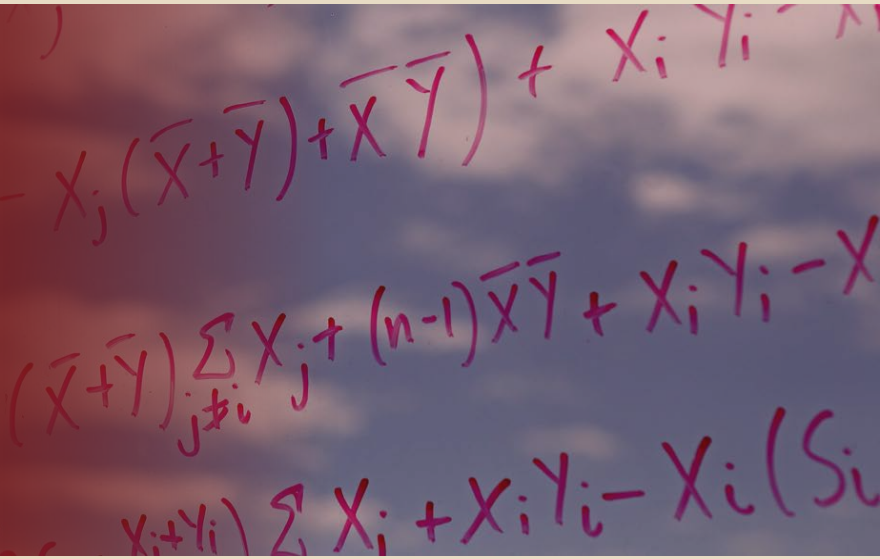
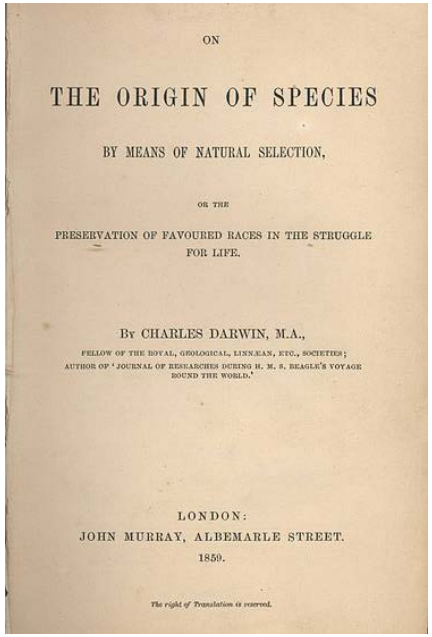
SANTA FE INSTITUTE

The Roles, Function and Impacts of Humans in Complex Ecological Networks

Jennifer A. Dunne, Santa Fe Institute



Darwin (1859) On The Origin of Species



ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

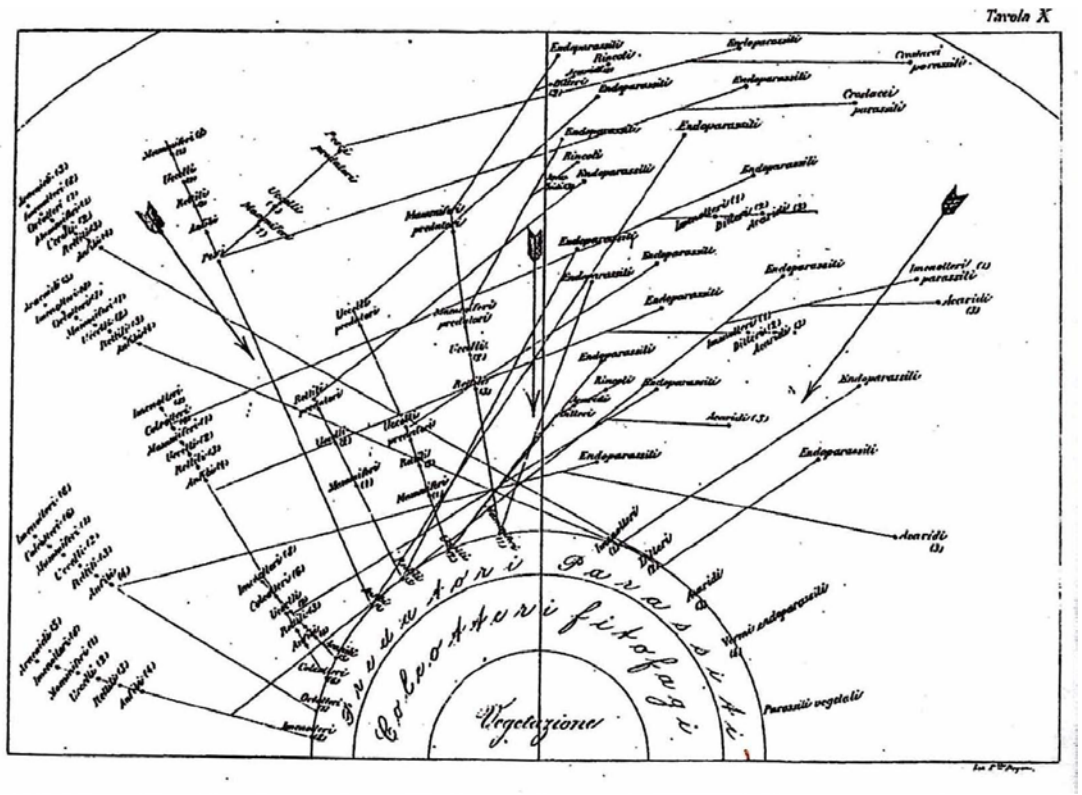
By CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNEAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

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.

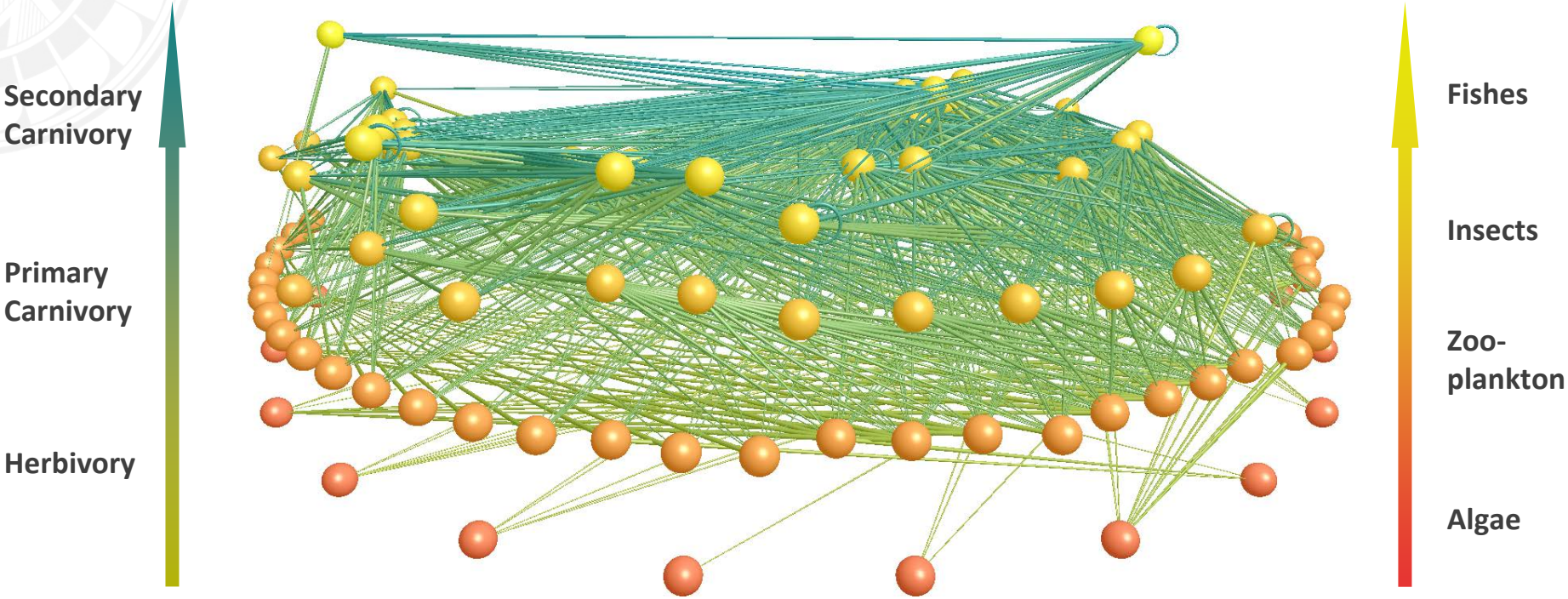
Lorenzo Camerano, 1880



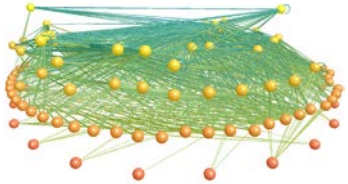
15 taxa:
Plants
Parasitic plants
Worms
Amphibians
Reptiles
Fish
Birds
Mammals
Crustaceans
Spiders
Insects

Camerano (1880) On the equilibrium of living beings by means of reciprocal destruction.
Atti della Reale Accademia delle Scienze di Torino

Little Rock Lake, Wisconsin

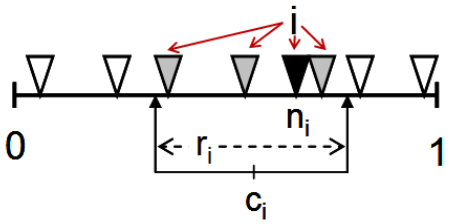


Martinez. 1991. *Ecological Monographs.*
Artifacts or attributes? Effects of resolution on the Little Rock Lake food web.



- **Ecological Network Structure**

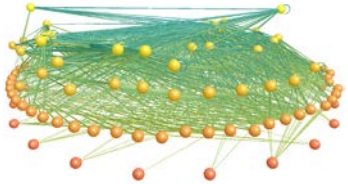
The Niche Model



Nature 2000

Simple rules yield complex food webs

Richard J. Williams & Neo D. Martinez



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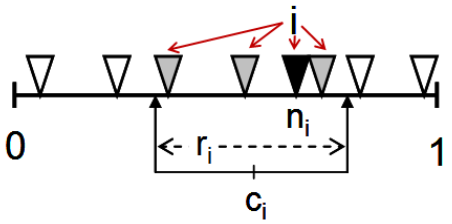

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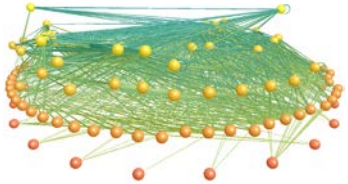
- **Complex Trophic Dynamics**

Ecology Letters, (2012) doi: 10.1111/j.1461-0248.2012.01777.x

LETTER

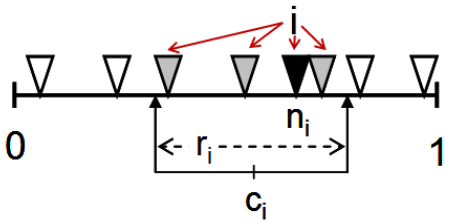
Mechanistic theory and modelling of complex food-web dynamics in Lake Constance

Alice Boit,[1]* Neo D. Martinez,[2] Richard J. Williams[3,4] and Ursula Gaedke[1]



- **Ecological Network Structure**

The Niche Model



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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 Gaedke[1]

- **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. Williams[1] and Neo D. Martinez[1]

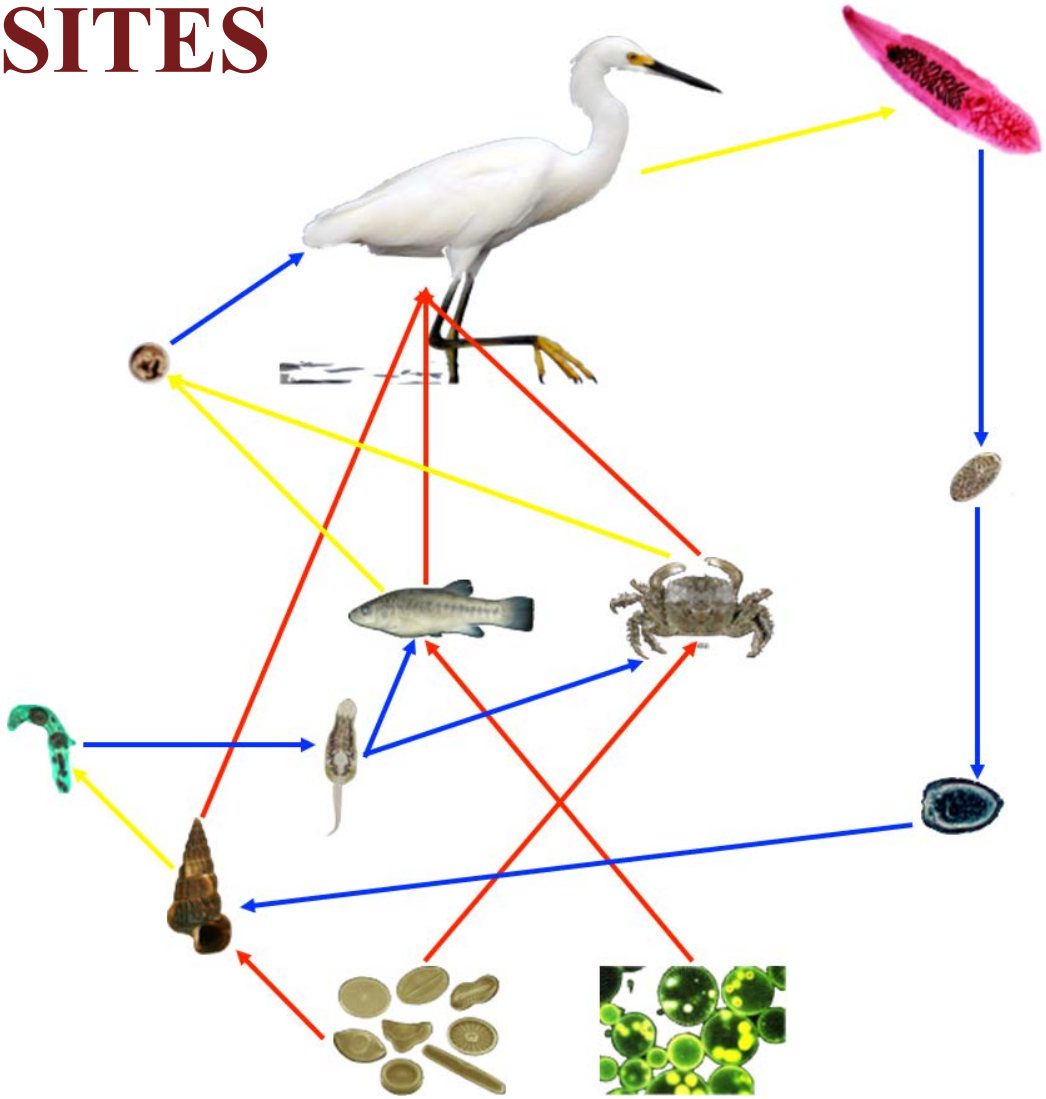
Ecology Letters, (2006) 9: 1228–1236 doi: 10.1111/j.1461-0248.2006.00978.x

LETTER

Allometric scaling enhances stability in complex food webs

Ulrich Brose,[1,2]* Richard J. Williams[2,3] and Neo D. Martinez[2]

PARASITES



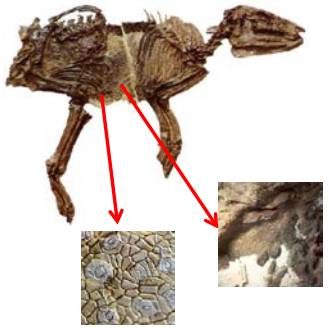
DEEP TIME

Geologic Time Scale

PHANEROZOIC	CENOZOIC	QUATERNARY		0	HOLOCENE
					PLEISTOCENE
		TERTIARY	NEOGENE	1.65	PLIOCENE
					MIOCENE
			PALEOGENE	23.8	OLIGOCENE
					EOCENE
					PALEOCENE
	MESOZOIC	CRETACEOUS		65	
		JURASSIC		144.8	
		TRIASSIC		200	
	PALEOZOIC	PERMIAN		251	
		CARBONIFEROUS		300	
		DEVONIAN		355	
		SILURIAN		418	
		ORDOVICIAN		441	
		CAMBRIAN		490	
PRECAMBRIAN		EDIACARAN		544	
				570	
				4000+	

Millions of years ago (ma)

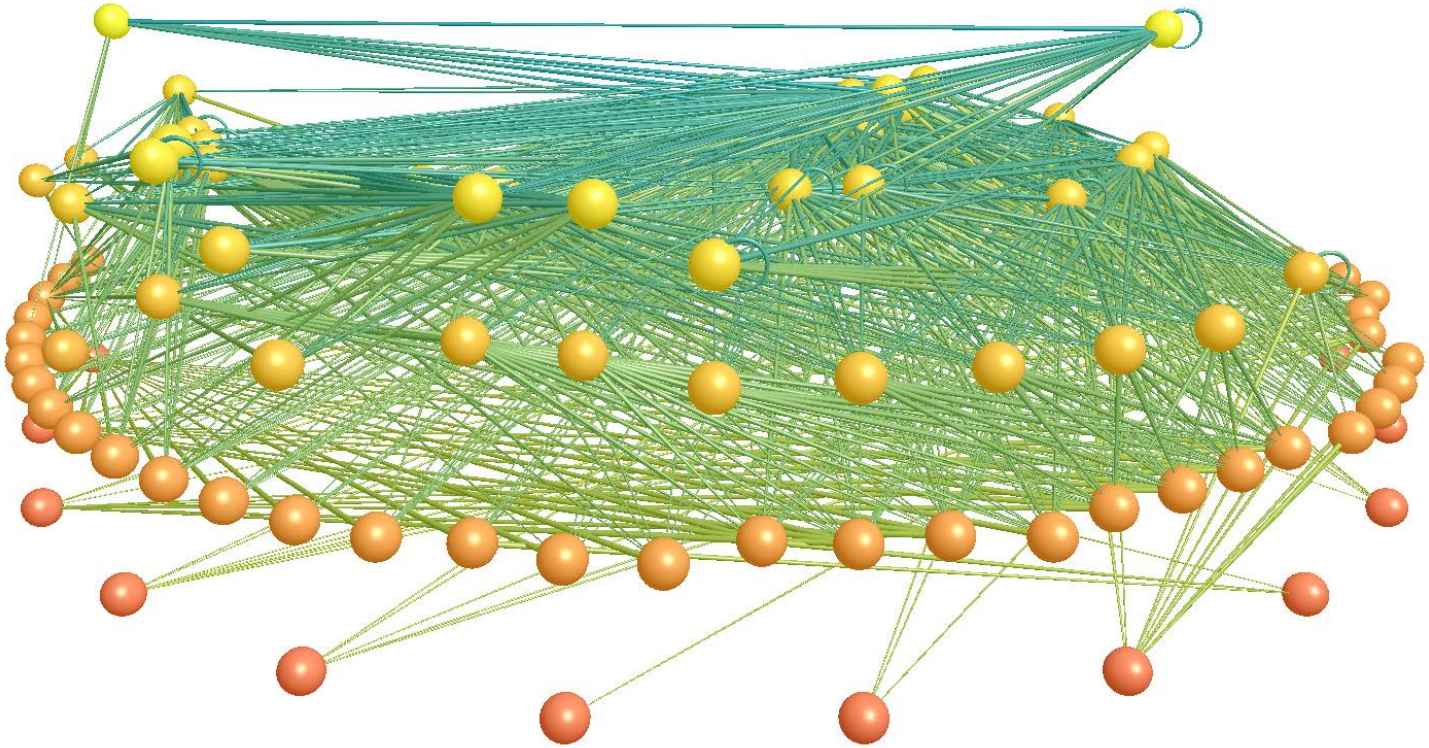
Messel Shale (48 Ma)



Burgess Shale (505 Ma)

Chengjiang Shale (520 Ma)

What about *Homo sapiens?*



Using ecological networks to:

- Assess human impacts on ecosystems
- Understand human roles in ecosystems
- Investigate aspects of sustainability

I. Human Impacts on Ecological Networks

Adriatic Sea Region

Egypt

Ecosystems (2011) 14: 198–222
DOI: 10.1007/s10021-010-9404-8

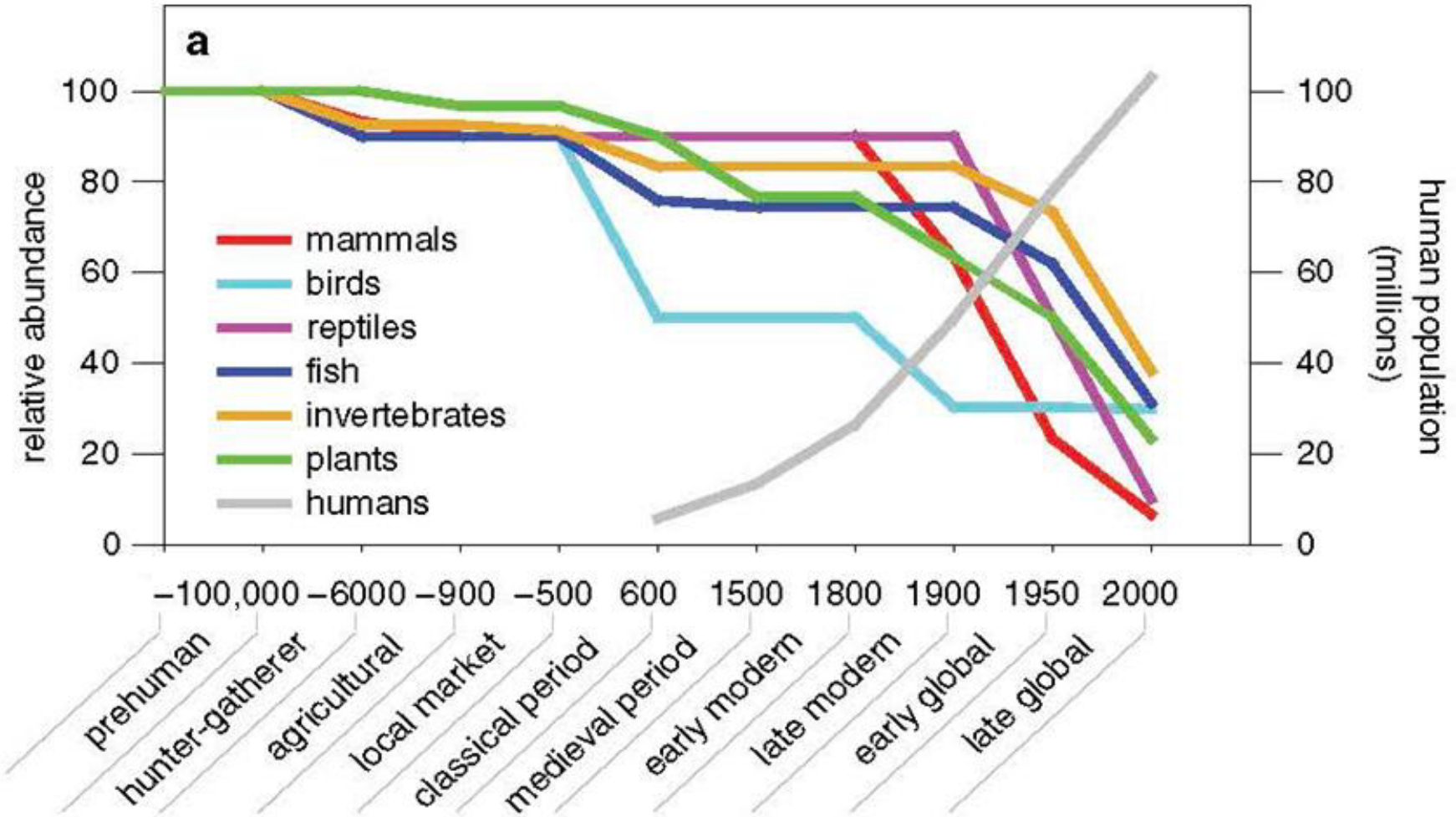
ECOSYSTEMS

Historical Changes in Marine Resources, Food-web Structure and Ecosystem Functioning in the Adriatic Sea, Mediterranean

Heike K. Lotze,[1]* Marta Coll,[1,2] and Jennifer A. Dunne[3,4]

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

Species Abundances



The Dwindling Web

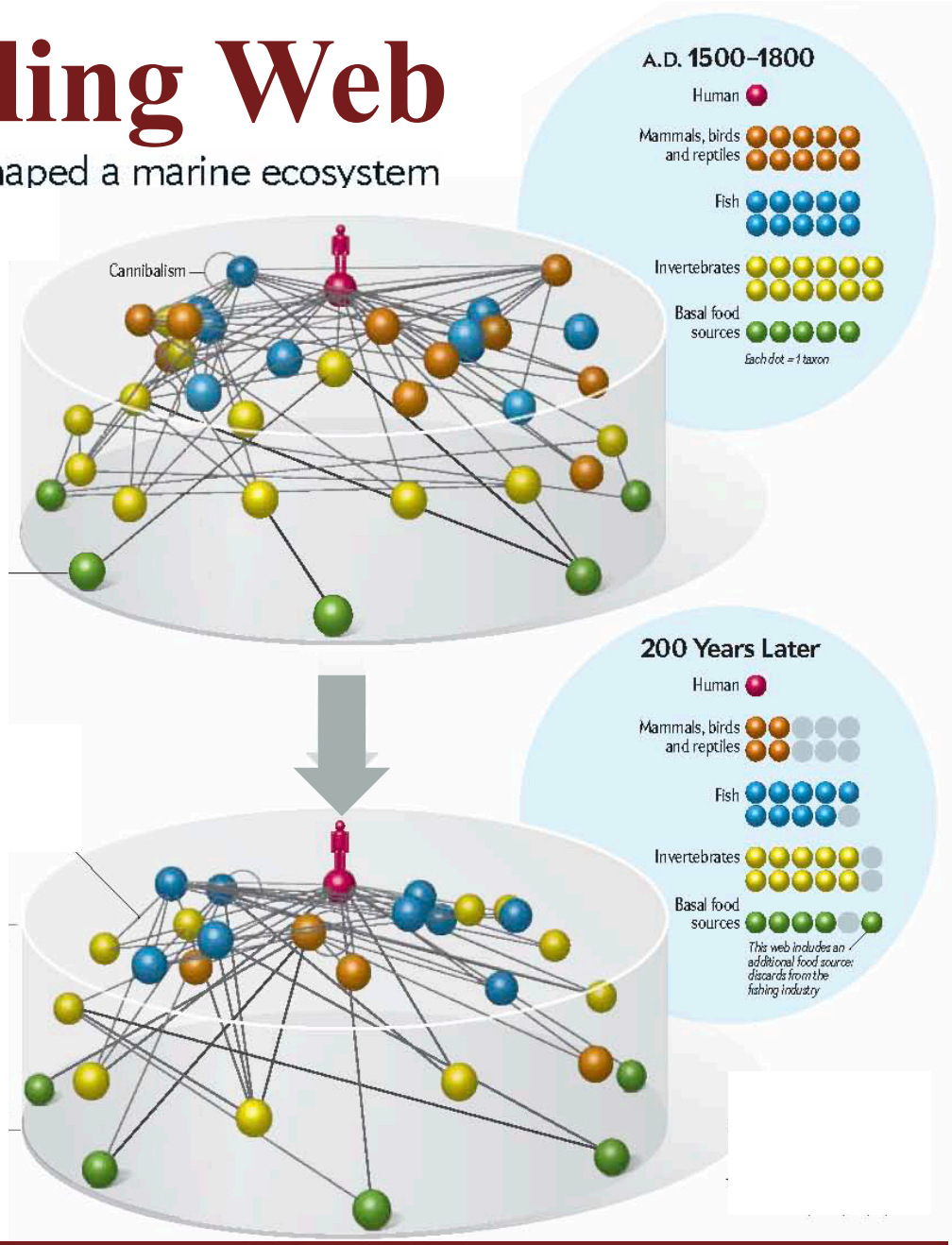
How human exploitation has reshaped a marine ecosystem

Early Modern

25% Taxa ⬇

Robustness ⬇

Late Global



Scientific American 2012

PNAS

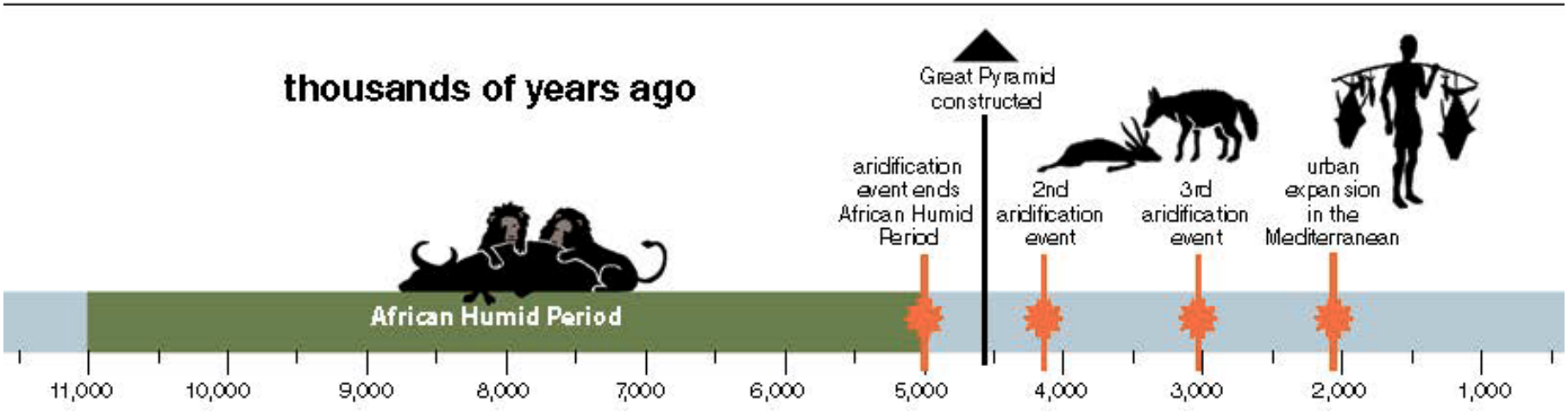
Collapse of an ecological network in Ancient Egypt

Justin D. Yeakel[a,b,c,1,2], Mathias M. Pires[d,2], Lars Rudolf[e,f,2], Nathaniel J. Dominy[g,h], Paul L. Koch[i], Paulo R. Guimarães, Jr.[d], and Thilo Gross[e,f]

[a]Department of Ecology and Evolutionary Biology, University of California, Santa Cruz, CA 95064; [b]Earth to Oceans Research Group, Simon Fraser University, Burnaby, BC, Canada V5A 1S6; [c]Santa Fe Institute, Santa Fe, NM 87501; [d]Departamento de Ecologia, Universidade de São Paulo, CEP 05508-090, São Paulo, SP, Brazil; [e]Department of Engineering and Mathematics, University of Bristol, Bristol BS8 1UB, United Kingdom; [f]Max Planck Institute for the Dynamics of Complex Systems, D-01187 Dresden, Germany; Departments of [g]Anthropology and [h]Biological Sciences, Dartmouth College, Hanover, NH 03755; and [i]Department of Earth and Planetary Sciences, University of California, Santa Cruz, CA 95064

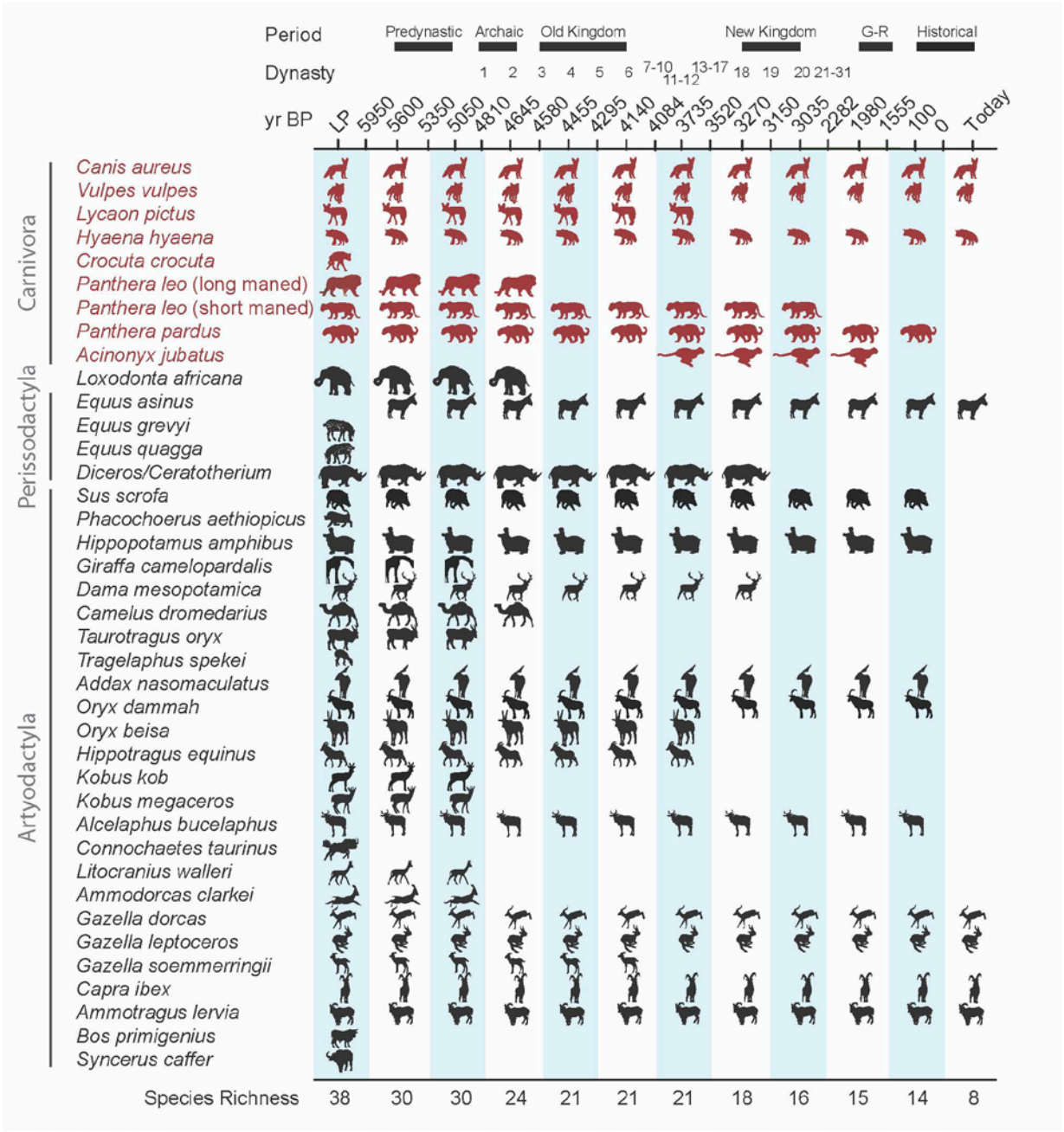
Edited by Justin S. Brashares, University of California, Berkeley, CA, and accepted by the Editorial Board August 11, 2014 (received for review May 8, 2014)

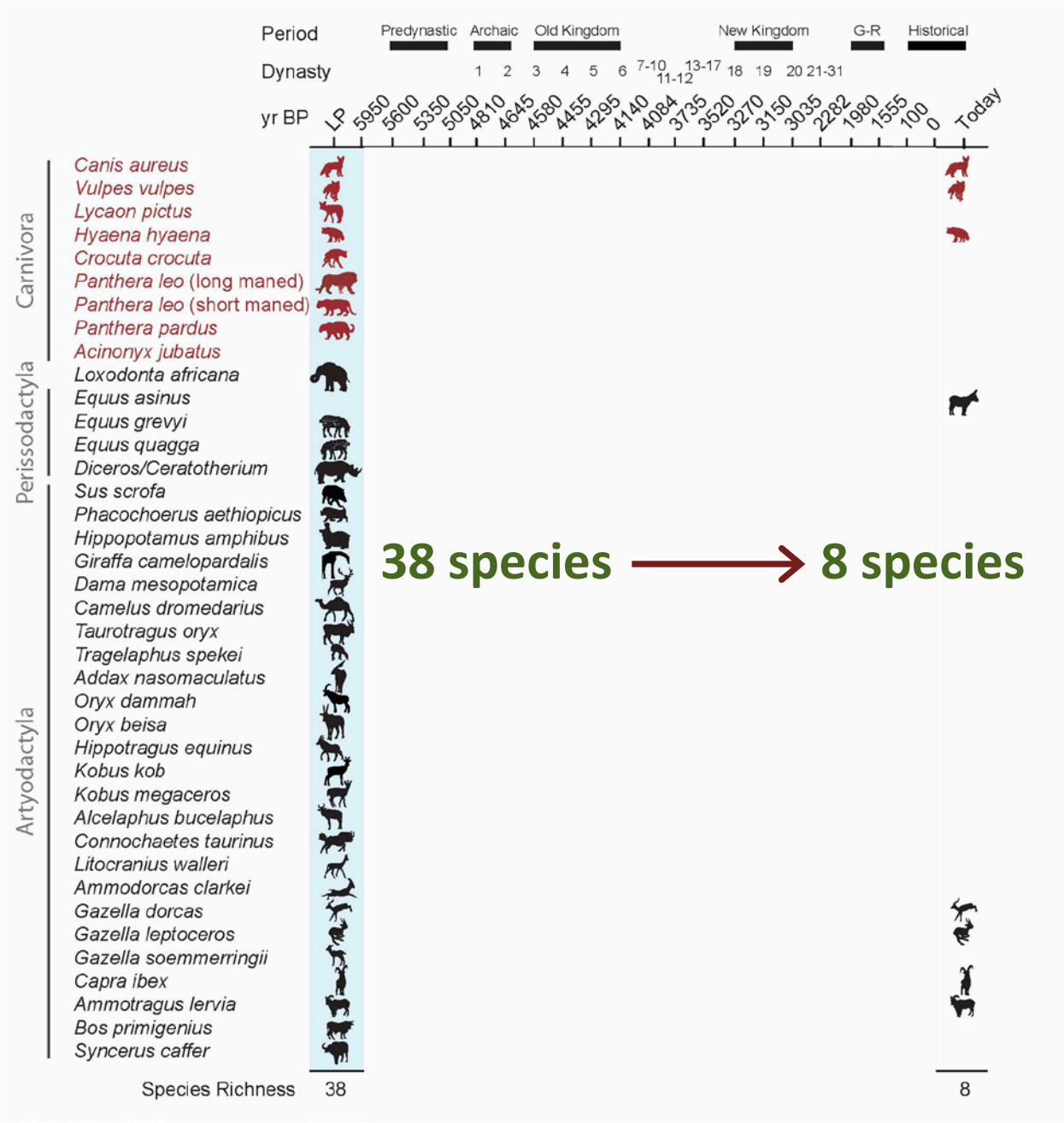
Timeline of Egypt



Hierakonpolis Palette: 5150 yrs old

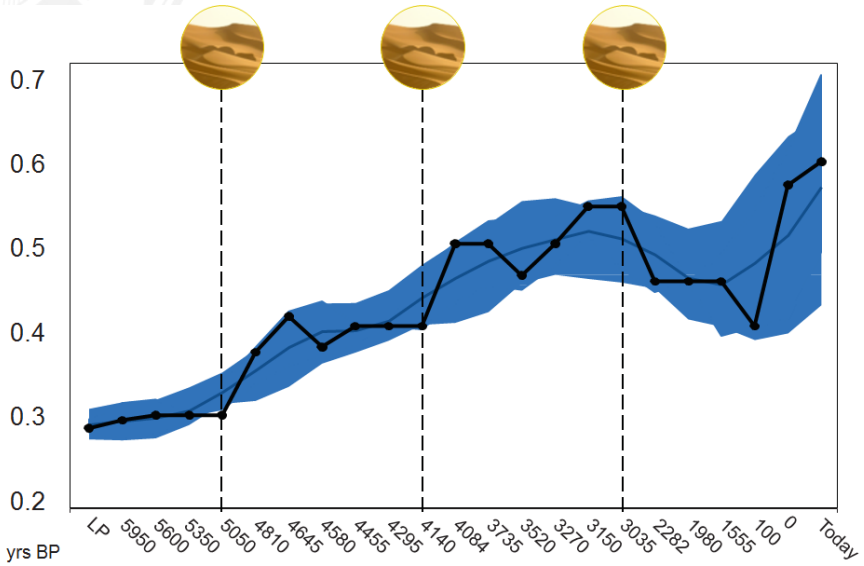
Panel from Tutankhamun's Painted Box: 3000 yrs old


Period
Predynastic
Archaic
Old Kingdom
New Kingdom
G-R
Historical
Dynasty
1 2 3 4 5 6 7-10 11-12 13-17 18 19 20 21-31
yr BP
LP 5950 5600 5350 5050 4810 4645 4580 4455 4295 4140 4084 3735 3520 3270 3150 3035 2282 1980 1555 100 0 Today
Carnivora
Perissodactyla
Artyodactyla
Canis aureus
Vulpes vulpes
Lycaon pictus
Hyaena hyaena
Crocuta crocuta
Panthera leo (long maned)
Panthera leo (short maned)
Panthera pardus
Acinonyx jubatus
Loxodonta africana
Equus asinus
Equus grevyi
Equus quagga
Diceros/Ceratotherium
Sus scrofa
Phacochoerus aethiopicus
Hippopotamus amphibus
Giraffa camelopardalis
Dama mesopotamica
Camelus dromedarius
Taurotragus oryx
Tragelaphus spekei
Addax nasomaculatus
Oryx dammah
Oryx beisa
Hippotragus equinus
Kobus kob
Kobus megaceros
Alcelaphus bucelaphus
Connochaetes taurinus
Litocranius walleri
Ammodorcas clarkei
Gazella dorcas
Gazella leptoceros
Gazella soemmerringii
Capra ibex
Ammotragus lervia
Bos primigenius
Syncerus caffer
Species Richness
38 30 30 24 21 21 21 18 16 15 14 8

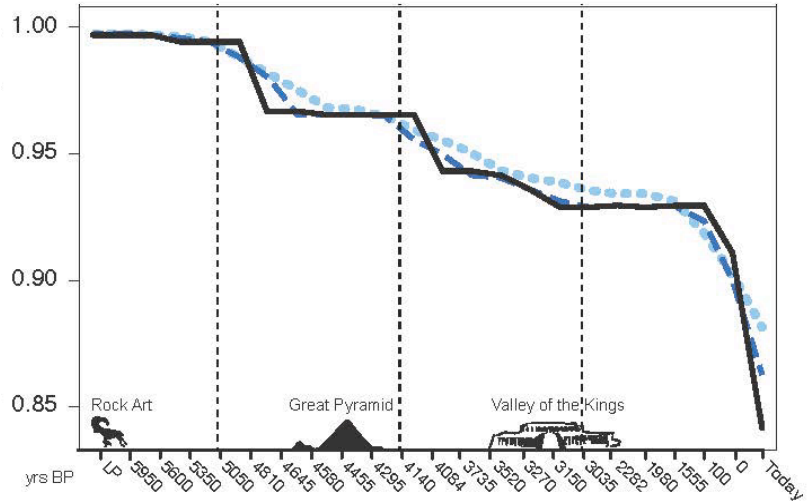


38 species → 8 species

Increasing Predator-Prey Ratio Through Time



Fewer Dynamically Stable Food Webs Through Time

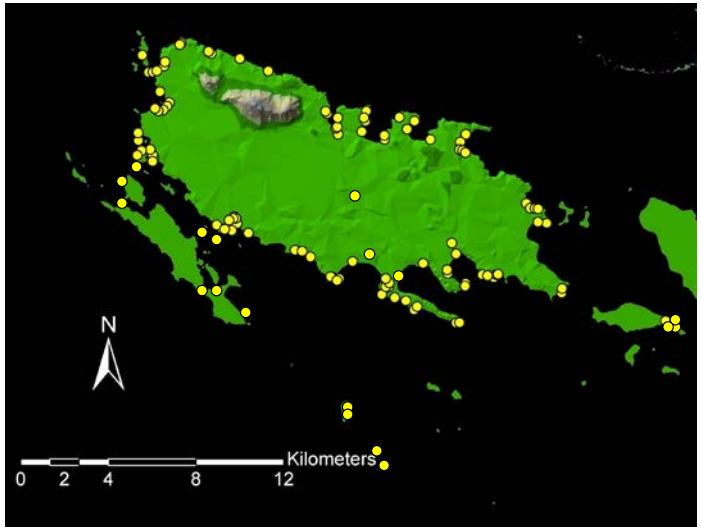


II. Humans Roles in Food Webs

Dunne *et al.* (2016) The roles and impacts of human hunter-gatherers in North Pacific marine food webs. *Scientific Reports.*

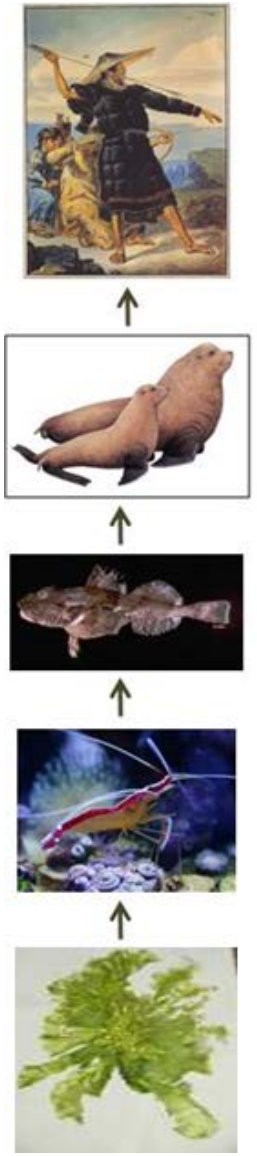
- What roles did pre-industrial humans play in North Pacific food webs?
- How did human foragers compare to other species?
- What can we learn about sustainability from how humans interacted with and impacted other species?

The Sanak Archipelago

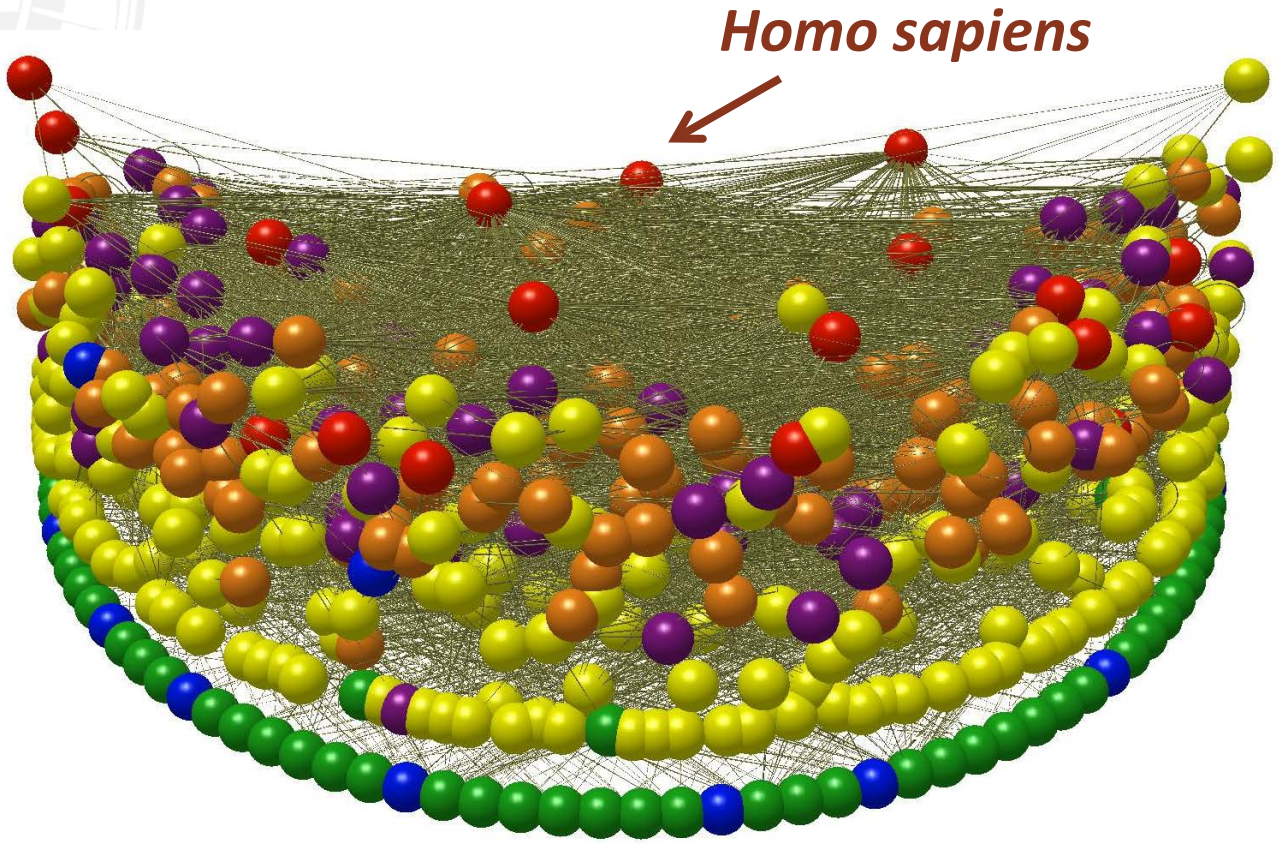


- Far-eastern end of Aleutian archipelago
- Ice-free for 16,000 yrs
- 6,000 yr human record, 128 known sites
- Integrate archeological, ecological & climatic data

Human Trophic Roles: Network Structure



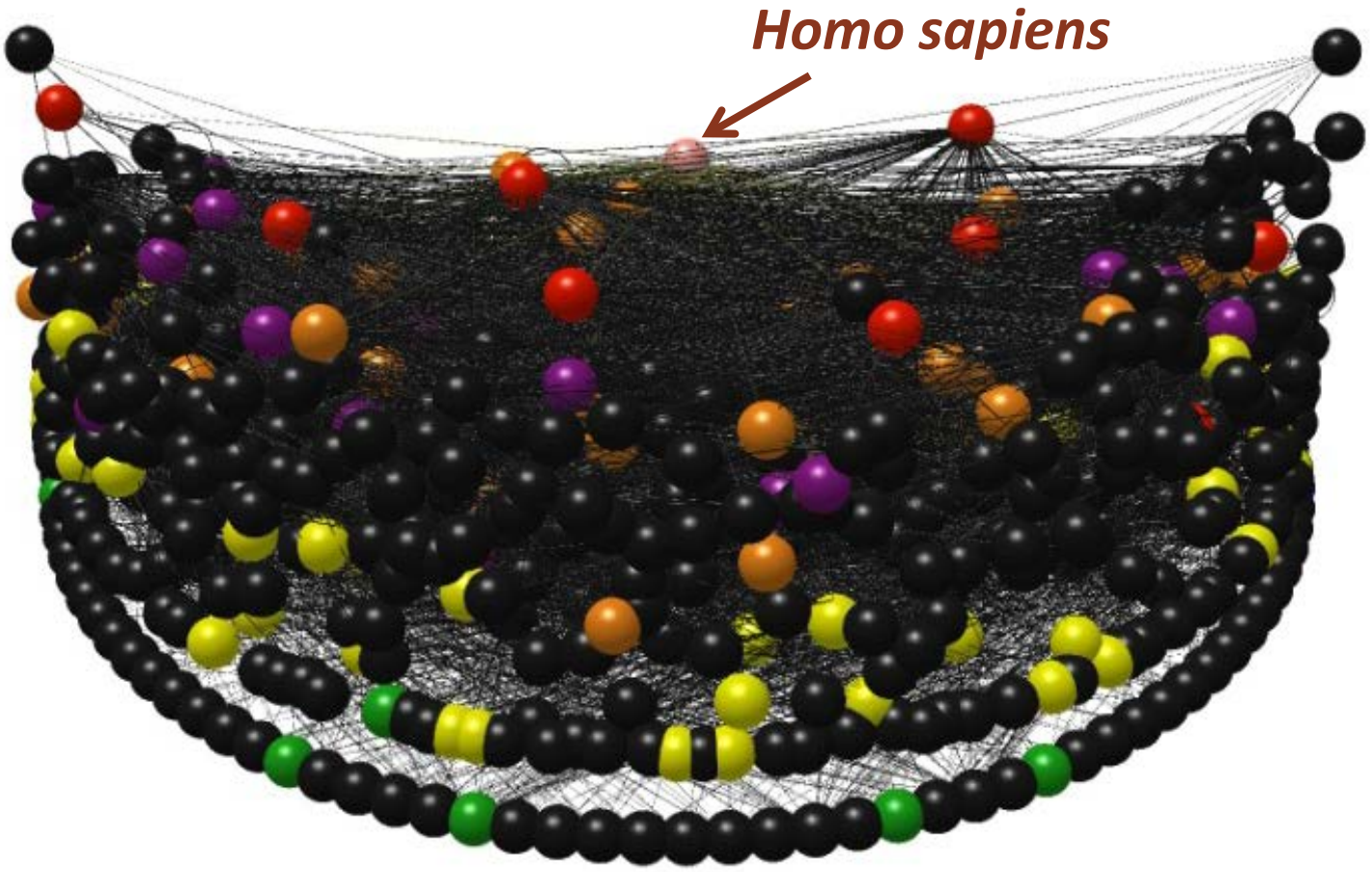
Sanak Nearshore Marine Food Web



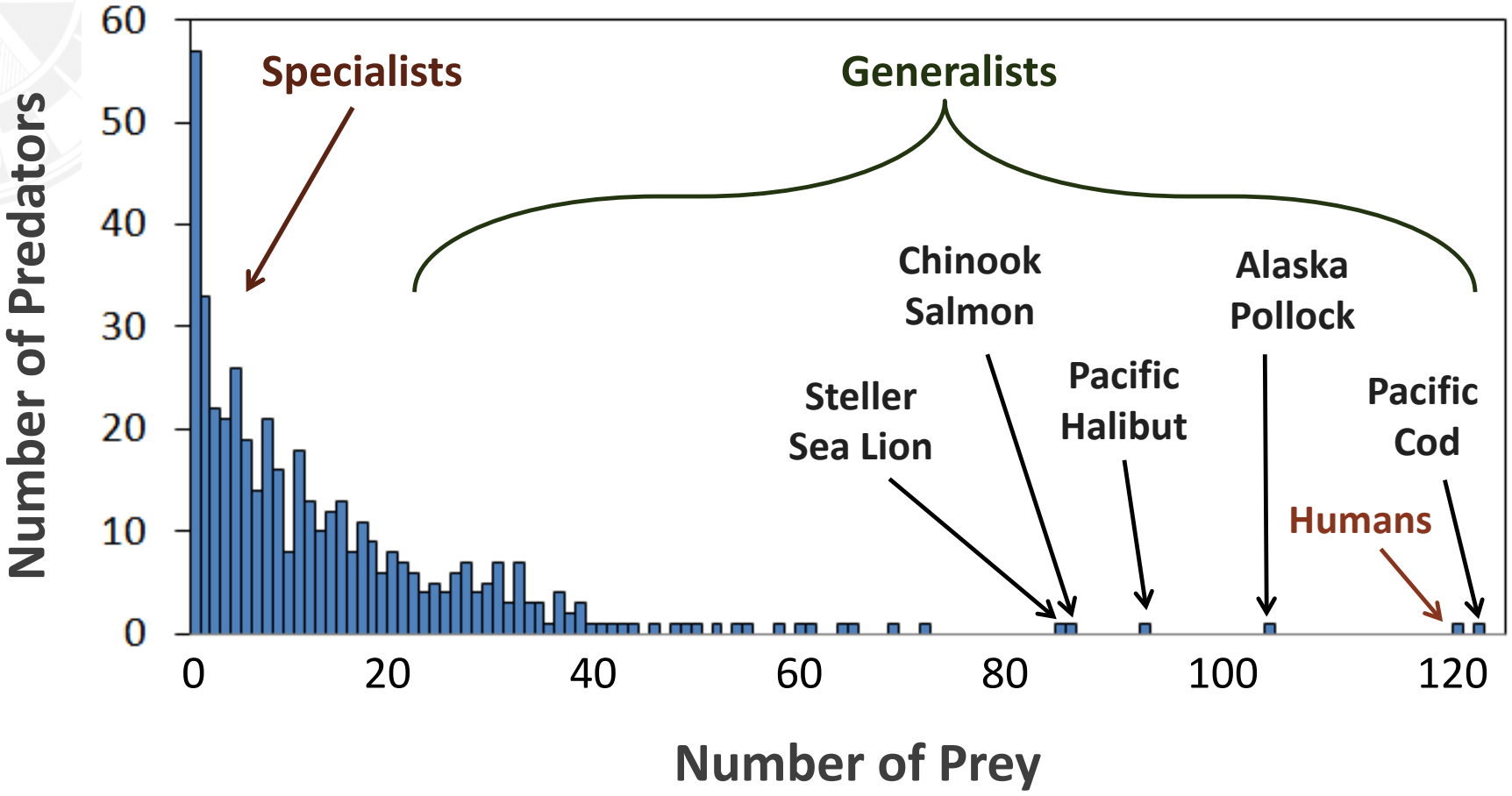
- Birds (64)
- Mammals (21)
- Fish (139)
- Invertebrates (222)
- Algae (54)
- Misc (13)

513 taxa, 6774 feeding links, 13 links per species

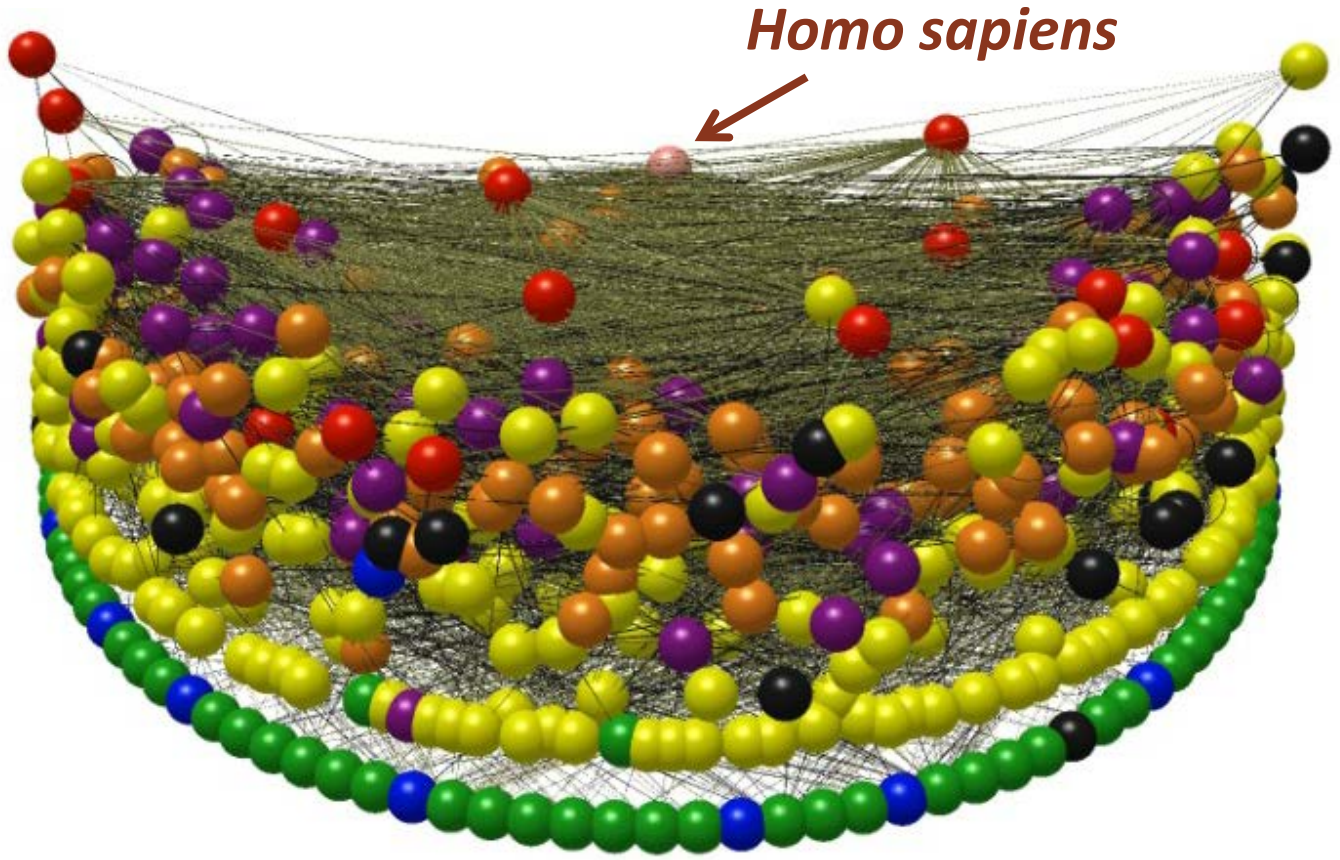
Humans Fed on 122 Taxa (24%)



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?

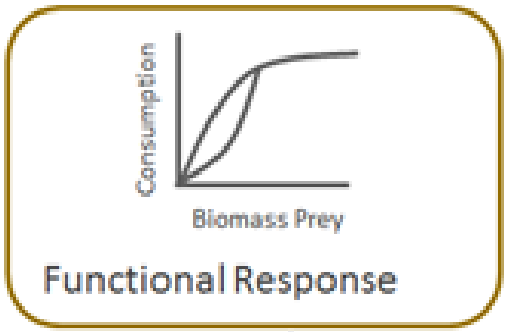
Changes in species biomasses:

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

Allometric Trophic Network (ATN) Model

Changes in species biomasses:

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



mass-specific metabolic rate

$$B_i' = -x_i B_i + \sum_{j=resources} x_i y B_i F_{ij} - \sum_{j=consumers} x_j y B_j F_{ji} / e_{ji}$$

Biomass$_i$ at time t

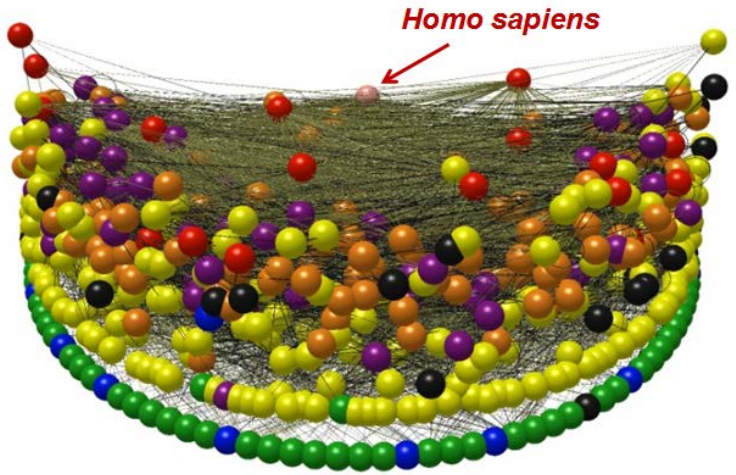
max metabolic-specific ingestion rate

assimilation efficiency

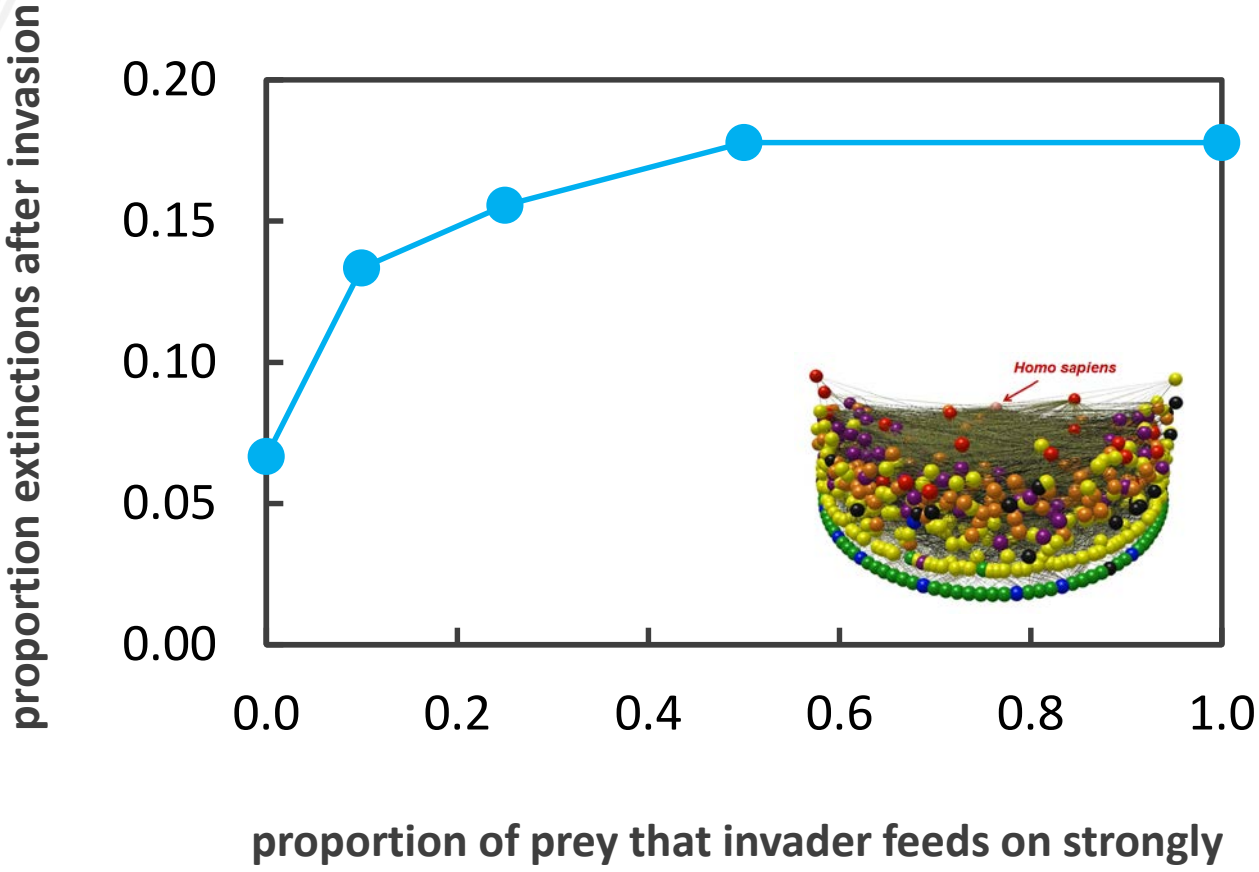
An *In Silico* Experiment:

Impact of invasion by human-like taxon on ecological persistence

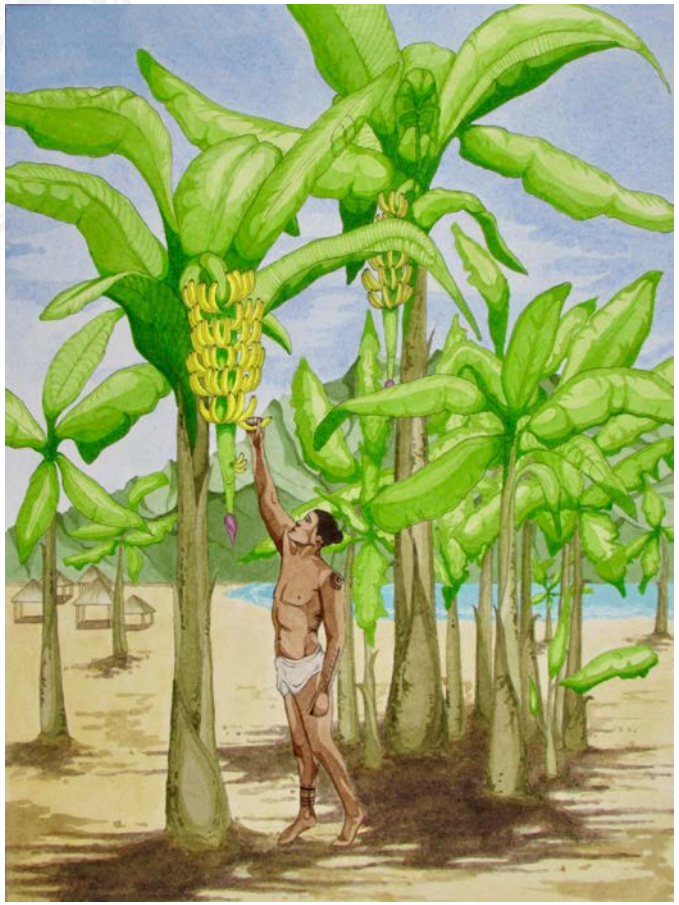
- Create a “zoo” of dynamically persistent model food webs
- Include prey-switching by generalist species
- Invade each web with an omnivorous super-generalist species
- Hunting tech: vary fraction of invader's links that are strong
- How many extinctions follow?



Impact of Human Invader on Extinctions



III. Beyond Trophic Interactions



Dunne, Kahn, Kirch, Wood *et al.* In prep.

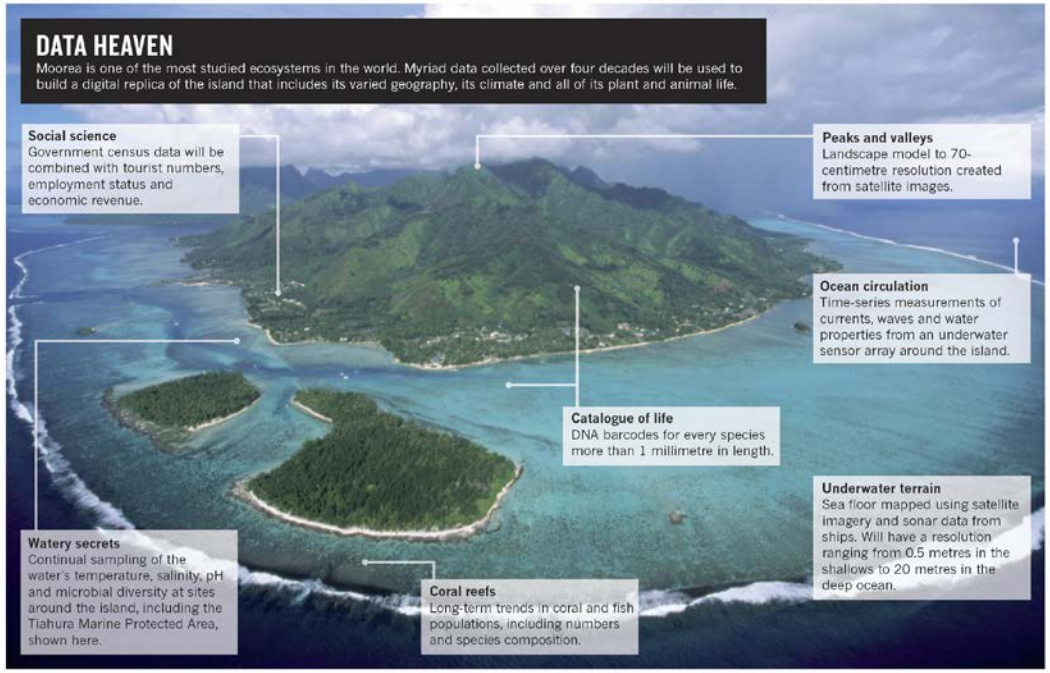
Socio-Ecosystem Dynamics of Natural-Human Networks on Polynesian Islands

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)
- Spencer Wood (U Washington)

Moorea

Island Digital Ecosystem Avatar



ENVIRONMENT

Tropical paradise inspires virtual ecology lab

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

PACIFIC OCEAN

NATIONAL GEOGRAPHIC

Powered by ORACLE Google

Society Islands

Mo’orea

- 1.5 M years old
- 132/58 km^2 land/lagoon
- Low Deforestation
- Pop ~16,000

Gambier Islands

Mangareva

- 6 M years old
- 25/400 km^2 land/lagoon
- High Deforestation
- Pop ~1200

On 12 September, 1997, the people of Taumako launched an authentic Polynesian voyaging canoe (*vaka*). The name of the type of vaka is *Te Puke*. The name of the *Te Puke* is *Vaka Taumako* – "a voyaging canoe for Taumako." (http://vaka.org/1998/02/525/)



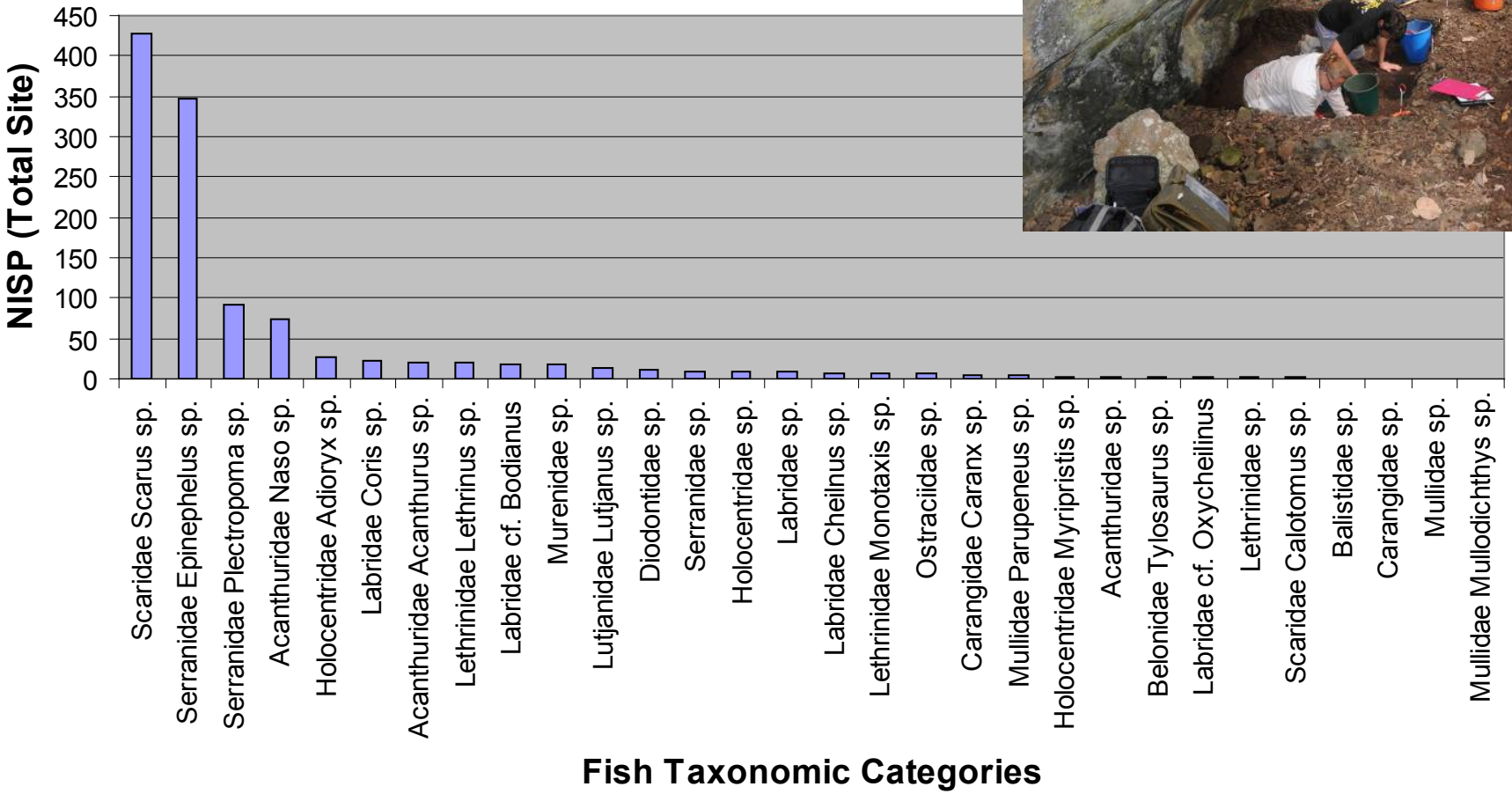




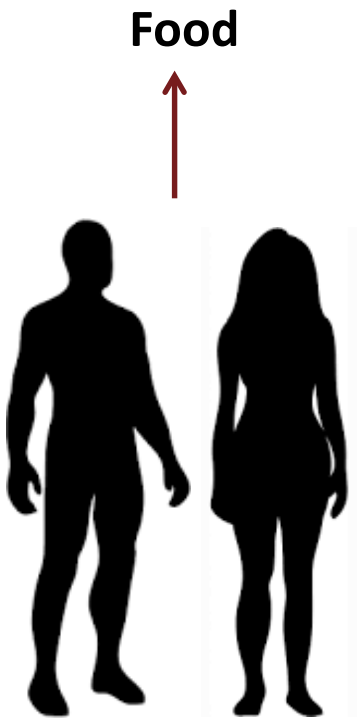




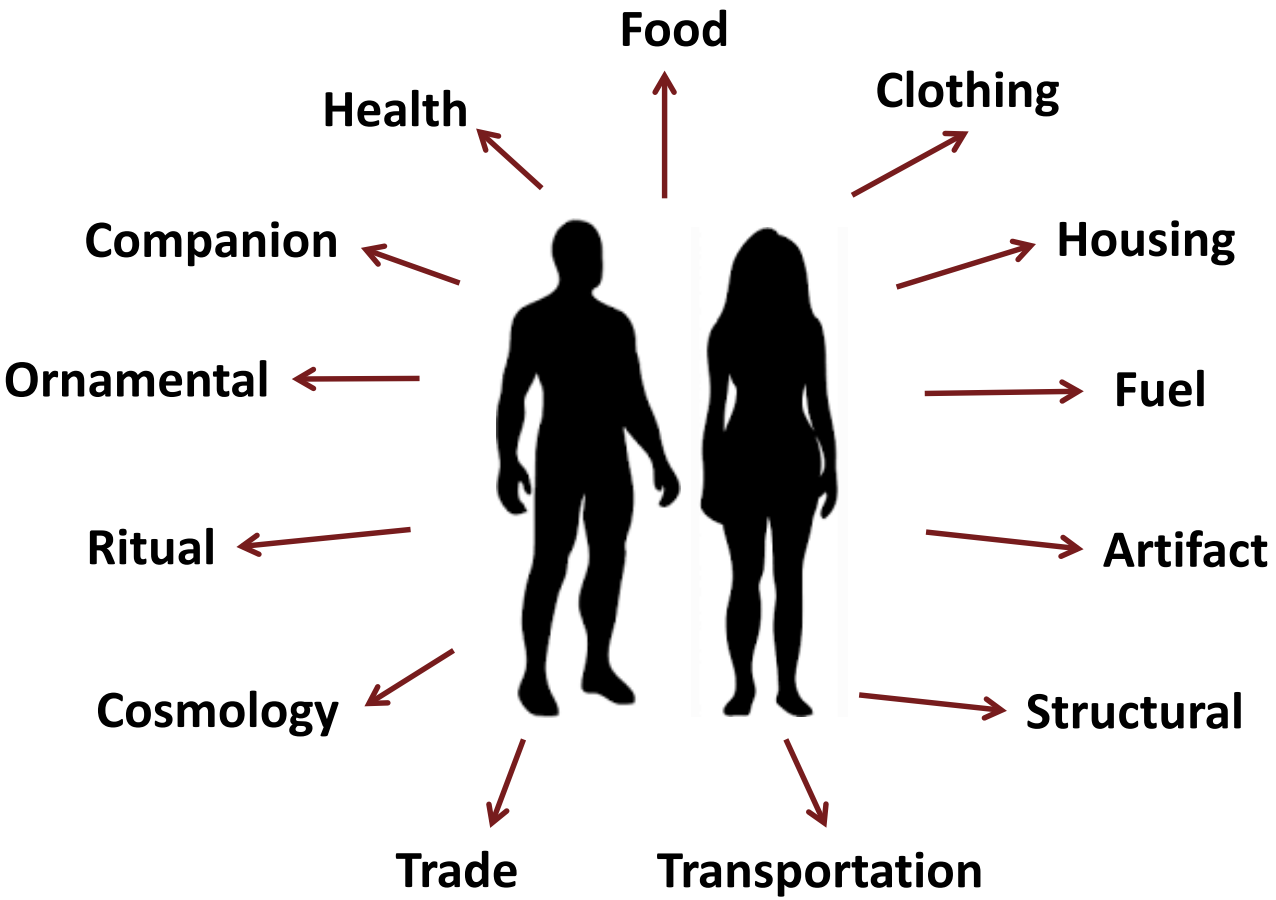
The Nenega-Iti Rockshelter



Human Interactions with Other Species



Human Interactions with Other Species



Multiple Uses

Turbo: Food, Fishhooks, Peelers

Human Use of Species on Mangareva

Archaeological & Ethnographic Data

330+ Taxa

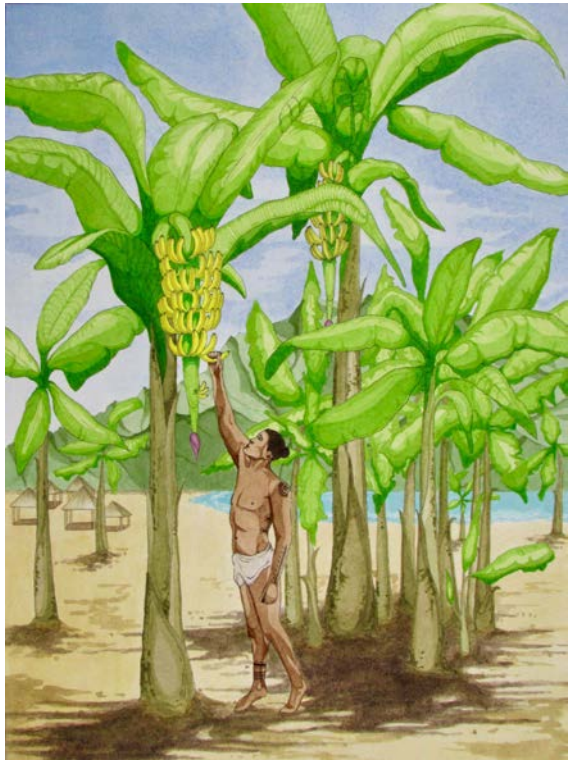
Food	283
Artifact	32
Ornamental	27
Fuel	12
Medicine	4
Clothing	3
Housing	3
Ritual	1

Food

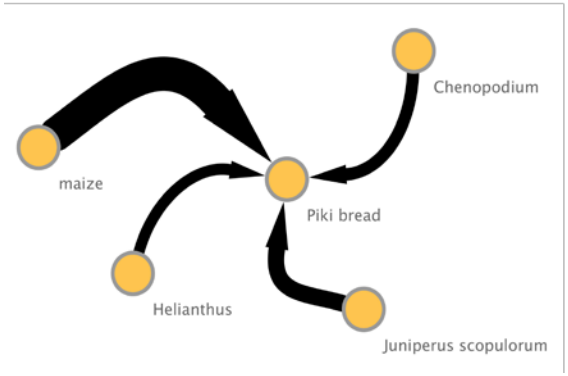
- 170 marine fishes
- 53 marine inverts
- 36 plants
- 18 birds
- 4 mammals
- 2 algae

Simple vs. Complex Interactions

Human eats banana



Human eats corn



Maize: Main ingredient for piki bread

Chenopodium: Purple dye for piki bread

Helianthus: A hood over piki stone to lock in moisture

Juniperus scopulorum: Fuel for cooking; ash as ingredient for bread

Plant Oil or Animal Fat: To cook piki bread on piki stone

IV. Comparison & Synthesis

South Pacific Islands
Pat Kirch, Jenny Kahn

Central Europe
Philip Verhagen

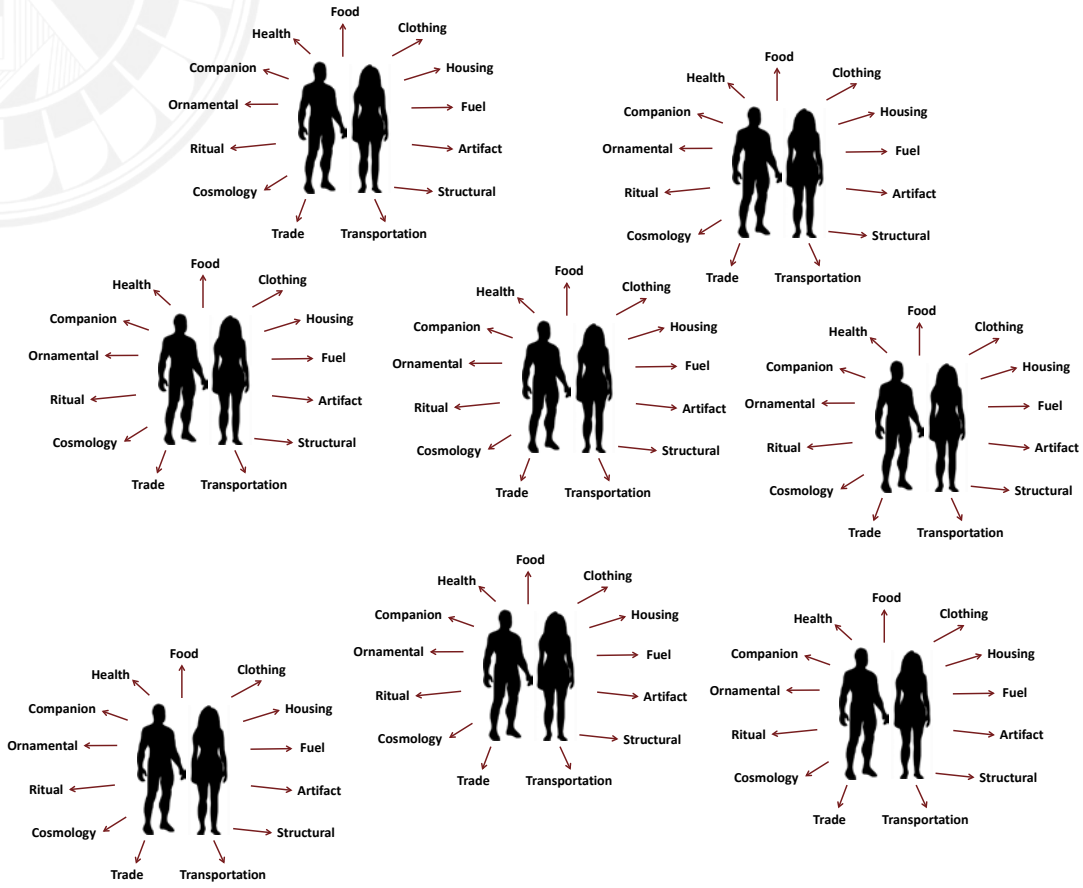
North Pacific Coast
Iain McKechnie, Spencer Wood

North Atlantic Islands
Andy Dugmore

Western Desert Australia
Rebecca Bliege Bird, Stefani Crabtree

Southwest United States
Stefani Crabtree

How Human Interactions with Biodiversity Shape Socio-Ecological Dynamics & Sustainability



In relation to constraints & opportunities:

- **Ecology**
  - → habitat, species richness, taxa
- **Environment**
  - → climate, geography
- **Culture**
  - → mode of production, social organization, norms

The ArchaeoEcology Project (TAEP)

Lessons & Opportunities:

- Humans often unravel food webs (population increases, hunting, agriculture, urbanization, industrialization)
- Effects exacerbated by other factors (natural & anthropogenic climate change)
- Food webs becoming more simplified, less robust to species loss, less stable given perturbations
- However, humans can invade a system and not initiate cascading extinctions/instabilities
- New research agenda: Myriad ways that humans interact with other species over space and time
- Simple vs. complex interactions: technology development & use
- Human use patterns related to ecological & environmental context, innovation & cultural dynamics, modes of production, etc.

Final Thoughts:

- Utility of ecological network approaches
- Humans as ecological actors
- The power of deep time: lessons from the past
- The power of transdisciplinary approaches
- The power of comparative synthesis