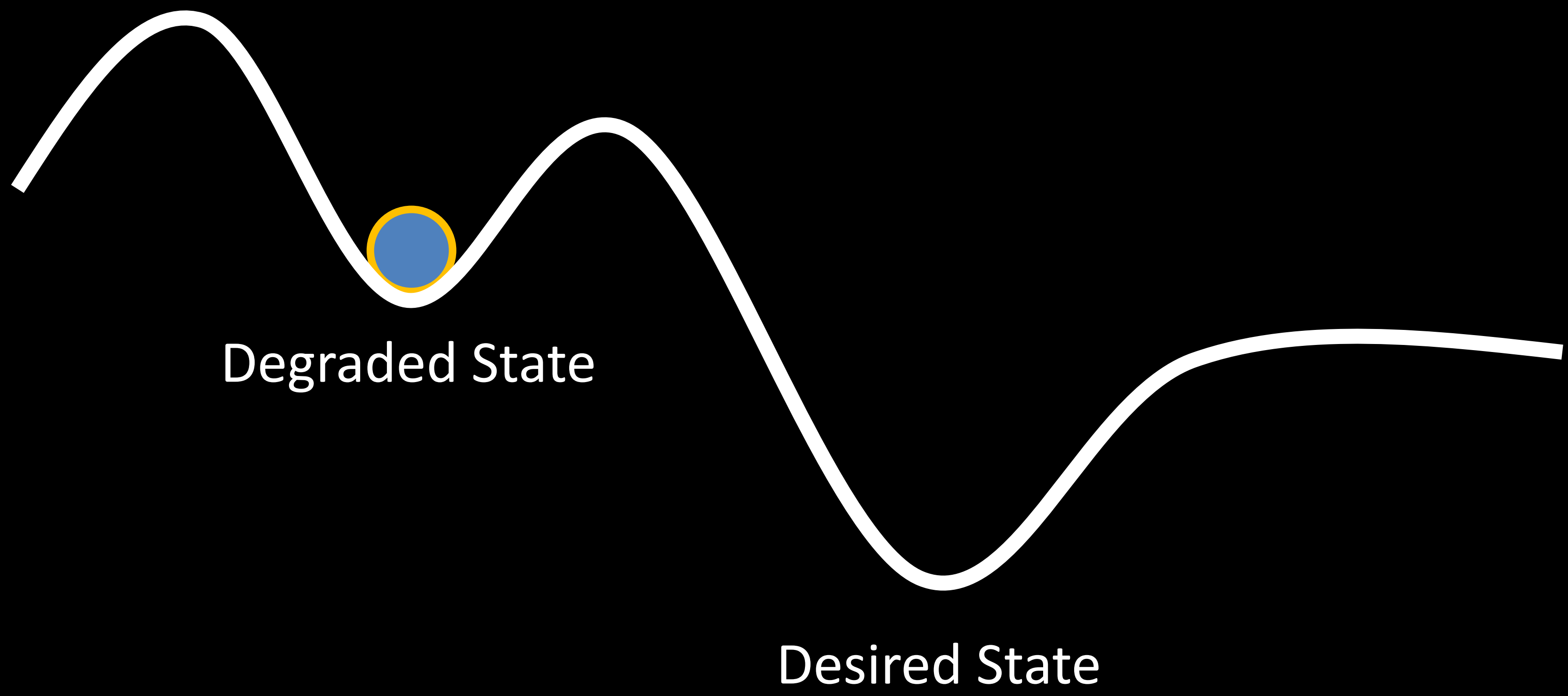
Ecosystem states, stability, and resilience



Ecosystem states, stability, and resilience



Ecosystem states, stability, and resilience



What’s a “desired” or “degraded” state?

What’s a “desired” or “degraded” state?

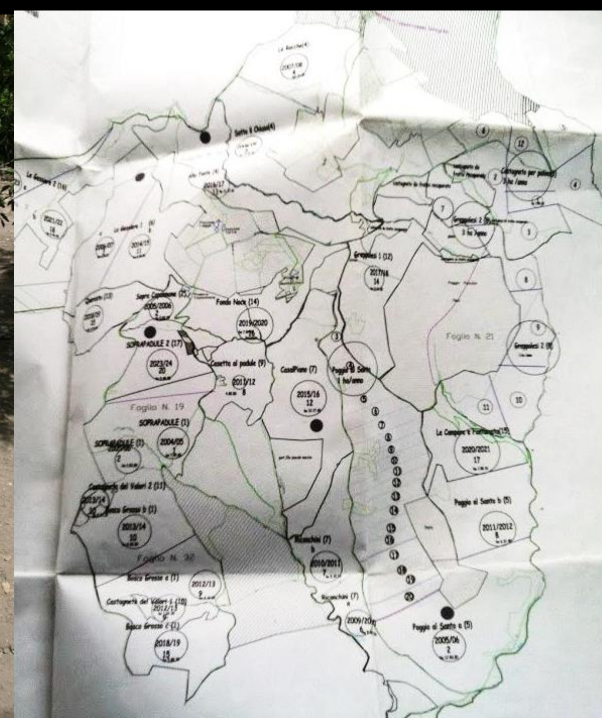
Earth Repair

A TRANSATLANTIC HISTORY
OF ENVIRONMENTAL RESTORATION

Marcus Hall

Spannocchia, Tuscany, Italy


Spannocchia
Tuscany, Italy



0 Years

2 Years

3 Years

5 Years

15 Years

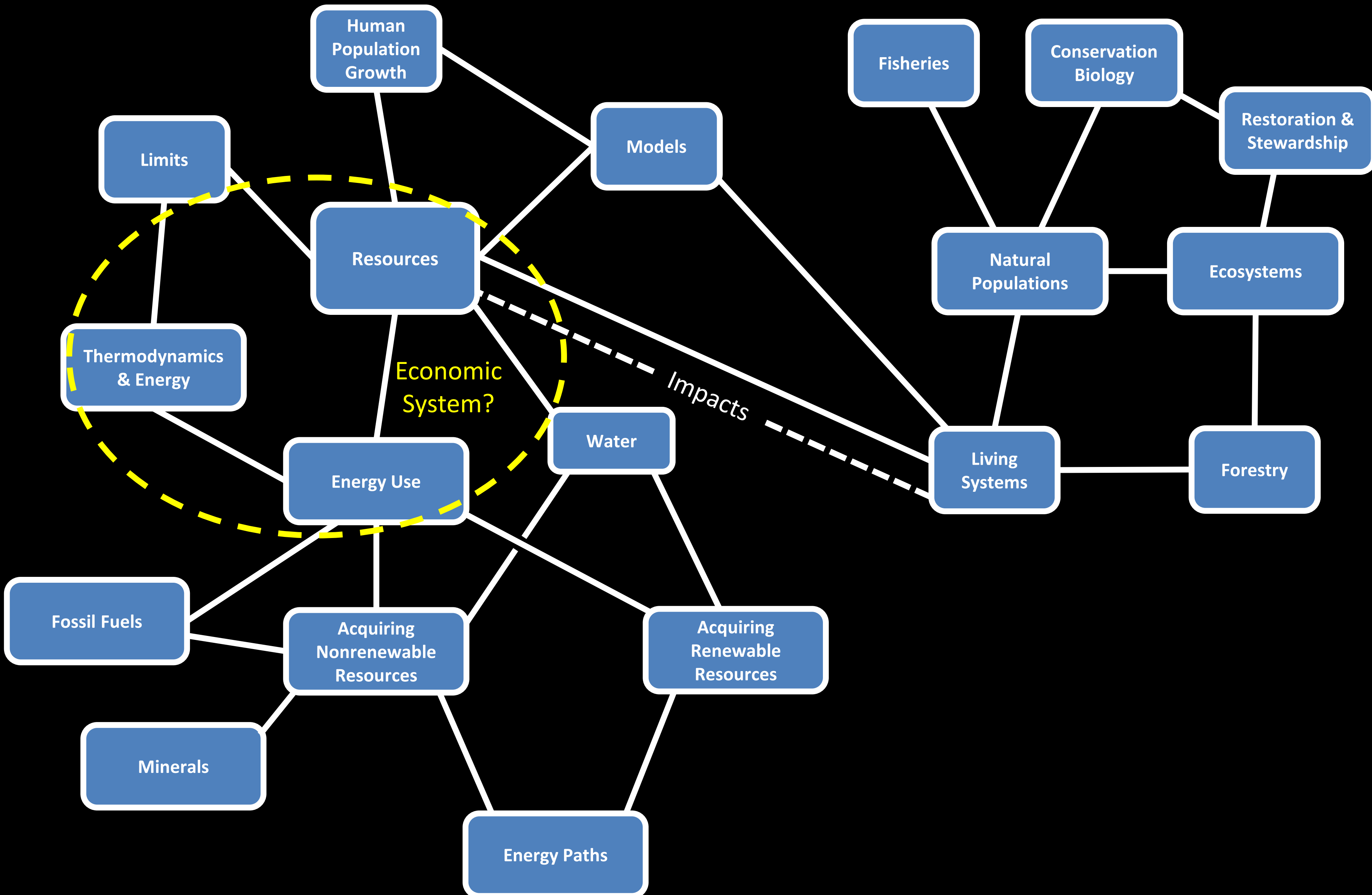
25-30 Years

Earth Repair

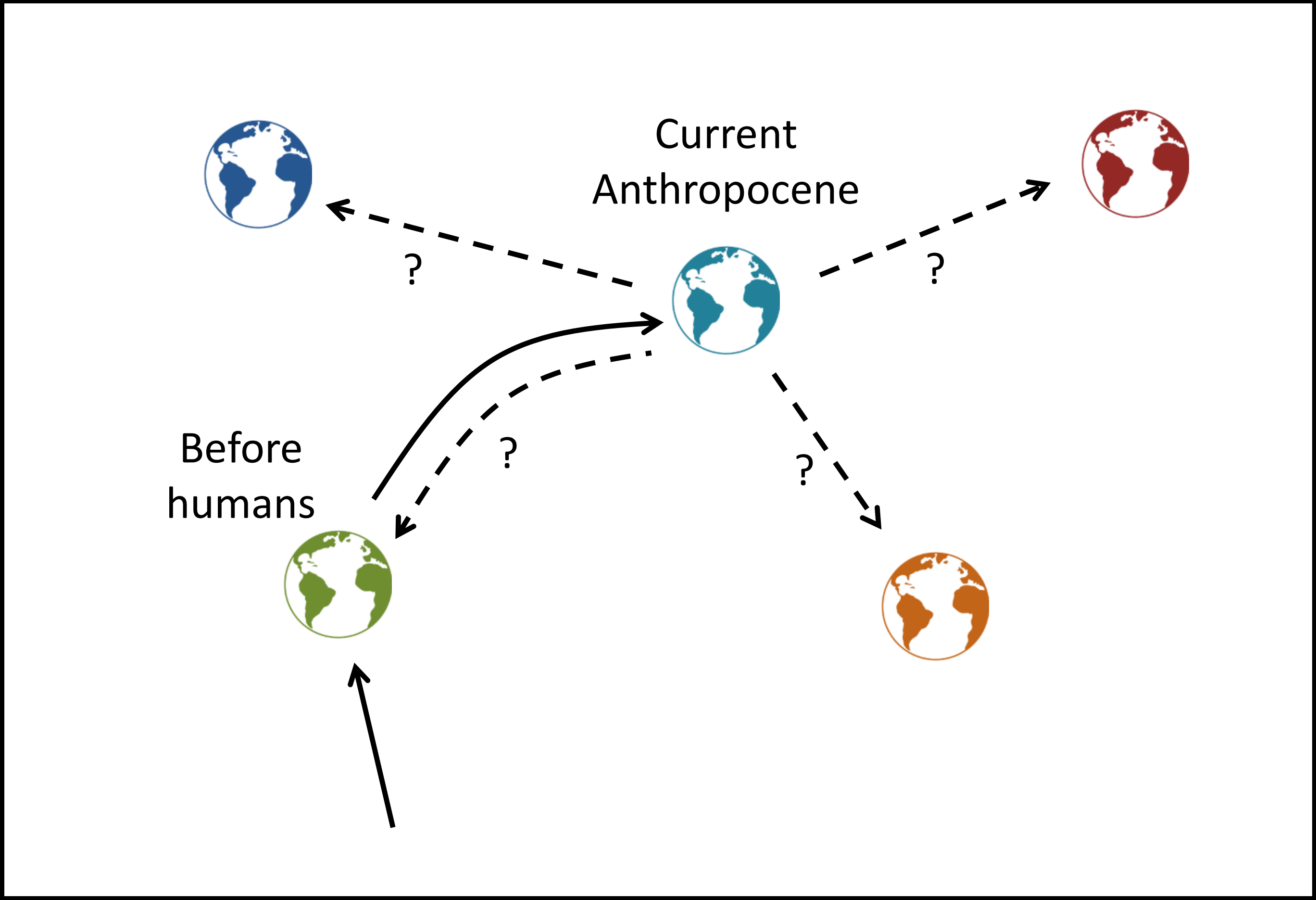
A TRANSATLANTIC HISTORY
OF ENVIRONMENTAL RESTORATION

Marcus Hall

Course Map


Human Population Growth
Models
Fisheries
Conservation Biology
Restoration & Stewardship
Limits
Resources
Natural Populations
Ecosystems
Thermodynamics & Energy
Economic System?
Impacts
Water
Living Systems
Forestry
Energy Use
Fossil Fuels
Acquiring Nonrenewable Resources
Acquiring Renewable Resources
Minerals
Energy Paths

“State space” for the Earth



THE PLANET OF NO RETURN

HUMAN RESILIENCE ON AN ARTIFICIAL EARTH

ERLE ELLIS

Being responsible stewards of the Anthropocene will require embracing the ecological benefits of increasing agricultural productivity and livable cities.

PERSPECTIVE

Used planet: A global history

Erle C. Ellis[a,1], Jed O. Kaplan[b], Dorian Q. Fuller[c], Steve Vavrus[d], Kees Klein Goldewijk[e], and Peter H. Verburg[f]

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Edited by B. L. Turner, Arizona State University, Tempe, AZ, and approved April 3, 2013 (received for review November 6, 2012)

Human use of land has transformed ecosystem pattern and process across most of the terrestrial biosphere, a global change often described as historically recent and potentially catastrophic for both humanity and the biosphere. Interdisciplinary paleoecological, archaeological, and historical studies challenge this view, indicating that land use has been extensive and sustained for millennia in some regions and that recent trends may represent as much a recovery as an acceleration. Here we synthesize recent scientific evidence and theory on the emergence, history, and future of land use as a process transforming the Earth System and use this to explain why relatively small human populations likely caused widespread and profound ecological changes more than 3,000 y ago, whereas the largest and wealthiest human populations in history are using less arable land per person every decade. Contrasting two spatially explicit global reconstructions of land-use history shows that reconstructions incorporating adaptive changes in land-use systems over time, including land-use intensification, offer a more spatially detailed and plausible assessment of our planet's history, with a biosphere and perhaps even climate long ago affected by humans. Although land-use processes are now shifting rapidly from historical patterns in both type and scale, integrative global land-use models that incorporate dynamic adaptations in human–environment relationships help to advance our understanding of both past and future land-use changes, including their sustainability and potential global effects.

Anthropocene | environmental history | holocene | niche construction | agriculture

Human populations and their use of land have now transformed ecosystem pattern and process across most of the terrestrial biosphere (1, 2), causing major global changes in biodiversity (3), biogeochemistry (4–6), geomorphic processes (7), and climate (8). Together with other anthropogenic changes in the Earth system that may herald the emergence of a new geological epoch, the Anthropocene (9, 10), the global changes caused by human use of land are generally portrayed as the result of an unchecked and accelerating process that is mostly recent in origin (11) and therefore presents an impending catastrophe for humanity, the biosphere, and the Earth system in general (3, 12). This article investigates this hypothesis by assessing whether global changes caused by human use of land are mostly recent and result from processes that are now accelerating.

Although prehistoric human populations were capable of transforming terrestrial ecosystems around the world, these early anthropogenic changes have yet to be understood as global change processes and are generally portrayed by global change scientists as localized and insignificant compared with contemporary changes in the Earth system (11, 14).

Global change science has focused on the emergence of industrial processes over the past three centuries as the critical period within which anthropogenic global change processes, including land use, became significant forces driving global changes in the Earth System (14–18). As a result of this emphasis and the prior absence of adequate tools, theory, and data, quantitative global land-use histories for earlier periods of the Holocene have only recently been developed (4, 19–21). Although these new global land-use histories remain at an early stage of development, the adoption of technologies enabling dramatic increases in food production from a given area of agricultural land (23). Processes of land-use intensification, if viewed more broadly as adaptive processes by which human populations systematically adopt increasingly productive land-use technologies, have major implications for understanding the dynamics of land use and its potential impacts over the Holocene (24), as will be shown by examining the spatially explicit predictions of two different global models of land-use history.

Quantitative Global Modeling of Land-Use History

The first spatially explicit global land-use reconstructions date to the 1980s (25, 26), with land-use histories covering the past three centuries emerging in the late 1990s

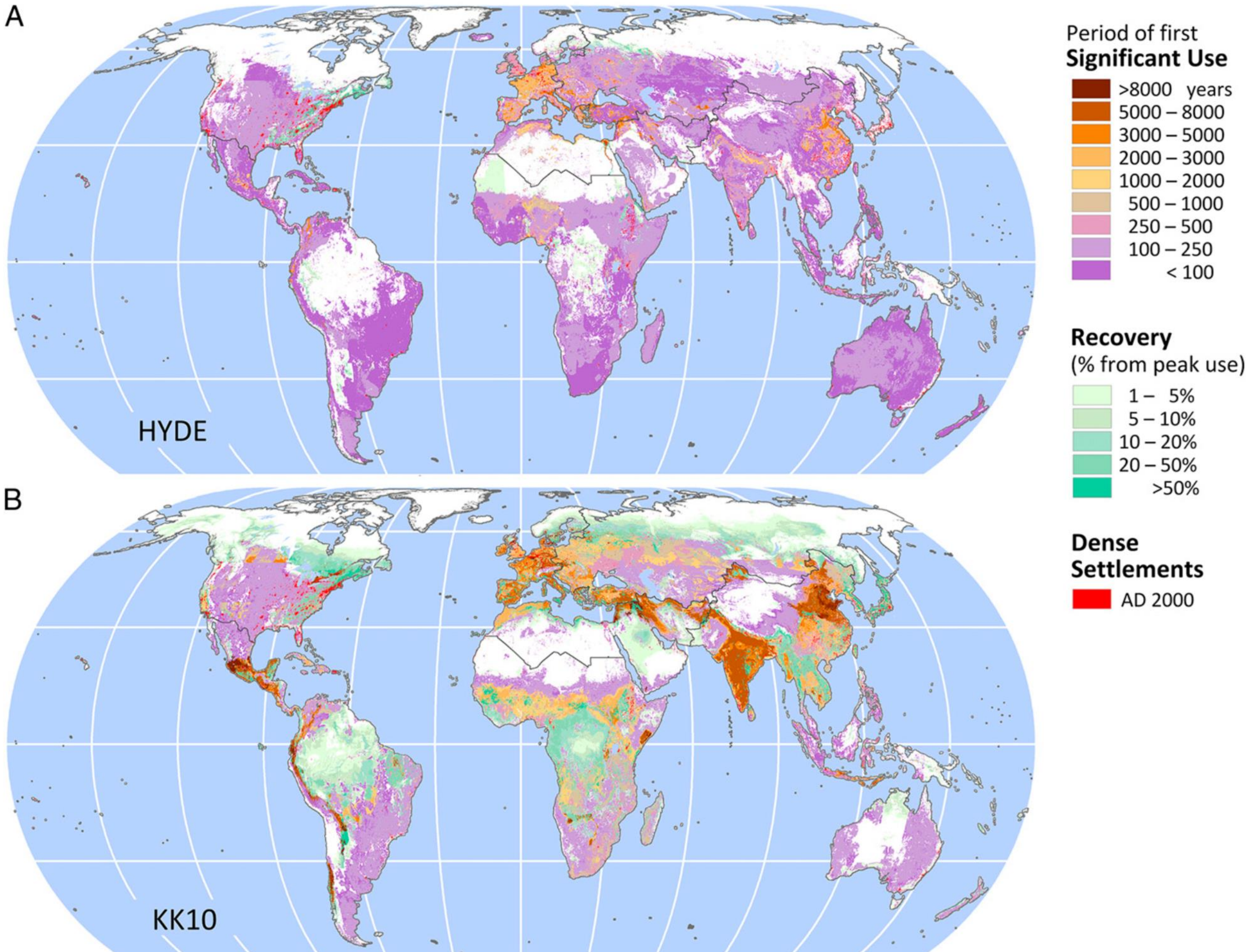

Fig. 1. Time period of first significant land use and recovery from peak land use, 6000 B.C. to A.D. 2000, based on historical reconstructions from the HYDE (*A*) and KK10 (*B*) models. Dense settlements from ref. 1; black lines delimit regions in Fig. 2. Eckert IV projection.

KK10 - Assumes Decreasing Per Cap Land Use Through Time

"Land Use" ~ Land Use per Cap. × Population

?

KK10 → ?

↘ Increased Efficiency (Agriculture)

? ↗ Overall consumption

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https://doi.org/10.5194/essd-14-1581-2022

Open Access Earth System Science Data

European pollen-based REVEALS land-cover reconstructions for the Holocene: methodology, mapping and potentials

Esther Githumbi[1,2], Ralph Fyfe[3], Marie-Jose Gaillard[2], Anna-Kari Trondman[2,4], Florence Mazier[5], Anne-Birgitte Nielsen[6], Anneli Poska[1,7], Shinya Sugita[8], Jessie Woodbridge[3], Julien Azuara[9], Angelica Feurdean[10,11], Roxana Grindean[11,12], Vincent Lebreton[9], Laurent Marquer[13], Nathalie Nebout-Combourieu[9], Miglė Stančikaitė[14], Ioan Tanţău[11], Spassimir Tonkov[15], Lyudmila Shumilovskikh[16], and LandClimII data contributors[+]

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Abstract. Quantitative reconstructions of past land cover are necessary to determine the processes involved in climate–human–land-cover interactions. We present the first temporally continuous and most spatially extensive pollen-based land-cover reconstruction for Europe over the Holocene (last 11 700 cal yr BP). We describe how vegetation cover has been quantified from pollen records at a $1^\circ \times 1^\circ$ spatial scale using the "Regional Estimates of VEgetation Abundance from Large Sites" (REVEALS) model. REVEALS calculates estimates of past regional vegetation cover in proportions or percentages. REVEALS has been applied to 1128 pollen records across Europe and part of the eastern Mediterranean–Black Sea–Caspian corridor (30–75° N, 25° W–50° E) to reconstruct the percentage cover of 31 plant taxa assigned to 12 plant functional types (PFTs) and 3 land-cover types (LCTs). A new synthesis of relative pollen productivities (RPPs) for European plant taxa was performed for this reconstruction. It includes multiple RPP values (≥ 2 values) for 39 taxa and single values for 15 taxa

Estimates of “Open” land cover (can include naturally unforested or cleared by humans)

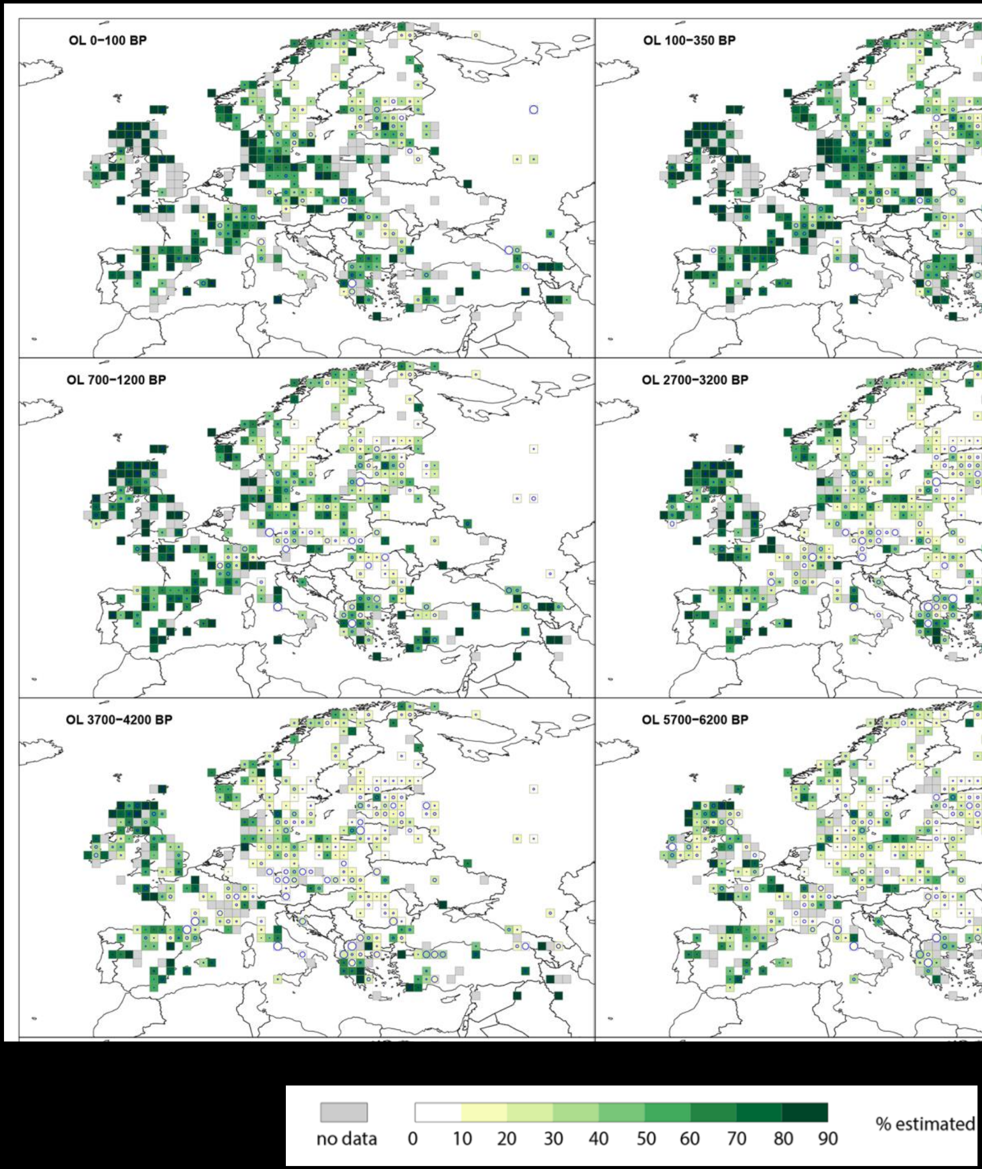


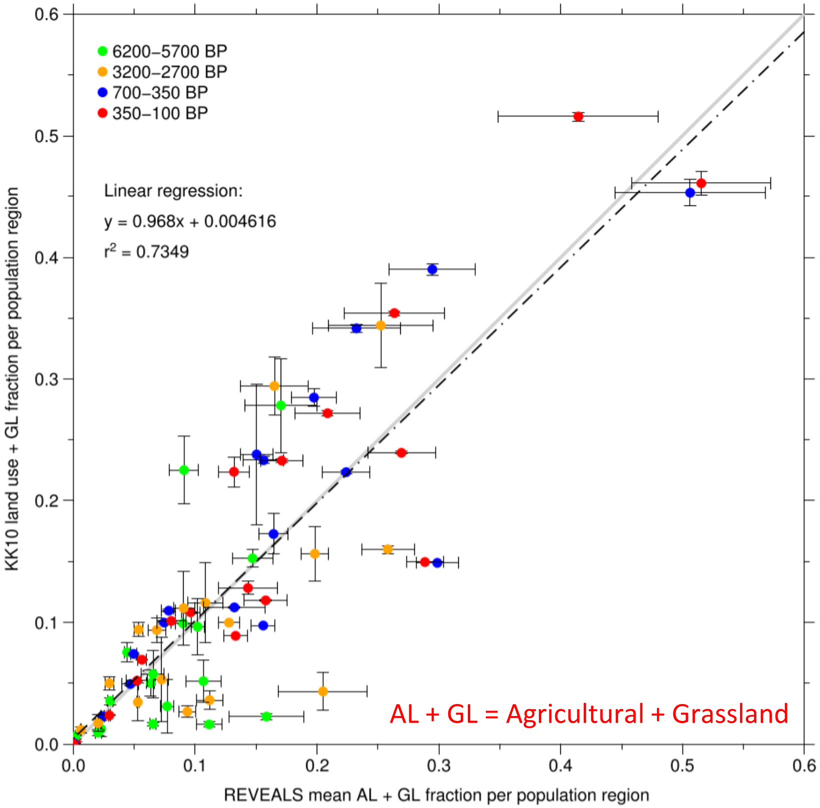
Figure 2. Grid-based REVEALS estimates of open land (OL) cover for eight Holocene time windows. Percentage cover of open land in 10 % intervals represented by increasingly darker shades of green from 20 %. Grey cells: cells without pollen data for the time window but with pollen data in other time windows. Circles in grid cells represent the coefficient of variation (CV; the standard error divided by the REVEALS estimate). When SE $\geq$ REVEALS estimate, the circle fills the entire grid cell, and the REVEALS estimate is not different from zero. This occurs mainly where REVEALS estimates are low.

land

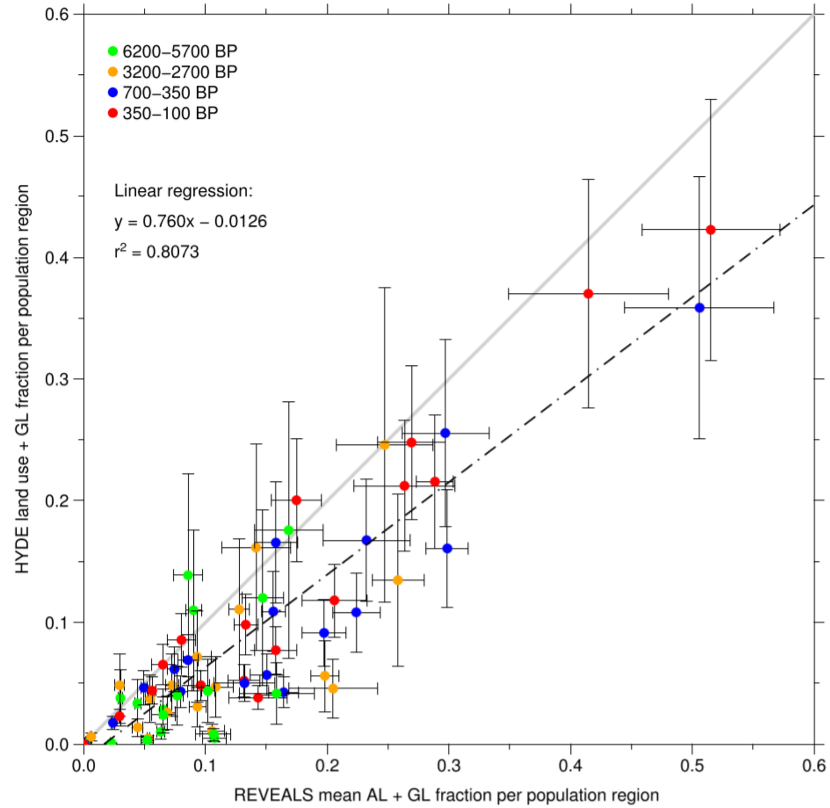
Article

Constraining the Deforestation History of Europe: Evaluation of Historical Land Use Scenarios with Pollen-Based Land Cover Reconstructions

Jed O. Kaplan [1,2,*], Kristen M. Krumhardt [3], Marie-José Gaillard [4], Shinya Sugita [5], Anna-Kari Trondman [4], Ralph Fyfe [6], Laurent Marquer [7], Florence Mazier [7] and Anne Birgitte Nielsen [8]



(**a**) REVEALS compared to KK10



(**b**) REVEALS compared to HYDE

ALCC = Anthropogenic Land Cover Change

Figure 5. Comparison between REVEALS and the ALCC scenarios at the population region scale. REVEALS open land fraction is plotted against land use + non-forest fractions for (**a**) KK10 and (**b**) HYDE. The dashed line is a linear regression through the data, while the 1:1 line is shown in light gray. The vertical error bars in the KK10 correlation indicate the range associated with the six possible KK10 scenarios, while for HYDE the error bars reflect the authors' published temporally-varying uncertainty estimate (see Methods).

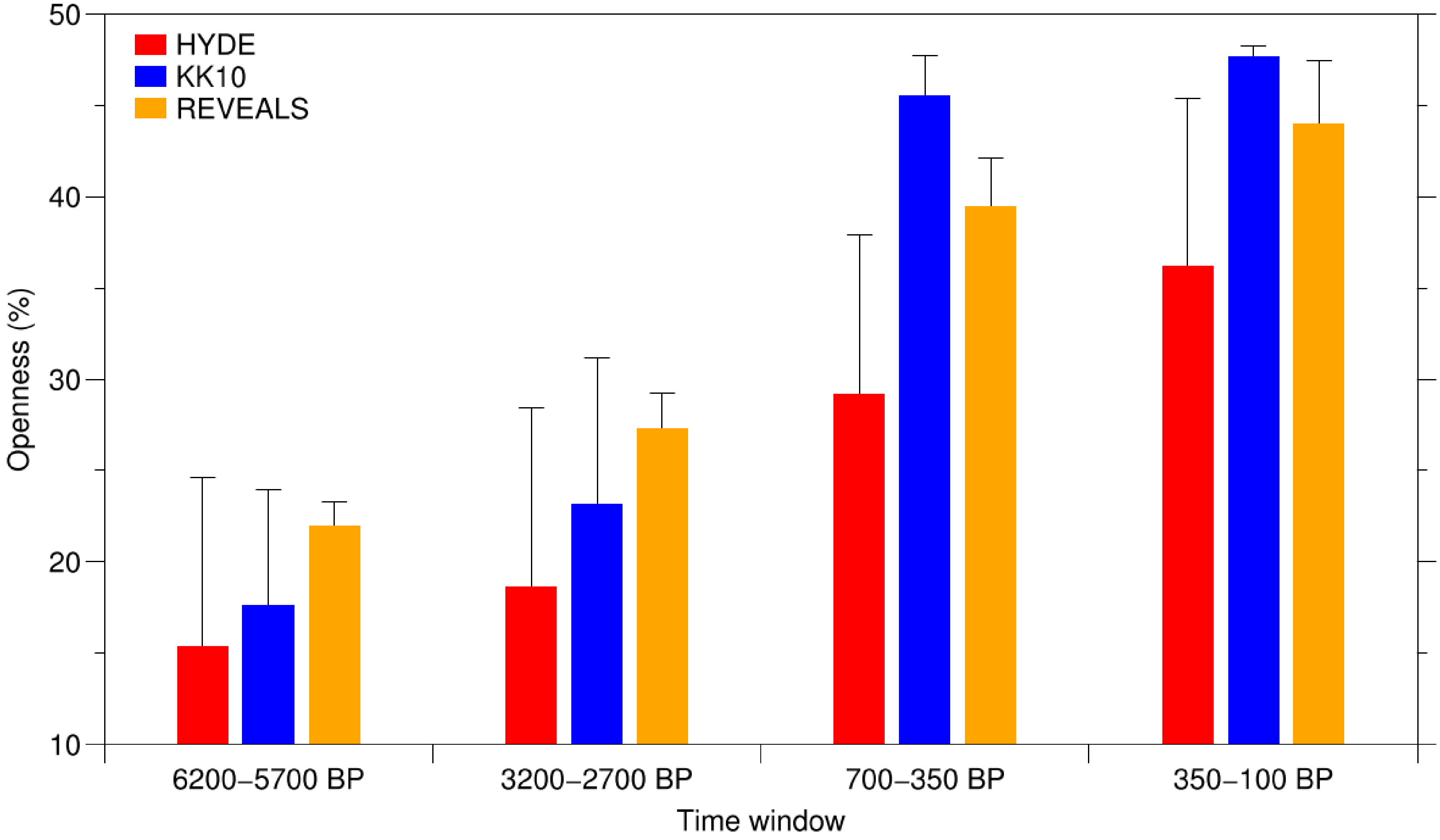
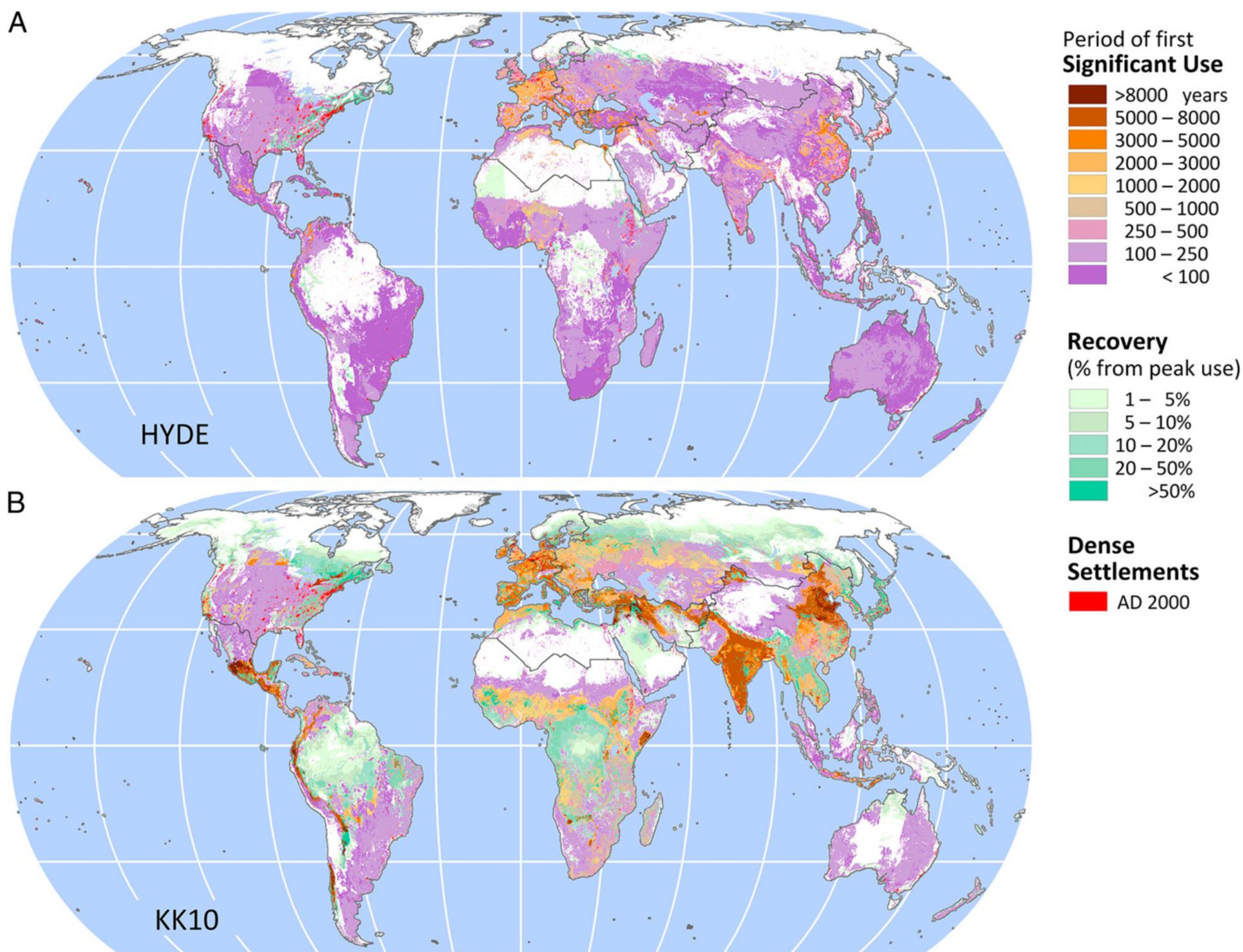


Figure 6. Percent open land (non-forested) within the study area for KK10 and HYDE modeled land use and the REVEALS reconstructions. Total open areas were summed and divided by the total area of the grid cells with REVEALS data for each time period.



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HUMAN RESILIENCE ON AN ARTIFICIAL EARTH

ERLE ELLIS

Being responsible stewards of the Anthropocene will require embracing the ecological benefits of increasing agricultural productivity and livable cities.

Do you agree with Ellis that “the sustainability of human civilization” is not really at stake? Reactions? Thoughts?

As far as food and other basic resources are concerned, we remain far from any physically determined limits to the growth and sustenance of our populations. For better or for worse, humans appear fully capable of continuing to support a burgeoning population by engineering and transforming the planet.

While there is nothing particularly good about a planet hotter than our ancestors ever experienced -- not to mention one free of wild forests or wild fish -- it seems all too evident that human systems are prepared to adapt to and prosper in the hotter, less biodiverse planet that we are busily creating

The Earth we have inherited from our ancestors is now our responsibility. It is not natural limits that will determine whether this planet will sustain a robust measure of its evolutionary inheritance into the future. Our powers may yet exceed our ability to manage them, but there is no alternative except to shoulder the mantle of planetary stewardship. A good, or at least a better, Anthropocene is within our grasp. Creating that future will mean going beyond fears of transgressing natural limits and nostalgic hopes of returning to some pastoral or pristine era. Most of all, we must not see the Anthropocene as a crisis, but as the beginning of a new geological epoch ripe with human-directed opportunity.

Biodiversity

"Land Sharing" → Agro-ecosystems

"Land Sparing" → Intense agriculture (High Yield)

↳ less land used

“State space” for the Earth