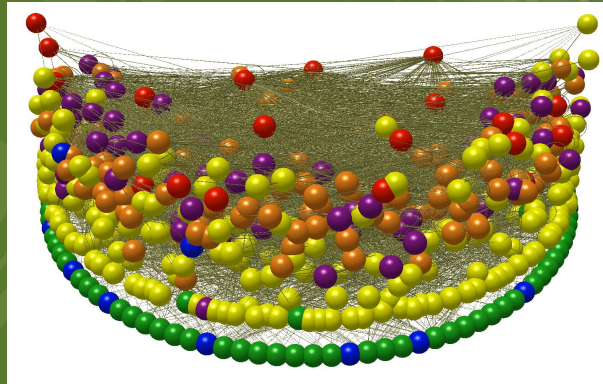




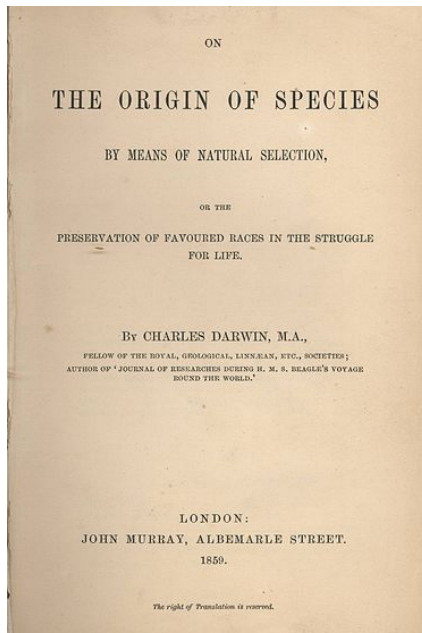
Human Roles, Behavior, & Impacts in Complex Ecological Networks

Jennifer A. Dunne, Santa Fe Institute



$$\begin{aligned}\frac{\partial f}{\partial x} &= 0 \Rightarrow y = 0 \\ 1 - y - 2x &= 0 \\ \Rightarrow x &= \frac{1}{2}(1 - y) \\ \frac{\partial f}{\partial y} &= 0 \Rightarrow x = 0 \text{ or } \\ y &= \frac{1}{2}(1 - x)\end{aligned}$$

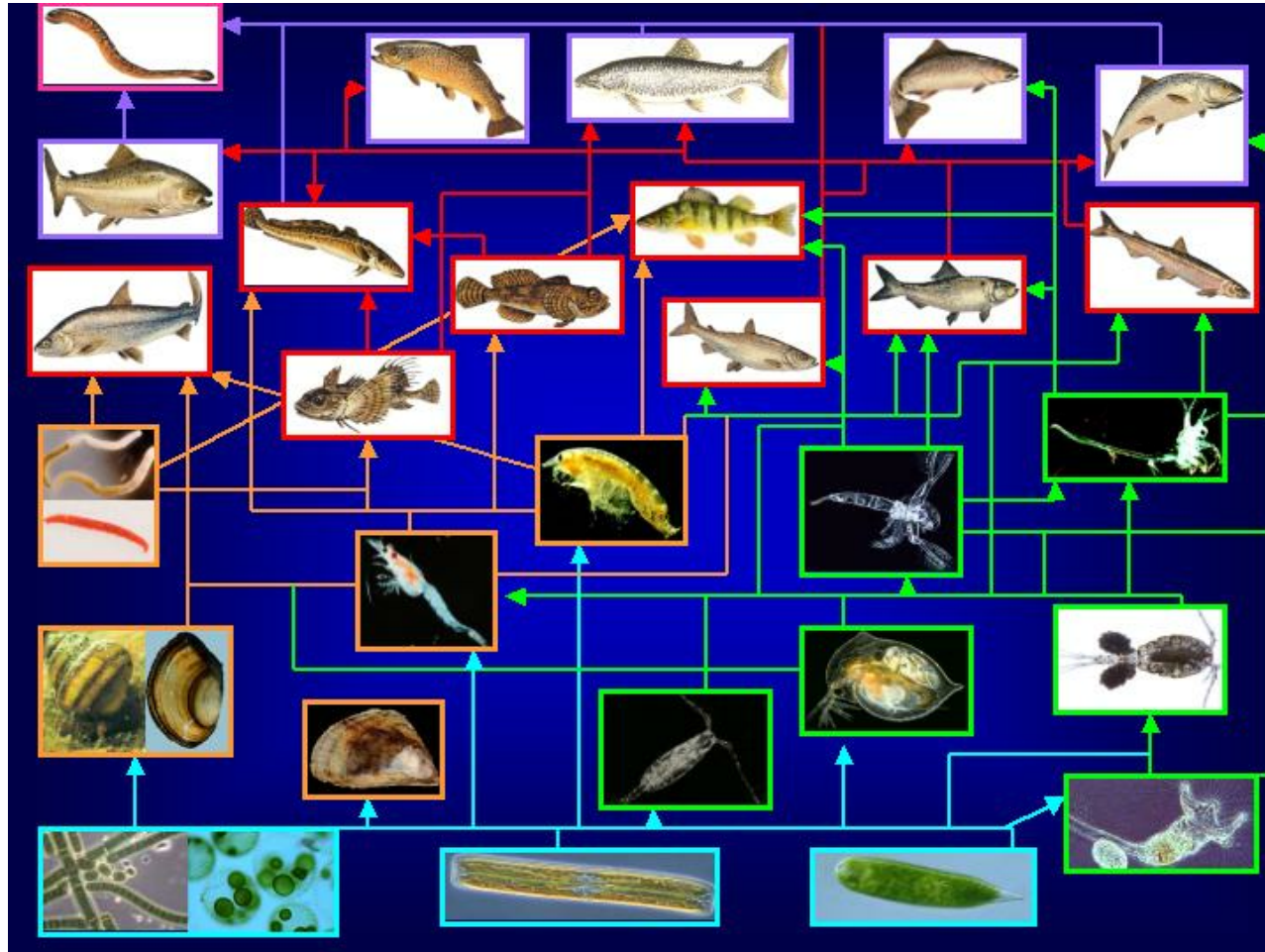
Darwin (1859) On The Origin of Species



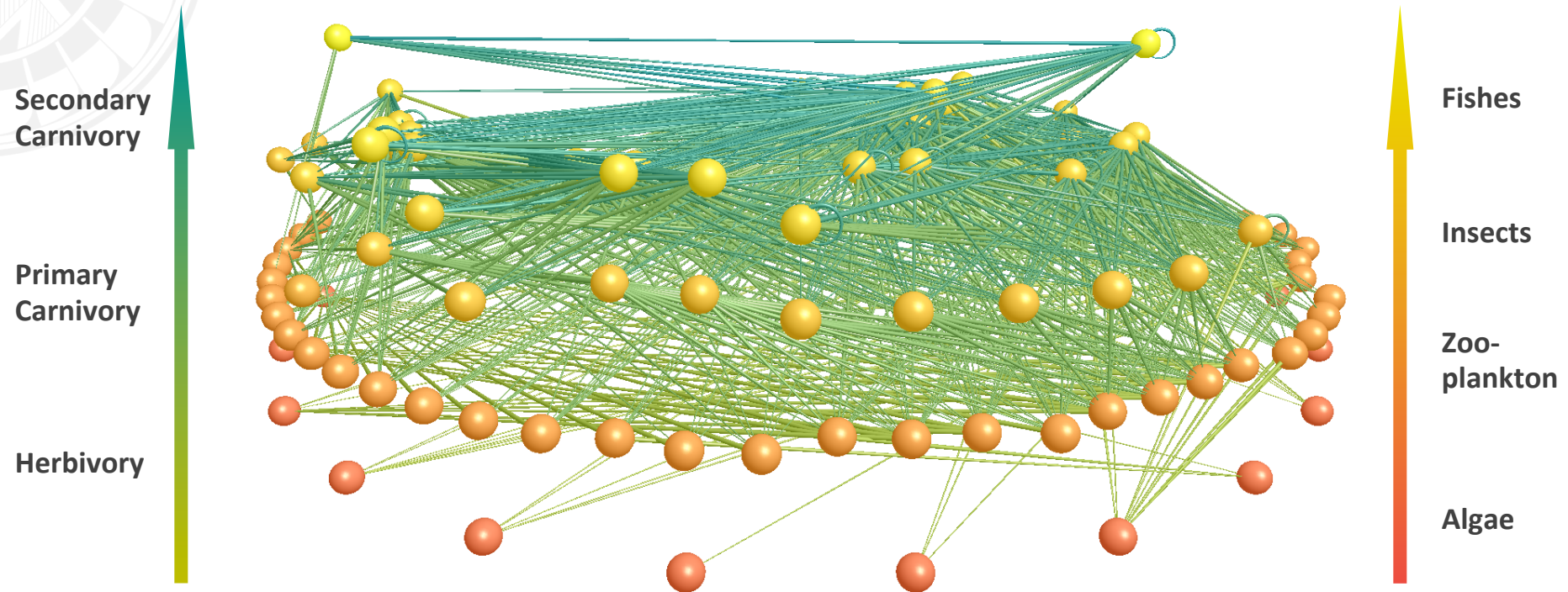
It is interesting to contemplate an entangled bank...these elaborately constructed forms... *dependent on each other in so complex a manner*, have all been produced by laws acting around us.

The Architecture of Ecological Interdependence

Food Webs: Networks of Biomass and Energy Flows



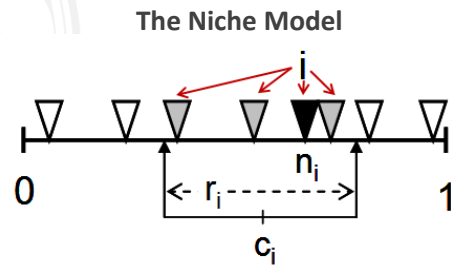
Little Rock Lake, Wisconsin



Martinez. 1991. *Ecological Monographs*.

Artifacts or attributes? Effects of resolution on the Little Rock Lake food web.

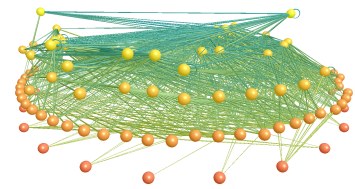
• Ecological Network Structure



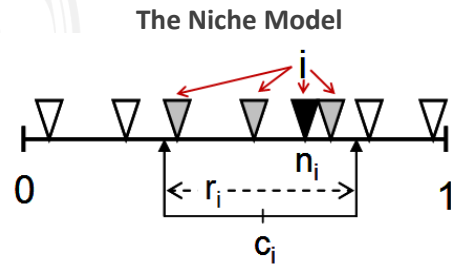
Nature 2000

Simple rules yield complex food webs

Richard J. Williams & Neo D. Martinez



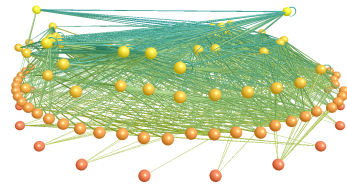
• Ecological Network Structure



Nature 2000

Simple rules yield complex food webs

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• Complex Trophic Dynamics

Ecology Letters, (2012)

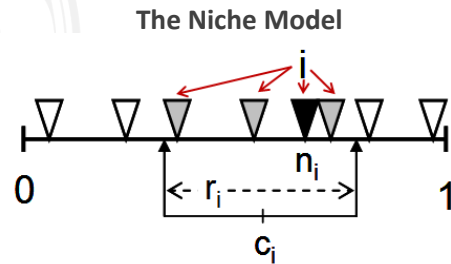
doi: 10.1111/j.1461-0248.2012.01777.x

LETTER

Mechanistic theory and modelling of complex food-web dynamics in Lake Constance

Alice Boit,^{1*} Neo D. Martinez,²
Richard J. Williams^{3,4} and Ursula
Gaedke⁵

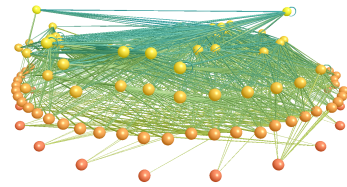
• Ecological Network Structure



Nature 2000

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LETTER

Mechanistic theory and modelling of complex food-web dynamics in Lake Constance

Alice Boit,^{1*} Neo D. Martinez,²
Richard J. Williams^{3,4} and Ursula
Gaedke¹

• Ecosystem Robustness, Stability & Function

Ecology Letters, (2002) 5: 558–567

REPORT

Network structure and biodiversity loss in food webs: robustness increases with connectance

Jennifer A. Dunne,^{1,2*} Richard J.
Williams¹ and Neo D. Martinez¹

Ecology Letters, (2006) 9: 1228–1236

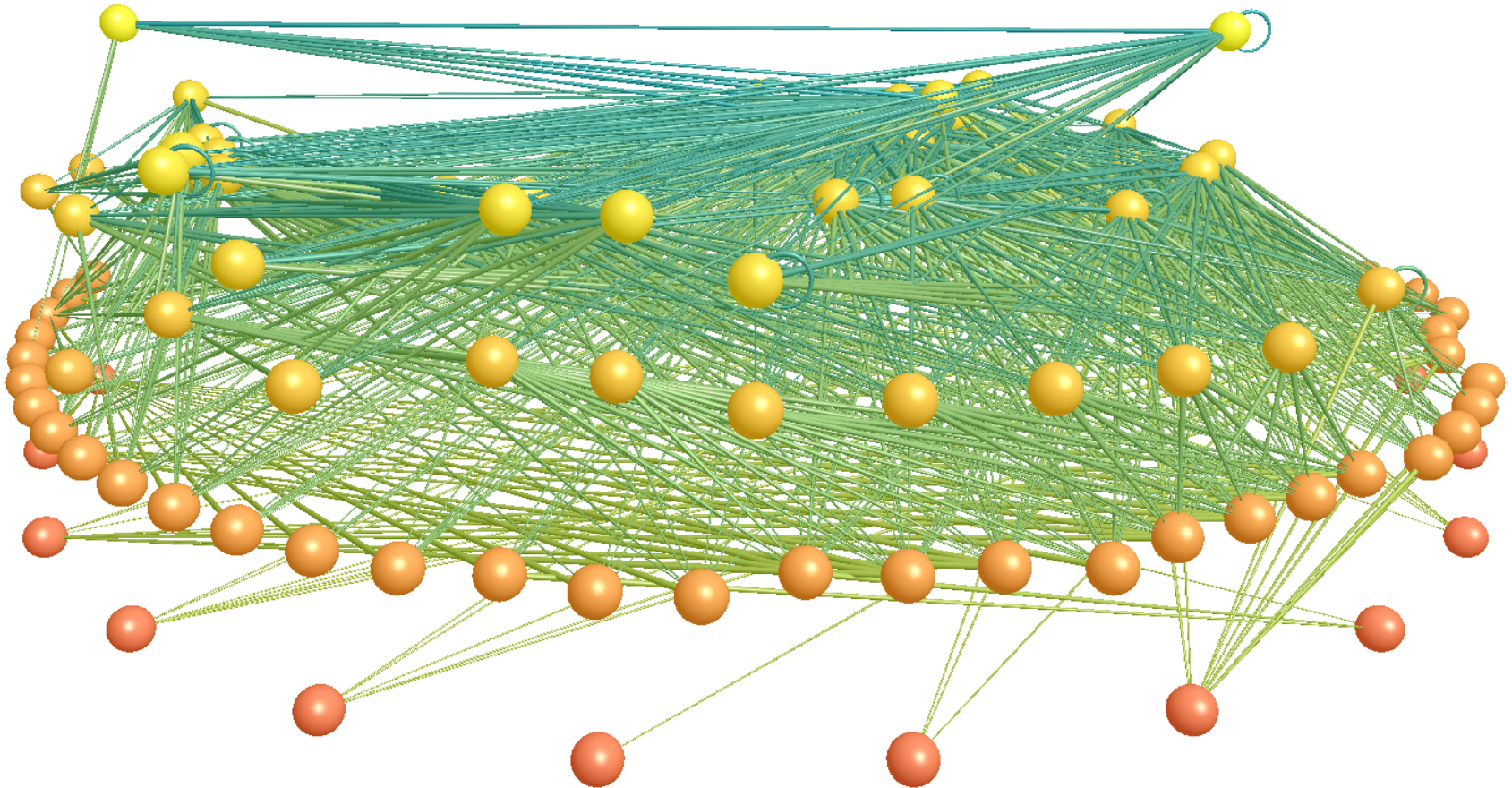
doi: 10.1111/j.1461-0248.2006.00978.x

LETTER

Allometric scaling enhances stability in complex food webs

Ulrich Brose,^{1,2*} Richard J.
Williams^{2,3} and Neo D. Martinez²

What about *Homo sapiens*?





- **Human impacts on food webs**
- Human roles in food webs
- New lessons for sustainability



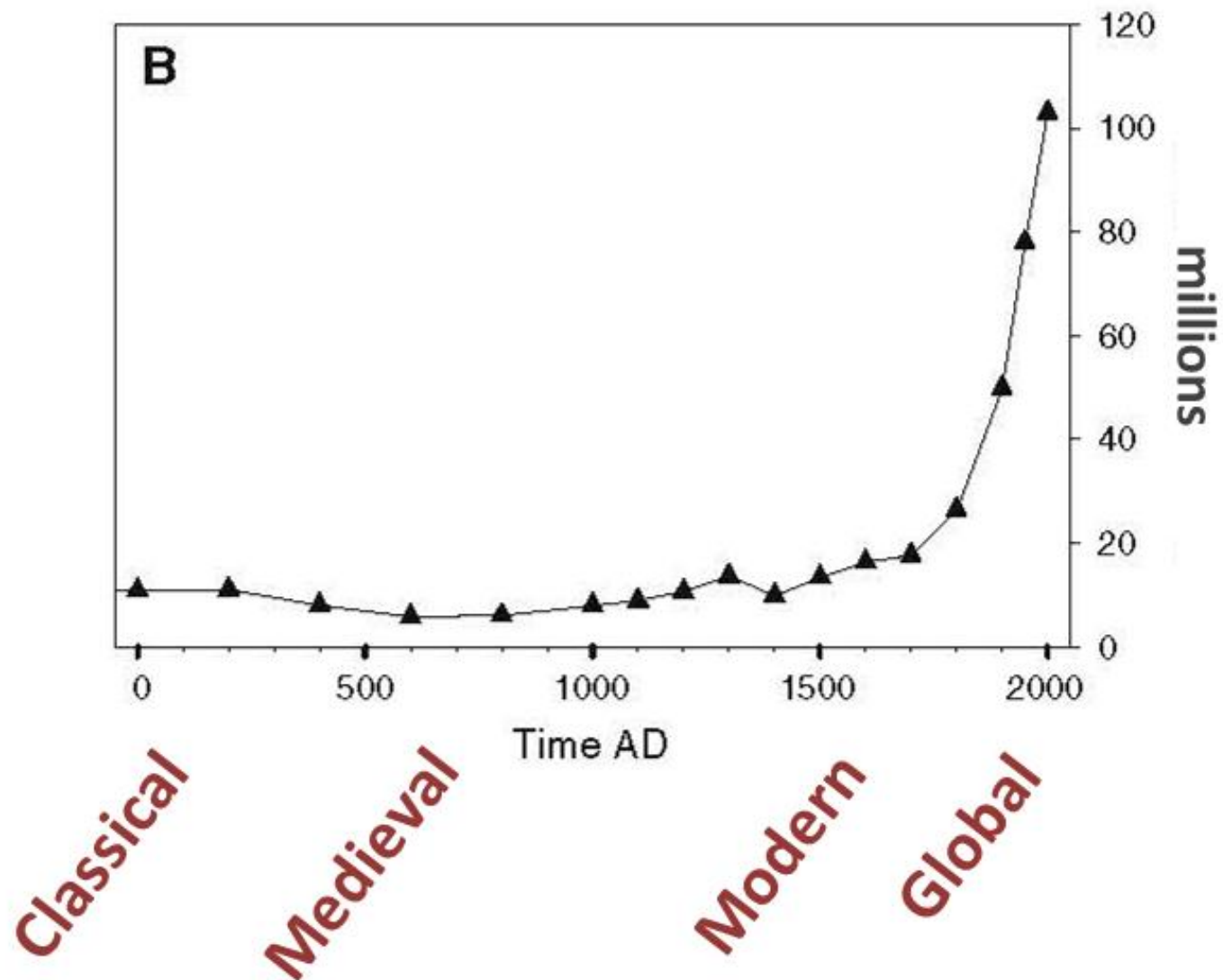




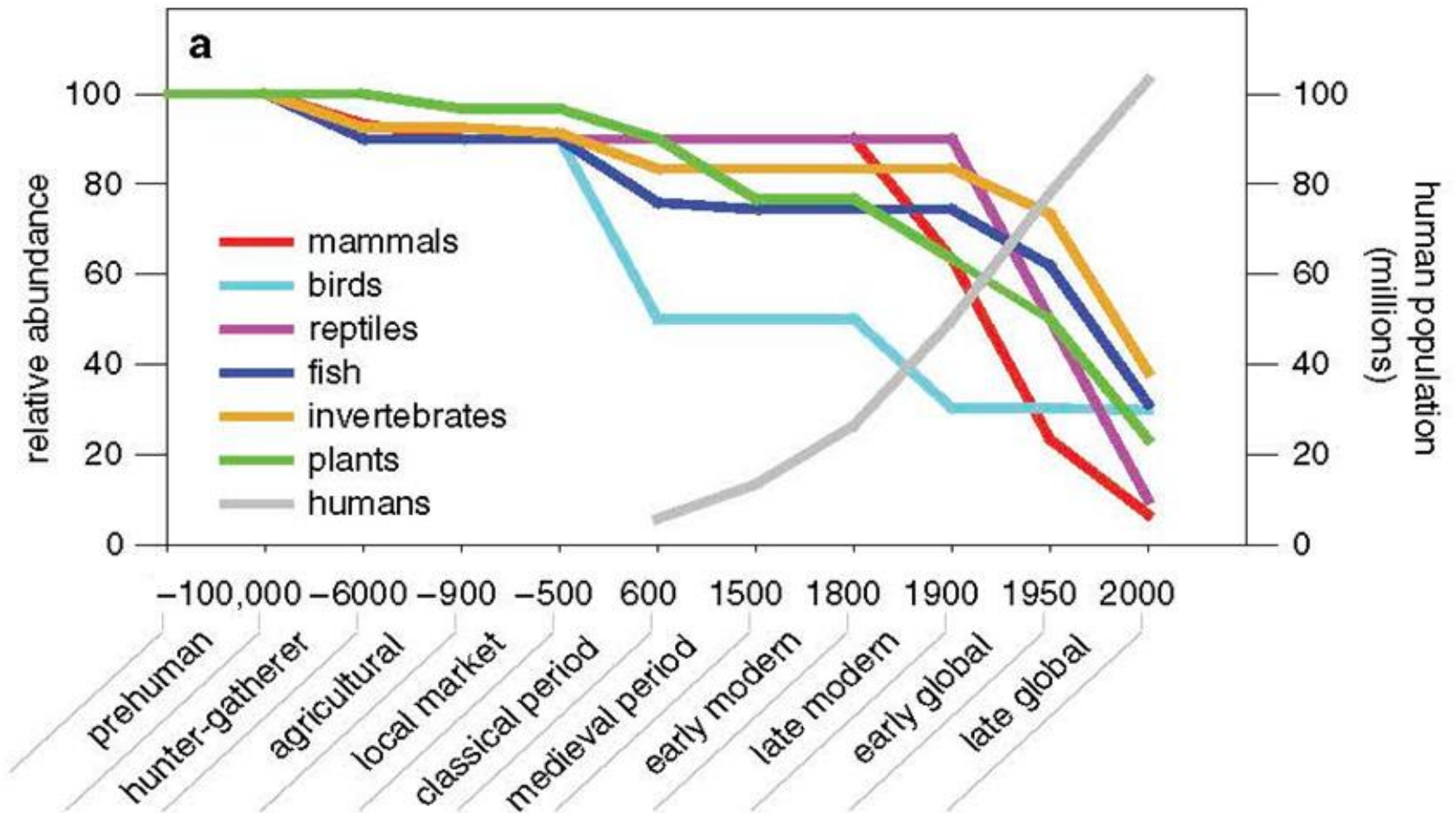


Time	Cultural Period
<100,000 BC	Prehuman
100,000-6000 BC	Hunter-Gatherer
6000-900 BC	Agricultural
900-500 BC	Local Market
500 BC-600 AD	Classical
600-1500 AD	Medieval
1500-1800 AD	Early Modern
1800-1900 AD	Late Modern
1900-1950 AD	Early Global
1950-2000 AD	Late Global

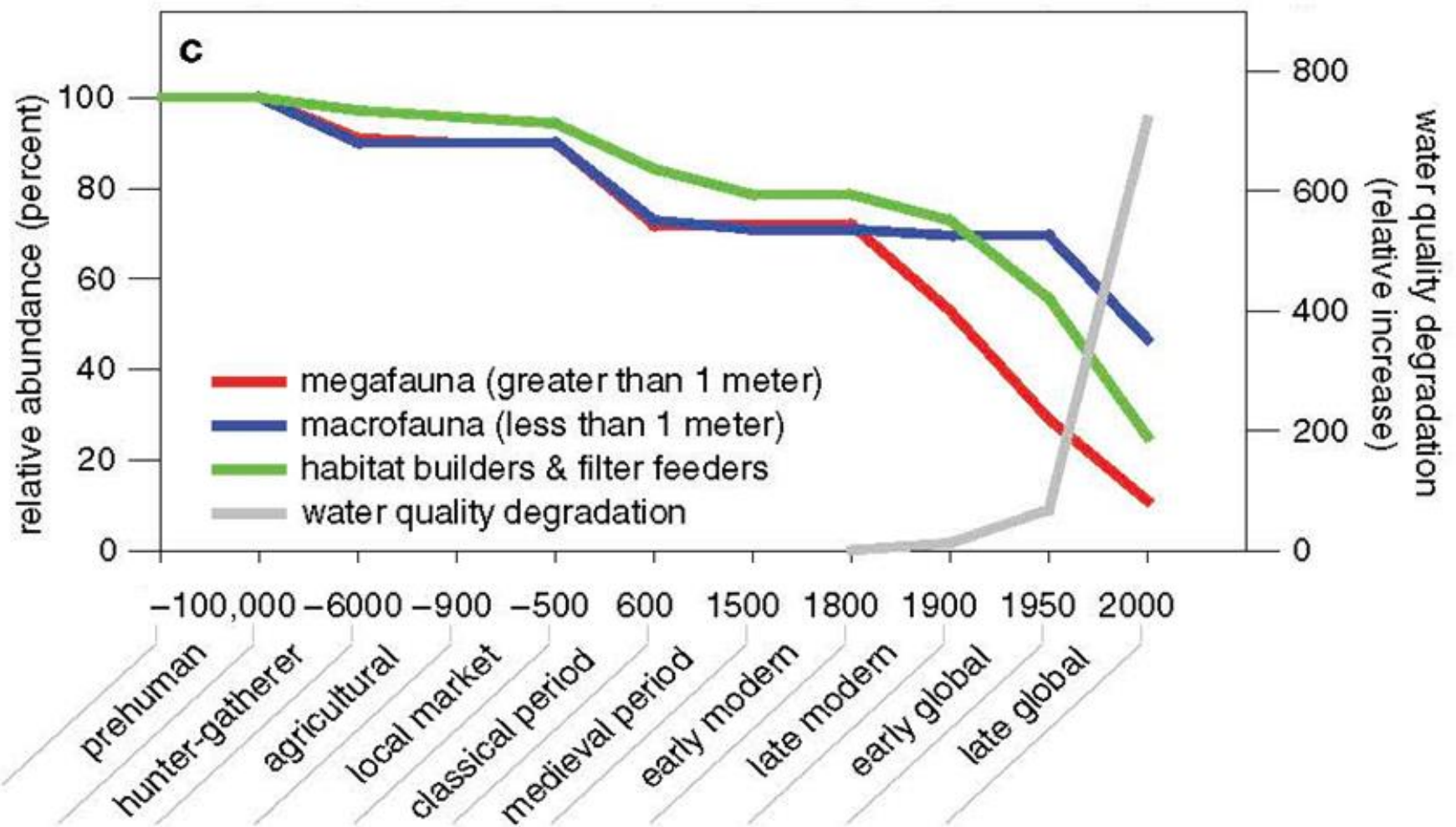
Adriatic Human Population



Species Abundances



Species & Water Quality



The Dwindling Web

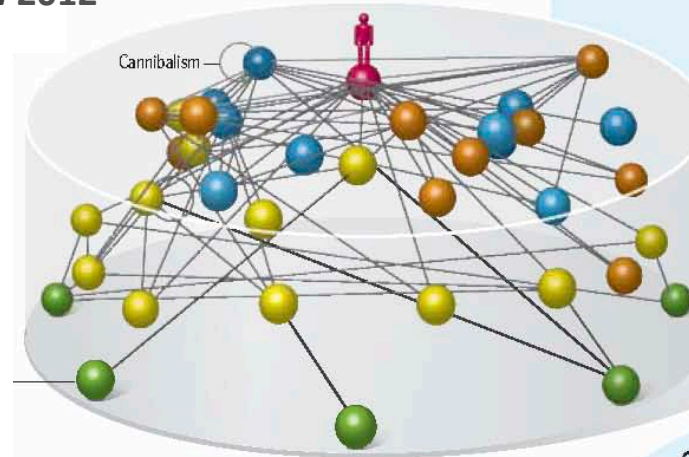
Scientific American 2012

Early Modern

25% Taxa ↓

Robustness ↓

Late Global



A.D. 1500–1800

Human

Mammals, birds
and reptiles

Fish

Invertebrates

Basal food
sources

Each dot = 1 taxon

200 Years Later

Human

Mammals, birds
and reptiles

Fish

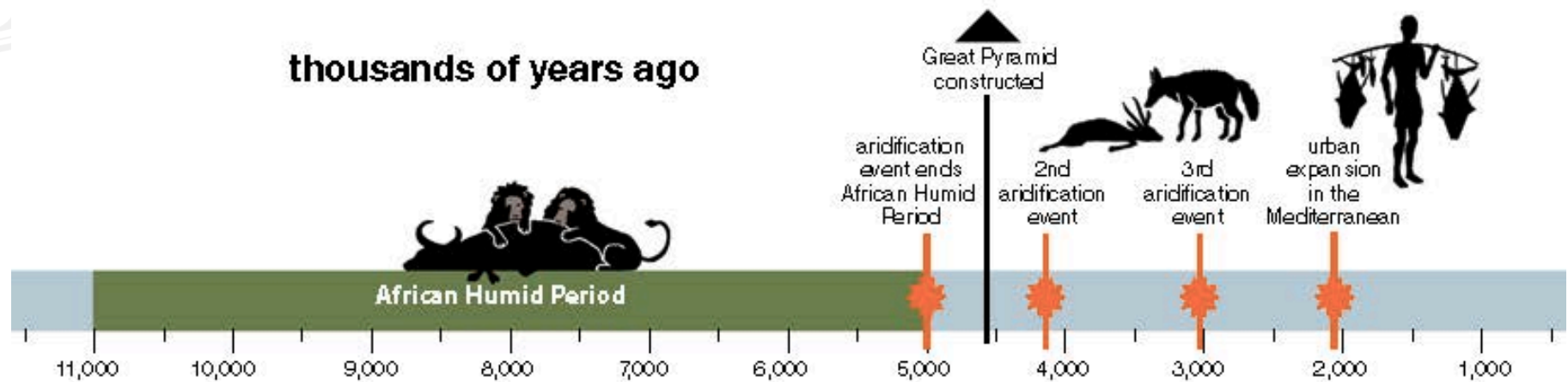
Invertebrates

Basal food
sources

This web includes an
additional food source:
discards from the
fishing industry

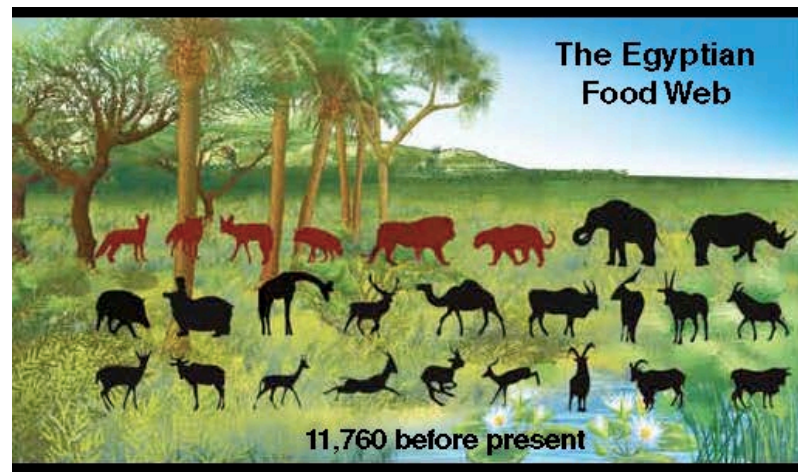


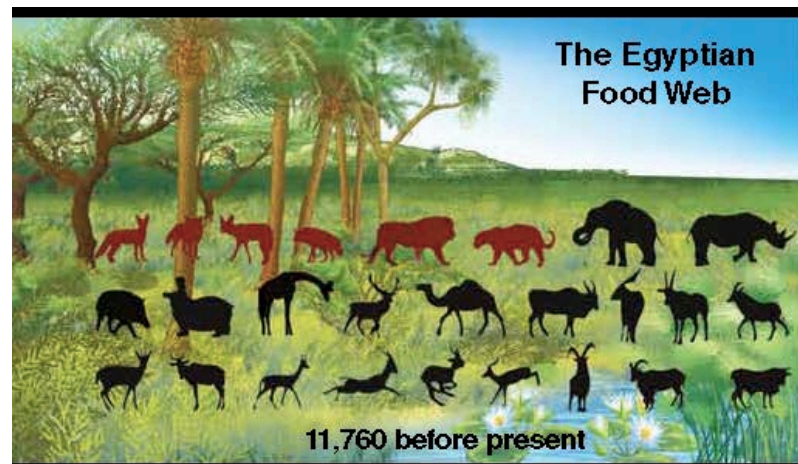
Timeline of Egypt

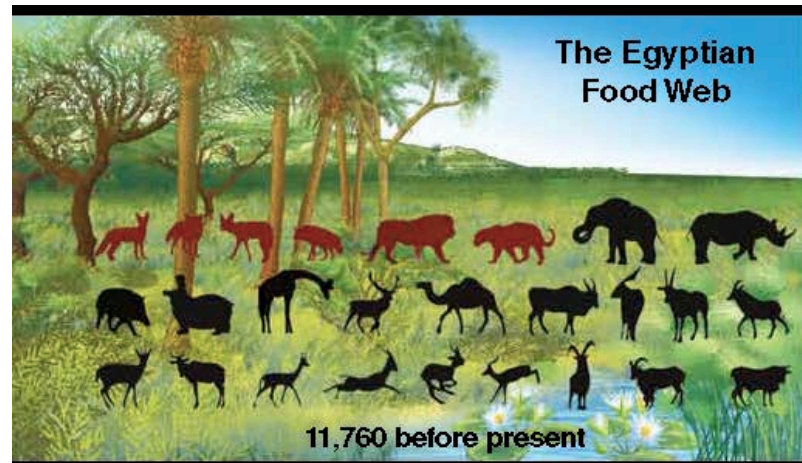






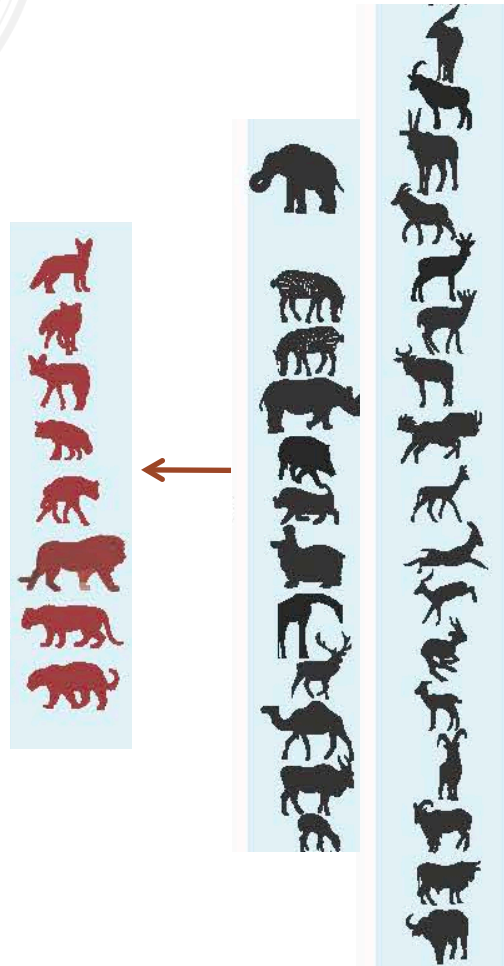




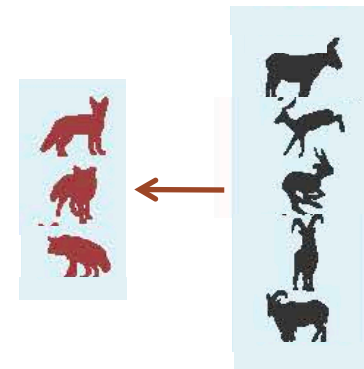


Collapse of an Ecological Network

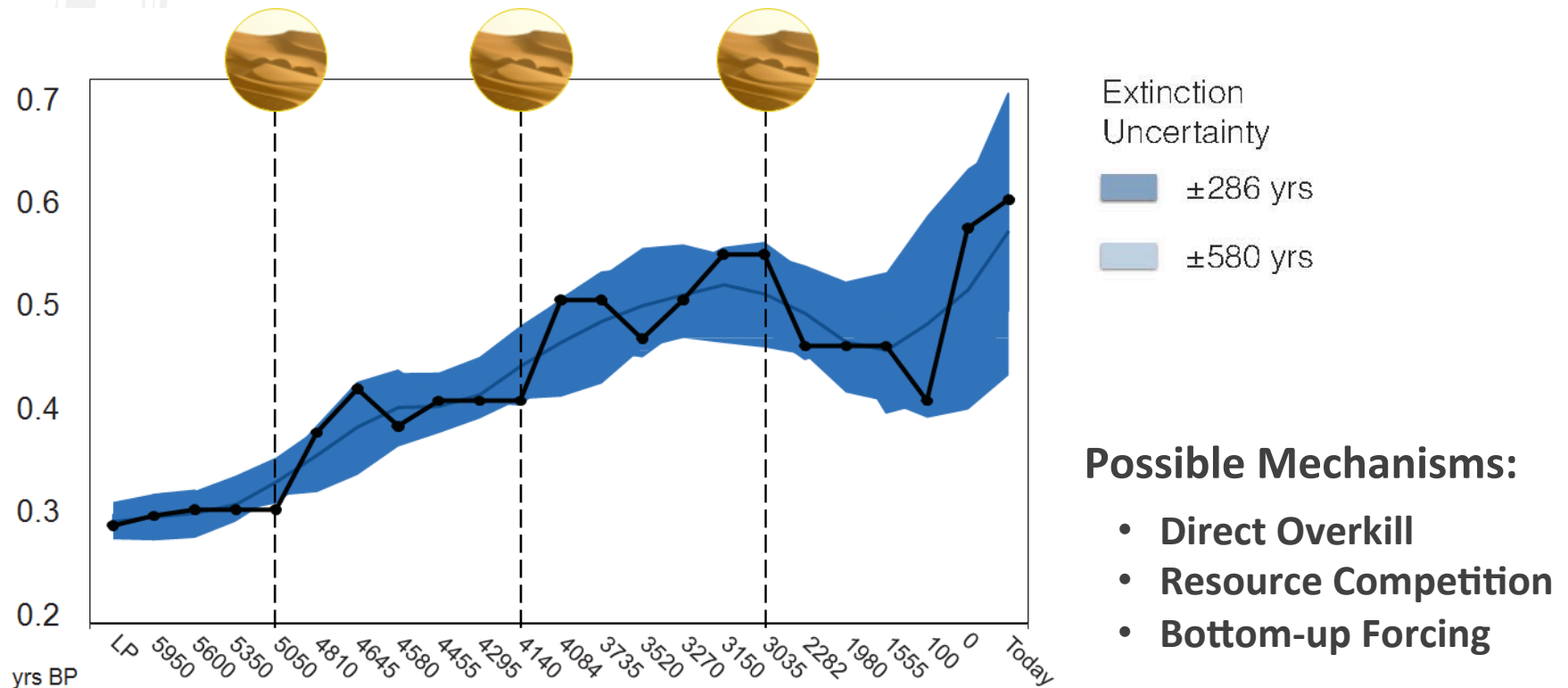
12,000 Years Ago



Present Day



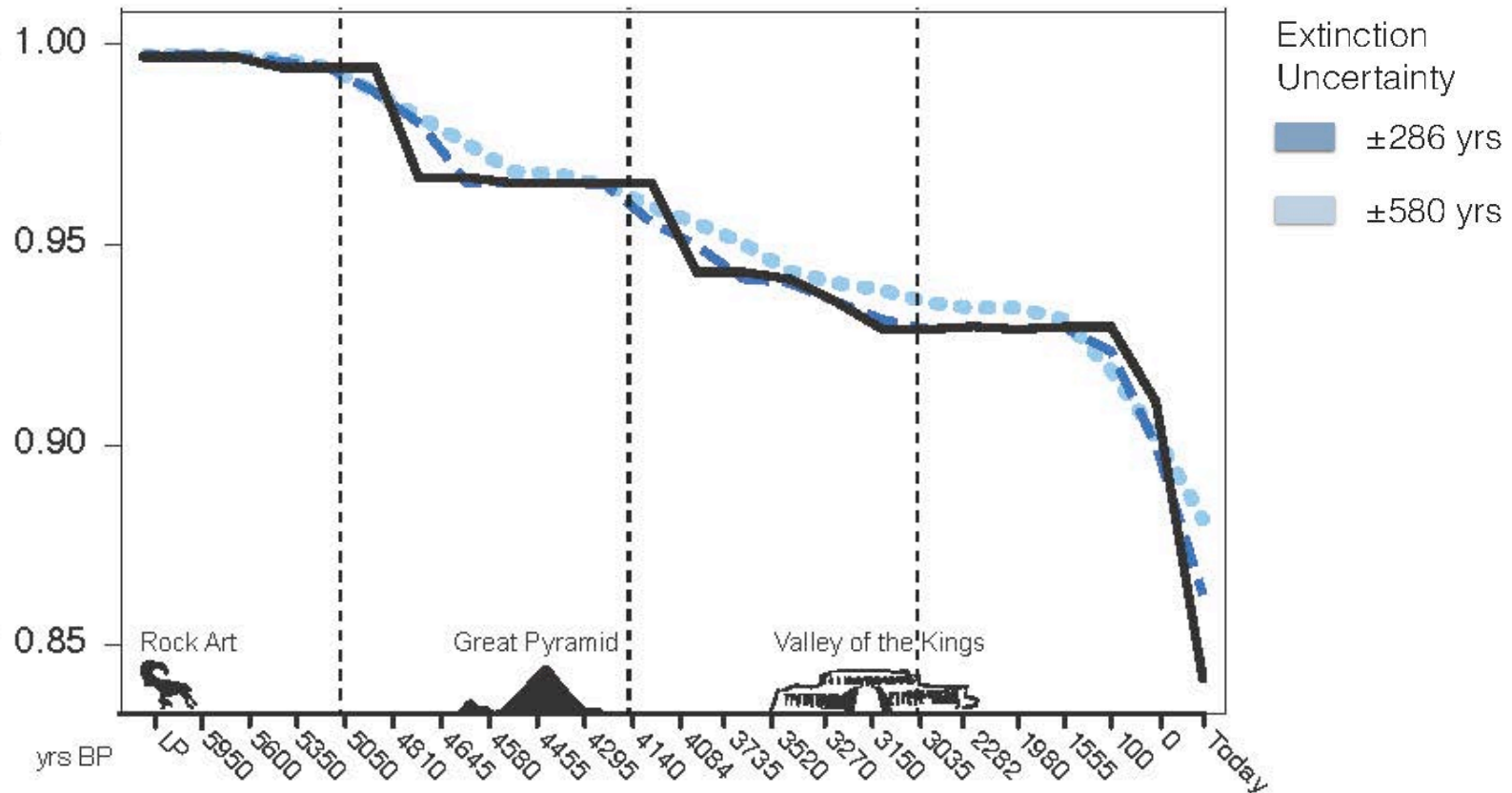
Predator-Prey Ratio Increases Through Time



Relatively more herbivores than predators went extinct.

Extinctions were nonrandom and coincided with desertification episodes.

Proportion of Dynamically Stable Food Webs Decreases Through Time



Simulate small perturbation to populations, assess local dynamic stability





- Human impacts on food webs
- **Human roles in food webs**
- **New lessons for sustainability**





The Sanak Biocomplexity Project



Herb Maschner (PI)
Buck Benson
Matthew Betts
Joseph Cornell
Jennifer Dunne
Bruce Finney
Nancy Huntly
Jim Jordan
Nicole Misarti
Kate Reedy-Maschner
Roly Russell
Amber Tews
Rich Williams
Spencer Wood

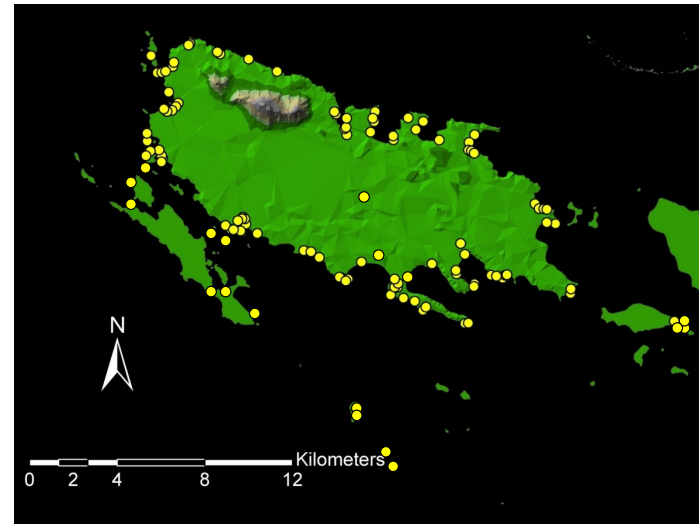


Maschner *et al.* 2009. *Pacific Science*. An introduction to the biocomplexity of Sanak Island, Western Gulf of Alaska.



- **What roles did pre-industrial humans play in North Pacific food webs?**
- **How did human foragers compare to other species?**
- **What can we learn about sustainability from how humans interacted with and impacted other species?**

The Sanak Archipelago



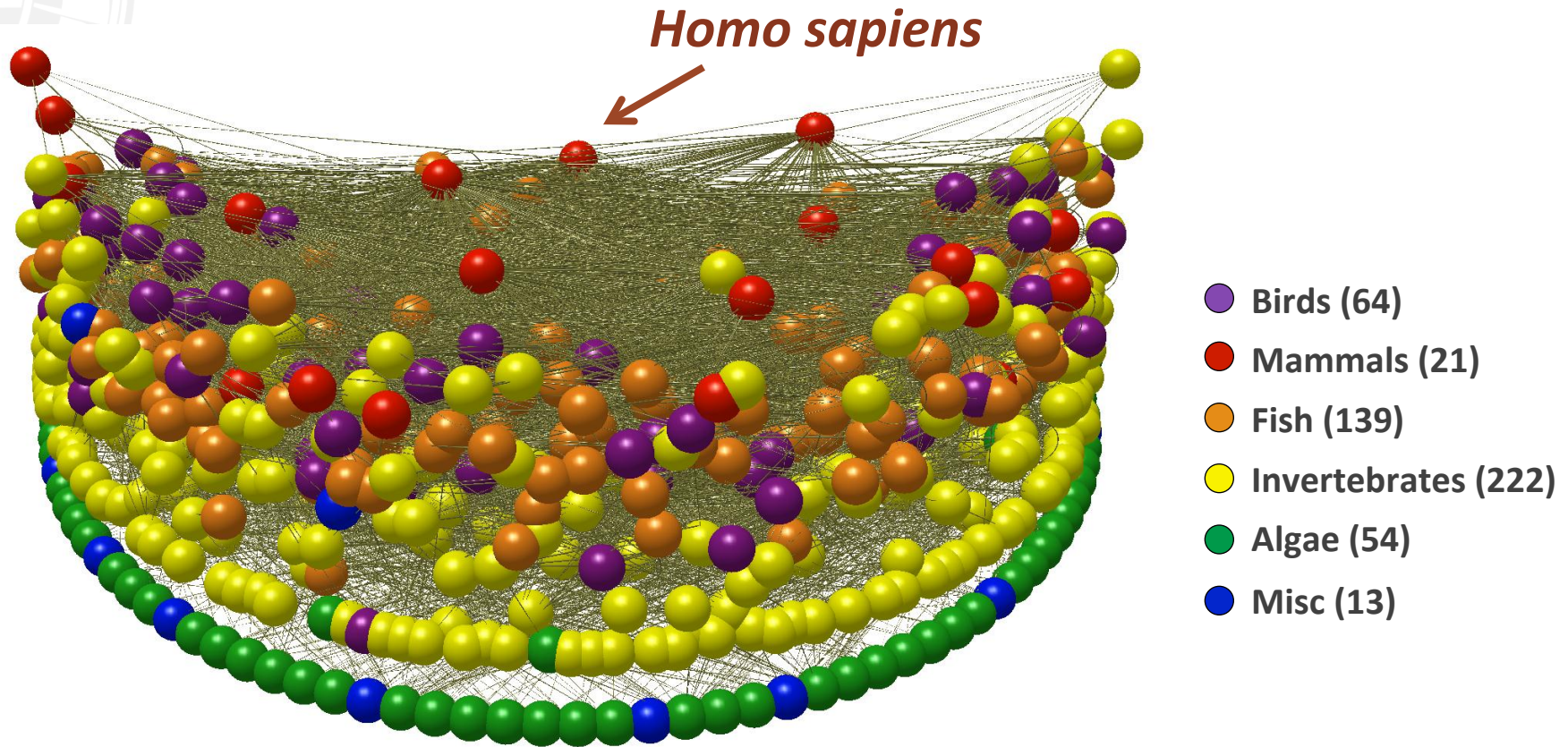
- Far-eastern end of Aleutian archipelago
- Ice-free for 16,000 yrs
- 6,000 yr human record, 128 known sites
- Integrate archeological, ecological & climatic data



Human Trophic Roles: Network Structure

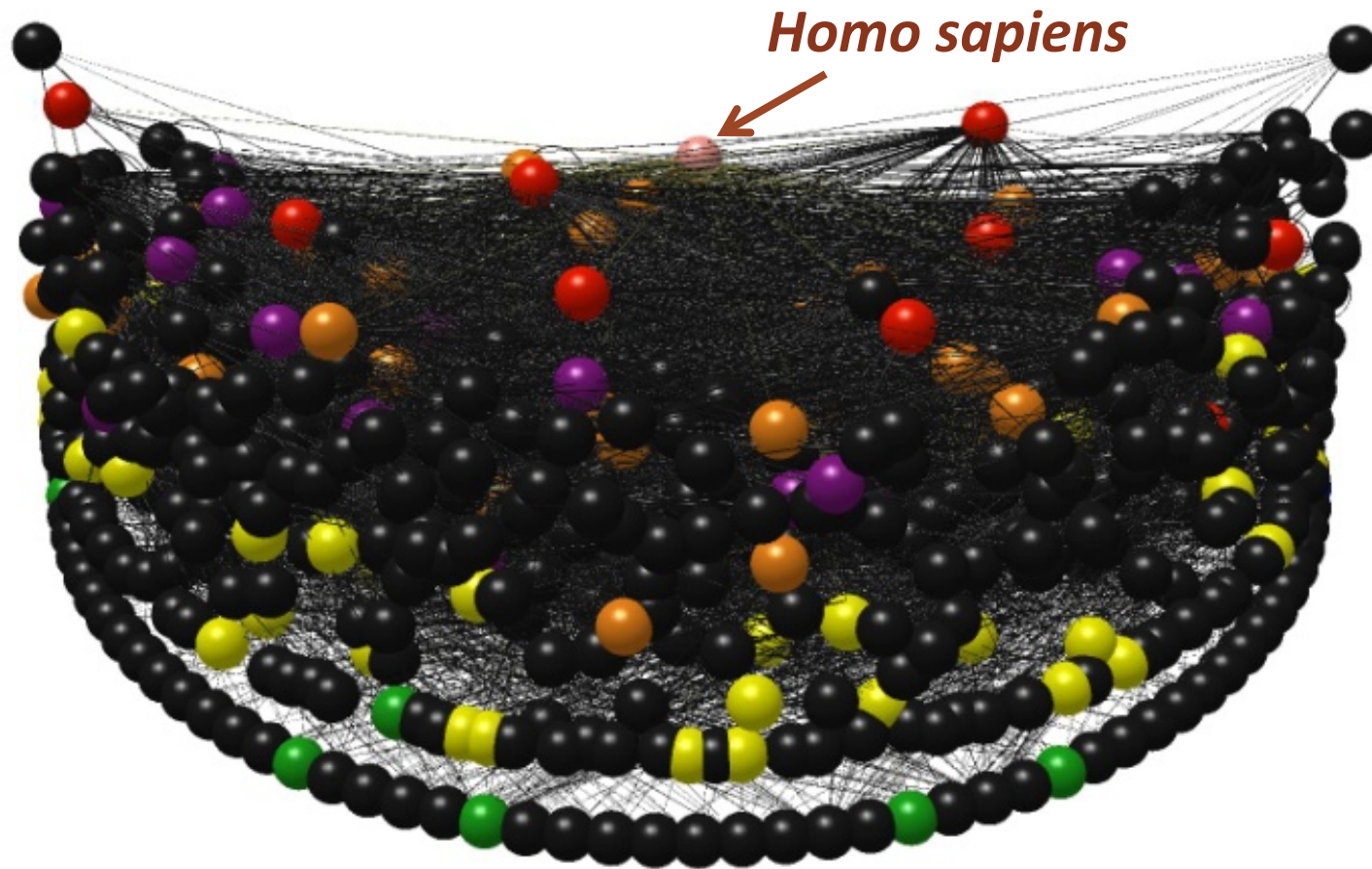


Sanak Nearshore Food Web

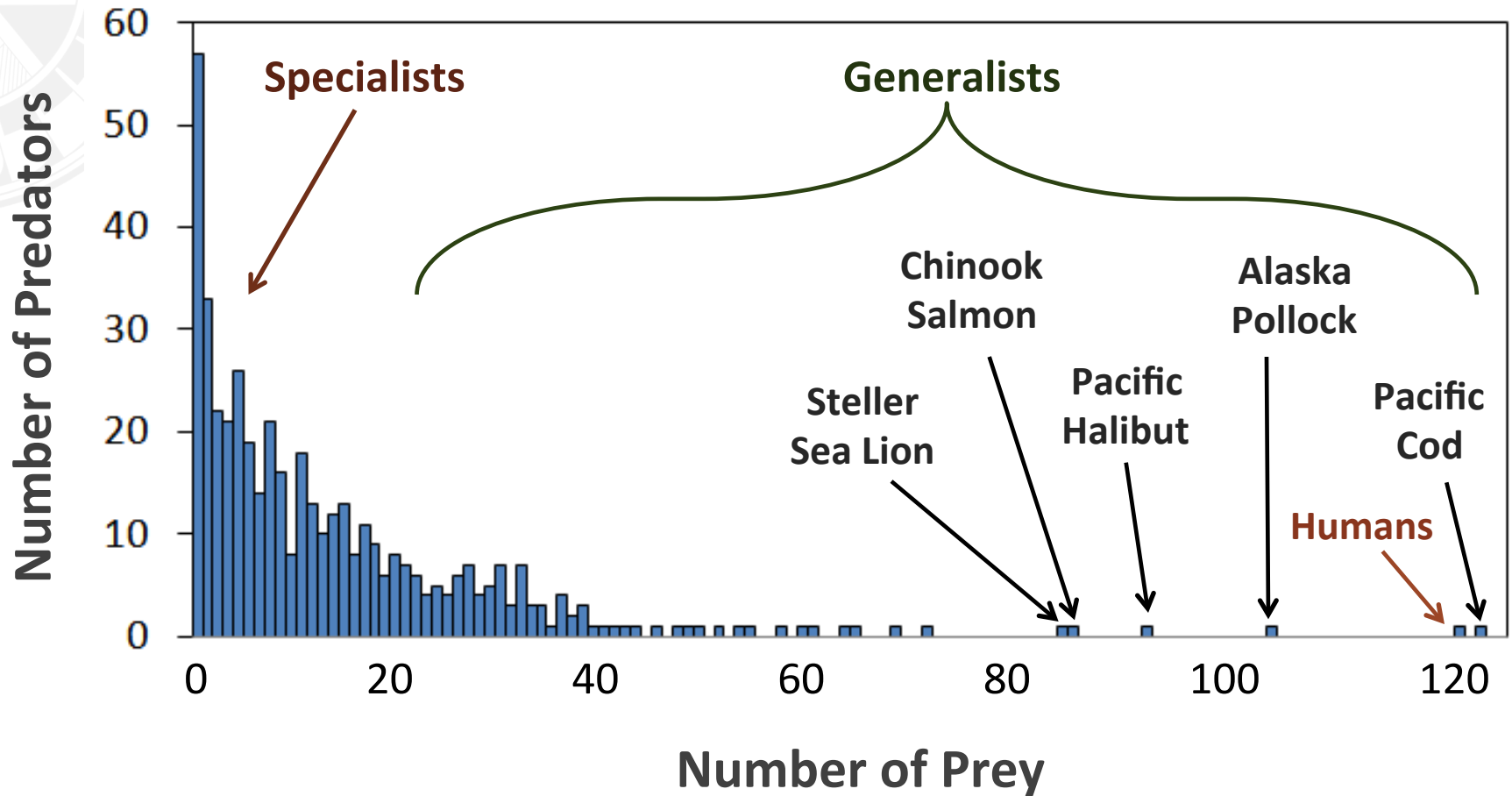


513 taxa, 6774 feeding links, 13 links per species

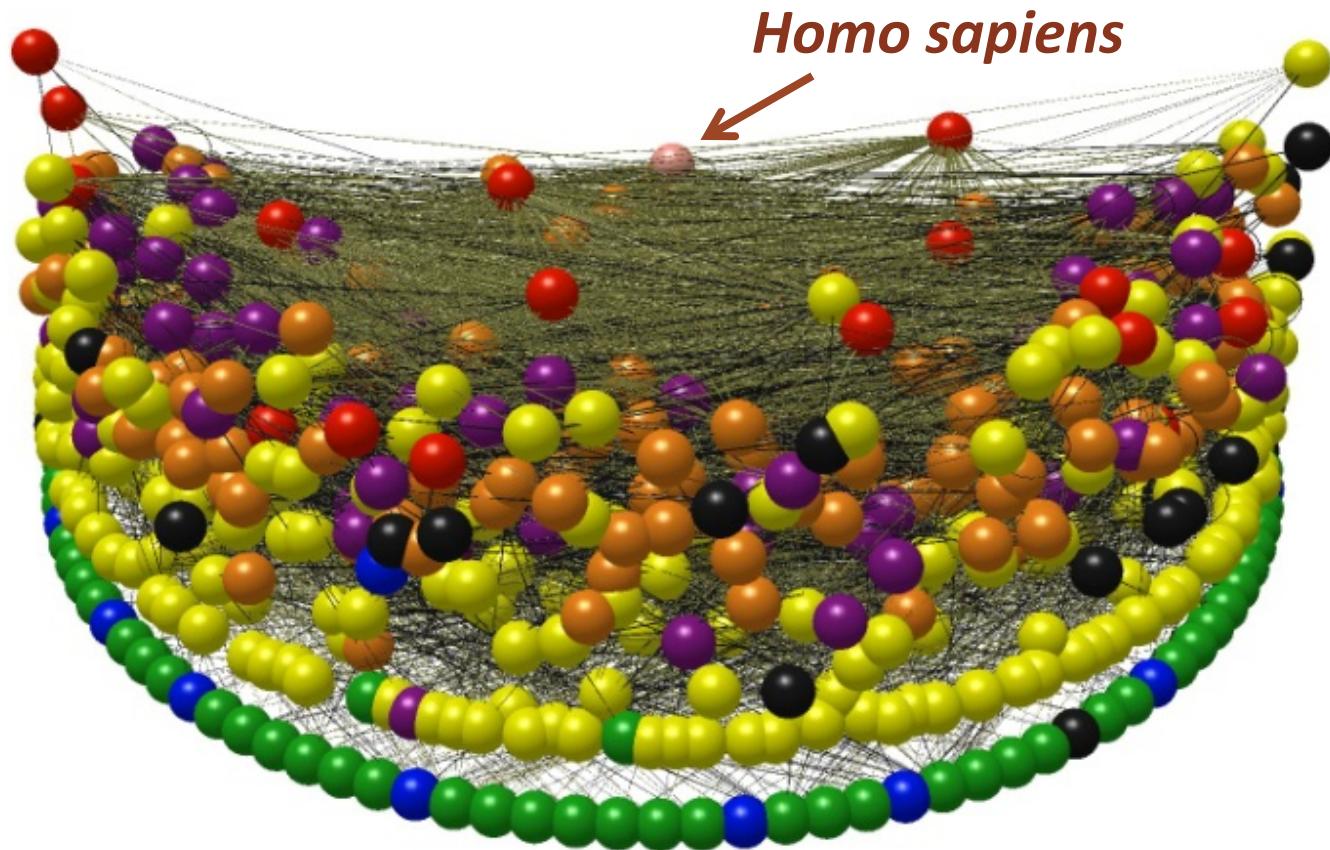
Humans Fed on 122 Taxa (24%)



How Many Prey?



96% of Marine Species Within 2 Links of Humans



491 of 513 species



Human Roles:

- Super-generalists
- Highly omnivorous
- Short path lengths
- Used hunting technology



Human Impacts?

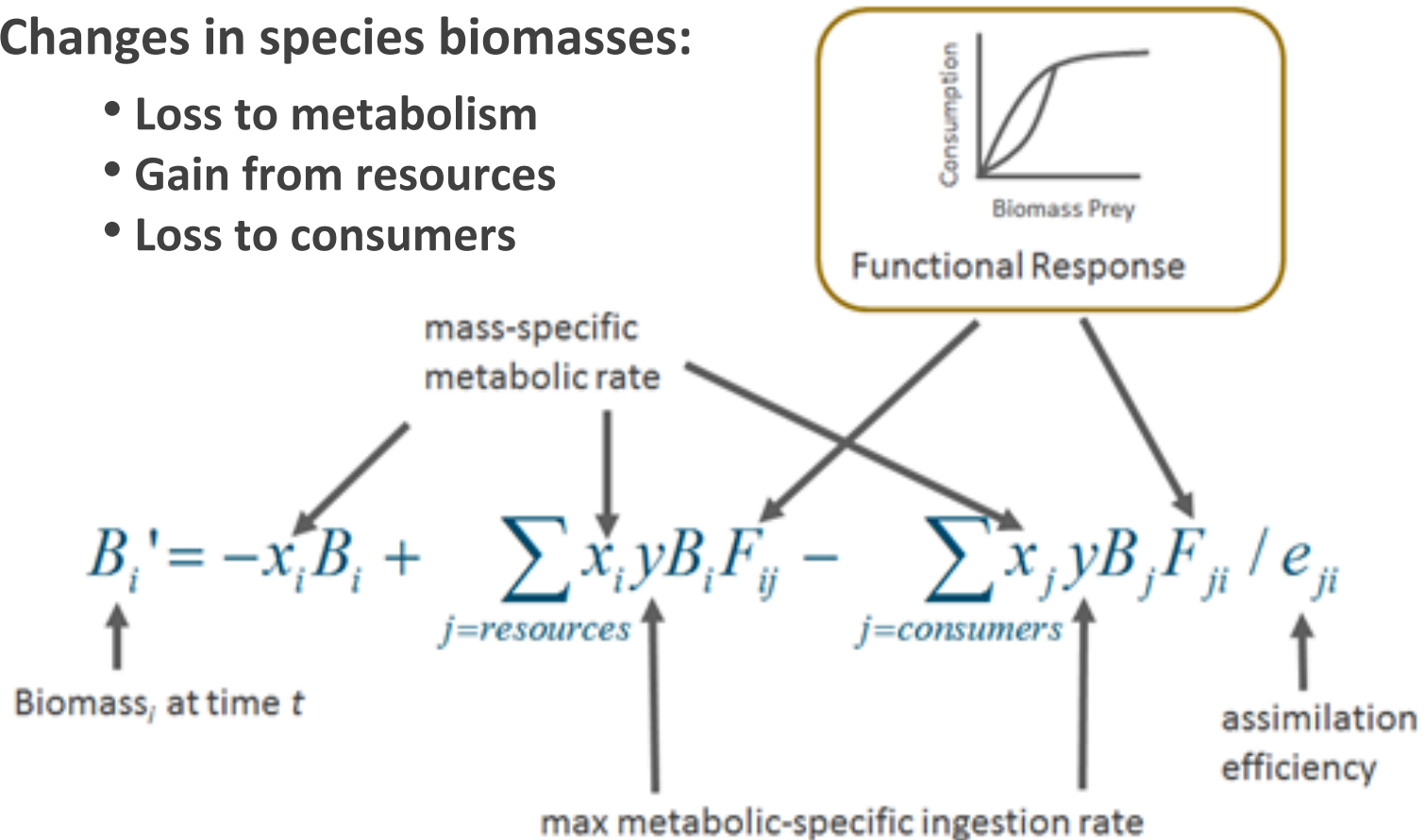
Changes in species biomasses:

- Loss to metabolism
- Gain from resources
- Loss to consumers

Human Impacts?

Changes in species biomasses:

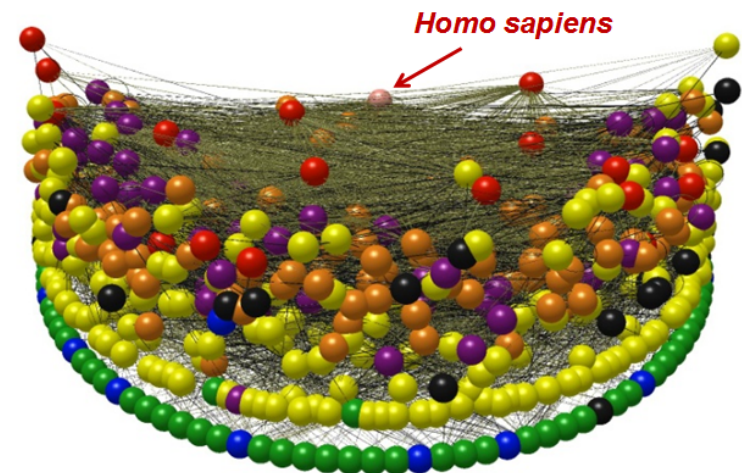
- Loss to metabolism
- Gain from resources
- Loss to consumers



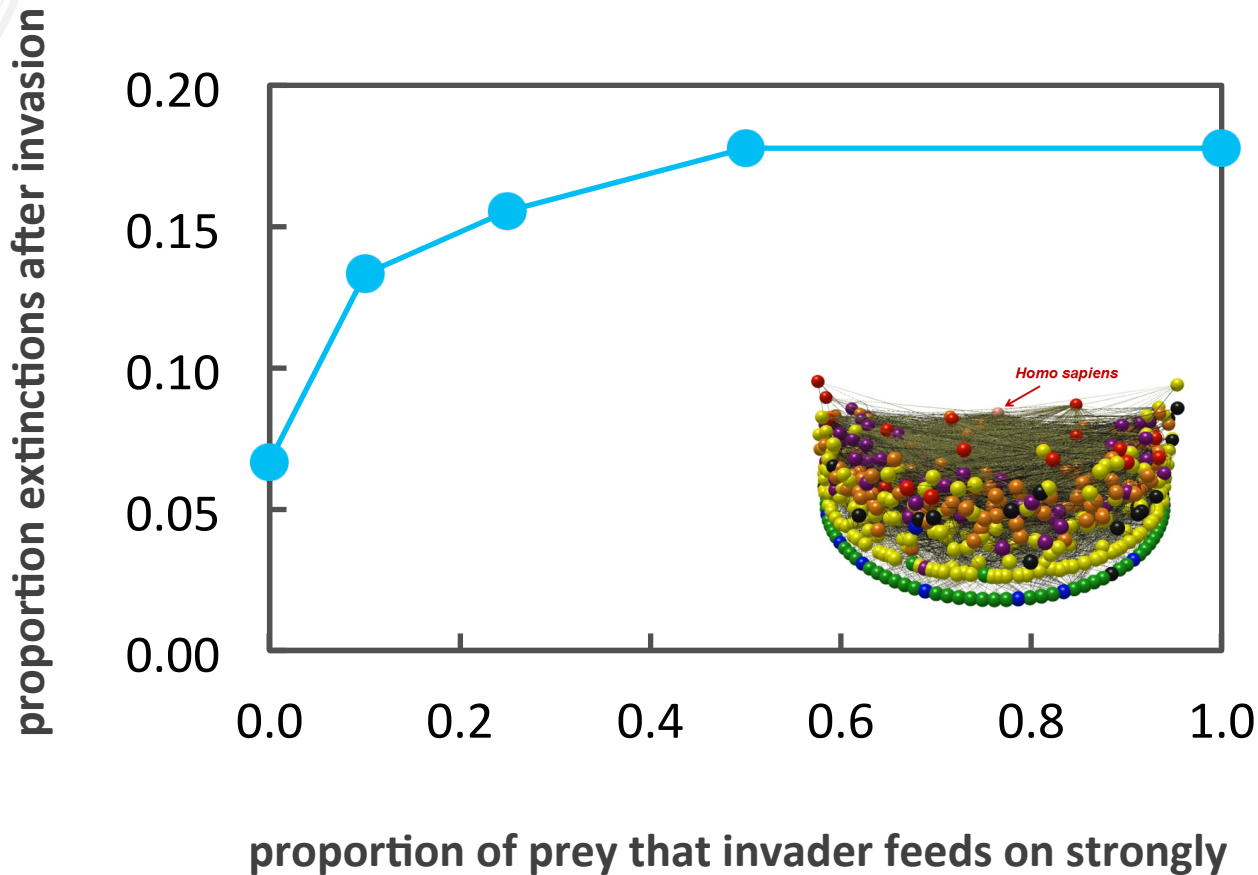
An *In Silico* Experiment:

Impact of invasion by human-like taxon on ecological persistence

- Create a “zoo” of dynamically persistent model food webs
- Include prey-switching by generalist species
- Invade each web with an omnivorous super-generalist species.
- Hunting tech: vary fraction of invader's links that are strong.
- How many extinctions follow?

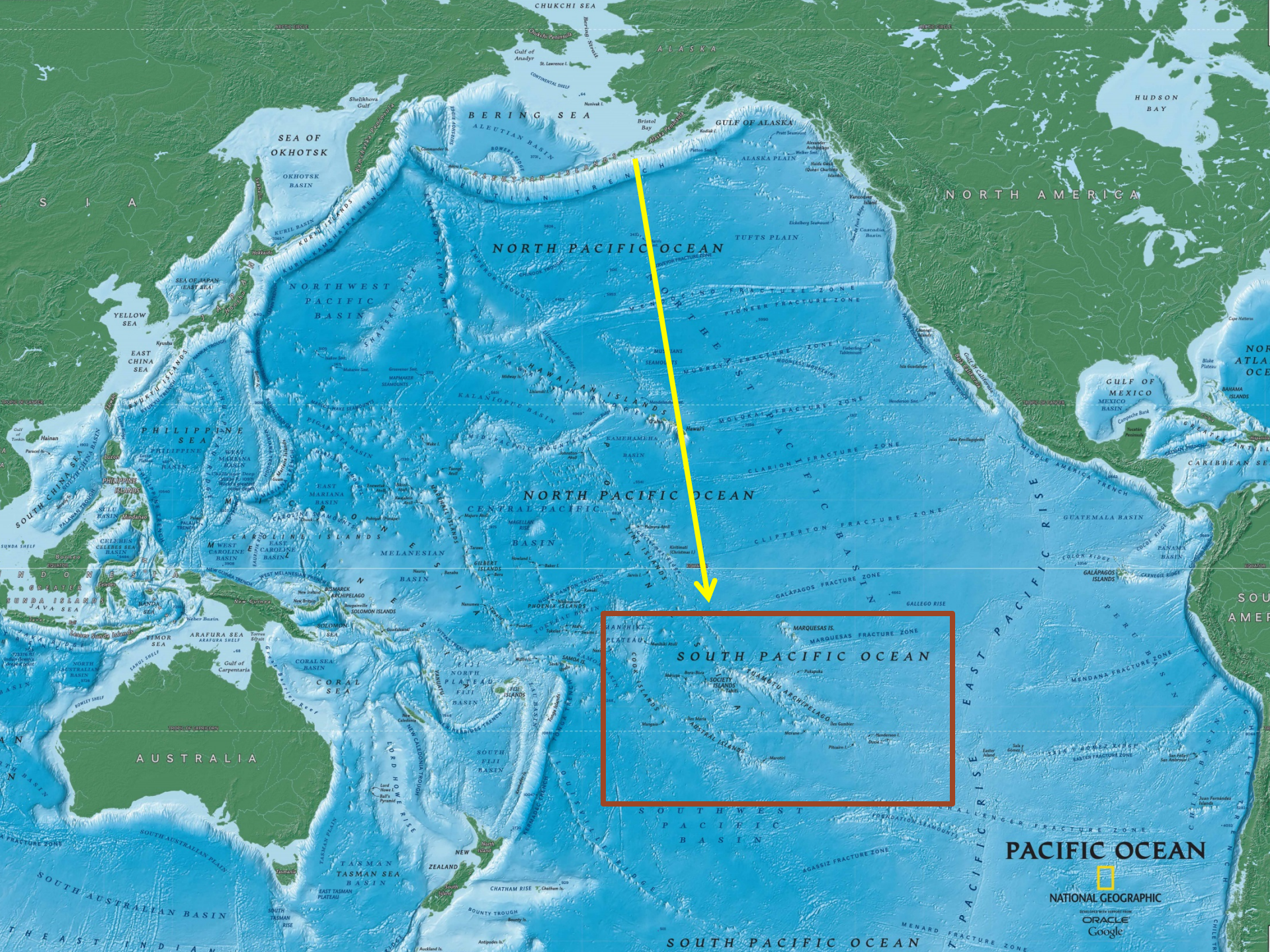


Impact of Human Invader on Extinctions









PACIFIC OCEAN

NATIONAL GEOGRAPHIC
ORACLE
Google



Socio-Ecosystem Dynamics of Natural-Human Networks on Polynesian Islands



Mo'orea



Ra'iatea



Maupiti



Mangareva

NSF Coupled Natural-Human Systems DEB-1212243

- Neo Martinez (U AZ Tucson, PI)
- Neil Davies (UC Berkeley/Gump Field Station)
- Jennifer Dunne (Santa Fe Institute)
- Jennifer Kahn (College of William & Mary)
- Pat Kirch (UC Berkeley)



Society Islands



Mo'orea

- 1.5 M years old
- 132/58 km² land/lagoon
- Low Deforestation
- Pop ~16,000

Gambier Islands



Mangareva

- 6 M years old
- 25/400 km² land/lagoon
- High Deforestation
- Pop ~1200



1. Compile & Analyze Ecological Networks

- **Human-centered use networks over 1000 years of presence**
 - **Highly resolved habitat-specific food webs for Mo'orea, based on DNA barcode and Biocube data, adding humans**
-

2. Develop Model of Natural-Human System Dynamics

- **Integrate humans & human demography in ecological networks by modeling them as:**
 - Ecological entities
 - Agricultural entities
 - Economic entities
- **Parameterize models with island-specific data and explore socio-ecological dynamics, comparing to known trends**
- **Explore dynamics, robustness, stability of socio-ecological networks**

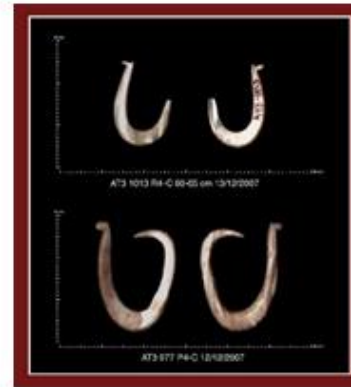




Human Interactions with Other Species

- Food/Drink
- Medicinal
- Clothing
- Ritual
- Fuel
- Housing
- Ornamental
- Artifacts

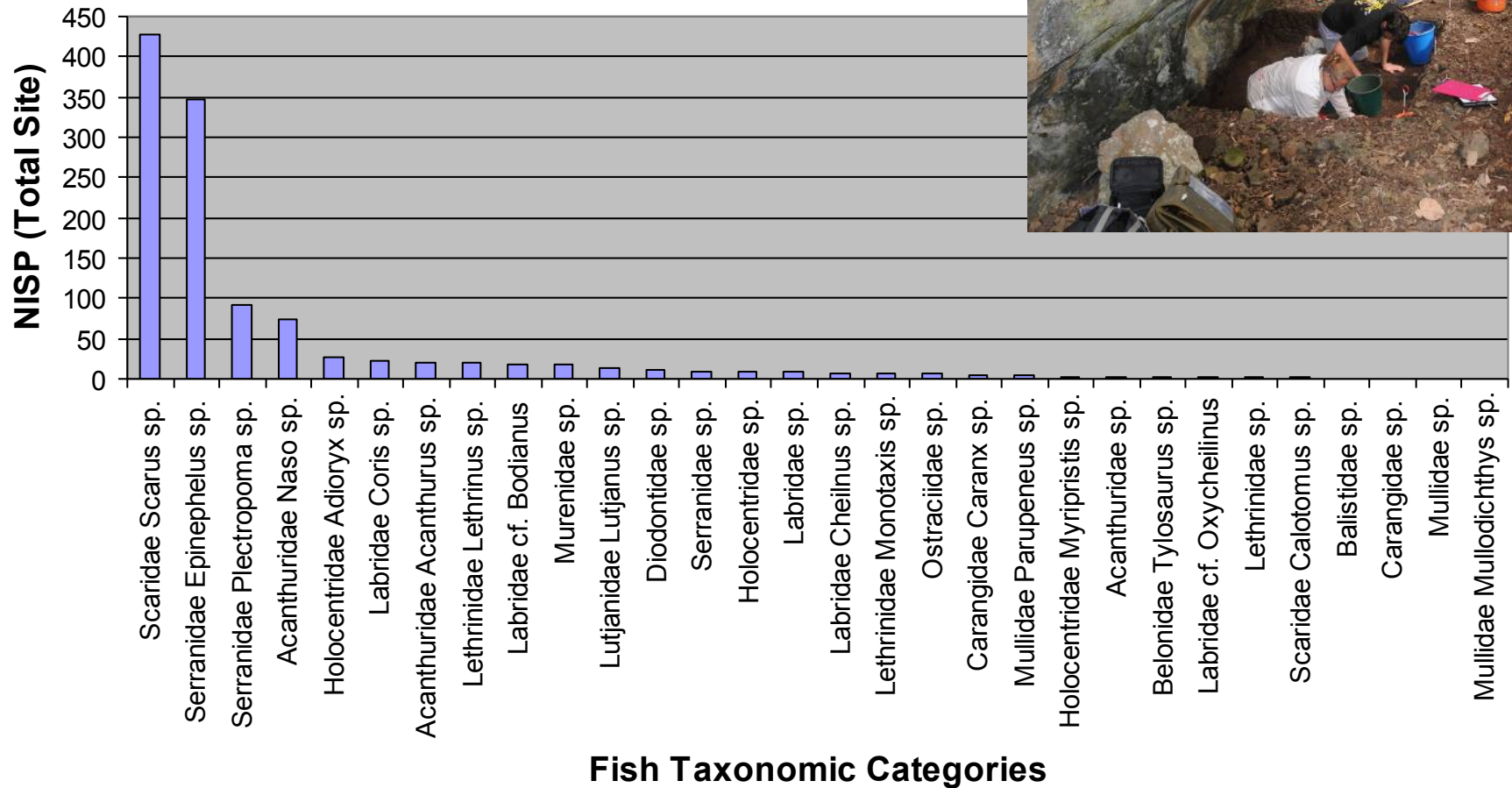
Turbo: Food, Fishhooks, Peelers



Mangareva (Gambier Islands)



The Nenega-Iti Rockshelter



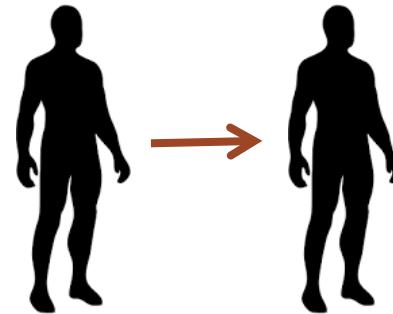
Human Use of Species on Mangareva

330+ Taxa

Food	→	283
Artifact	→	32
Ornamental	→	27
Fuel	→	12
Medicine	→	4
Clothing	→	3
Housing	→	3
Ritual	→	1

Food

- 170 marine fishes
- 53 marine inverts
- 36 plants
- 18 birds
- 4 mammals
- 2 algae



S. Pacific Polynesian Islands



North Pacific Coast



Iceland



Southwest US Pueblos



DATA HEAVEN

Moorea is one of the most studied ecosystems in the world. Myriad data collected over four decades will be used to build a digital replica of the island that includes its varied geography, its climate and all of its plant and animal life.

Social science

Government census data will be combined with tourist numbers, employment status and economic revenue.

Peaks and valleys

Landscape model to 70-centimetre resolution created from satellite images.

Ocean circulation

Time-series measurements of currents, waves and water properties from an underwater sensor array around the island.

Catalogue of life

DNA barcodes for every species more than 1 millimetre in length.

Watery secrets

Continual sampling of the water's temperature, salinity, pH and microbial diversity at sites around the island, including the Tiahura Marine Protected Area, shown here.

Coral reefs

Long-term trends in coral and fish populations, including numbers and species composition.

Underwater terrain

Sea floor mapped using satellite imagery and sonar data from ships. Will have a resolution ranging from 0.5 metres in the shallows to 20 metres in the deep ocean.

ENVIRONMENT

Tropical paradise inspires virtual ecology lab

Digital version of Moorea will provide a way to experiment with an entire ecosystem.

Modeling All Life On Earth...Or At Least on One Island

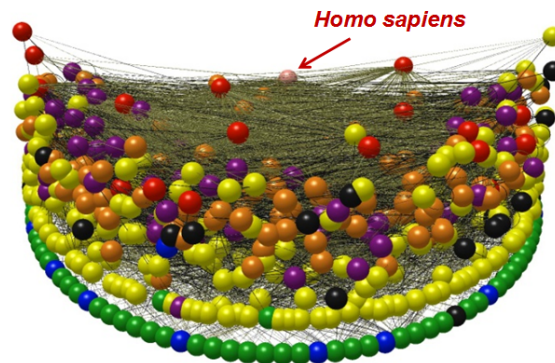
 **Moorea**

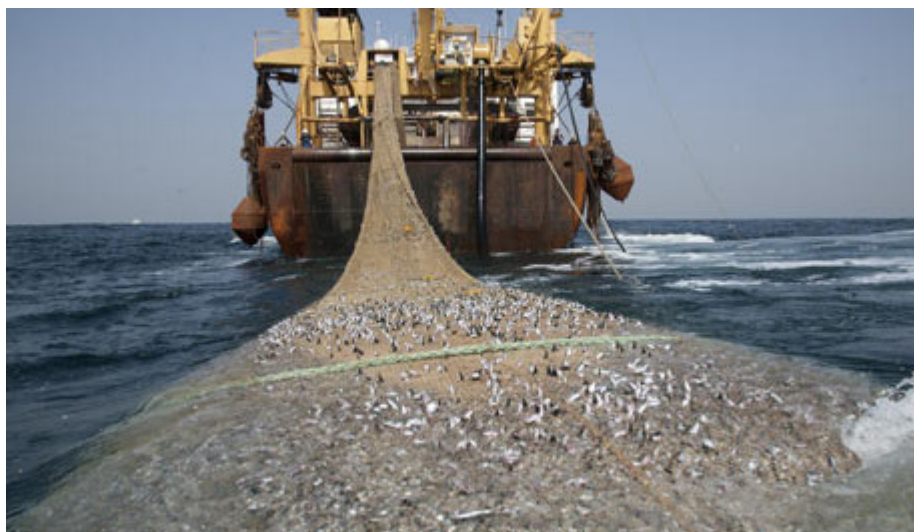
Island Digital Ecosystem Avatar



Opportunities for Sustainability/Conservation:

- Utility of ecological network analysis & modeling framework
- Include humans explicitly in ecological models
- Power of case studies: Specificity $\longleftrightarrow$ Generality
- Lessons from the past: The power of deep time
- Interaction between structural & dynamical roles
- Ecological vs. agricultural vs. economic roles
- Importance of demography, adaptive behavior, etc.







FEATURE ARTICLE

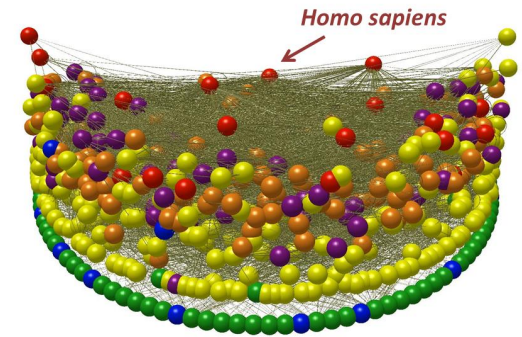
Modern Lessons from Ancient Food Webs

From the Cambrian Burgess Shale to ancient Egypt, food webs share surprising structural attributes. When redundancy is lost, the threat of extinction grows.

by Justin D. Yeakel and Jennifer A. Dunne

***American Scientist* 103: 188-195 (Cover Article, May-June Issue)**

Thanks!



Spencer Wood (Stanford, U Washington)
Herb Maschner (U South Florida, Tampa)
Nancy Huntly (Utah State U)
Rich Williams (mappr)
Neo Martinez (U Arizona)
Pat Kirch (UC Berkeley)
Jenny Kahn (William & Mary)
Neil Davies (UC Berkeley, Gump)
Heike Lotze (Dalhousie U)
Justin Yeakel (Santa Fe Institute)



National Science Foundation
WHERE DISCOVERIES BEGIN



SANTA FE INSTITUTE