Extinction

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Biology Department

Woods Hole Oceanographic Institution

Woods Hole Oceanographic Institution

- Largest private non-profit ocean sciences institution
- Operates joint Ph.D. program with MIT

- ~150 faculty (most “environmental”)
- Departments
  - Biology
  - Marine Chemistry and Geochemistry
  - Marine Geology and Geophysics
  - Physical Oceanography
  - Applied Ocean Physics and Engineering
  - Program in Marine Policy
- Institutes
  - Ocean Life Institute
  - Coastal Ocean Institute
  - Ocean and Climate Change Institute
  - Deep Ocean Exploration Institute

MIT/WHOI Joint Program in Oceanography/Applied Ocean Science and Engineering

Awards joint MIT-WHOI Ph.D. degree

~130 students

~800 graduates

offer ~ 70 MIT classes (Courses 2, 7, 12)

- MIT Director of the Joint Program
  - Professor Paola Rizzoli
- WHOI VP for Academic Affairs and Dean
  - James Yoder
- web.mit.edu/mit-whoi/
- www.whoi.edu/education

Extinction

- How much?
- Why?
- How to analyze it?
- How is it managed?

How much extinction?

- Geological average lifespan of species ~10^6 years
- Recent average lifespan of birds and mammals ~10^4 years
- Projected immediate future lifespan ~10^2 - 10^3 years
- Extinction rates above background by factor of ~10^4
- We are in the middle of the 6th great extinction event in the history of life on earth

Projecting extinction rates NOT easy

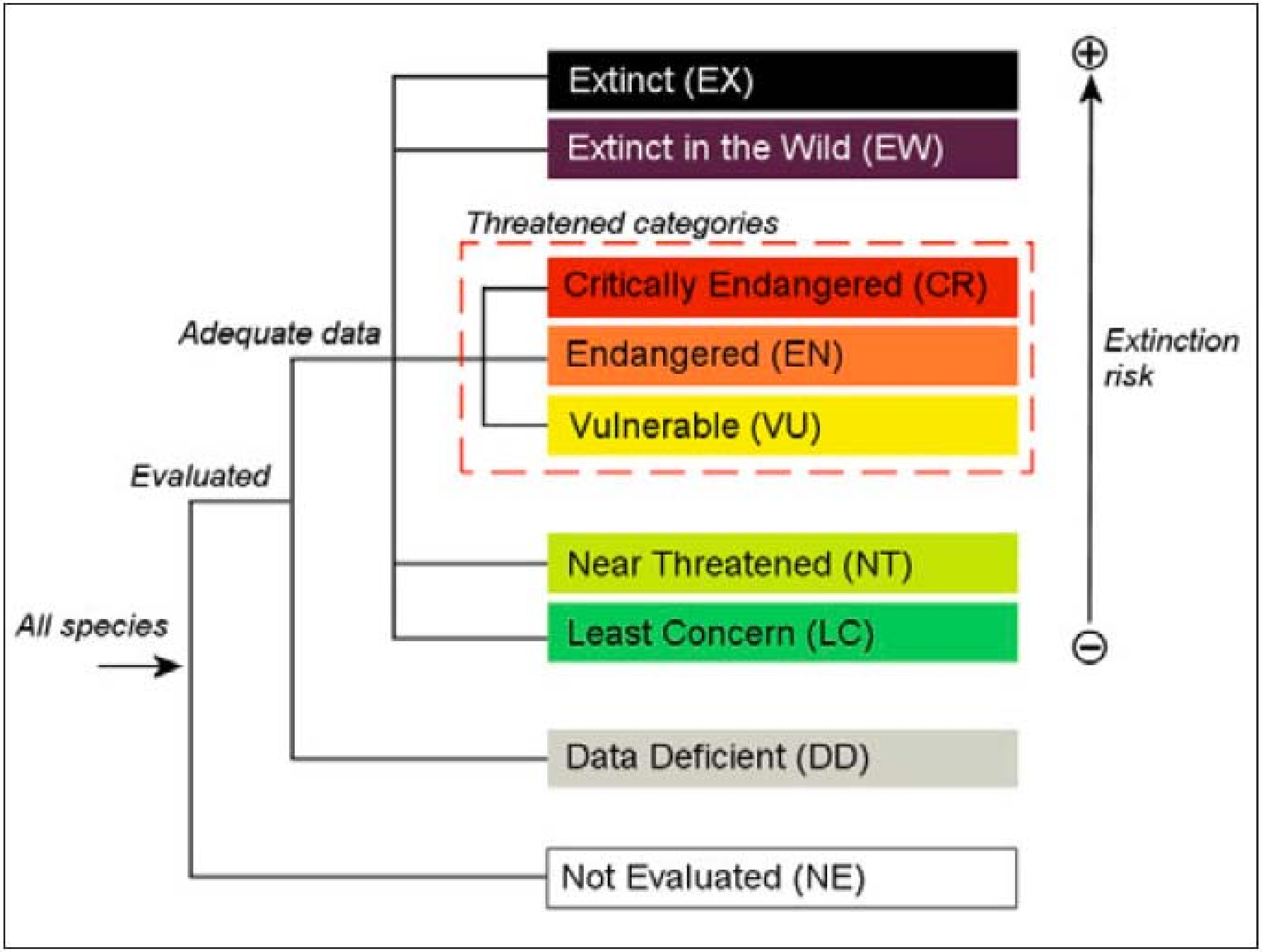
- Species-area relationships

  $$S = cA^z \quad z \sim 0.25$$

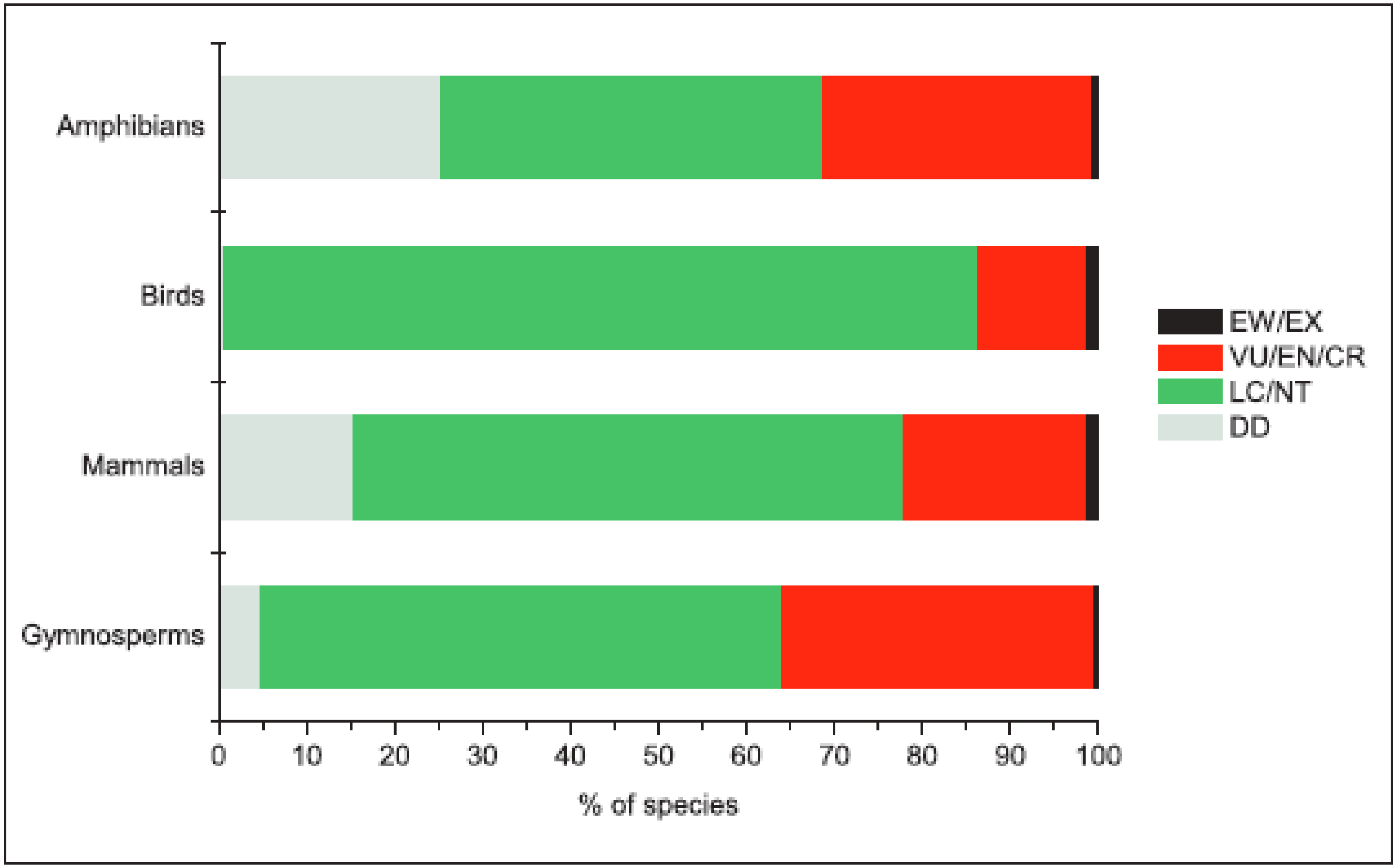
- Trends in IUCN classification of threatened species
- Estimates of extinction probability
- Branching processes in phylogenetic trees
- How many species are there anyway? ($\sim 7\text{x}10^6$ or
  - "... a true total anywhere in the range 3 to 100 million could turn out to be correct..." R. May)

International Union for the Conservation of Nature (IUCN)

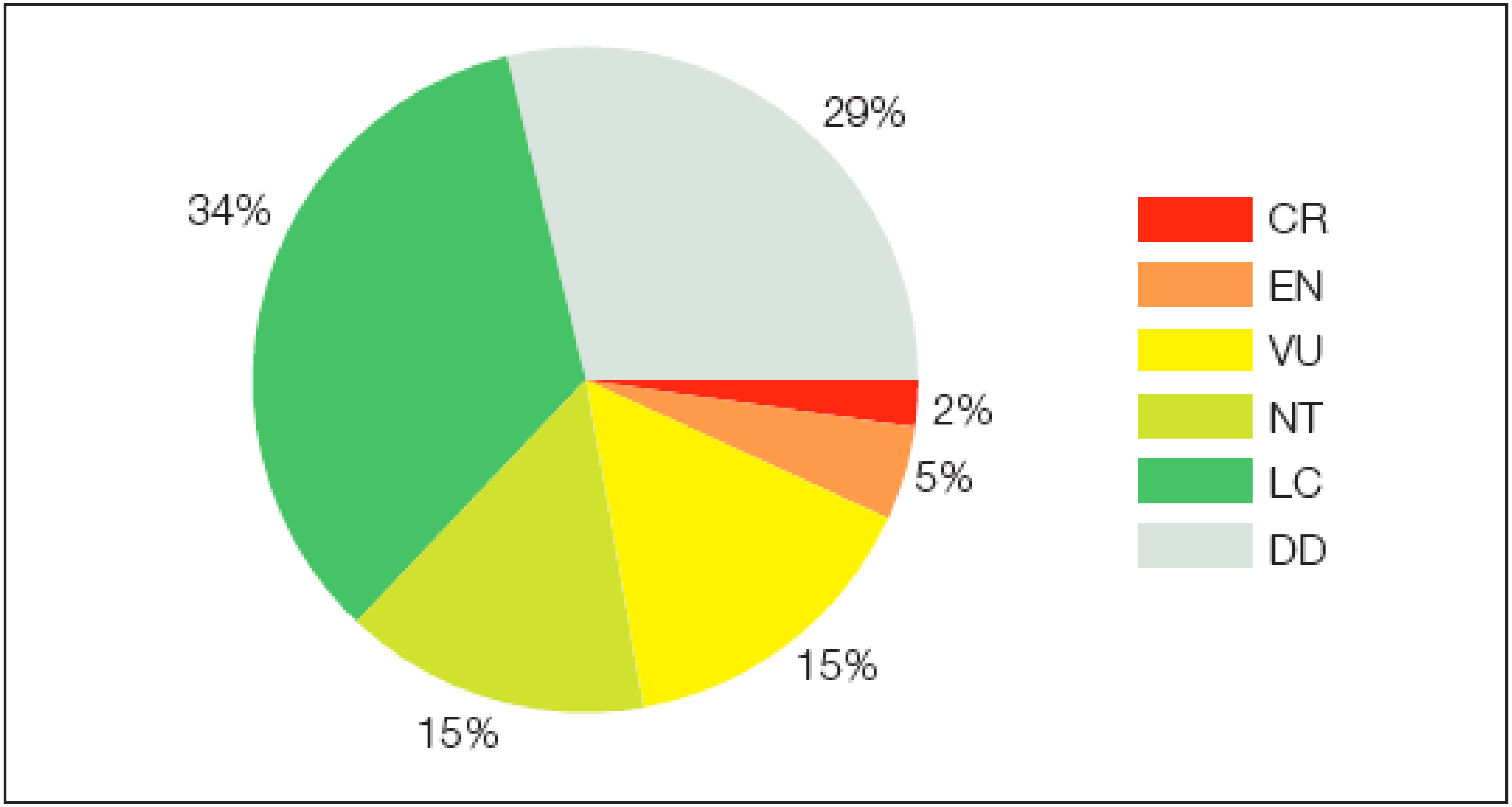
- “Red Book” or Red List of Threatened Species www.iucn.org/redlist/
- Classification of species



Structure of the Red List Categories.



Proportions of species by threat category for four comprehensively assessed groups (a) amphibians, (b) birds, (c) mammals and (d) gymnosperms.



Summary of 2008 Red List Categories for all sharks, rays, chimaeras, groupers, reef-building corals, seabirds, marine mammals and marine turtles (2544 species).

Causes of extinction

- Habitat degradation or destruction
- Overexploitation
- Pollution
- Invasive species
- Disease

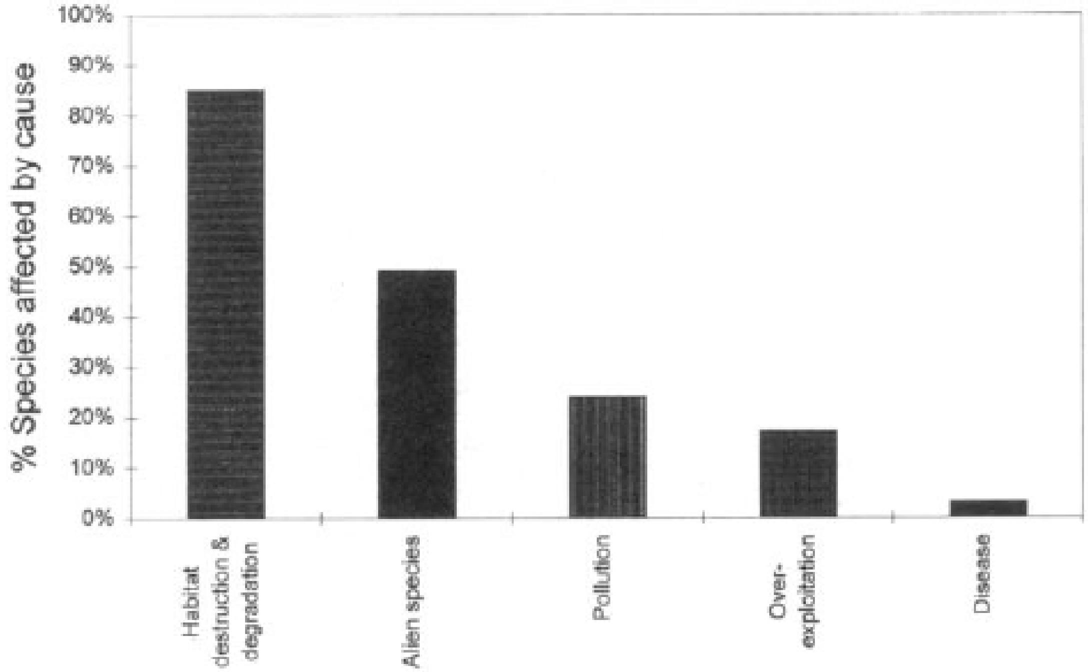
Table 2. Percentages of species in different groups that are imperiled by habitat degradation and loss, alien species, pollution, overexploitation, and disease. Categories are nonexclusive and therefore do not sum to 100.

Cause	All species (n = 1880)	Verte-brates (n = 494)	Inverte-brates (n = 331)	Plants (n = 1055)	Mammals (n = 85)	Birds (n = 98)	Reptiles (n = 38)	Amphi-bians (n = 60)	Fishes (n = 213)	Fresh-water mussels (n = 102)	Crayfish (n = 67)	Tiger beetles (n = 6)	Butter-flies and skippers (n = 33)	Other inverte-brates (n = 104)
Habitat degrada-tion/loss	85	92	87	81	89	90	97	87	94	97	52	100	97	94
Alien species	49	47	27	57	27	69	37	27	53	17	4	0	36	52
Pollution	24	46	45	7	19	22	53	45	66	90	28	0	24	19
Overex-ploitation	17	27	23	10	45	33	66	17	13	15	0	33	30	46
Disease	3	11	0	1	8	37	8	5	1	0	0	0	0	0

Wilcove et al. 1998

Figure 1. The major threats to biodiversity. Data refer to species classified as imperiled by The Nature Conservancy and to all endangered, threatened, and proposed species, subspecies, and populations protected under the Endangered Species Act. See also Table 2.

threats to aquatic biodiversity in North



Wilcove et al. 1998



$$\hat{\mathbf{n}}_1 \;=\; \mathbf{A}_2\hat{\mathbf{n}}_2 \qquad (76)$$

$$\hat{\mathbf{n}}_2 \;=\; \mathbf{A}_1\hat{\mathbf{n}}_1 \qquad (77)$$

tor, and expanding $d\mathbf{A}/d\boldsymbol{\theta}^{\mathsf{T}}$ yields

$$\ldots\frac{\ldots\mathrm{c}\,\mathbf{A}_2}{\ldots d\boldsymbol{\theta}} + \mathbf{A}_2 d\hat{\mathbf{n}}_2 \qquad (78)$$

$$\ldots\frac{\ldots\mathrm{c}\,\mathbf{A}_2}{\ldots\boldsymbol{\theta}^{\mathsf{T}}} + (\hat{\mathbf{n}}_2^{\mathsf{T}} \otimes \mathbf{I}_s)\frac{\partial \mathbf{A}_2}{\partial \mathbf{n}_2^{\mathsf{T}}}\frac{d\hat{\mathbf{n}}_2}{d\boldsymbol{\theta}^{\mathsf{T}}} + \mathbf{A}_2\frac{d\hat{\mathbf{n}}_2}{d\boldsymbol{\theta}^{\mathsf{T}}} \qquad (79)$$

ranging the two equations yields the sensitivity for both he formulae, write $\mathbf{M}_i = \hat{\mathbf{n}}_i^{\mathsf{T}} \otimes \mathbf{I}_s$. Then

$$\ldots\boldsymbol{\theta}^{\mathsf{T}}\left(\ldots\hat{\mathbf{n}}_2\right) = \left(\ldots\mathbf{M}_1 \;\middle|\; 0\right)\begin{pmatrix} \frac{\partial \mathrm{vec}\,\mathbf{A}_1}{\partial \boldsymbol{\theta}^{\mathsf{T}}} \\ \frac{\partial \mathrm{vec}\,\mathbf{A}_2}{\partial \boldsymbol{\theta}^{\mathsf{T}}} \end{pmatrix}$$

$$+ \left[\left(\begin{array}{c|c} 0 & \mathbf{M}_2 \\ \mathbf{M}_1 & 0 \end{array}\right)\left(\begin{array}{c|c} \frac{\partial \mathrm{vec}\,\mathbf{A}_1}{\partial \mathbf{n}_1} & 0 \\ 0 & \frac{\partial \mathrm{vec}\,\mathbf{A}_2}{\partial \mathbf{n}_2} \end{array}\right) + \left(\begin{array}{c|c} 0 & \mathbf{A}_2 \\ \mathbf{A}_1 & 0 \end{array}\right)\right]\frac{d}{d\boldsymbol{\theta}^{\mathsf{T}}}\begin{pmatrix} \hat{\mathbf{n}}_1 \\ \hat{\mathbf{n}}_2 \end{pmatrix} \qquad (80)$$


the sensitivities gives

$$\begin{pmatrix} \hat{\mathbf{n}}_1 \\ \hat{\mathbf{n}}_2 \end{pmatrix} = \left[\mathbf{I}_{2s} - \left(\begin{array}{c|c} 0 & \mathbf{M}_2 \\ \mathbf{M}_1 & 0 \end{array}\right)\left(\begin{array}{c|c} \frac{\partial \mathrm{vec}\,\mathbf{A}_1}{\partial \mathbf{n}_1} & 0 \\ 0 & \frac{\partial \mathrm{vec}\,\mathbf{A}_2}{\partial \mathbf{n}_2} \end{array}\right) - \left(\begin{array}{c|c} 0 & \mathbf{A}_2 \\ \mathbf{A}_1 & 0 \end{array}\right)\right]^{-1}$$

$$\times \left(\begin{array}{c|c} 0 & \mathbf{M}_2 \\ \mathbf{M}_1 & 0 \end{array}\right)\begin{pmatrix} \frac{\partial \mathrm{vec}\,\mathbf{A}_1}{\partial \boldsymbol{\theta}^{\mathsf{T}}} \\ \frac{\partial \mathrm{vec}\,\mathbf{A}_2}{\partial \boldsymbol{\theta}^{\mathsf{T}}} \end{pmatrix} enum2cycle_sens \qquad (81)$$


atives of $\mathbf{A}_i$ are evaluated at $\hat{\mathbf{n}}_i$. The analogy with (23) is apparent. ivity of a 3-cycle reveals the pattern for higher periods:

$$\frac{d}{d\boldsymbol{\theta}^{\mathsf{T}}}\mathbb{N} = [\mathbf{I}_{3s} - \mathbb{A} - \mathbb{M}\mathbb{C}]^{-1}\,\mathbb{M}\mathbb{D} \qquad (82)$$

k matrices are defined as

$$\mathbb{N} \;=\; \begin{pmatrix} \hat{\mathbf{n}}_1^{\mathsf{T}} & \hat{\mathbf{n}}_2^{\mathsf{T}} & \hat{\mathbf{n}}_3^{\mathsf{T}} \end{pmatrix}^{\mathsf{T}} \qquad (83)$$

$$\mathbb{A} \;=\; \begin{pmatrix} 0 & 0 & \mathbf{A}_3 \\ \mathbf{A}_1 & 0 & 0 \\ 0 & \mathbf{A}_2 & 0 \end{pmatrix} \qquad (84)$$

$$\begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{pmatrix}(t+1) = \begin{pmatrix} 0 & F_2 & F_3 & F_4 \\ P_1 & 0 & 0 & 0 \\ 0 & P_2 & 0 & 0 \\ 0 & 0 & P_3 & 0 \end{pmatrix} \begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{pmatrix}(t)$$

$$\mathbf{n}(t+1) = \mathbf{A}\mathbf{n}(t)$$

Role of the dominant eigenvalue

$$\lim_{t\to\infty} \frac{\mathbf{n}(t)}{\lambda_1^t} = \mathbf{w}_1 \left(\mathbf{v}_1^* \mathbf{n}_0\right)$$

$$\begin{aligned}
\lambda_1 &= \text{asymptotic population growth rate} \\
\mathbf{w}_1 &= \text{stable stage distribution} \\
\mathbf{v}_1 &= \text{reproductive value distribution}
\end{aligned}$$

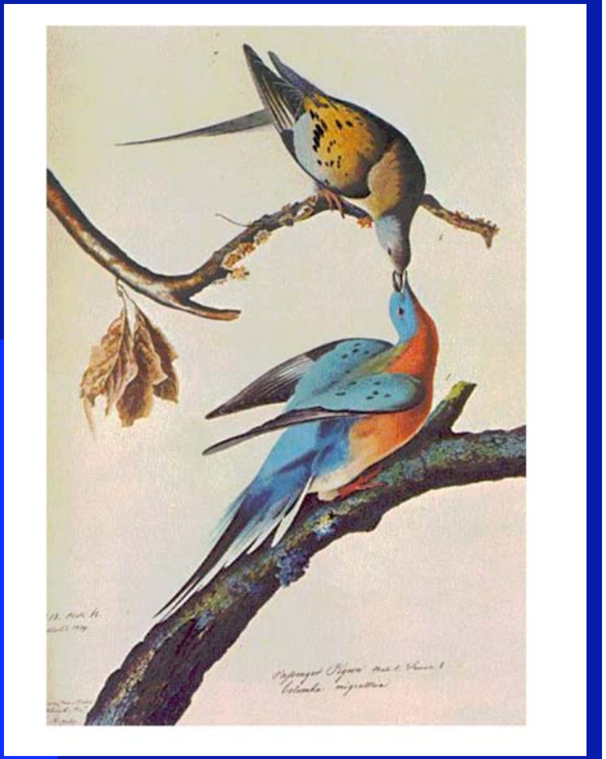
("Strong ergodic theorem" of demography)

Extinction

- an inherently demographic problem (gotta love that exponential growth)

> But I have satisfied myself, by long observation, that nothing but the gradual diminution of our forests can accomplish their decrease, as they not infrequently quadruple their numbers yearly, and always at least double it.
>
> John James Audubon
> *Ornithological Biography* (1831)

$$2 \leq \lambda \leq 4$$



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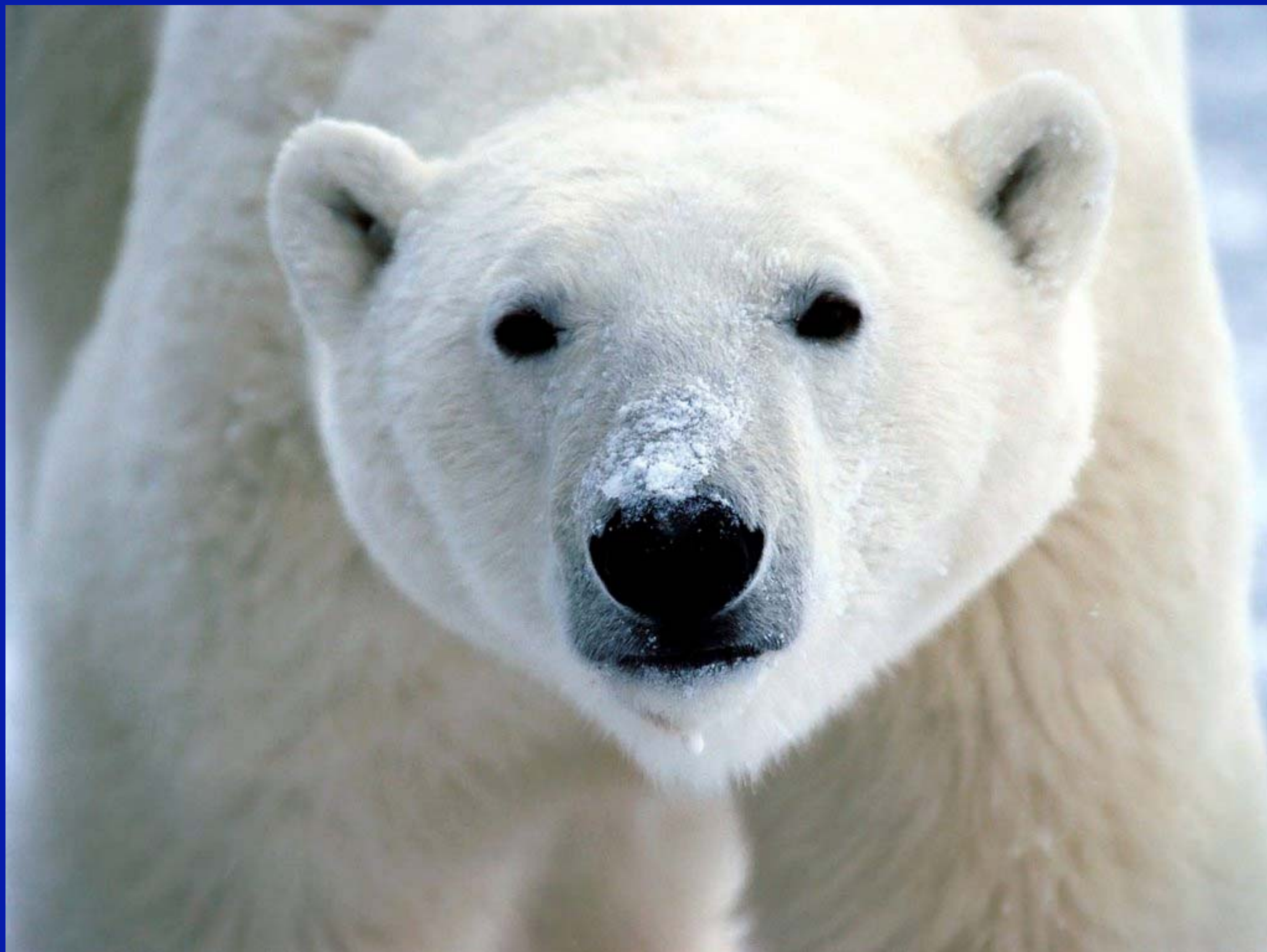
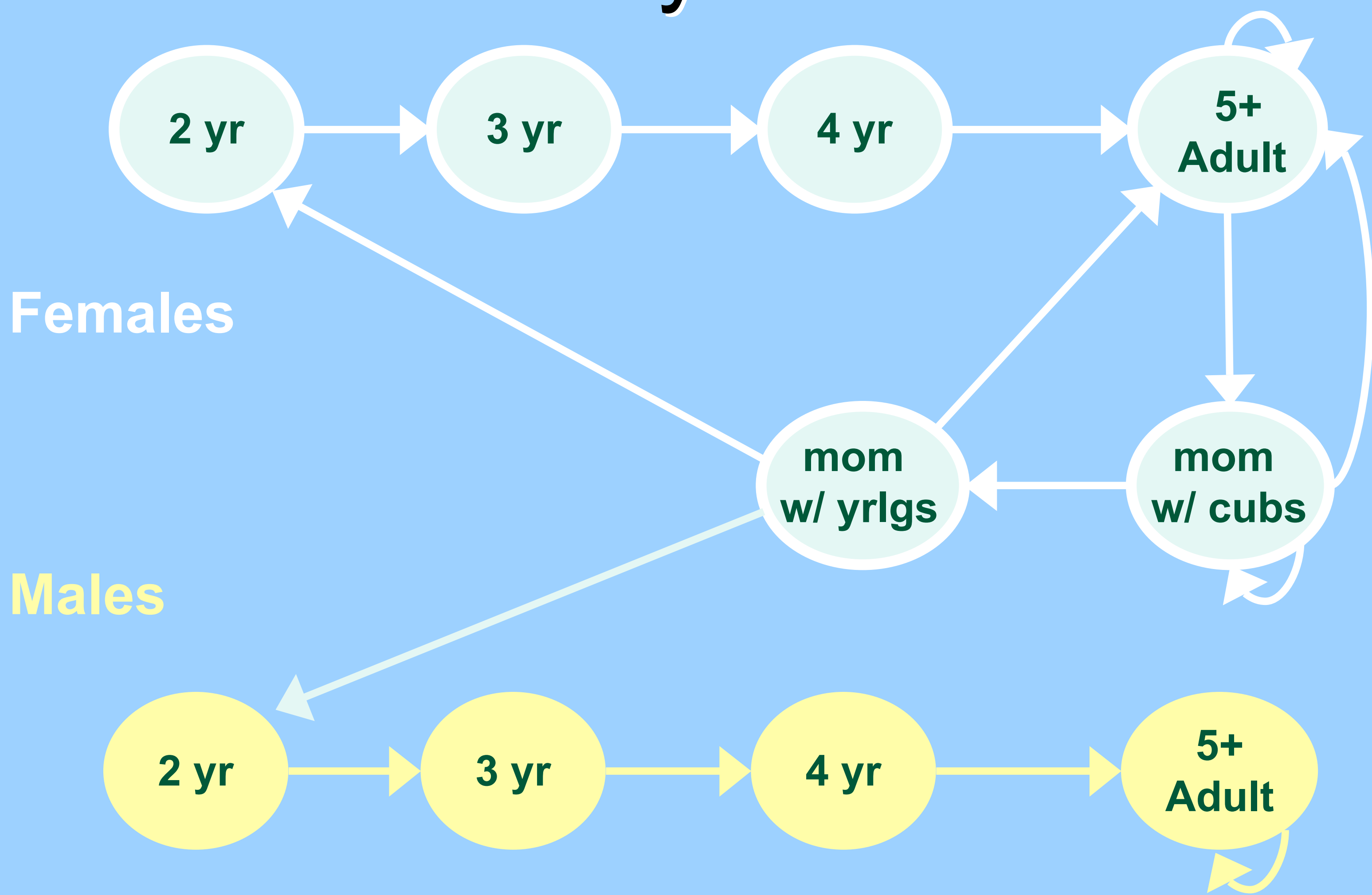


Denning

- Rely on snow drifts
- Enter dens in Oct/Nov/Dec
- Emerge in March/April

Southern Beaufort polar bear life cycle

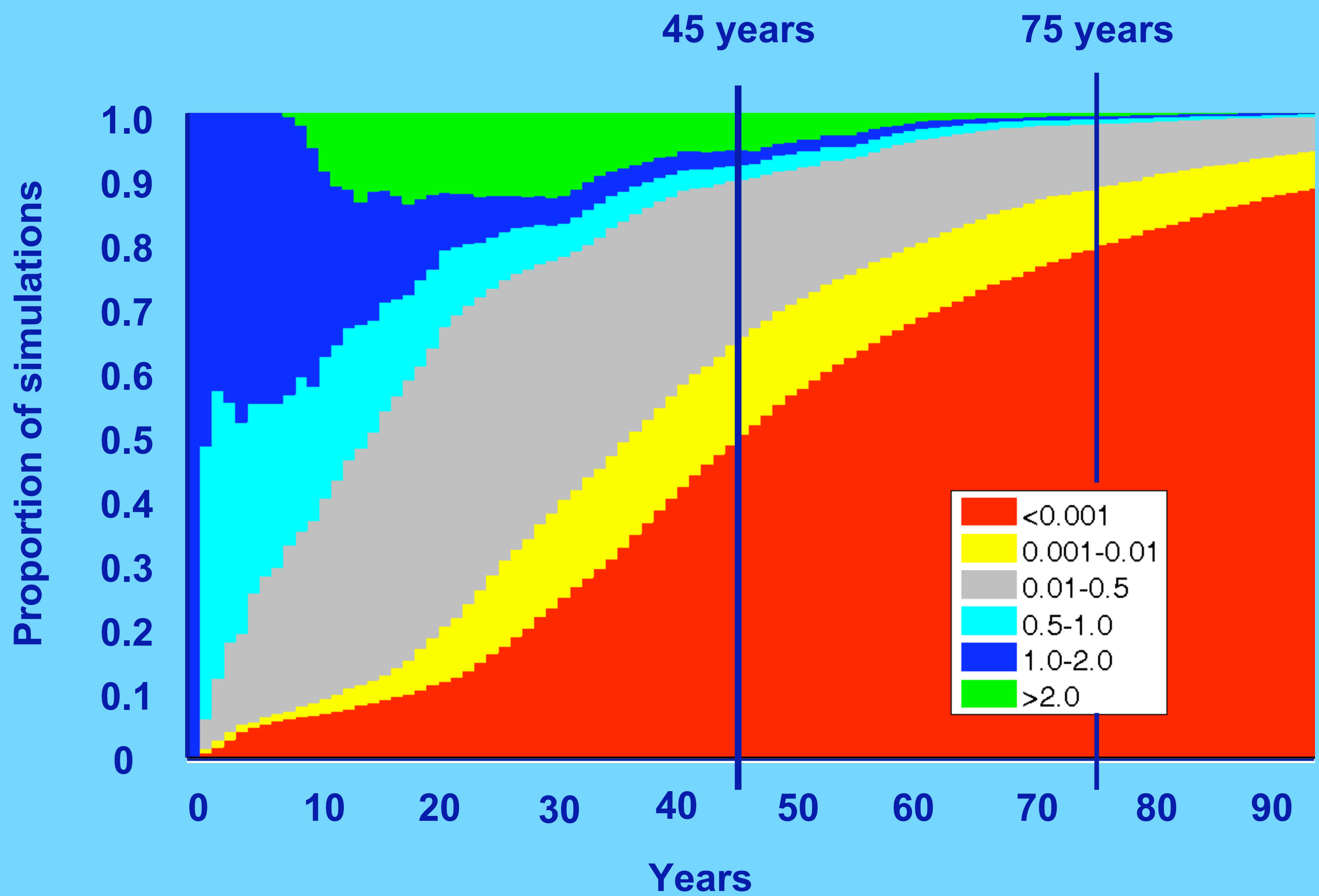


$$
\mathbf{A} = \left(\begin{array}{cccccc|cccc}
0 & 0 & 0 & 0 & 0 & \frac{\sigma_6\sigma_{L1}f}{2} & 0 & 0 & 0 & 0 \\
\sigma_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \sigma_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \sigma_3 & \sigma_4(1-\beta_4) & \sigma_5(1-\sigma_{L0})(1-\beta_5) & \sigma_6 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \sigma_4\beta_4 & \sigma_5(1-\sigma_{L0})\beta_5 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \sigma_5\sigma_{L0} & 0 & 0 & 0 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & 0 & \frac{\sigma_6\sigma_{L1}f}{2} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \sigma_7 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \sigma_8 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sigma_9 & \sigma_{10}
\end{array}\right)
$$

Deterministic population growth rate

Year	population growth rate	growth per year	# ice-free days
2001	1.06	+ 5.8%	90
2002	1.06	+5.8%	94
2003	1.04	+3.9%	119
2004	0.76	-27.0%	135
2005	0.80	-22.0%	134

Polar bears: population projections under climate model conditions



Managing extinction

- Endangered Species Act (ESA)
- Marine Mammal Protection Act (MMPA)
- Convention on International Trade in Endangered Species (CITES)

ENDANGERED SPECIES ACT OF 1973

[Public Law 93–205, Approved Dec. 28, 1973, 87 Stat. 884]

[As Amended Through Public Law 107–136, Jan. 24, 2002]

AN ACT To provide for the conservation of endangered and threatened species of fish, wildlife, and plants, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, [16 U.S.C. 1531 note] That this Act may be cited as the "Endangered Species Act of 1973".

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[Sec. 18. Annual cost analysis by the Fish and Wildlife Service.[1]]

FINDINGS, PURPOSES, AND POLICY

SEC. 2. [16 U.S.C. 1531] (a) FINDINGS.—The Congress finds and declares that—

(1) various species of fish, wildlife, and plants in the United States have been rendered extinct as a consequence of economic growth and development untempered by adequate concern and conservation;

(2) other species of fish, wildlife, and plants have been so depleted in numbers that they are in danger of or threatened with extinction;

(3) these species of fish, wildlife, and plants are of esthetic, ecological, educational, historical, recreational, and scientific value to the Nation and its people;

[1] Bracketed material does *not* appear in Act. Sec. 1012 of P.L. 100–478, 102 Stat. 2314, October 7, 1988, added sec. 18 of the Act but did not conform the table of contents of the Act.

Endangered Species Act

- Endangered species

(6) The term "endangered species" means any species which is in danger of extinction throughout all or a significant portion of its range other than a species of the Class Insecta determined by the Secretary to constitute a pest whose protection under the provisions of this Act would present an overwhelming and overriding risk to man.

Endangered Species Act

- Threatened species

(20) The term "threatened species" means any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

ESA 5 Factor Threat Analysis

A The present or threatened destruction, modification, or curtailment of habitat or range

B Overutilization for commercial, recreational, scientific, or educational purposes

C Disease or predation

D Inadequacy of existing regulatory mechanisms; or

E Other natural or manmade factors affecting continued existence

U.S. Fish & Wildlife Service

The Petition Process

For requests to list a species as threatened or endangered under the Endangered Species Act