Environments and Species Distributions are Changin

"At this point I wish to emphasize what I believe will ultimately prove to be the greatest value of our museum. This value will not, however, be realized until the lapse of many years, possibly a century, assuming that our material is safely preserved. And this is that the student of the future will have access to the original record of faunal conditions in California and the west, wherever we now work."

Joseph Grinnell, 1910
"The Uses and Methods of a Research Museum"
Popular Science Monthly

NEON

SOLELY FUNDED BY THE NATIONAL SCIENCE FOUNDATION

neon | NATIONAL ECOLOGICAL OBSERVATORY NETWORK®

ABOUT | SCIENCE | EDUCATION PROGRAMS | NEWS CENTER | CONTACT US | CAREERS

News Center

- News
- Construction
- Events
- Papers & Publications
- E-Newsletter
- Blog
- Media

Big Data Part II

This is the second piece in a three-part series about the status and future of Big Data in ecology. The ultimate goal of this series is to spur exploration and discussion of what Big Data means, technically and culturally, to the people who study the interactions between living things and their environment. We invite you to contribute to this discussion.

Big Data has already altered the way scientists view, study, and analyze the world, and appears poised to change the fields of ecology and environmental science forever. Deep and broad information on hundreds of biological and environmental variables collected across space and time will soon be at our fingertips. It may profoundly change the questions we are able to ask and answer about the world around us.

With DataONE launching in July 2012, one huge piece of the tools and knowledge needed to make sense and science of environmental Big Data has moved into place. More data-driven pieces will click into place when NEON shifts into full operations around 2017.

The journey toward the integration of Big Data into environmental science and ecology began in the last century. Sustained organizing efforts as well as parallel advances in technology are finally making it possible to realize some of the dreams of research visionaries of 40 or more years ago.

Part II:
Sharing the Challenges and Payoffs of Big Data

Part III:
Other People's Data

Part I:
The "Big" in Ecological Big Data

Natural History

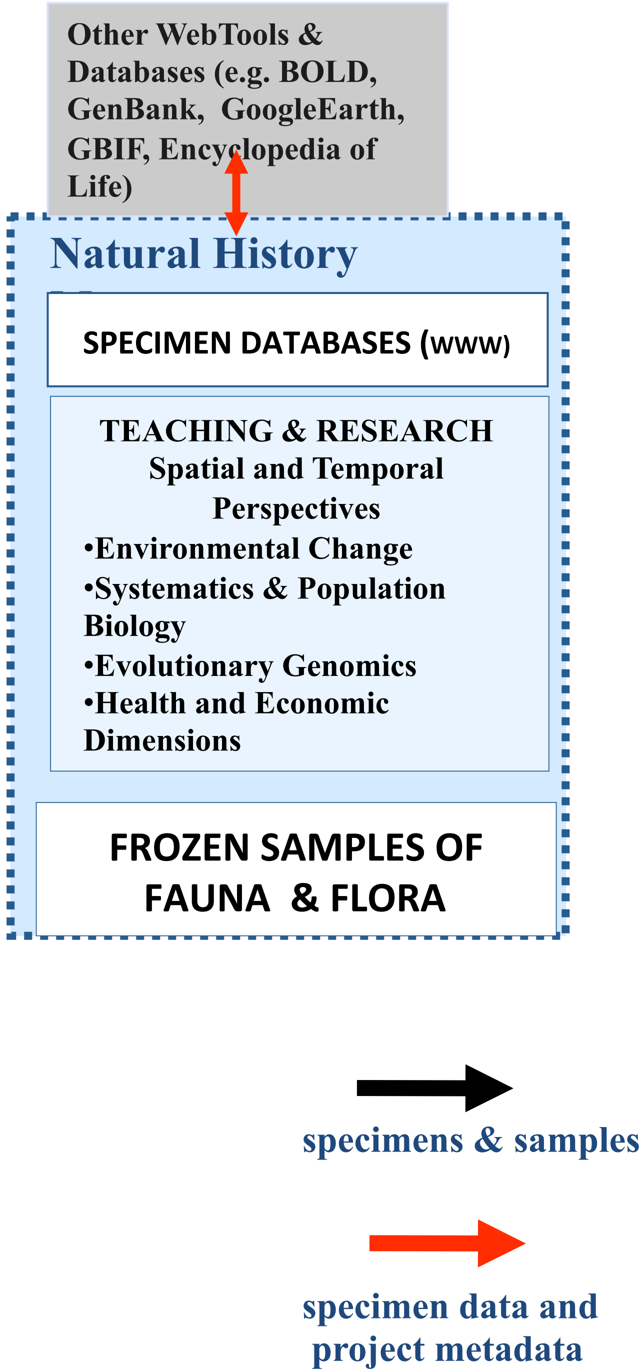
SPECIMEN DATABASES (WWW)

TEACHING & RESEARCH
Spatial and Temporal Perspectives

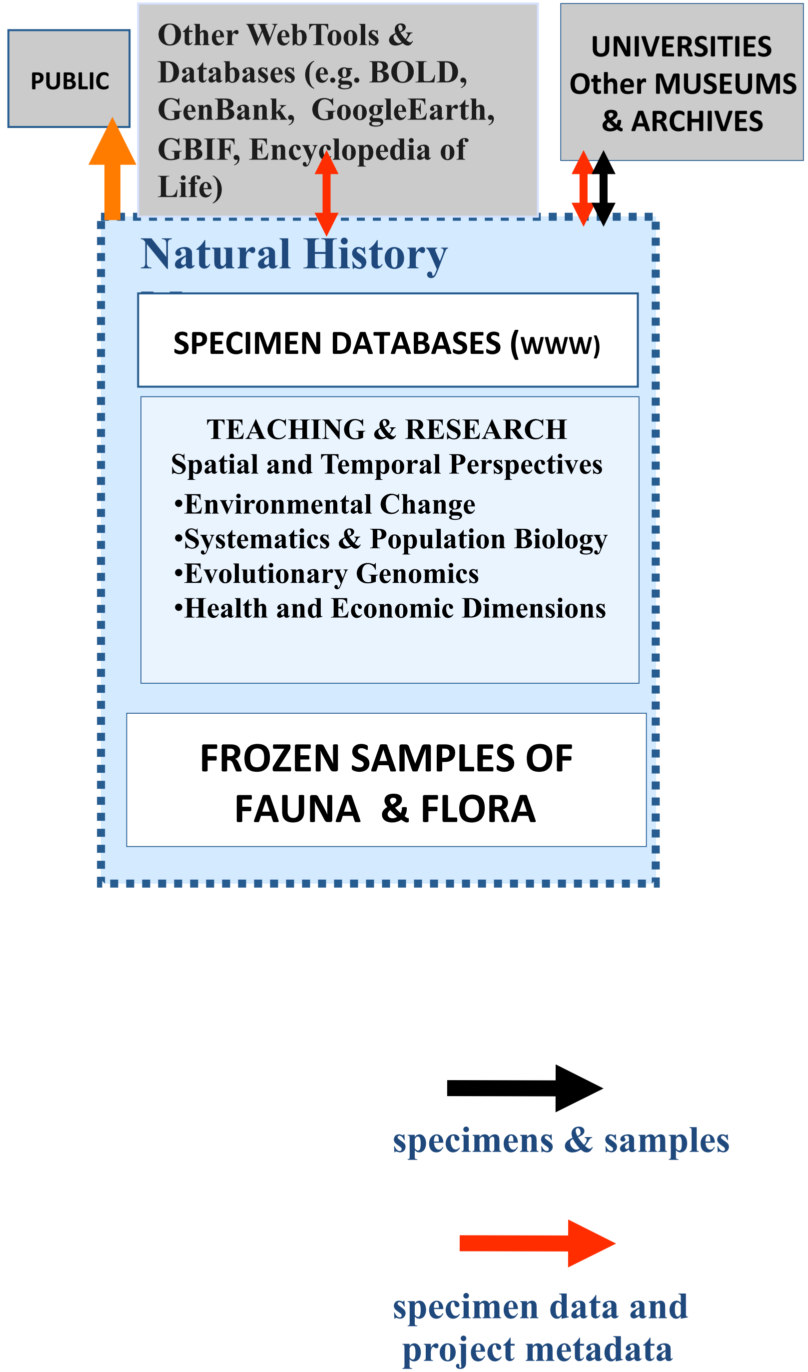
- **Environmental Change**
- **Systematics & Population Biology**
- **Evolutionary Genomics**
- **Health and Economic Dimensions**

SAMPLES OF FAUNA & FLORA

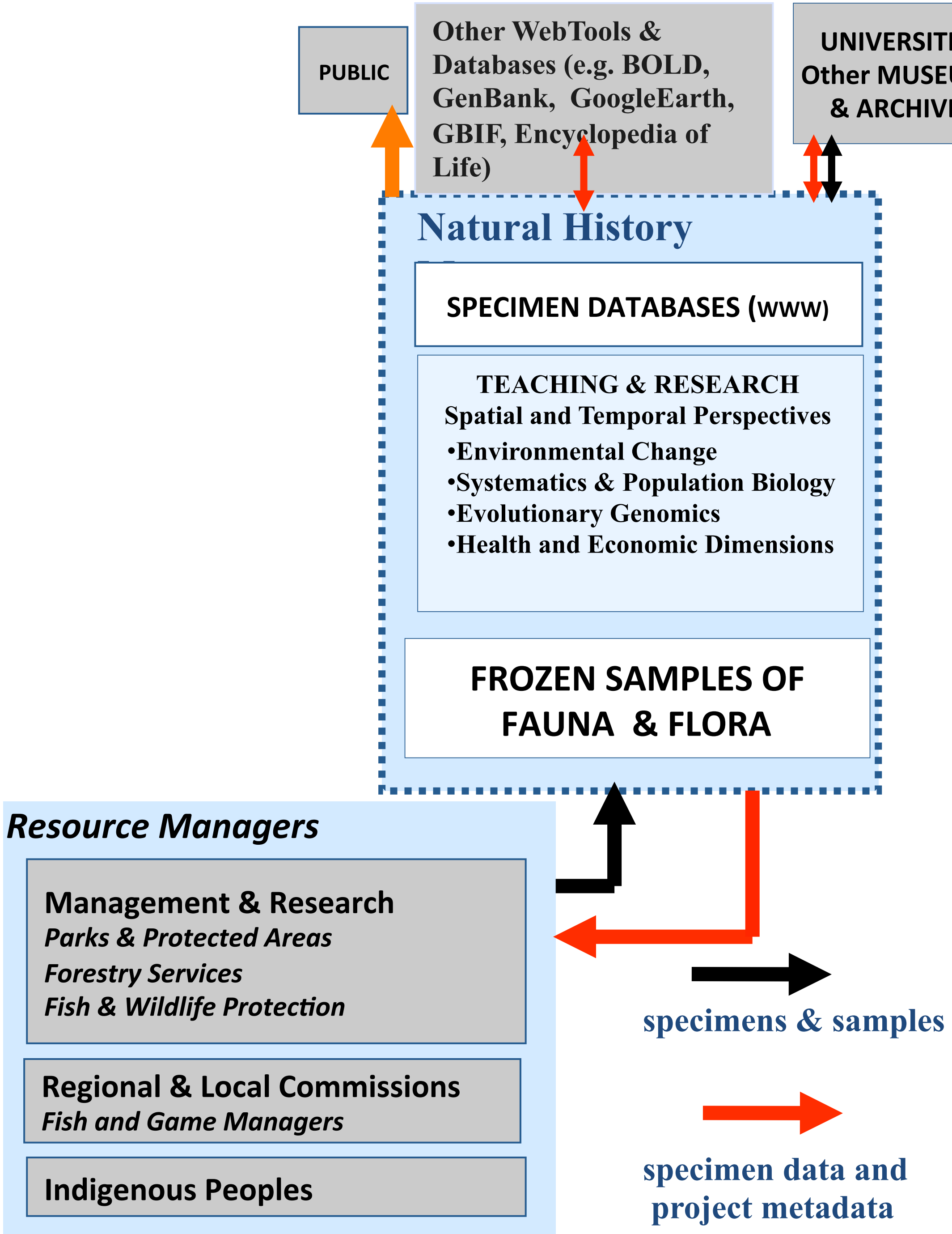
A Museum Approach to Observatories



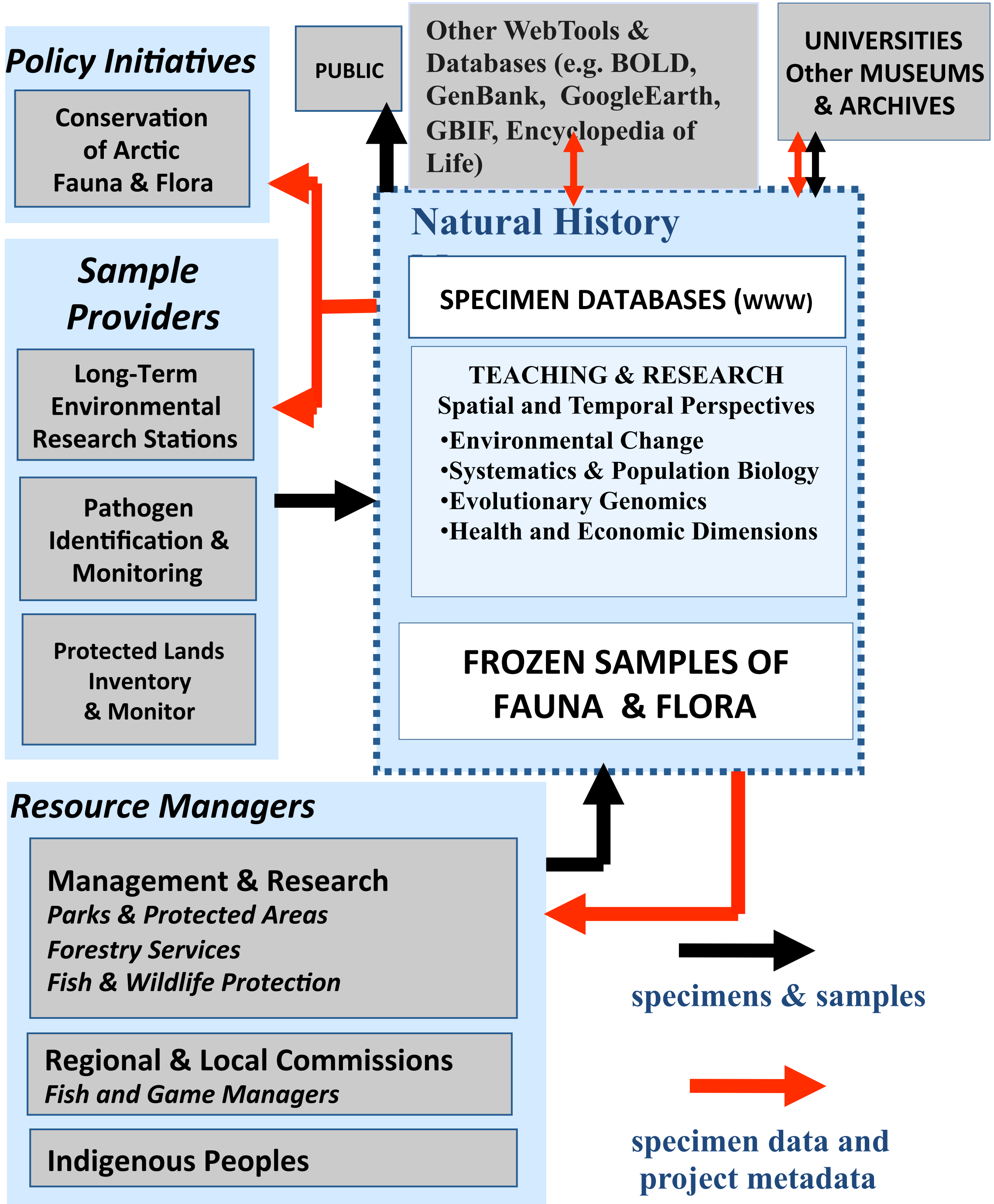
A Museum Approach to Observatories



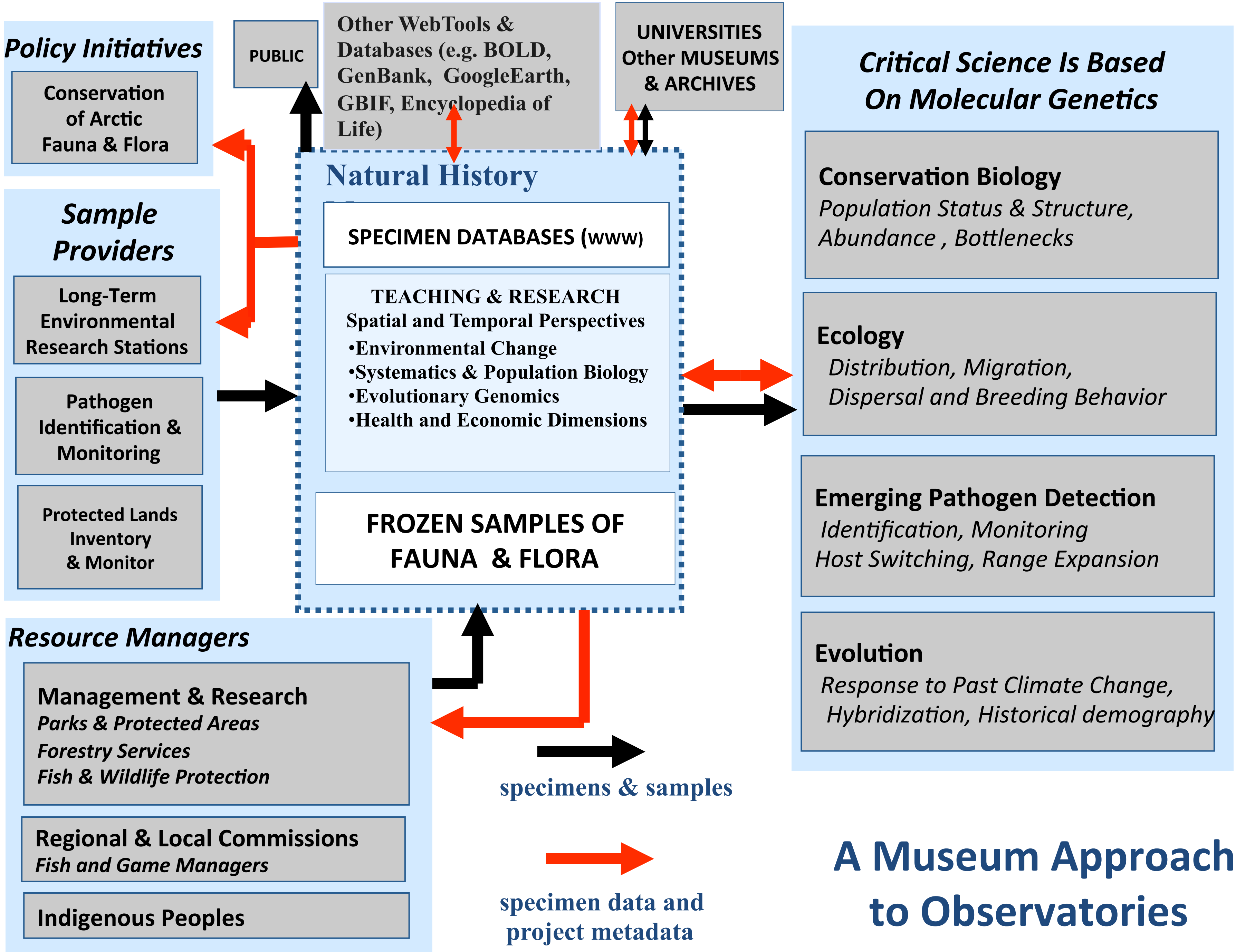
A Museum Approach to Observatories



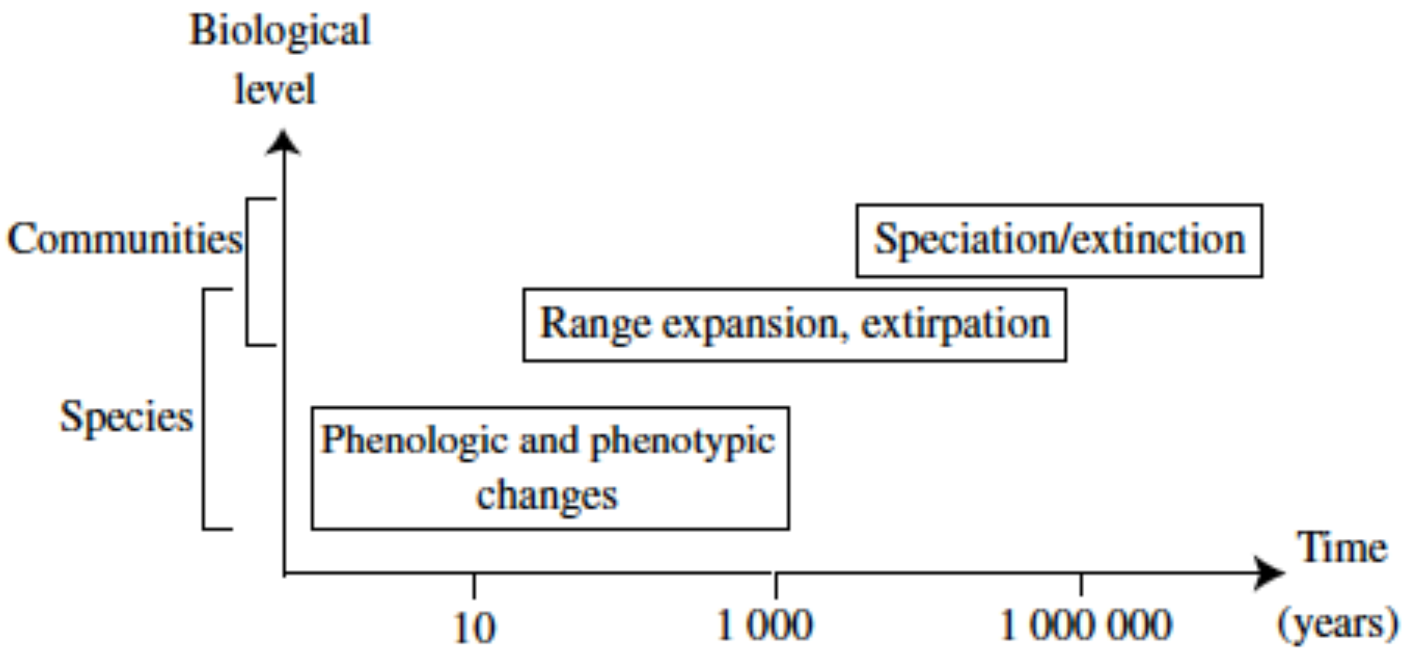
A Museum Approach to Observatories



A Museum Approach to Observatories


Policy Initiatives
Conservation of Arctic Fauna & Flora
Sample Providers
Long-Term Environmental Research Stations
Pathogen Identification & Monitoring
Protected Lands Inventory & Monitor
PUBLIC
Other WebTools & Databases (e.g. BOLD, GenBank, GoogleEarth, GBIF, Encyclopedia of Life)
UNIVERSITIES
Other MUSEUMS
& ARCHIVES
Natural History
SPECIMEN DATABASES (www)
TEACHING & RESEARCH
Spatial and Temporal Perspectives
•Environmental Change
•Systematics & Population Biology
•Evolutionary Genomics
•Health and Economic Dimensions
FROZEN SAMPLES OF FAUNA & FLORA
Critical Science Is Based On Molecular Genetics
Conservation Biology
Population Status & Structure, Abundance , Bottlenecks
Ecology
Distribution, Migration, Dispersal and Breeding Behavior
Emerging Pathogen Detection
Identification, Monitoring
Host Switching, Range Expansion
Evolution
Response to Past Climate Change, Hybridization, Historical demography
Resource Managers
Management & Research
Parks & Protected Areas
Forestry Services
Fish & Wildlife Protection
Regional & Local Commissions
Fish and Game Managers
Indigenous Peoples
specimens & samples
specimen data and project metadata
A Museum Approach to Observatories

Temporal scales of biological responses to climate change



Millien et al. 2006. Ecol Letters

Population/Species Specific Response to Climate Change

- Move
- Adapt--Adjust (fitness-related traits)
- Extirpation/Extinction

Move

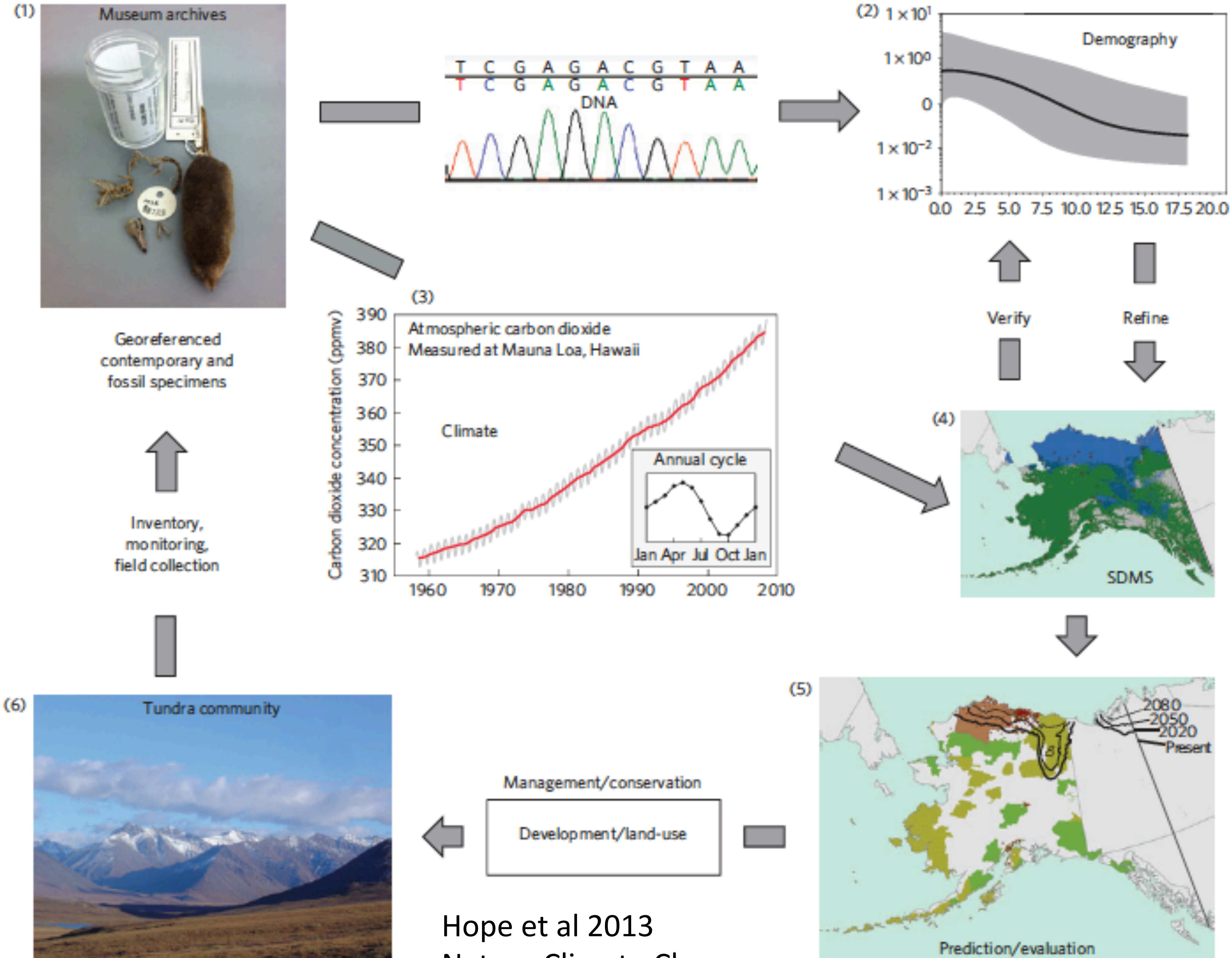
- With warming conditions individuals
  - Move up in elevation—(Grinnell Project)
  - Move to higher latitudes (musk-ox parasite)
  - Explore Velocity of Change

To assess these responses.

Need to know:

- species distribution*
- niche envelop*
- life history*
- vagility/dispersal
  - Assisted colonization (what source?*)

*museum data/specimens



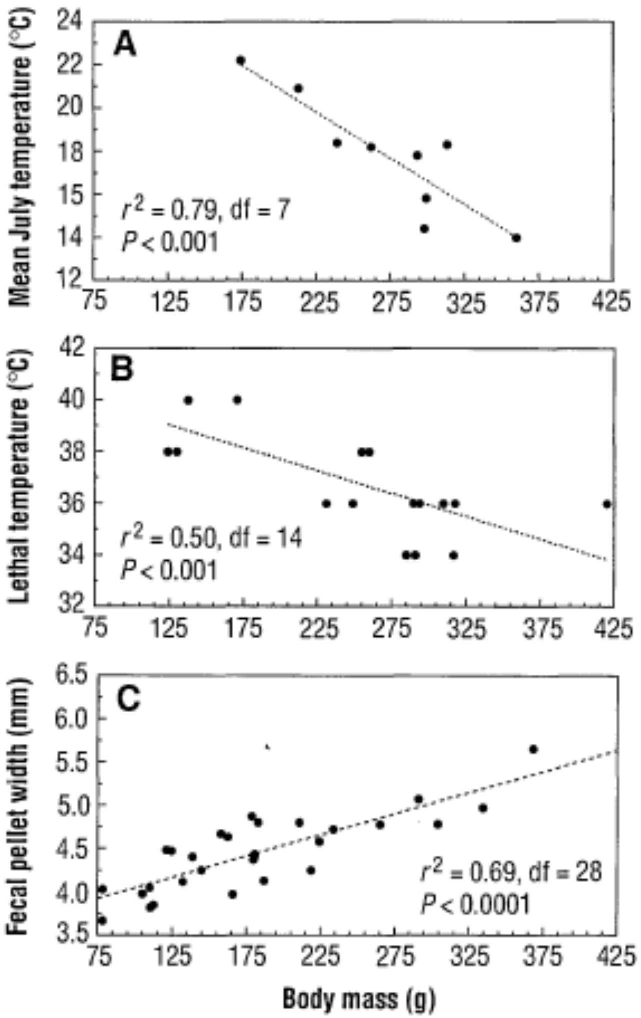
Hope et al 2013
Nature Climate Change

Population/Species Specific Response to Climate Change

- Move
- Adjust (fitness-related traits)
  - behavioral plasticity,
  - physiological plasticity
  - Adapt

Adapt

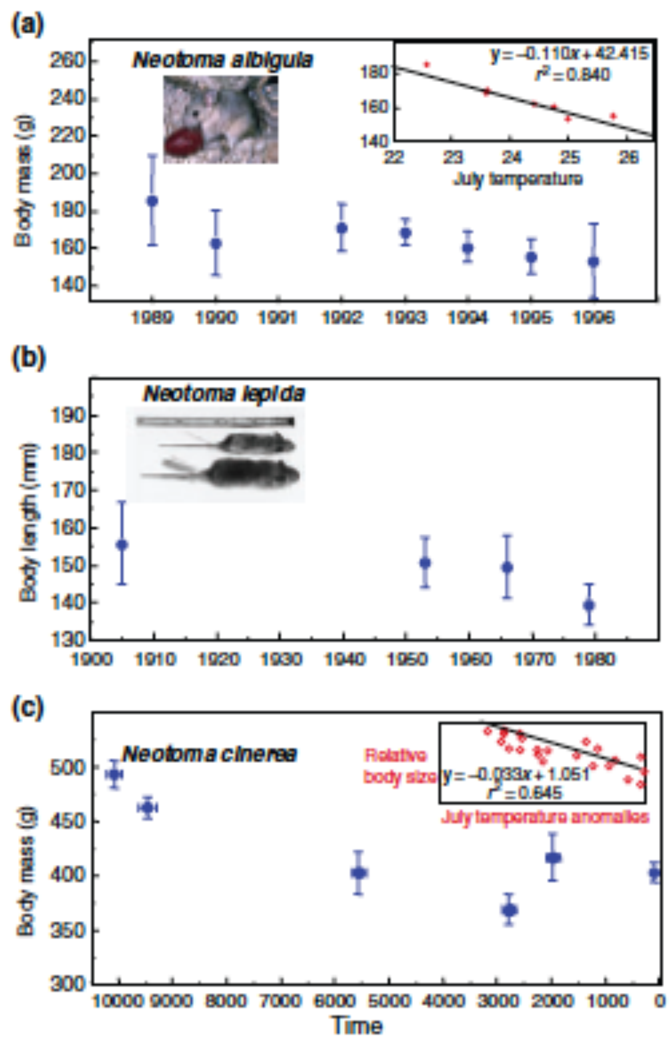
- Body size change –shrews, marten, pack rats



Smith et al 1996. Science.

Body mass and body length variation over time in woodrat species

Millien et al 2006. Ecol. Letters

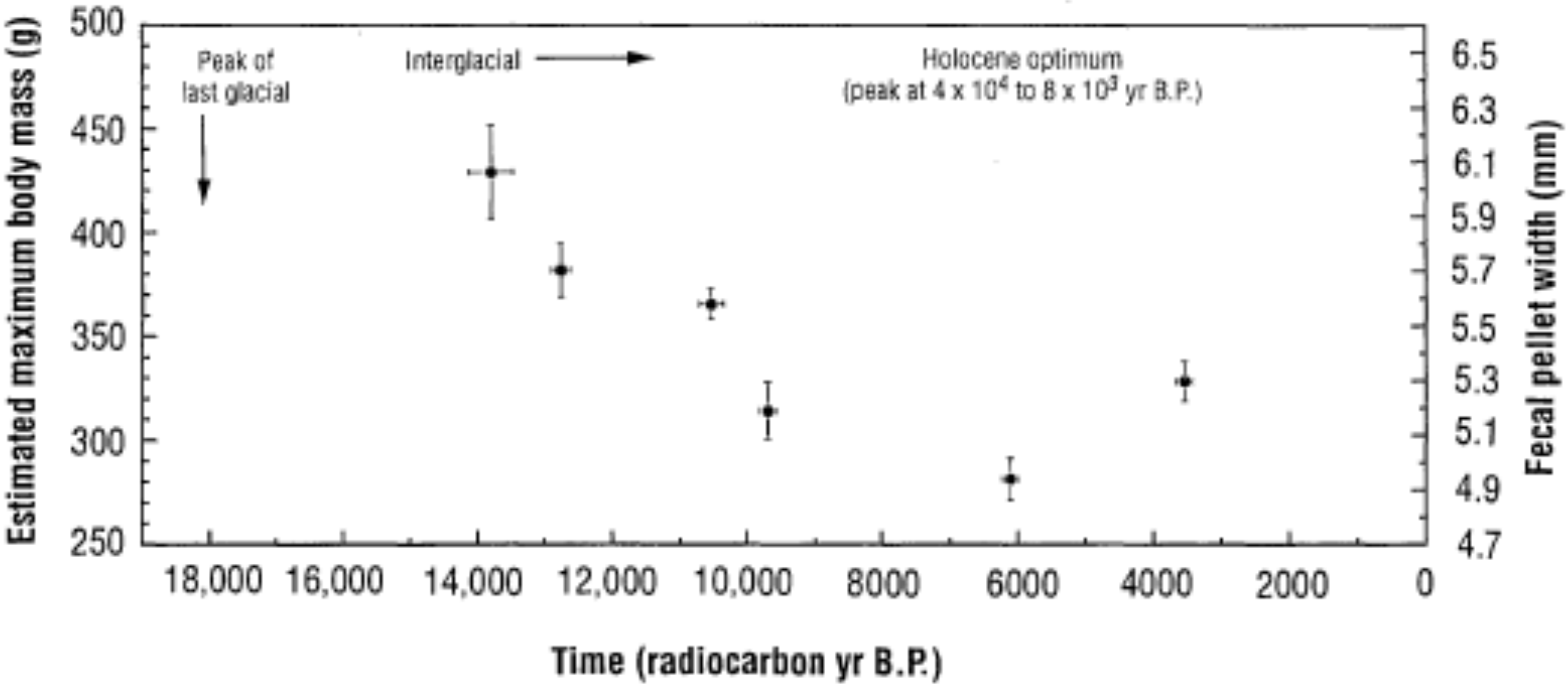


Years

Decades

Millenia

Body size changes of pack rats at Fishmouth Cave, Utah



Smith et al 1996. Science.

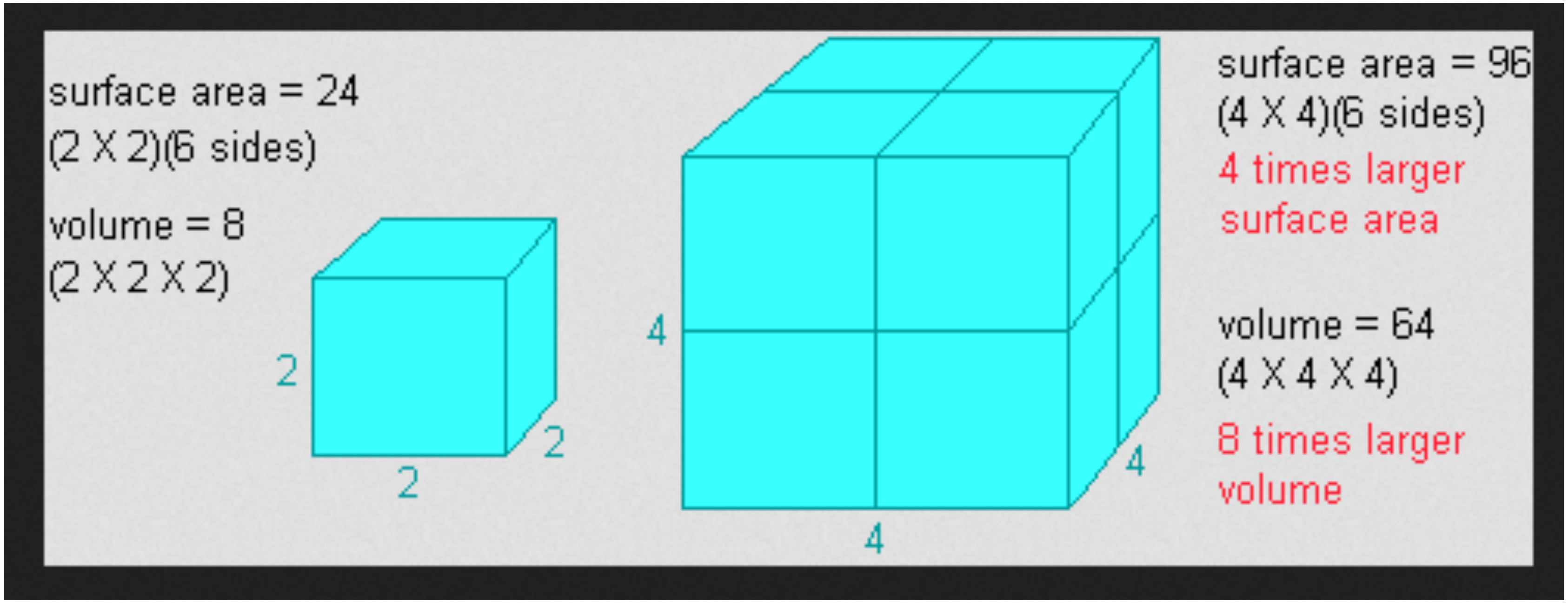
Body Size Changes

- Body size affects thermoregulation and energetics—volume to surface area

- **Bergmann's rule** – (ecogeographic principle) within a broadly distributed clade, larger-sized populations and species in colder environments, and species of smaller size are found in warmer regions

Body Size Changes

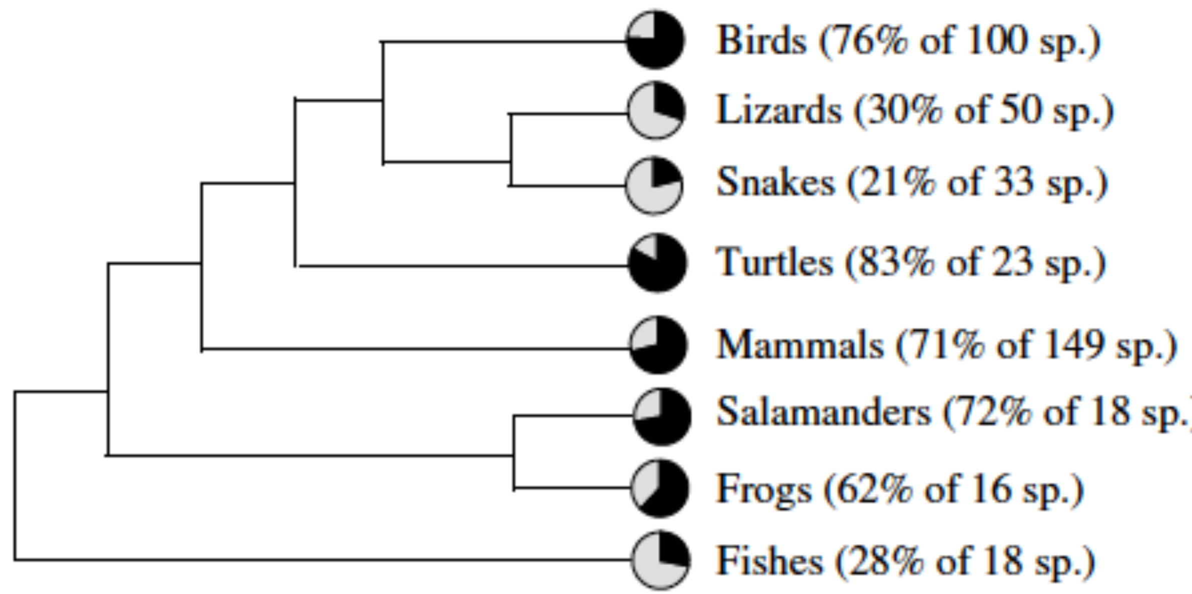
Bergmann's rule – (ecogeographic principle) within a broadly distributed clade, larger-sized populations and species in colder environments, and species of smaller size are found in warmer regions



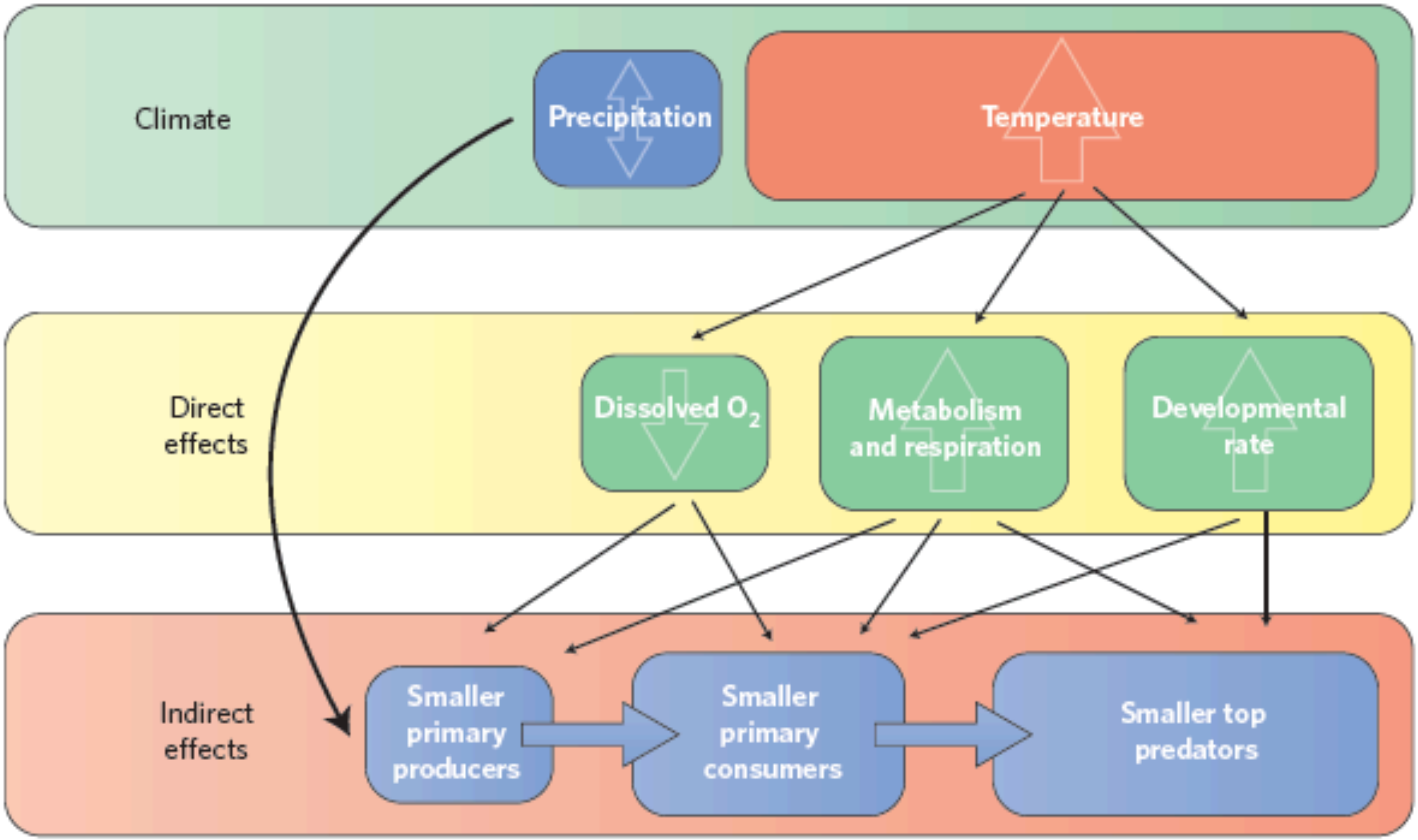
- Radiate less body heat per unit of mass
  - Warmer climates: body heat generated by metabolism needs to be dissipated.
  - Colder climates: need to retain body heat
- inherent lack of precision in quantifying responses to climate change

Extent of Bergmann's rule among vertebrates

Millien et al 2006.
Ecol Letters



Processes of climate change effects on organism size



Sheridan & Bickford 2011
Nature Climate Change

Each degree of warming

decrease body size by:

- 0.5–4% in marine invertebrates
- 6–22% in fish
- 1–3% in beetles
- 14% in salamanders

Sheridan & Bickford 2011
Nature Climate Change

Population/Species Specific Response to Climate Change

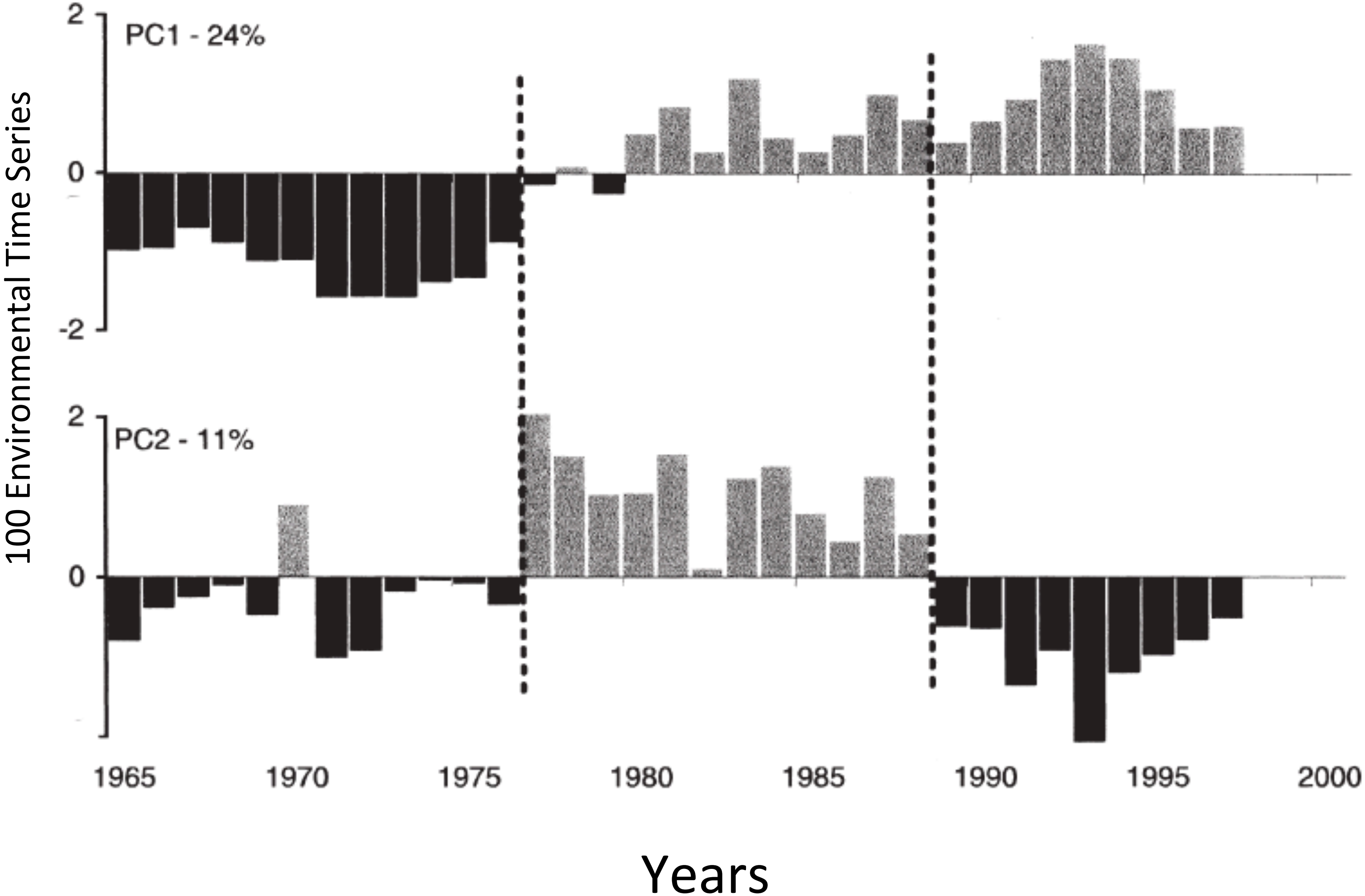
- Move
- Adjust (fitness-related traits)
  - Shorter term
    - behavioral plasticity,
    - physiological plasticity
  - Longer term Adaptations
- Extirpation/Extinction

Adjustment

- Life History Changes
  - timing of reproduction (specimen databases),
  - offspring number and size (specimen databases),
  - number of life cycles (northern parasites),
  - changes in prey or trophic level

Regime Shifts

North Pacific Regime Shift—Biological and Physical Changes



Hare & Mantua 2000
Progress in Oceanography

Impact on Biota?

North Pacific Regime Shift

- Shell, Hirons (isotopes of marine mammals)
  - Specimens from 1947 to 2000
    - Baleen of bowhead whales
    - Muscle, whiskers of seals, sea lions

Bottom up?—oceanographic change (climate)

or

Top down?---over fishing, predation, other

Stable isotopes from baleen of bowheads

Seasonal productivity higher 1947-1976

Drop in seasonal carbon fixation (30-40%)

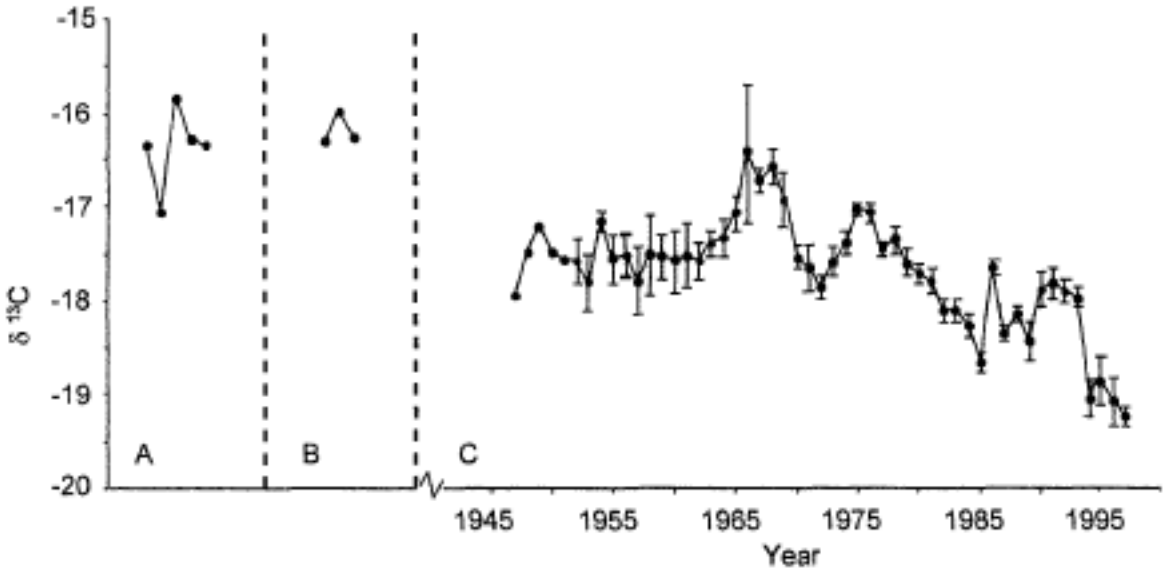


Fig. 2 Average annual Bering/Chukchi carbon isotope ratios in baleen from (A) partial baleen plate from Punuk Island, (2200 yr B.P.); (B) partial plate from St. Lawrence Island (ca. 1870 A.D.) and (C) from 37 whales taken over the past four decades (from Table 1).

Schell 2000. Limnology and Oceanography

No significant change in bone δ15N in North Pacific, but decrease in δ13C suggests decline in primary production (phytoplankton growth rate) at base of the foodweb, rather than a trophic level change due to prey switching.

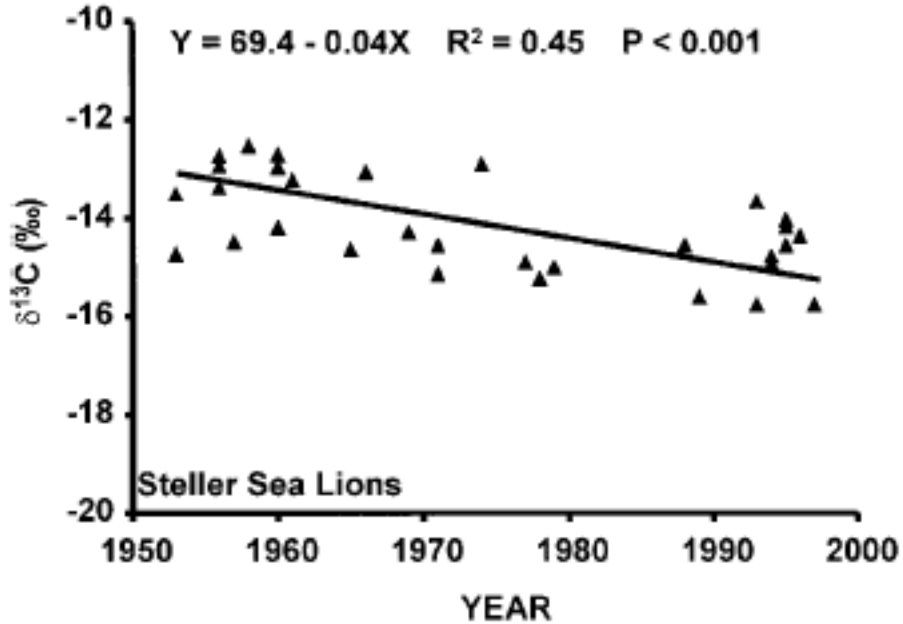
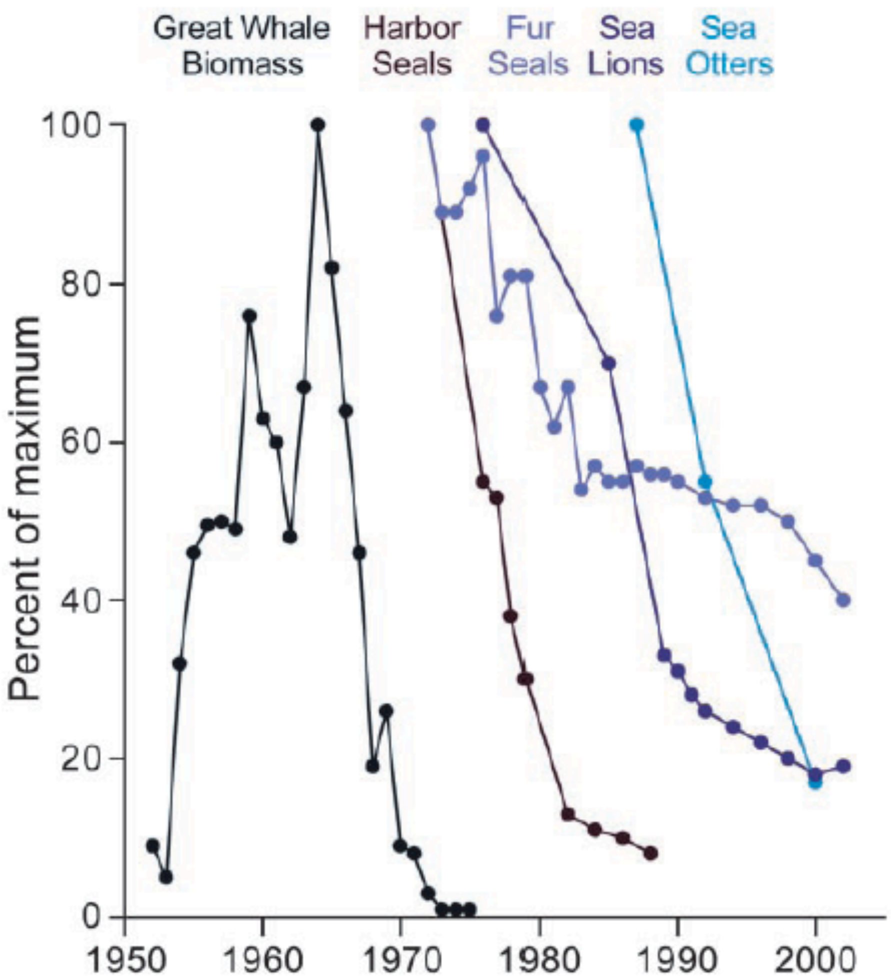


Fig. 3 $\delta^{13}C$ values of bone collagen for Steller sea lions for the Bering Sea and Gulf of Alaska, 1953–1997

Hirons et al 200. Oecologia

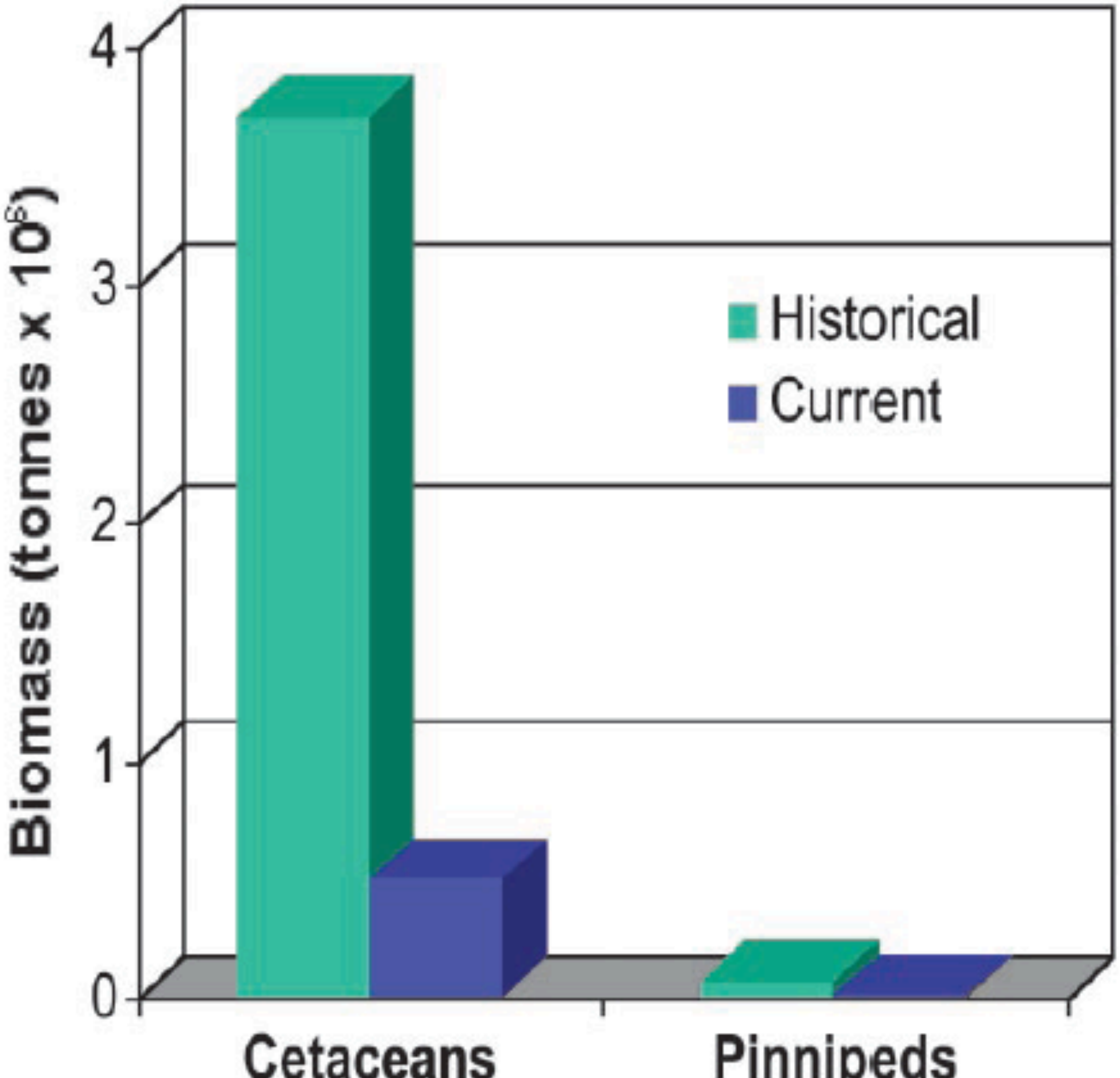
Sequential megafaunal collapse in the North Pacific Ocean: An ongoing legacy of industrial whaling?

Springer et al 2004 PNAS



Biomass Changes after Industrial Whaling

Springer et al 2004 PNAS



Killer whales

- Sea otter story

From oceans to the Southwest

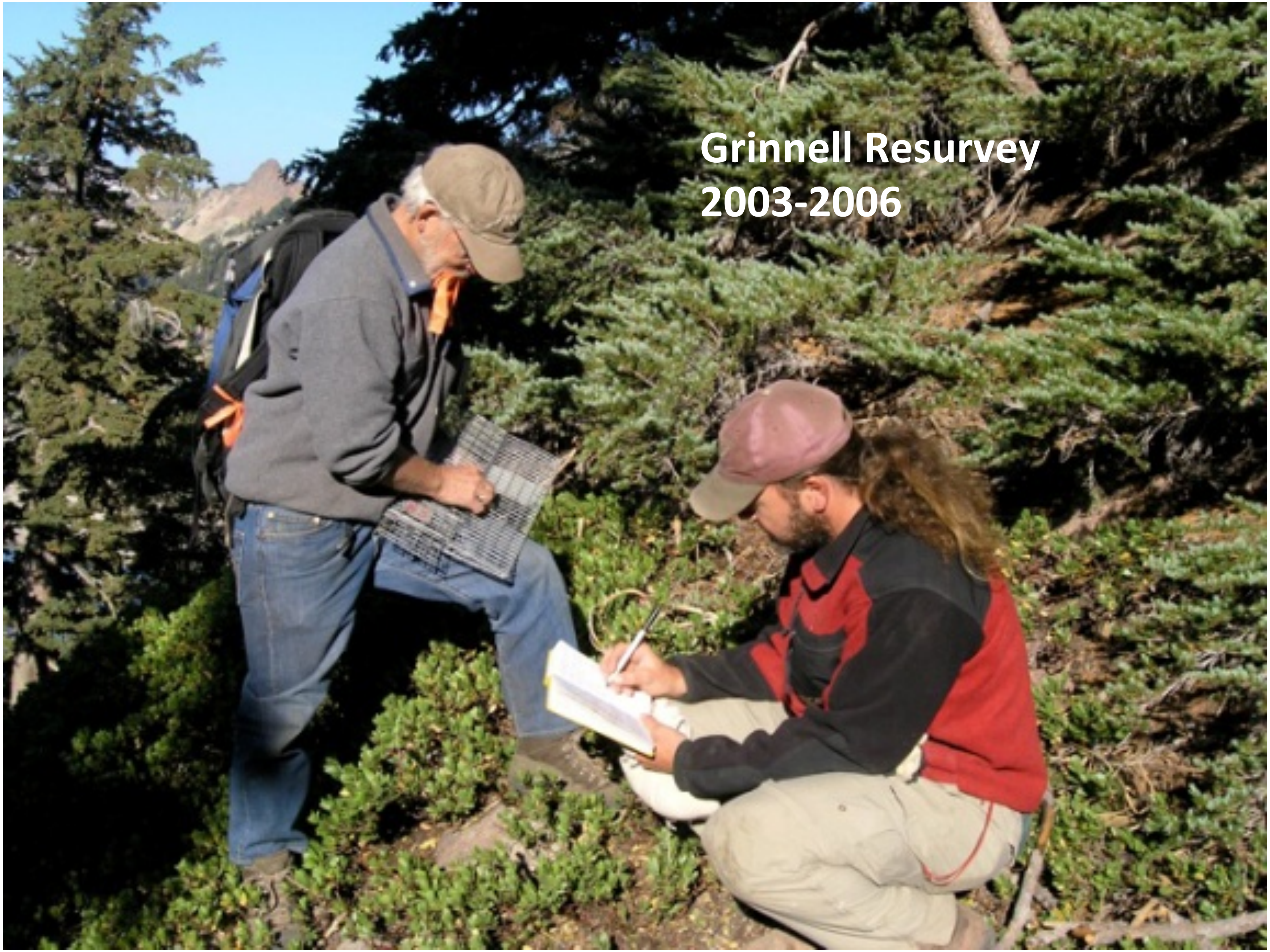
Museum of Vertebrate Zoology—Grinnell Project

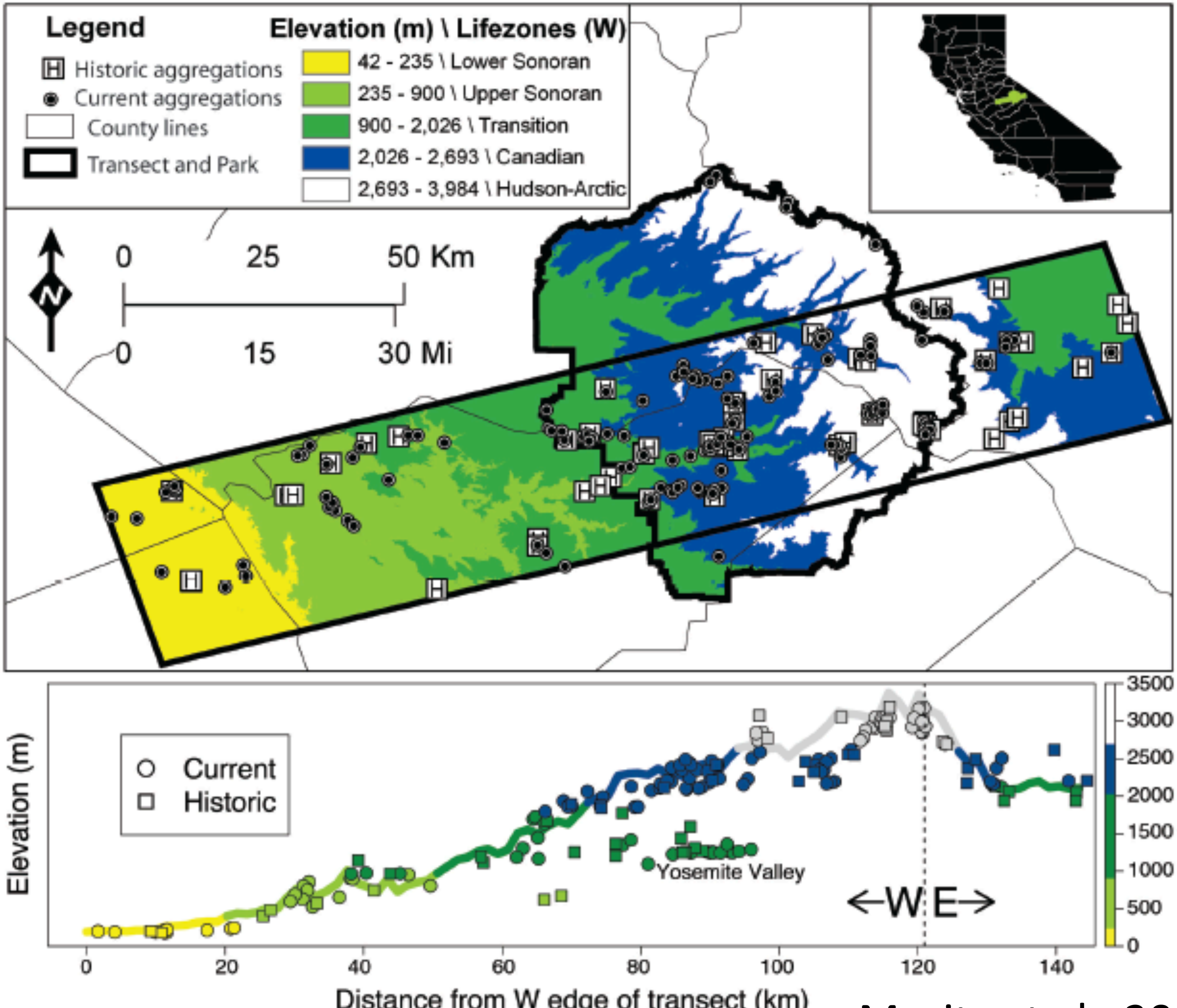
‘How can we use historical data to inform us about species response to climate change?

Original Grinnell Survey 1914-1920
2 Publications—
And specimens endure

Grinnell Resurvey 2003-2006
11 publications
And specimens endure

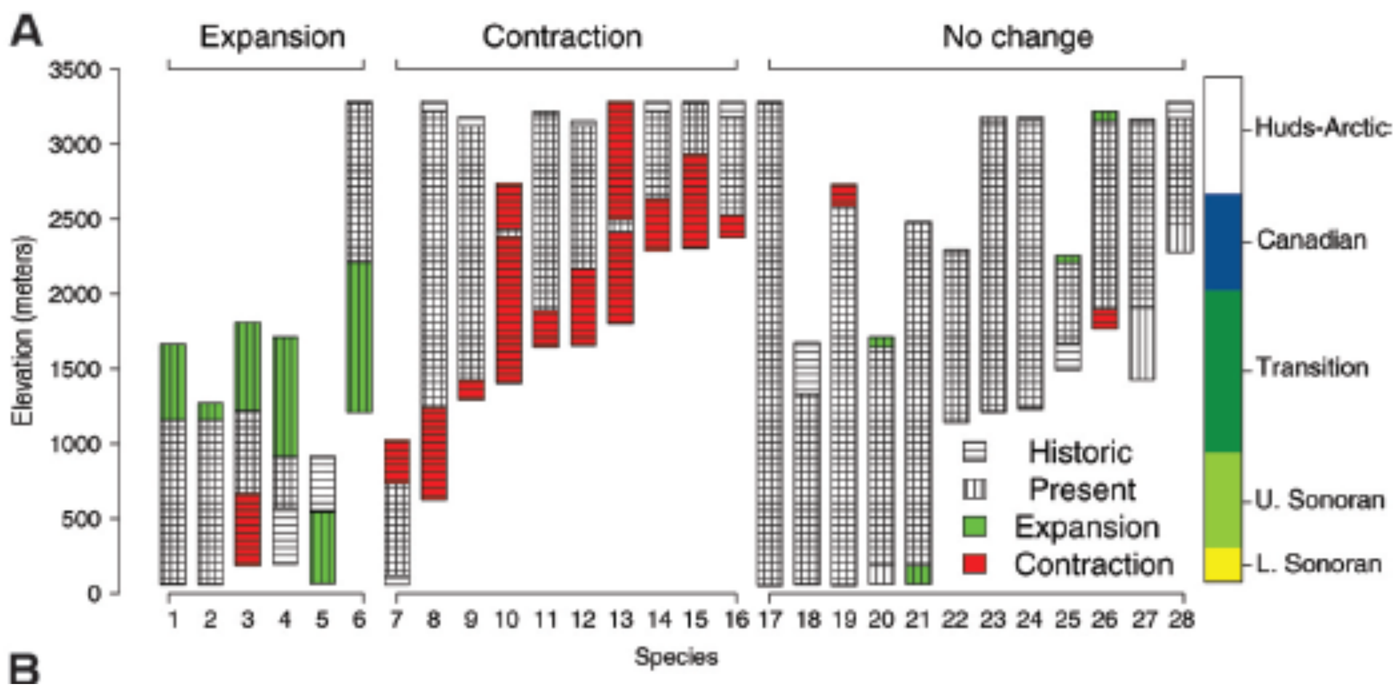
Museum of Vertebrate Zoology
Yosemite Field Expeditions
1914-1920


Grinnell Resurvey
2003-2006



Moritz et al., 2009. Science

~500 meters on average upward changes in elevational limits for half of 28 species monitored, consistent with ~3°C increase in minimum temperatures.



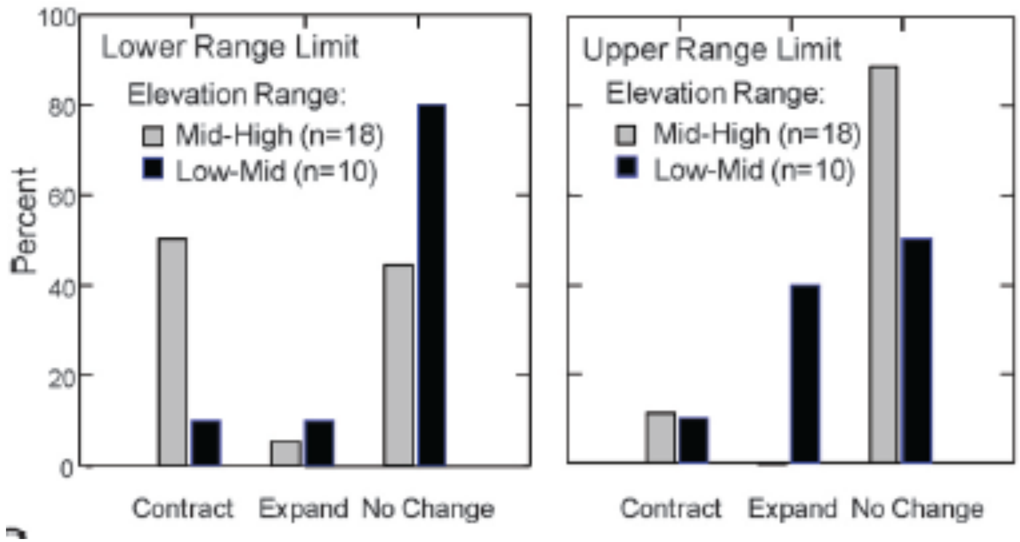
Significant Contraction

Significant Expansion

No Change" if range shifts were biologically trivial (<10% of previous elevation range) or of small magnitude (<100 m).

Moritz et al., 2009. Science

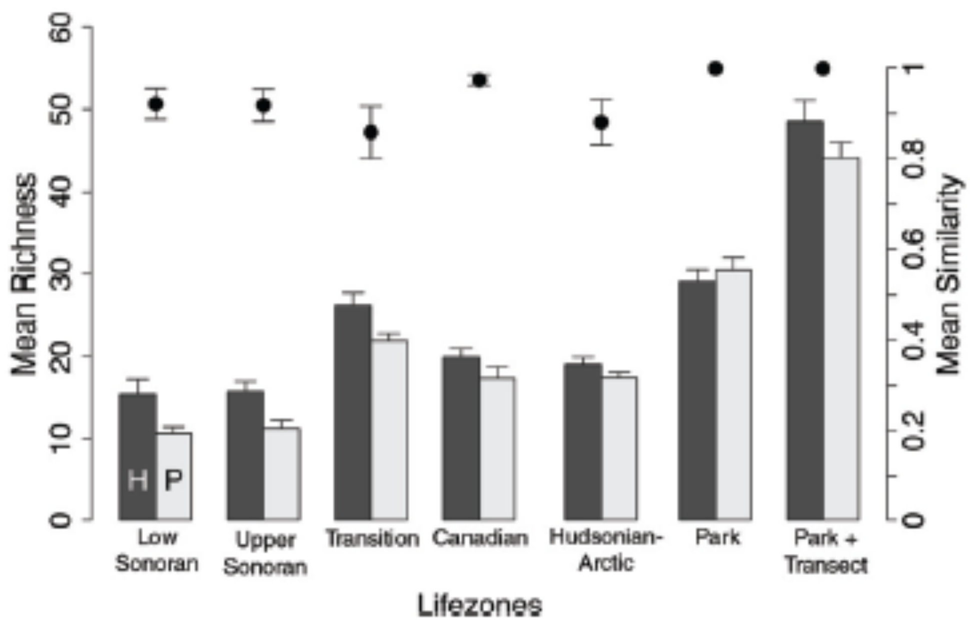
Changes in elevation-range limits for species



Comparison of changes in elevation-range limits for species that formerly had low- to mid-elevation versus mid- to high-elevation ranges (Table 1) across the transect.

Moritz et al., 2009. Science

Community richness across life zones



Mean (T SE) estimates of
species richness by era (bars: H, historic;
P, present; see also table S4 and fig. S4)
and community similarity (points) for individual
life zones, Yosemite National Park,
and the entire transect.

Moritz et al., 2009. Science

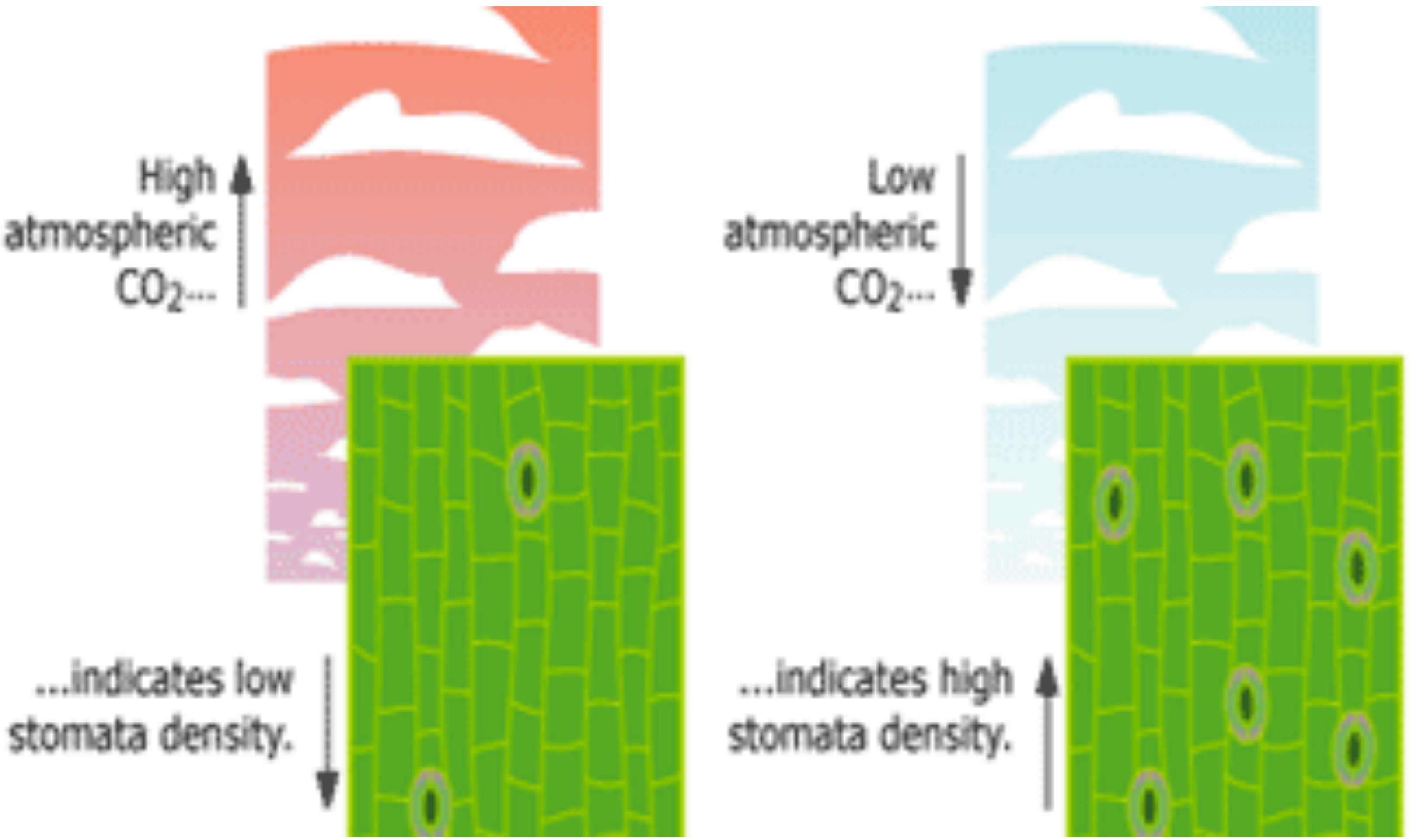
What more could be studied on these transects?

- The next steps……

Adapt

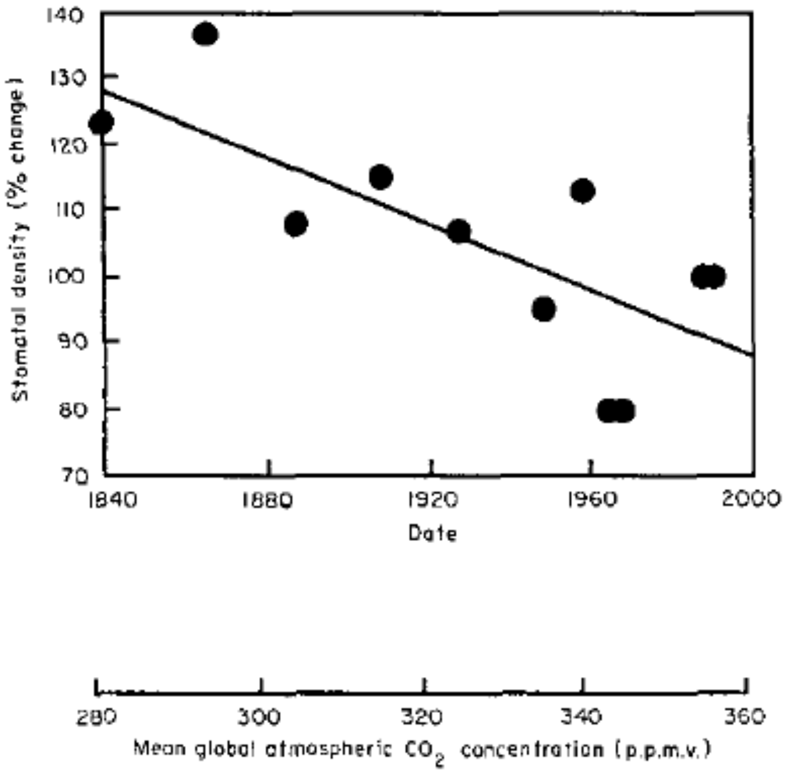
- Molecular physiology
  - Transcriptome work on rodents across Patagonia
- Diet—shift in stable isotopes
  - (Schell and Irons marine mammals)
- Plants?

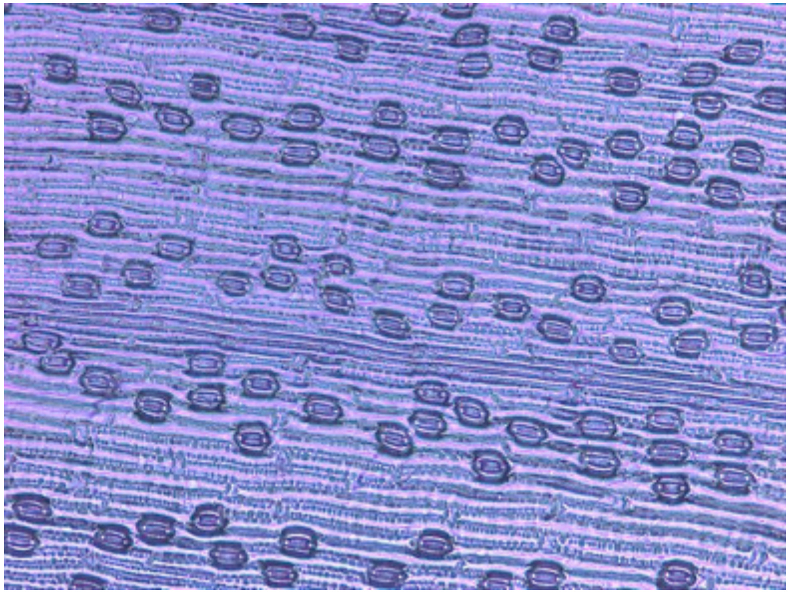
Adapt: Plants
Impact of Atmospheric *CO2* and *Temperature Change* on *Stomatal* Density



Changes in Stomatal Density in Leaves of Herbarium Oak Specimens

- Beerling and Chalander 1992. Annals of Botany

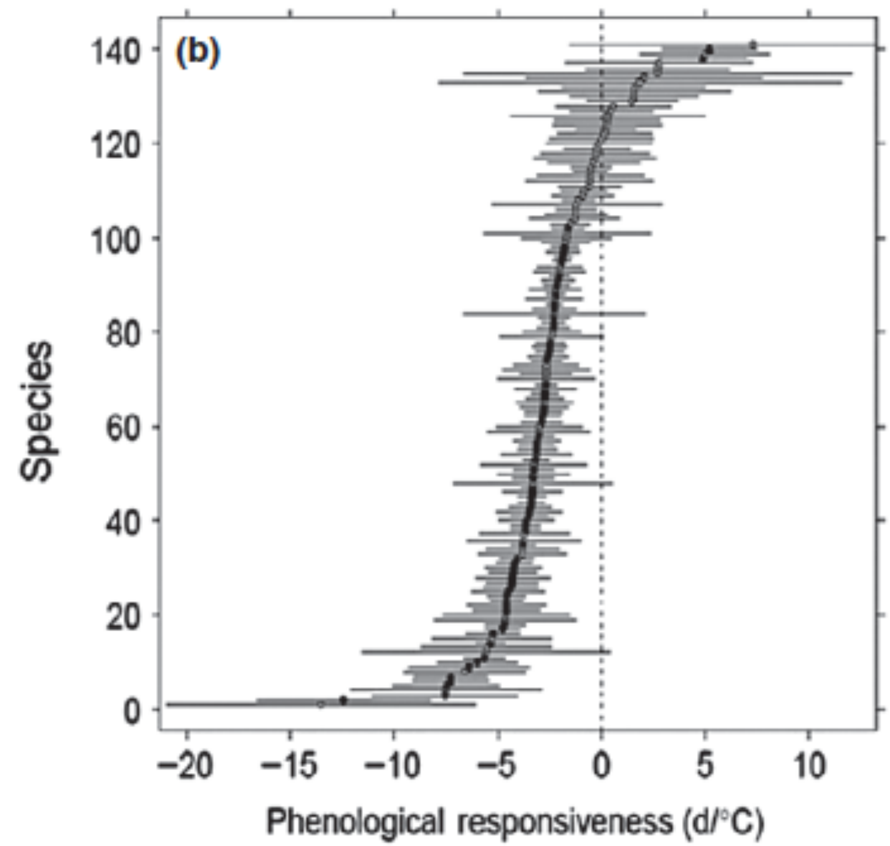




Adapt

- Phenology—reproduction, migration, hibernation/torpor, pollination, body condition, flowering time
  - Plants, birds, insects,

Phenological responsiveness to rising temperature among spring flowering species. (Topmost in each panel is reference and a positive shift represents earlier flowering with warming) N=5053 specimens



Calinger et al 2013 Ecol. Letters

Adapt

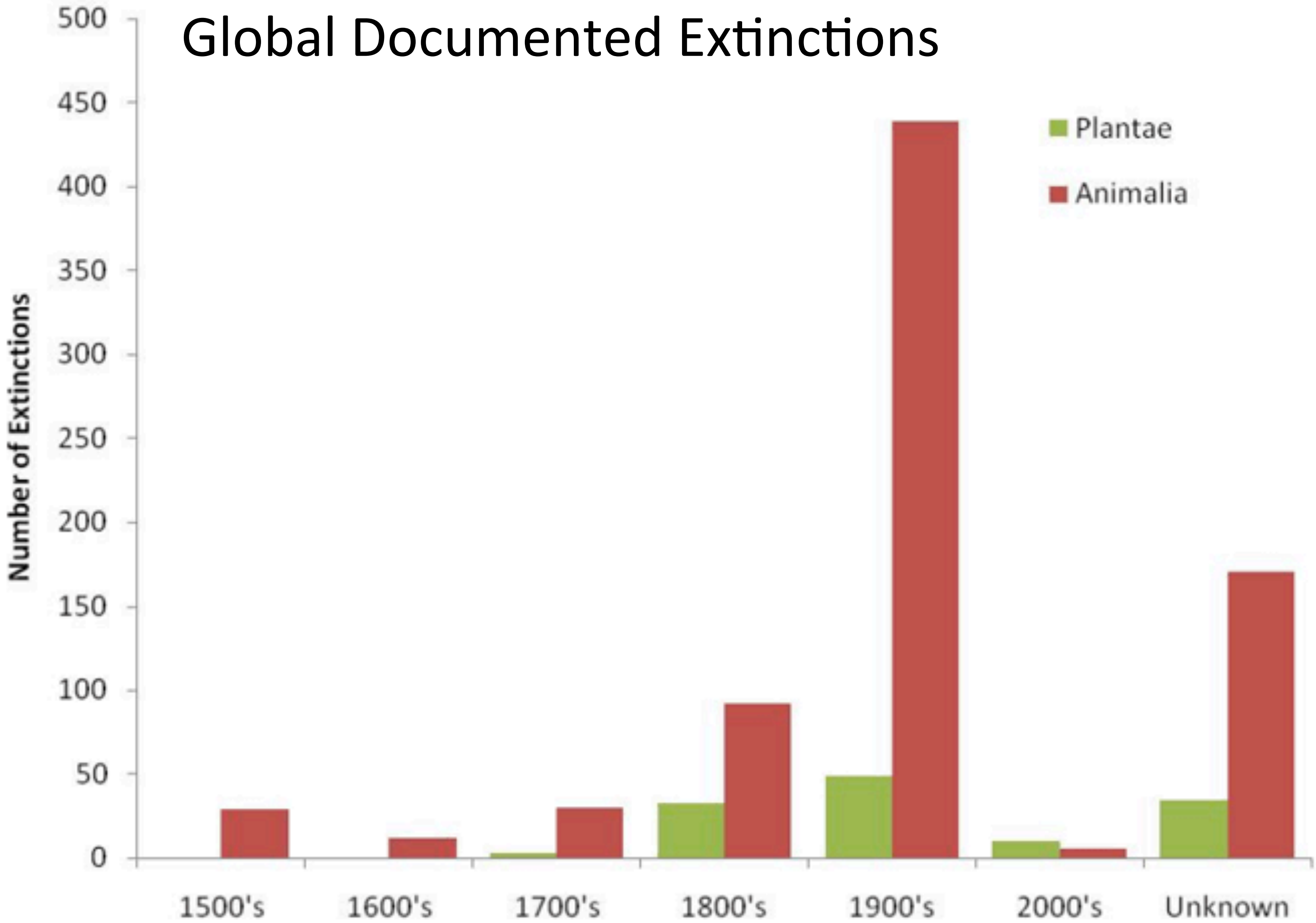
Examples

- Body size change –shrews, marten, pack rats
- Life History—reproduction, offspring number and size, number of life cycles (parasites)
- Physiology-
- Diet shifts—stable isotopes
- Molecular physiology
- Phylogenetics and Phylogeography
- Phenology—reproduction, migration, hibernation/torpor, pollination, body condition, flowering time
  - Plants, birds, insects, mammals

Museum specimens

- Museum collections show color morph frequencies in owls changed responding to climate change.
  - Galeotti, P. et al. (2009) Global changes and animal phenotypic responses: melanin-based plumage redness of scops owls increased with temperature and rainfall during the last century. Biol. Lett. 5, 532–534
- Feathers (sample) combined with analytical advances [41–46] now examine nutrition, stress, diet and size. Sampling multiple individuals across sites and over time would enable examination of stressors singly and in combination.

- Habitat conversion
- Pollutants
- Emerging pathogens
- Introduction of exotics
- Loss of biotic diversity


Global Documented Extinctions
Number of Extinctions
500
450
400
350
300
250
200
150
100
50
0
Plantae
Animalia
1500's
1600's
1700's
1800's
1900's
2000's
Unknown

Schipper et al 2008 Science

Total and Red List category	Mammal species by habitat		
	All	Land	Marine
Number of species (% of total)			
Total	5487	5282	120
EX	76 (1.4)	NA	NA
EW	2 (0.04)	NA	NA
CR	188 (3.4)	185 (3.5)	3 (2.5)
EN	448 (8.2)	436 (8.3)	12 (10.0)
VU	505 (9.2)	497 (9.4)	12 (10.0)
NT	323 (5.9)	316 (6.0)	7 (5.8)
LC	3109 (56.7)	3071 (58.1)	40 (33.3)
DD	836 (15.2)	777 (14.7)	46 (38.3)
Threat level (%)			
Threat level (range)	25 (21 to 36)	25 (21 to 36)	36 (23 to 61)

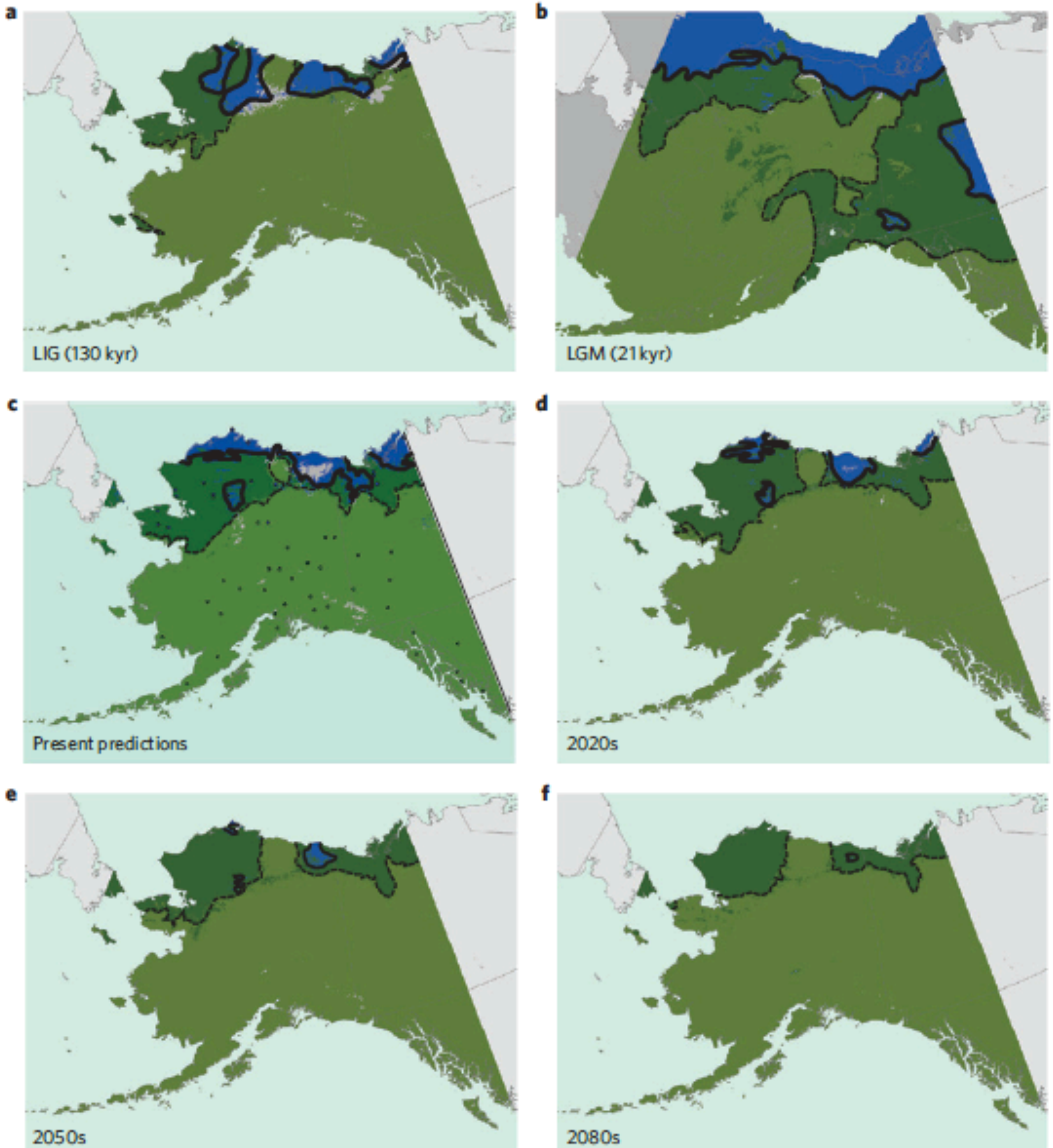
Global Conservation Status Mammals

Susceptibility to Extirpation

Response to heat waves

- Mass die-offs of endotherms
  - McKechnie, A.E. and Wolf, B.O. (2010) Climate change increases the likelihood of catastrophic avian mortality events during extreme heat waves. Biol. Lett. 6, 253–256
  - Welbergen, J.A. et al. (2008) Climate change and the effects of temperature extremes on Australian flying foxes. Proc. R. Soc. Lond. B 275, 419–425
- and ectotherms
  - Cerrano, C. et al. (2000) A catastrophic mass-mortality episode of gorgonians and other organisms in the Ligurian Sea (North western Mediterranean), summer 1999. Ecol. Lett. 3, 284–293

Potential Distributions

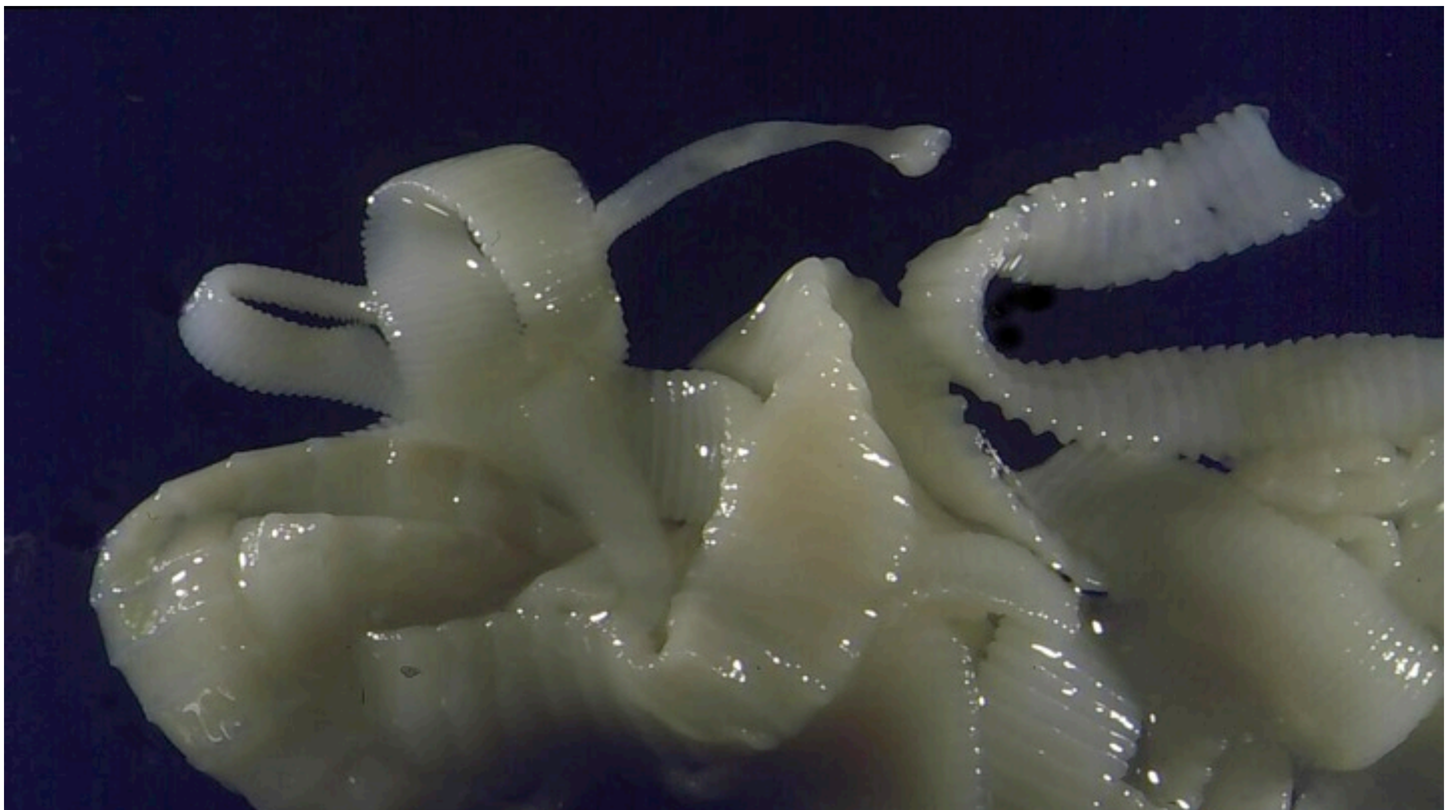


barren-ground shrew (blue)
masked shrew (light green)
both species (dark green)

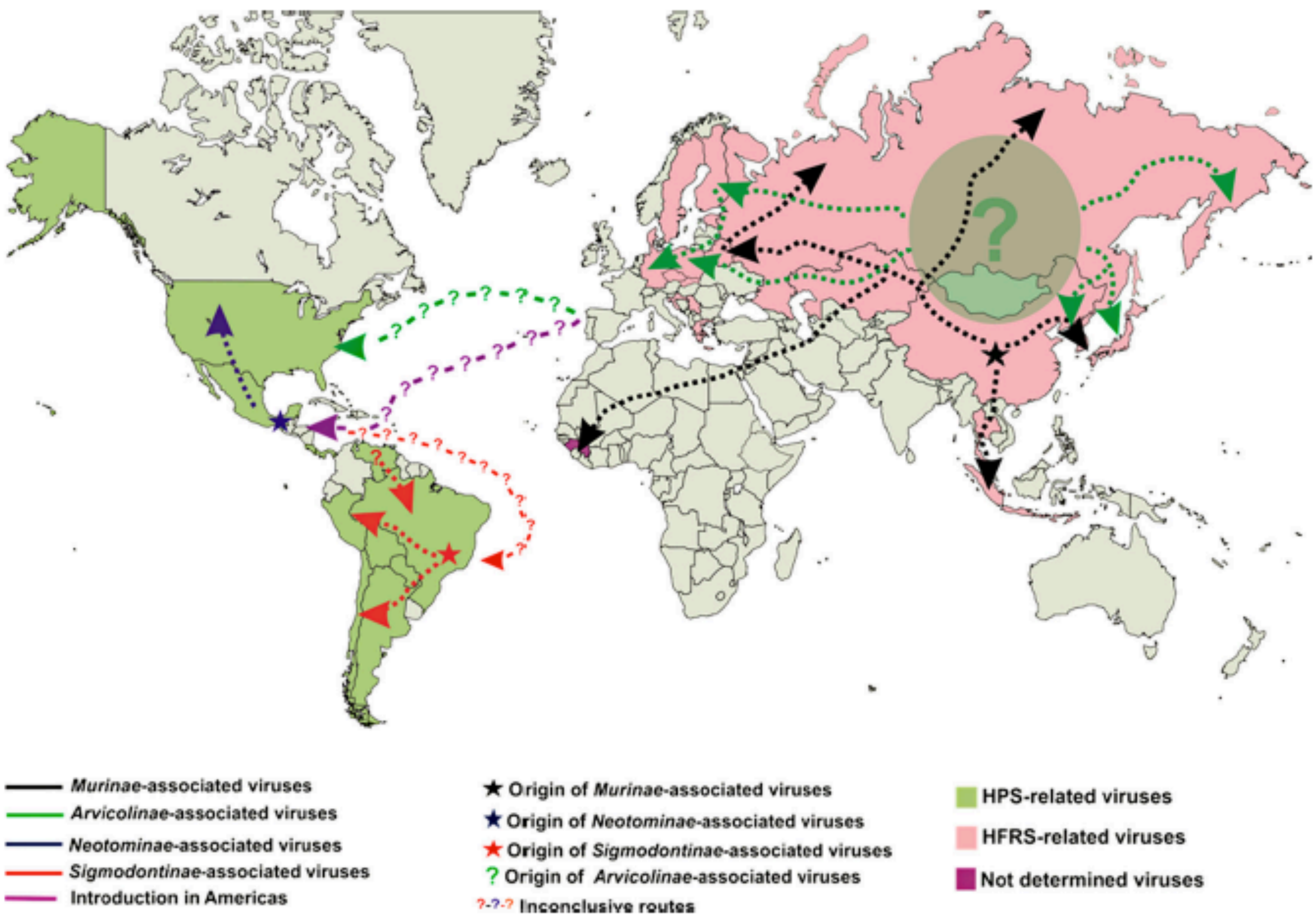
Hope et al 2013
Nature Climate Change

Community Level Response to Environmental Change

- Change in Competitive, Mutualistic or Parasitic Interactions



Probable origin and migratory routes of rodent-borne hantavirus



Souza et al. 2013. Infection, Genetics, & Evol

Community Level Response to Environmental Change

- Change in Competitive, Mutualistic or Parasitic Interactions
- Invasive Species

Community Level Response to Environmental Change

- Change Competitive, Mutualistic or Parasitic Interactions
- Invasive Species
- Changes in Community Composition
  - How is this identified or monitored?

Limitations of Museum Specimens and Challenges for Museums

- Deep and Wide
- Tracking Investigations
- Increasing Precision
- Finite Resource
- Standardize Field Methods
- Integrated Collections

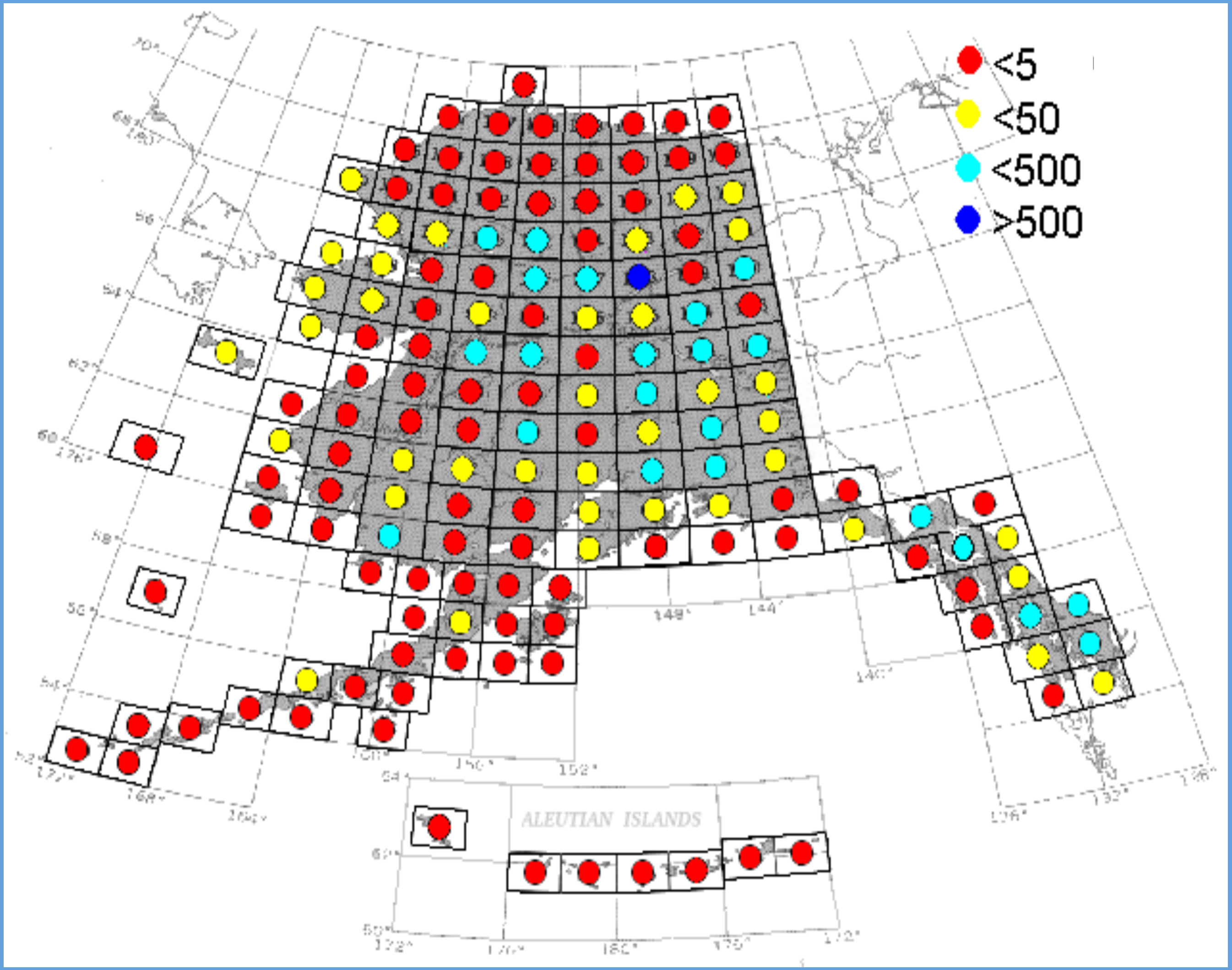
Challenges for Museums- 1

- Continue to Build the Resource
  - Well distributed over time and space
  - Large sample sizes
  - Archive new data (habitat, methods, etc
  - Archive multiple data sets
    - standard specimens
    - various tissue types
    - Parasites

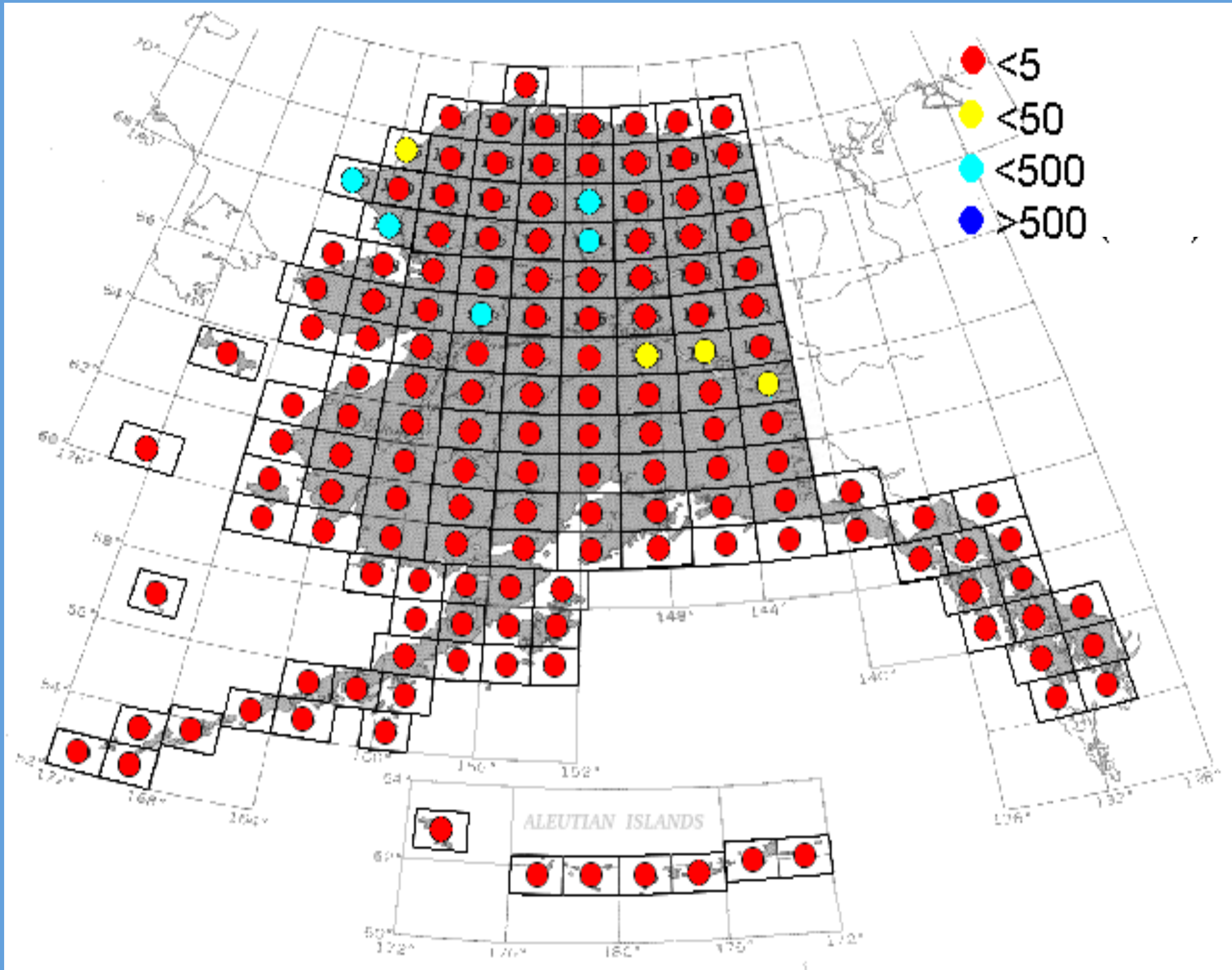
- Protocols for making material available
- Network for connecting scientists (and the general public)

Specimens of *Clethrionomys*

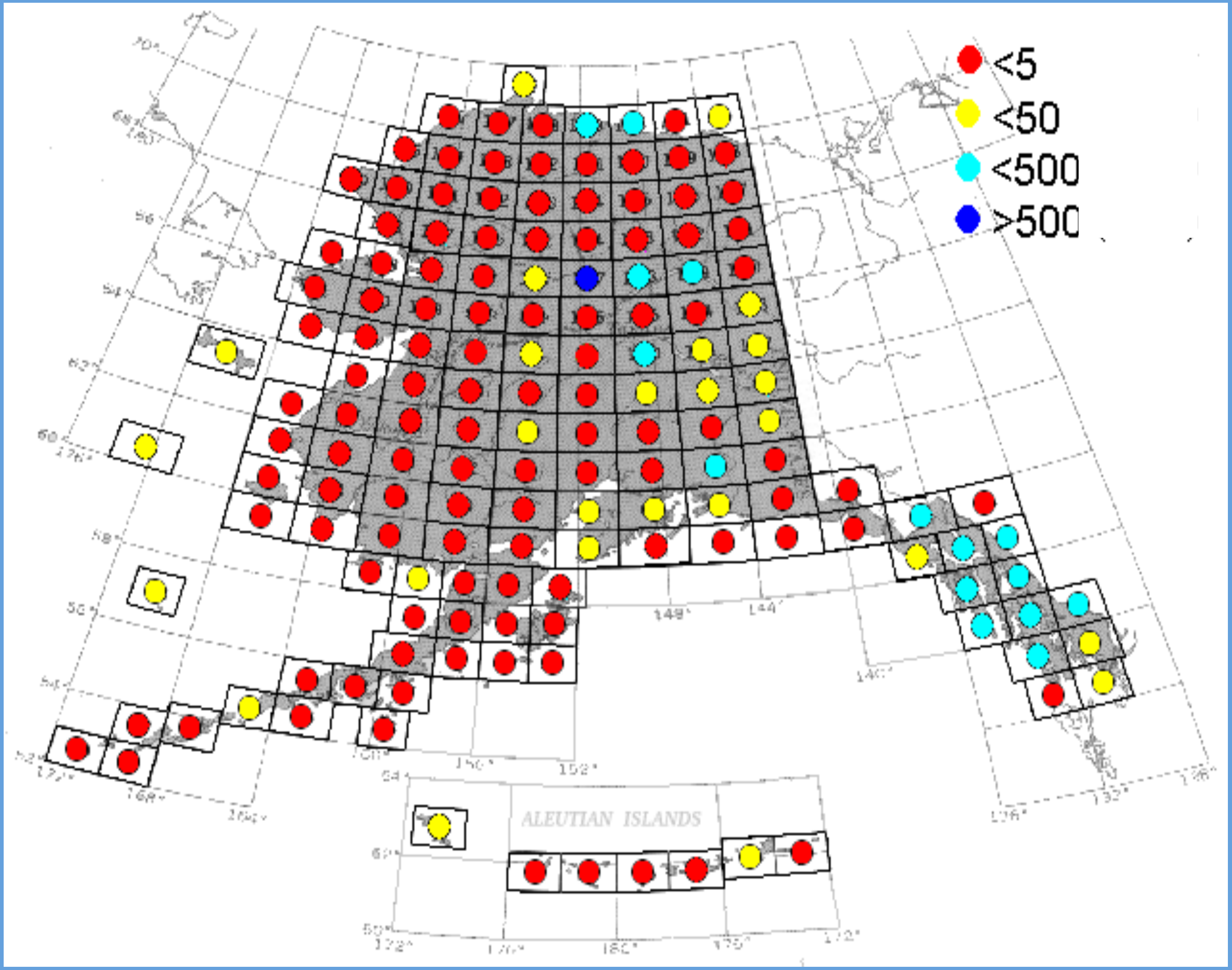
per USGS Quad (15,000 km^2)



Alces and *Rangifer* combined



All Mammals, one year (1997)



Challenges for Museums- 2

- Facilitate use for wide array of users
- Promote creativity, new uses and new ideas
- Train future generations of environmental scientists to explore and solve big questions
- Continue to build the resource

100 YEARS Journal of Ecology
British Ecological Society

Journal of Ecology 2013, **101**, 58–67 doi: 10.1111/1365-2745.12025

FORUM

Identification of 100 fundamental ecological questions

William J. Sutherland[1], Robert P. Freckleton[2], H. Charles J. Godfray[3],

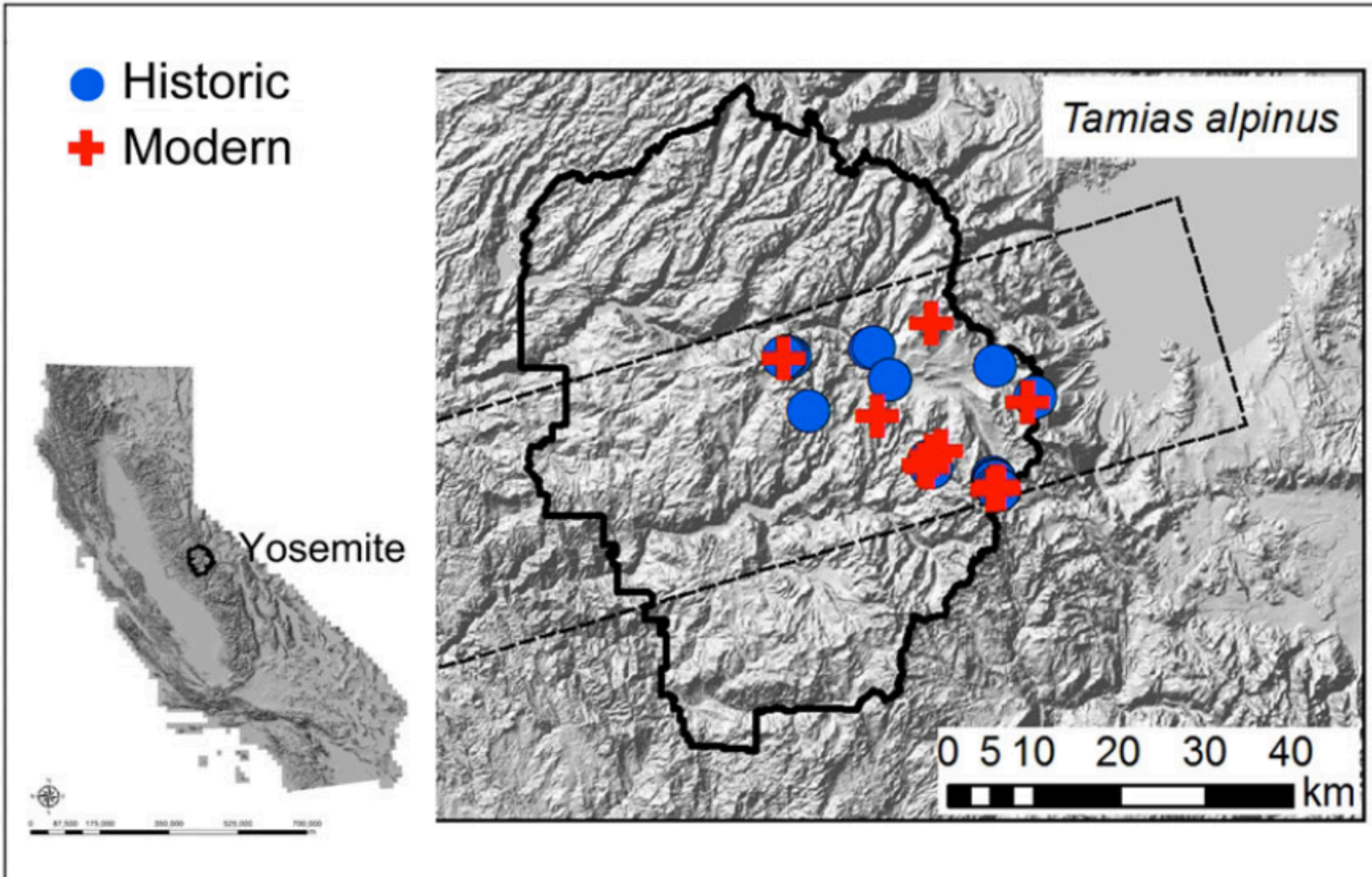
Integration Across Approaches

- Niches + Genetics + Adaption +

- Each specimen makes the connections-
  - Same individual
  - Multiple approaches

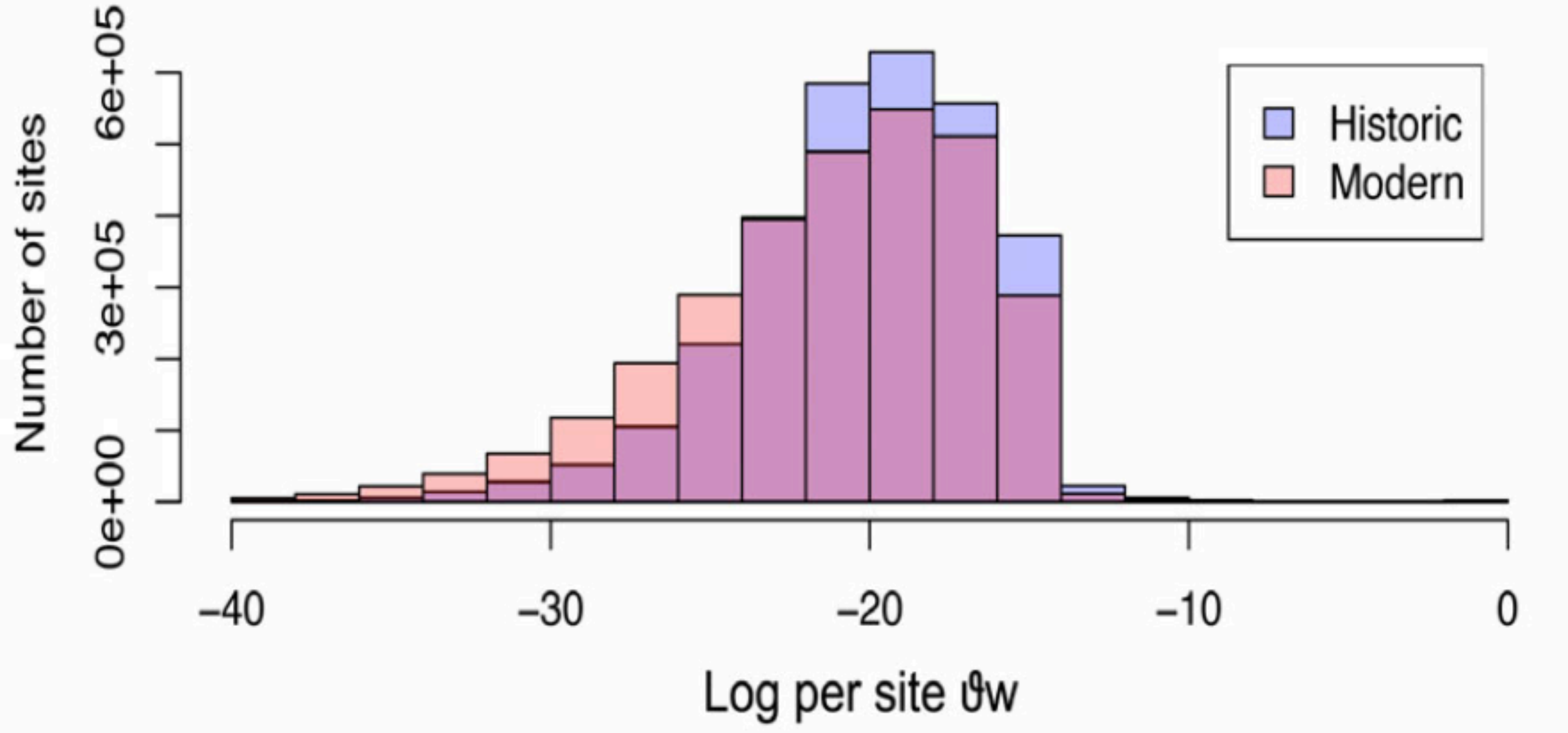
Museum Specimens - Historic Conditions

- **Parasite and disease screening**
  - Emergent diseases
  - Historical/baseline infection rates
  - Identifying new hosts or pathogens
- **Stable-isotope ratios and ecology**
  - predator/prey
  - seasonal diet shifts (whiskers, baleen)
  - primary productivity
- **Toxins**
  - mercury, POPS (marine mammals)
- **Analyses of genetic relationships**
  - among individuals, populations, species



Historical sampling localities (1915) are shown in blue circles and modern (2004–2008) in red.

Bi et al 2013. Molecular Ecology



for historic and modern *Tamias alpinus* populations. Histograms showing the frequencies of the log-transformed per site values of Θw (top) and π (bottom) calculated using allele frequencies weighted by their posterior probabilities The historic population is depicted in lavender and the modern population is in light pink as shown in the legend.

Bi et al 2013. Molecular Ecology