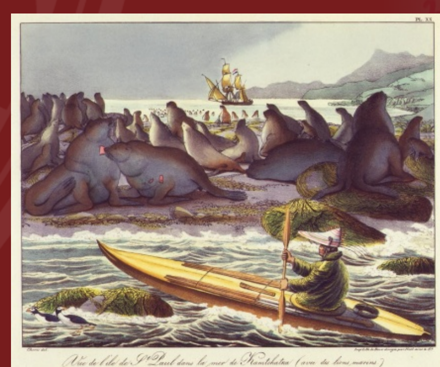
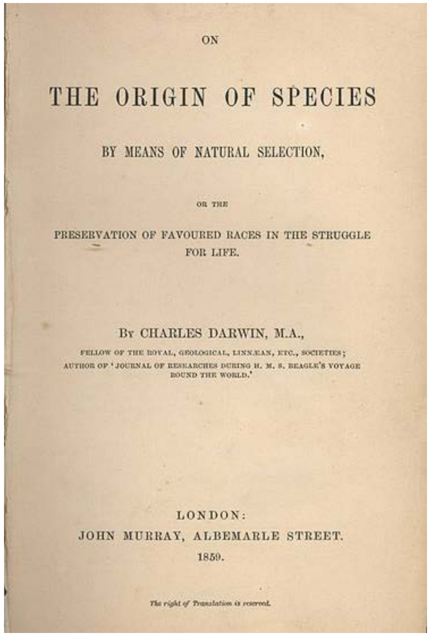
SANTA FE INSTITUTE

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

Jennifer A. Dunne, Santa Fe Institute



Darwin (1859) <u>On The Origin of Species</u>



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.,

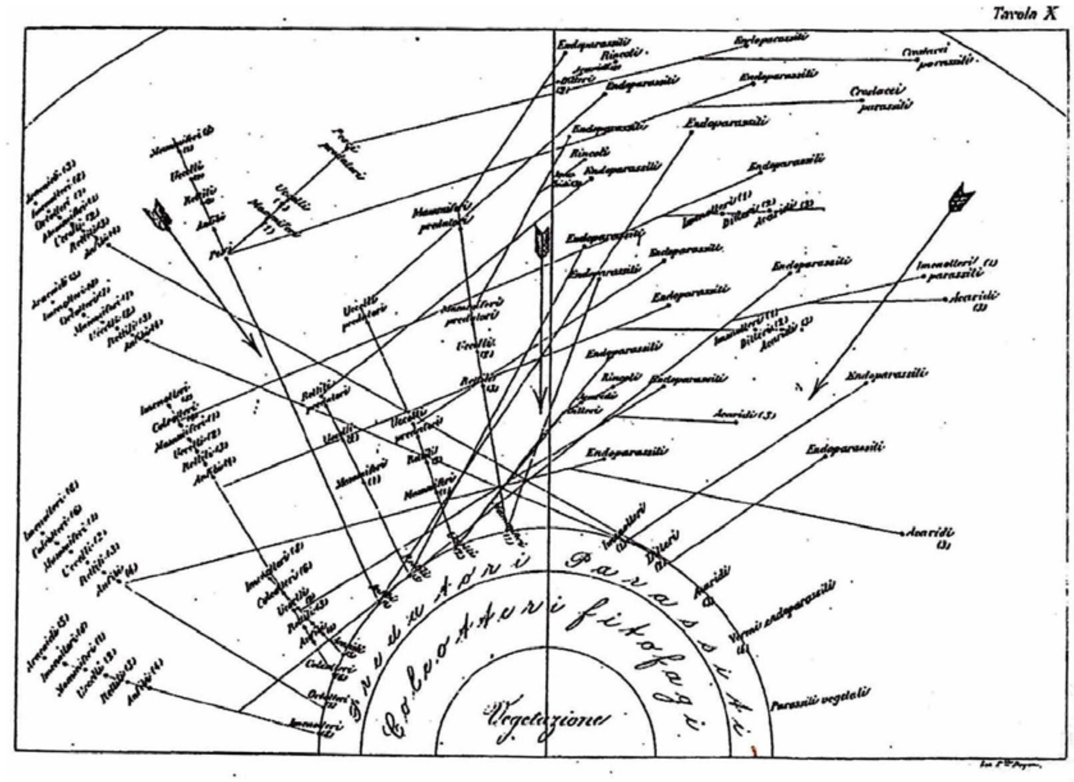
FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

The right of Translation is reserved.

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

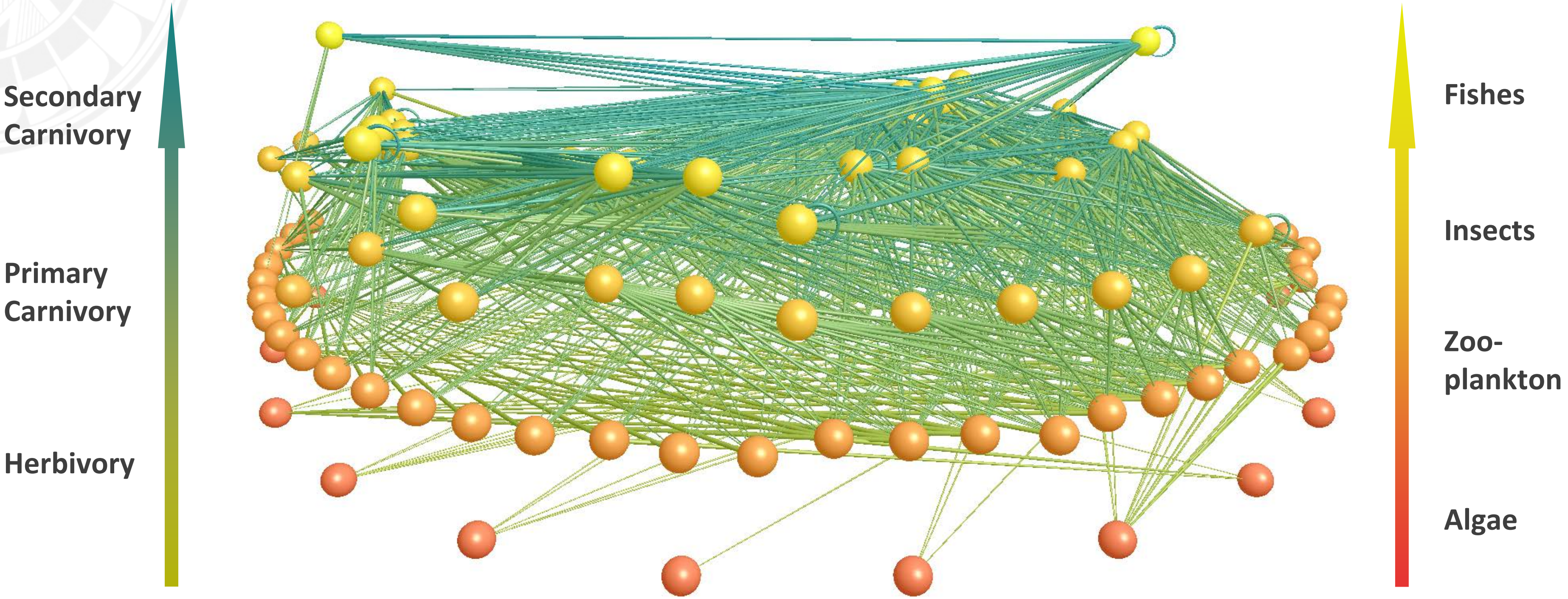


<u>15 taxa:</u>
Plants
Parassitic plants
Worms
Amphibians
Reptiles
Fish
Birds
Mammals
Crustaceans
Spiders
Insects

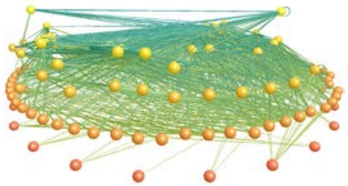
On the equilibrium of living beings by means of reciprocal destruction

Atti della Reale Accademia delle Scienze di Torino

Little Rock Lake, Wisconsin

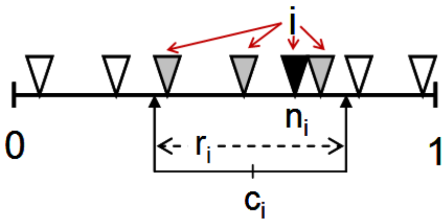


Martinez. 1991. *Ecological Monographs.*
Artifacts or attributes? Effects of resolution on the Little Rock Lake food web.



• Ecological Network Structure

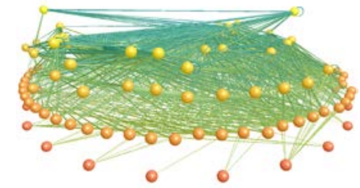
The Niche Model



Nature 2000

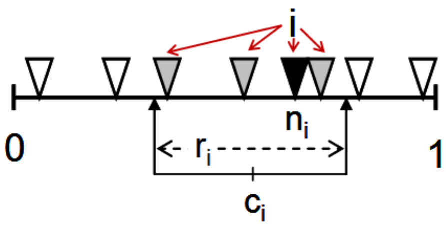
Simple rules yield complex food webs

Richard J. Williams & Neo D. Martinez



- **Ecological Network Structure**

The Niche Model



Nature 2000

Simple rules yield complex food webs

Richard J. Williams & Neo D. Martinez

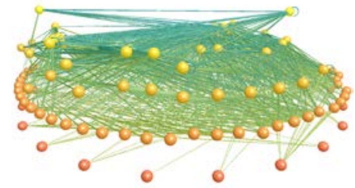
- **Complex Trophic Dynamics**

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

LETTER

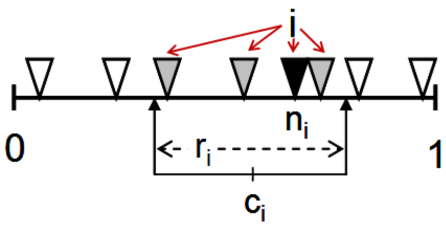
Mechanistic theory and modelling of complex food-web dynamics in Lake Constance

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]

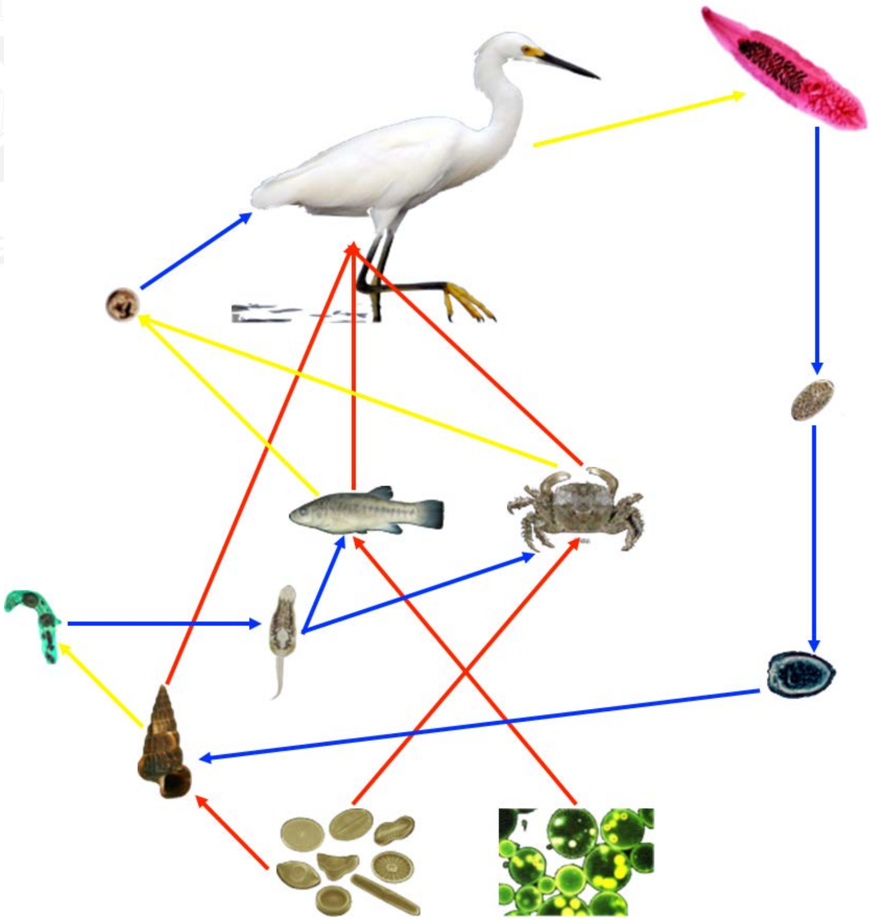
Ecology Letters, (2006) 9: 1228–1236 doi: 10.1111/j.1461-0248.2006.00978.x

LETTER

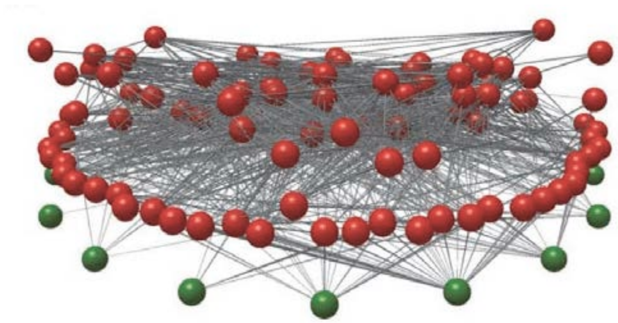
Allometric scaling enhances stability in complex food webs

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

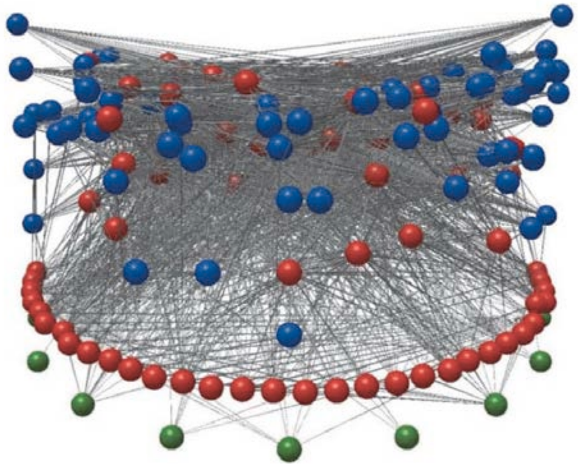
PARASITES



Food Web without Parasites

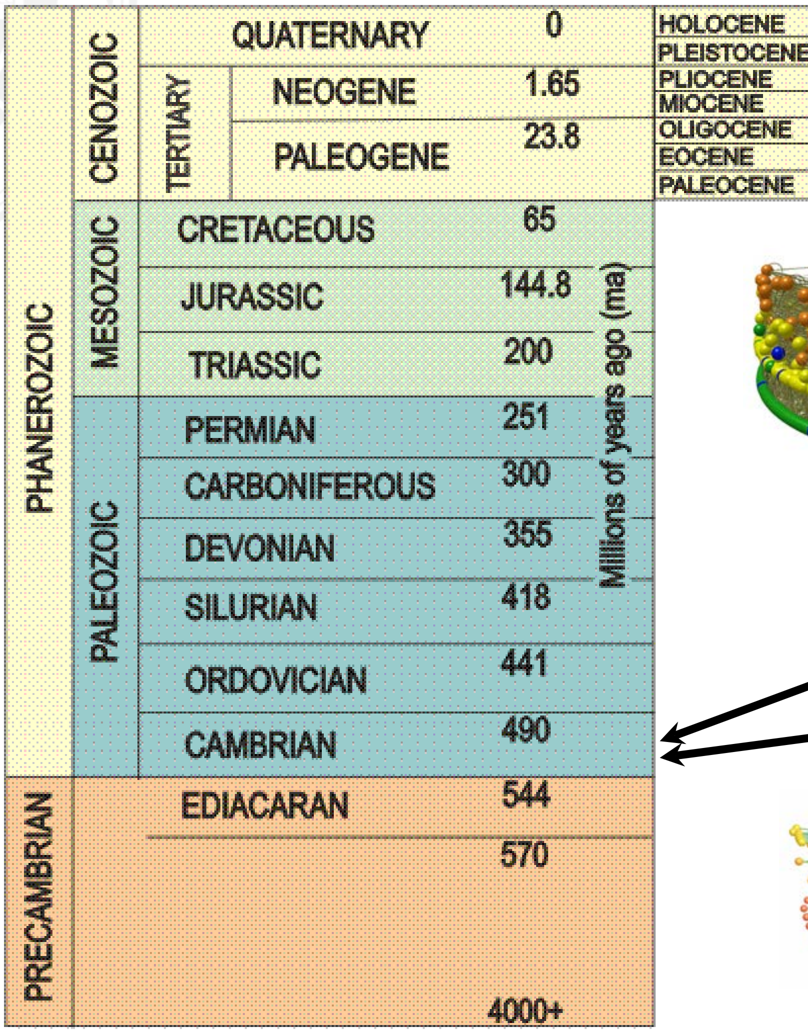


Food Web with Parasites

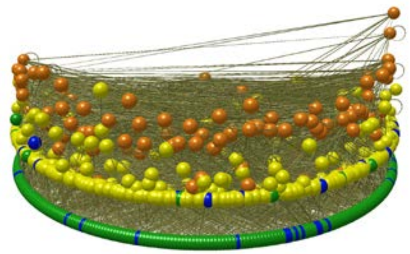


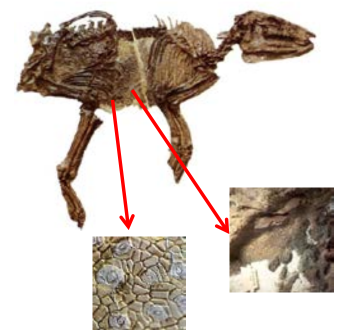
DEEP TIME

Geologic Time Scale



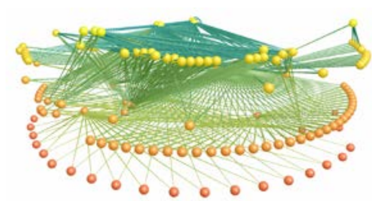
Messel Shale (48 Ma)



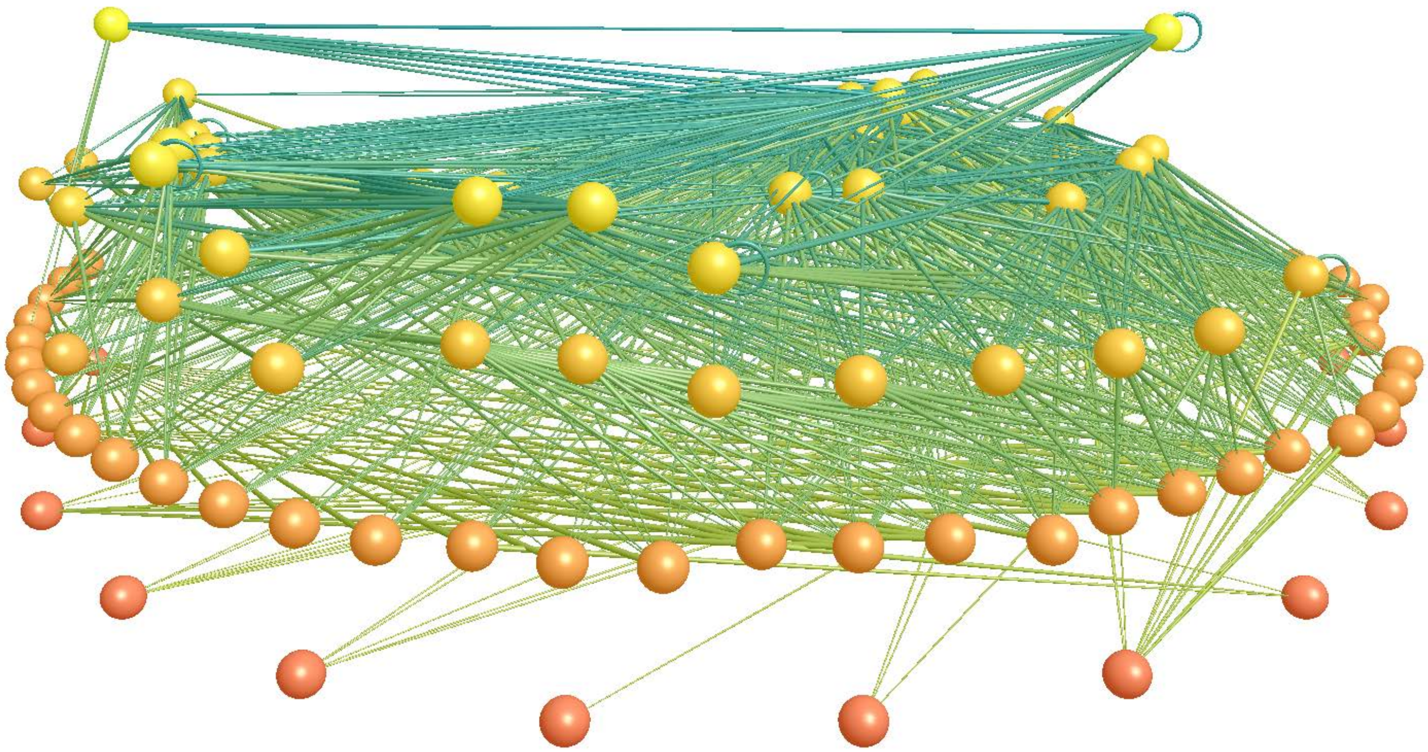


Burgess Shale (505 Ma)

Chengjiang Shale (520 Ma)

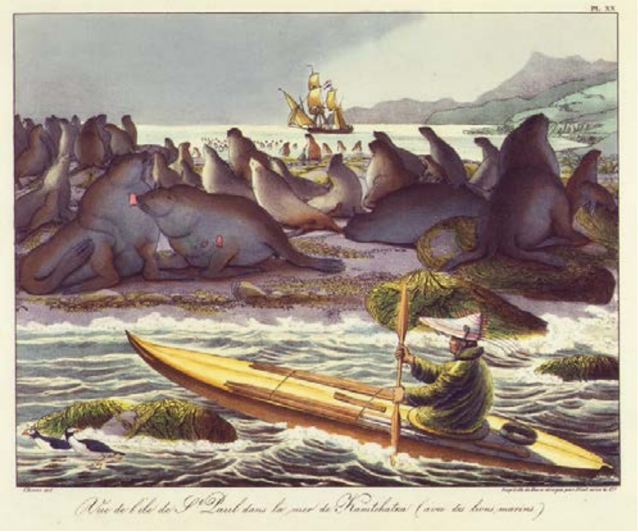


What about *Homo sapiens?*



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

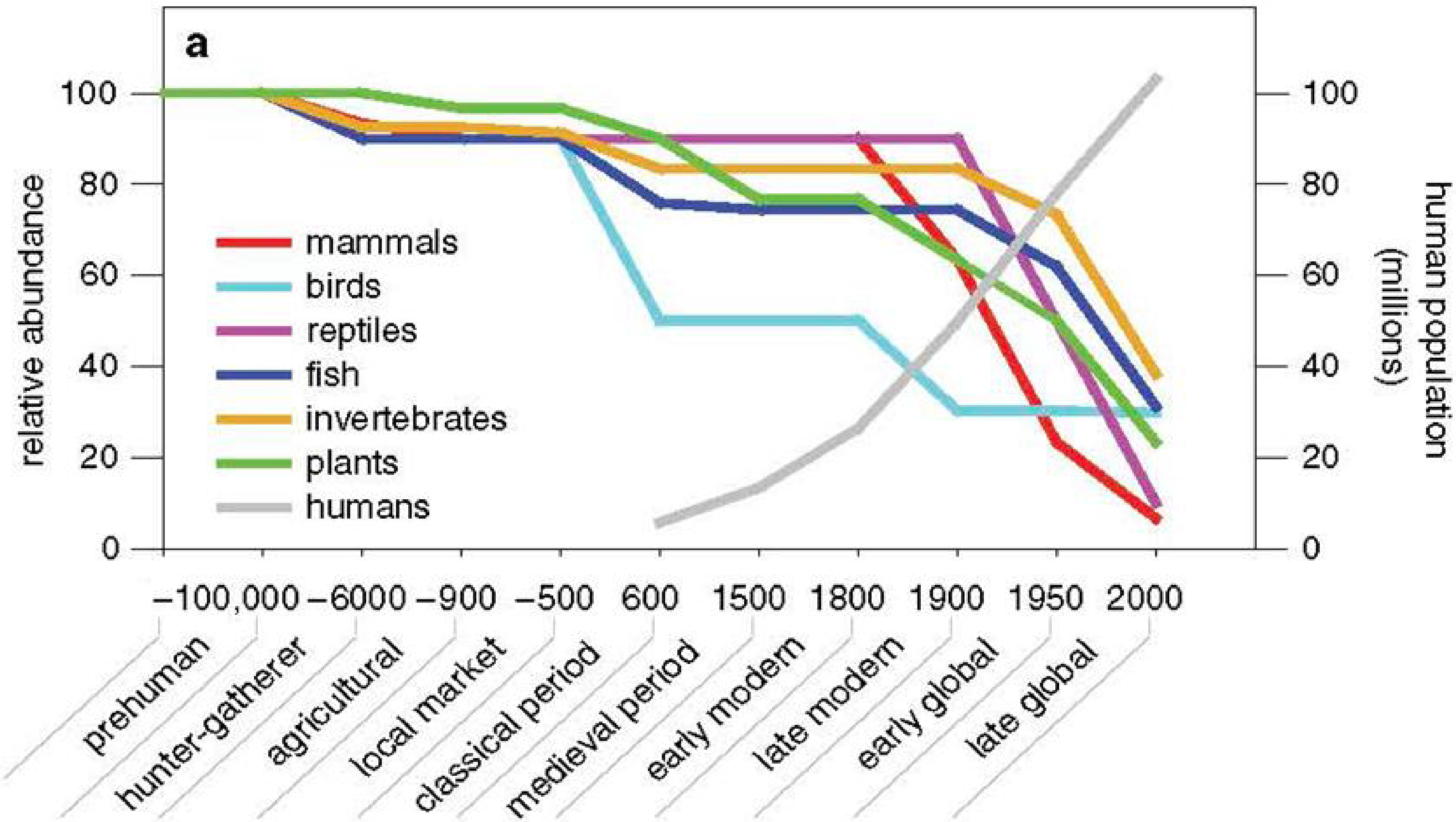
ECOSYSTEMS

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

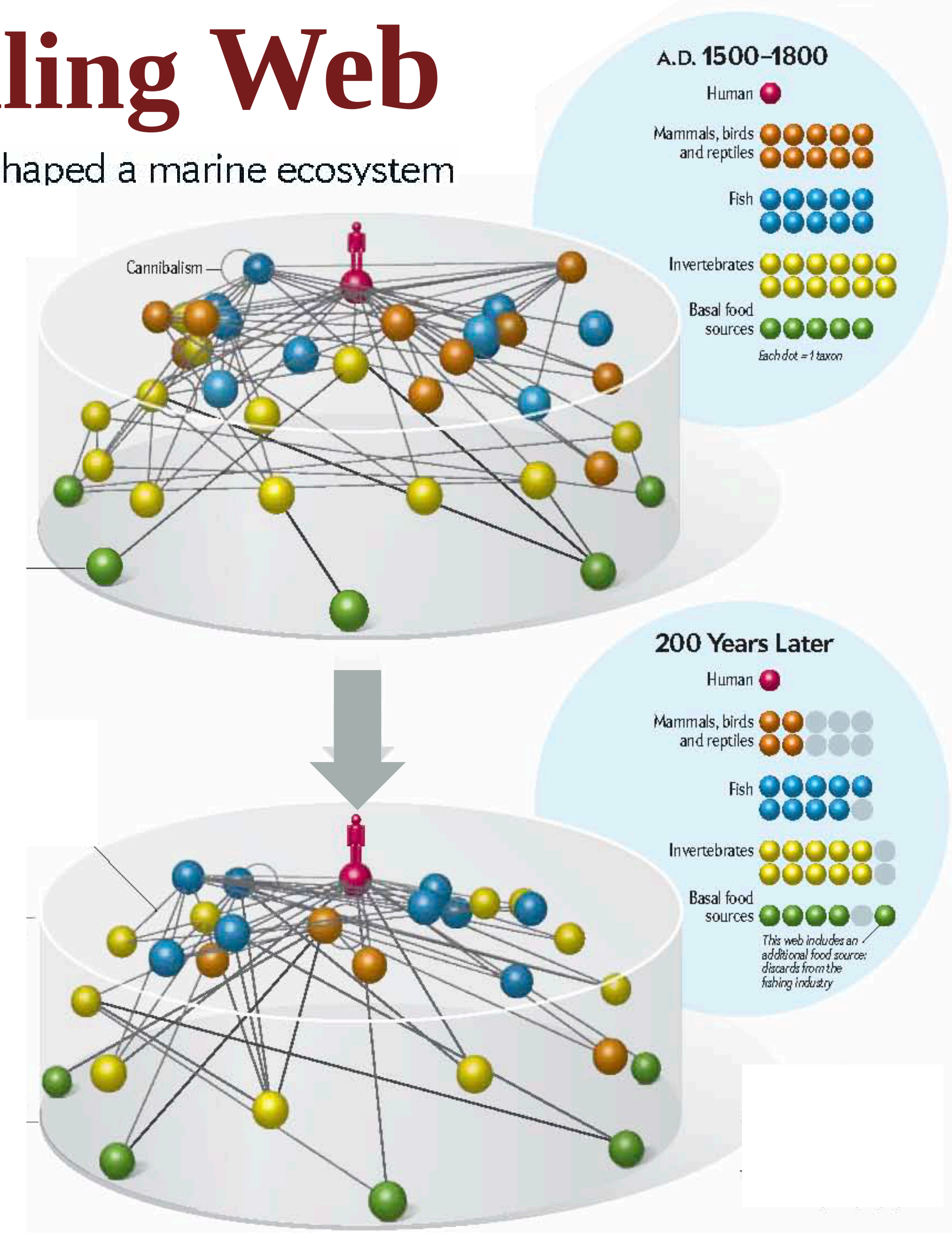
How human exploitation has reshaped a marine ecosystem

Early Model

25% Taxa ↓

Robustness ↓

Late Global



Scientific American 2012

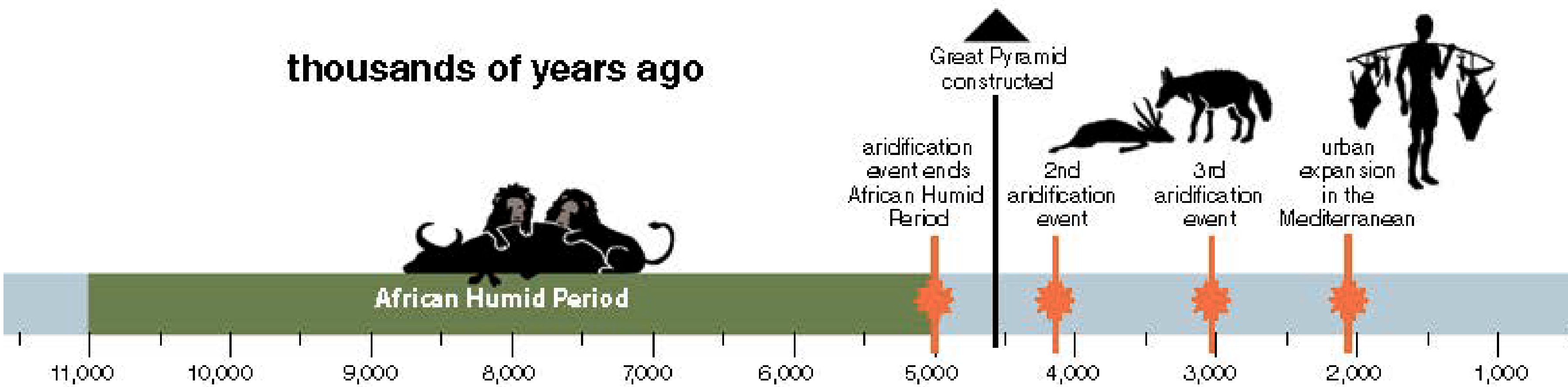
Collapse of an ecological network in Ancient Egypt

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

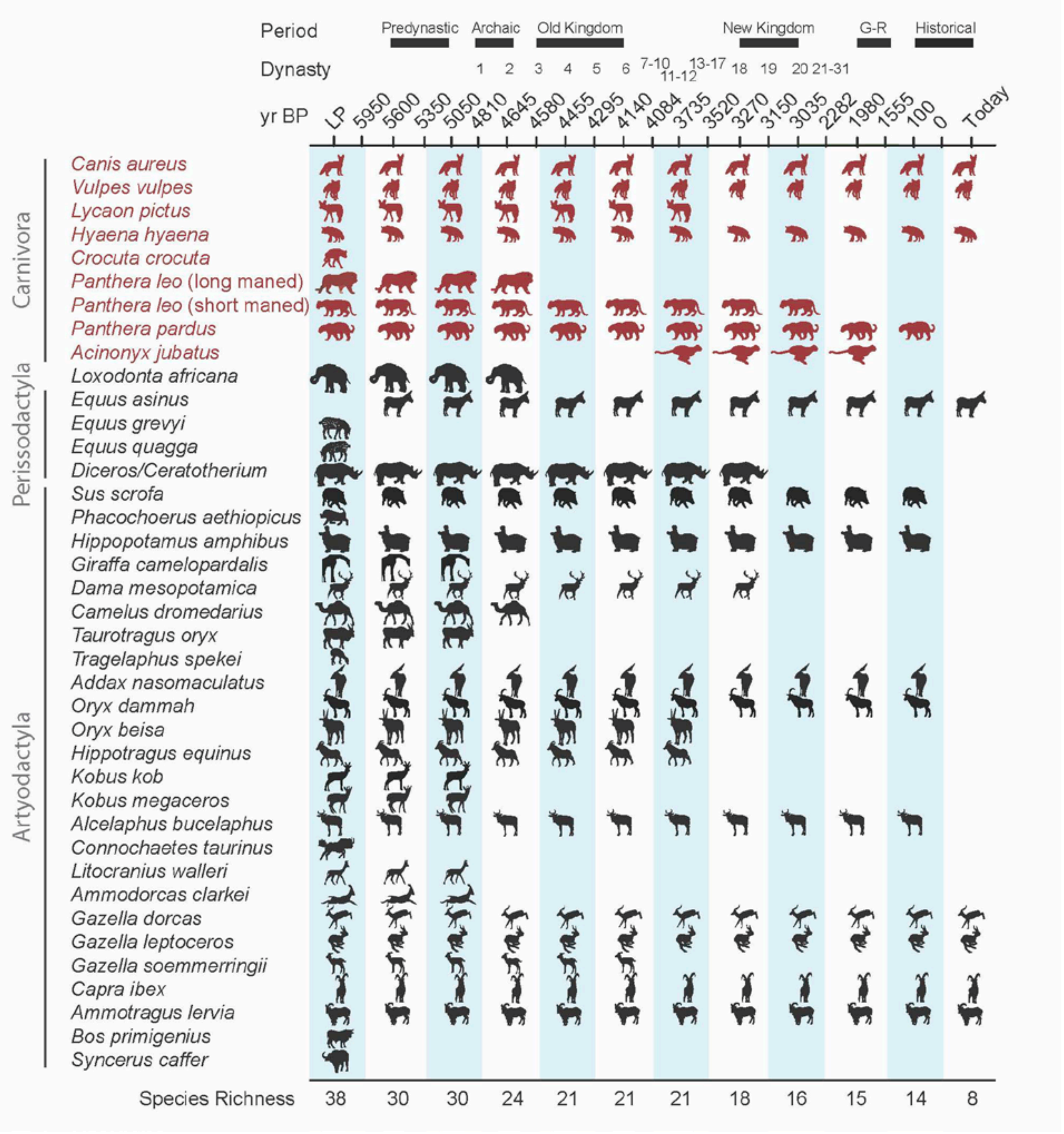
Edited by Justin S. Brashares, University of California, Berkeley, CA, and accepted by the Editorial Board August 11, 2014 (received for review May 8, 2014)

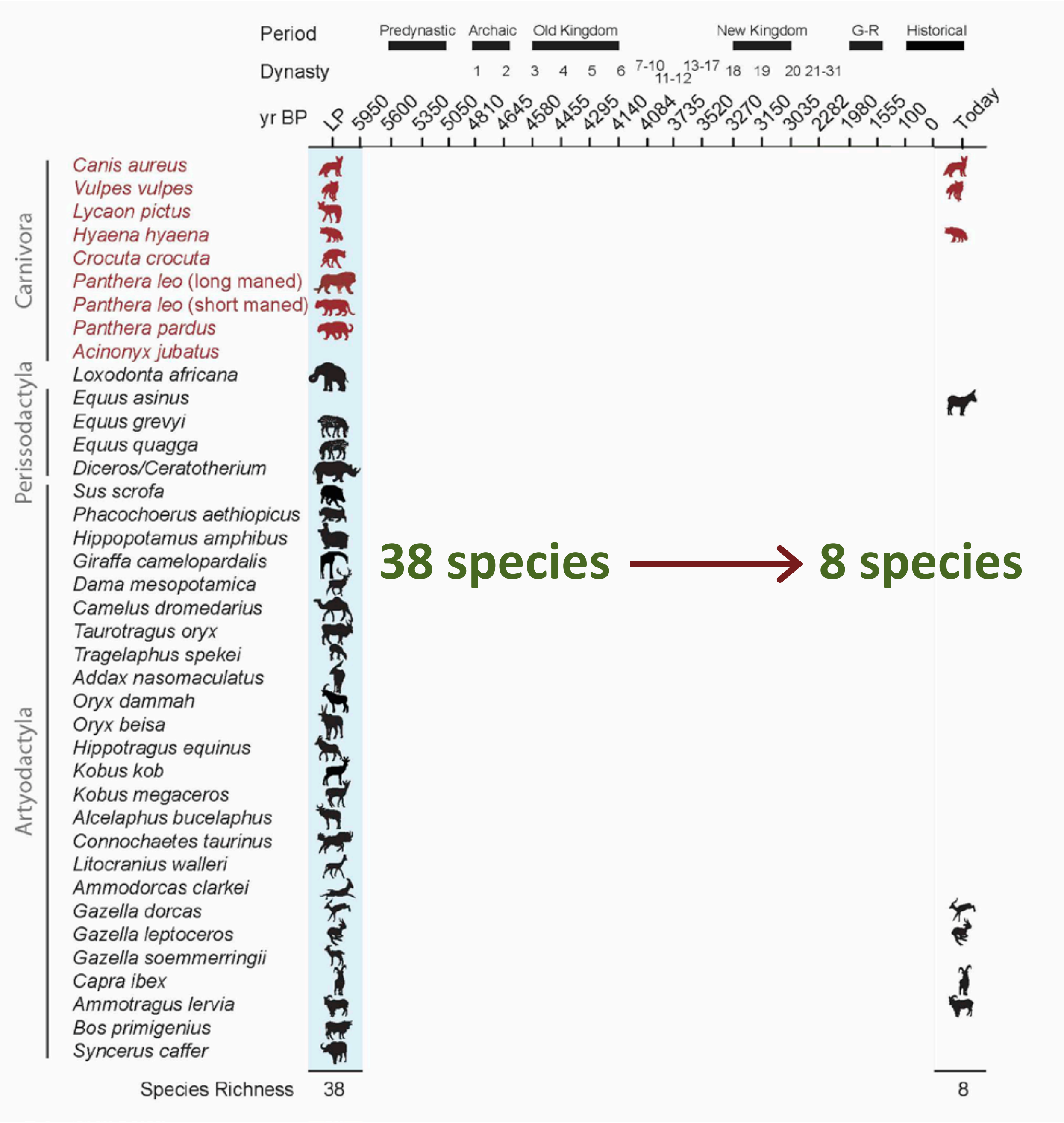
Timeline of Egypt



Panel from Tutankhamun's Painted Box: 3000 yrs old

Hierakonpolis Palette: 5150 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
Canis aureus
Vulpes vulpes
Lycaon pictus
Hyaena hyaena
Crocuta crocuta
Panthera leo (long maned)
Panthera leo (short maned)
Panthera pardus
Acinonyx jubatus
Perissodactyla
Loxodonta africana
Equus asinus
Equus grevyi
Equus quagga
Diceros/Ceratotherium
Artyodactyla
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



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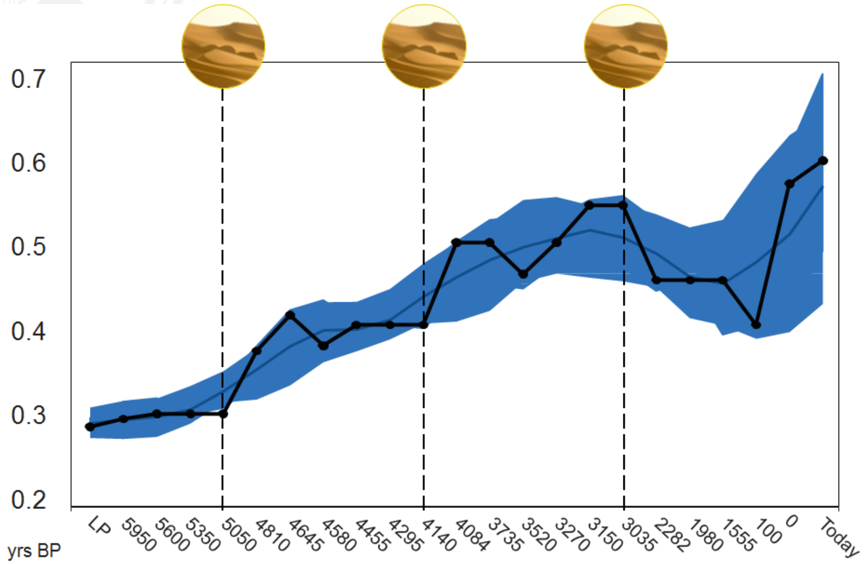
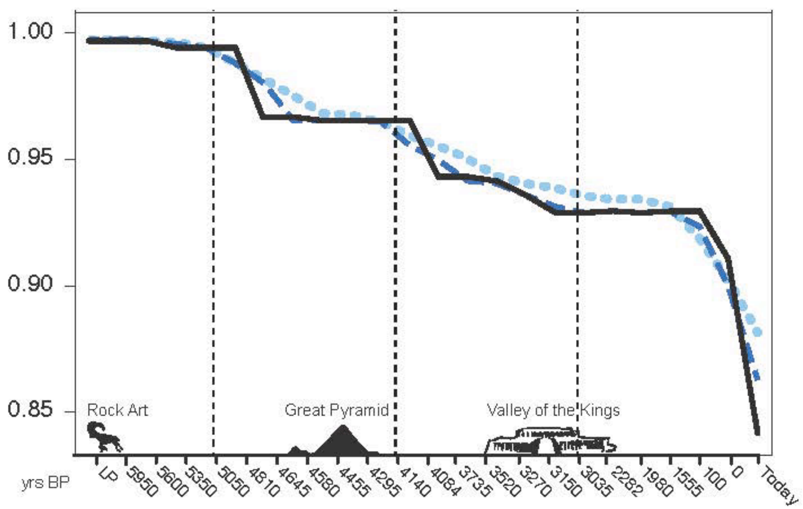
Addax nasomaculatus
Oryx dammah
Oryx beisa
Hippotragus equinus
Kobus kob
Kobus megaceros
Alcelaphus bucelaphus
Connochaetes taurinus
Litocranius walleri
Ammodorcas clarkei
Gazella dorcas
Gazella leptoceros
Gazella soemmerringii
Capra ibex
Ammotragus lervia
Bos primigenius
Syncerus caffer
Species Richness 38 8
38 species
8 species

Increasing Predator-Prey Ratio Through Time



Fewer Dynamically Stable Food Webs Through Time

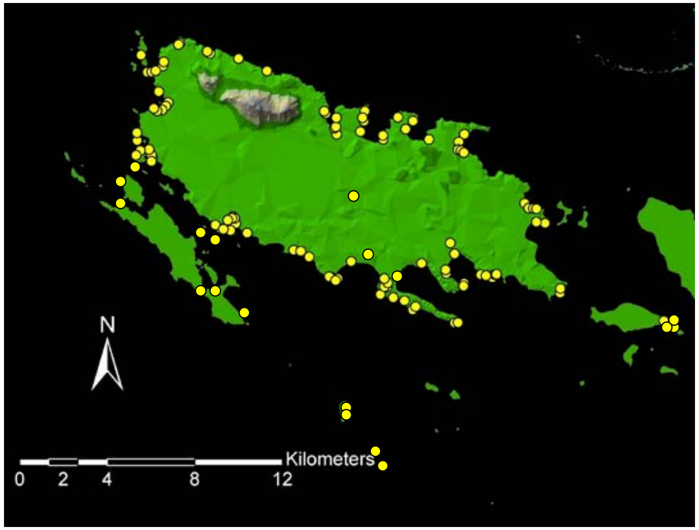


II. Humans Roles in Food Webs

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

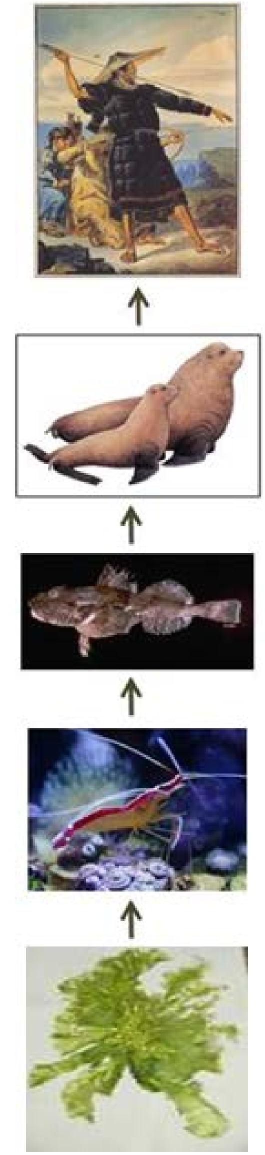
- What roles did pre-industrial humans play in North Pacific food webs?
- How did human foragers compare to other species?
- What can we learn about sustainability from how humans interacted with and impacted other species?

The Sanak Archipelago

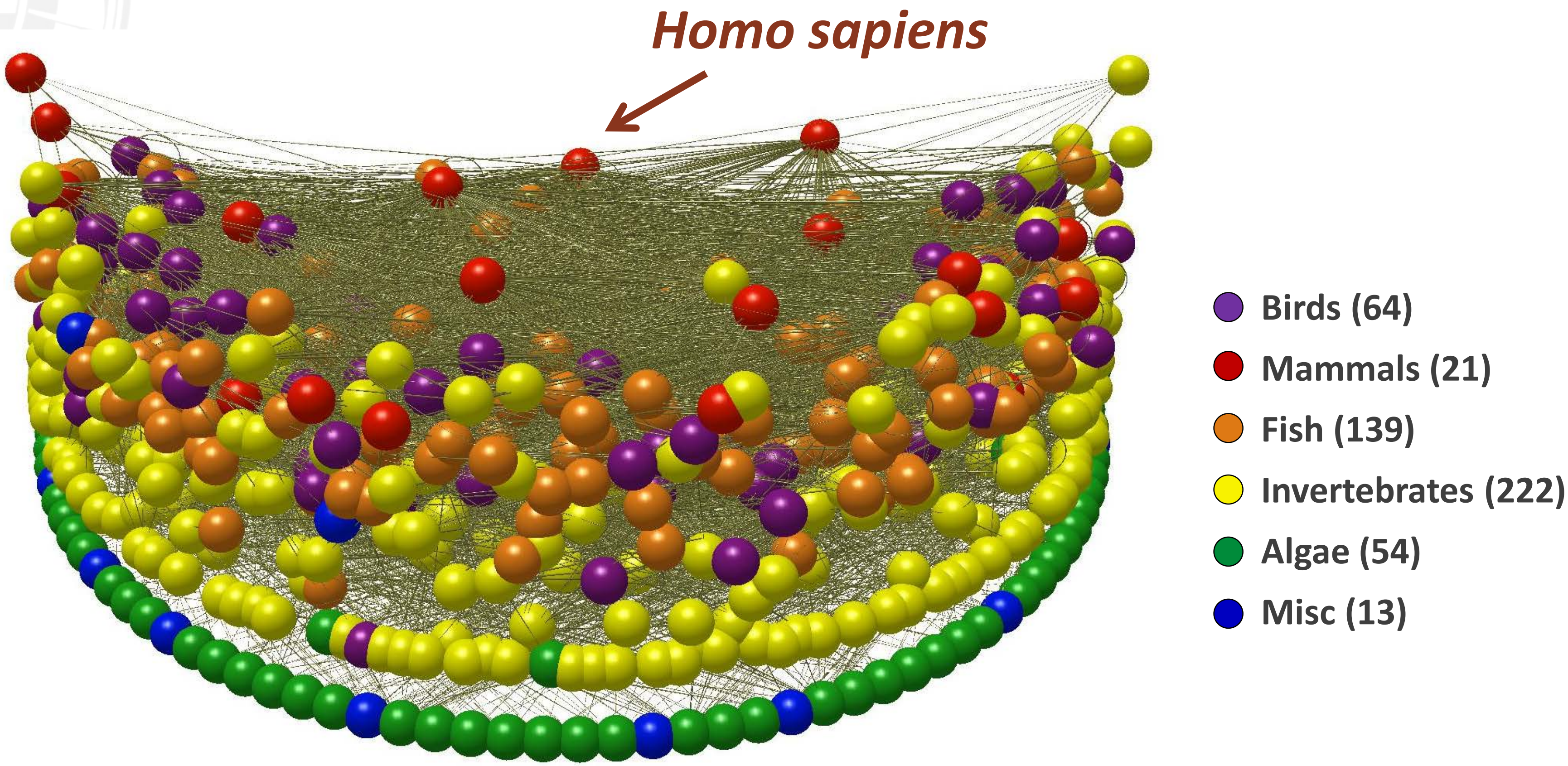


- **Far-eastern end of Aleutian archipelago**
- **Ice-free for 16,000 yrs**
- **6,000 yr human record, 128 known sites**
- **Integrate archeological, ecological & climatic data**

Human Trophic Roles: Network Structure

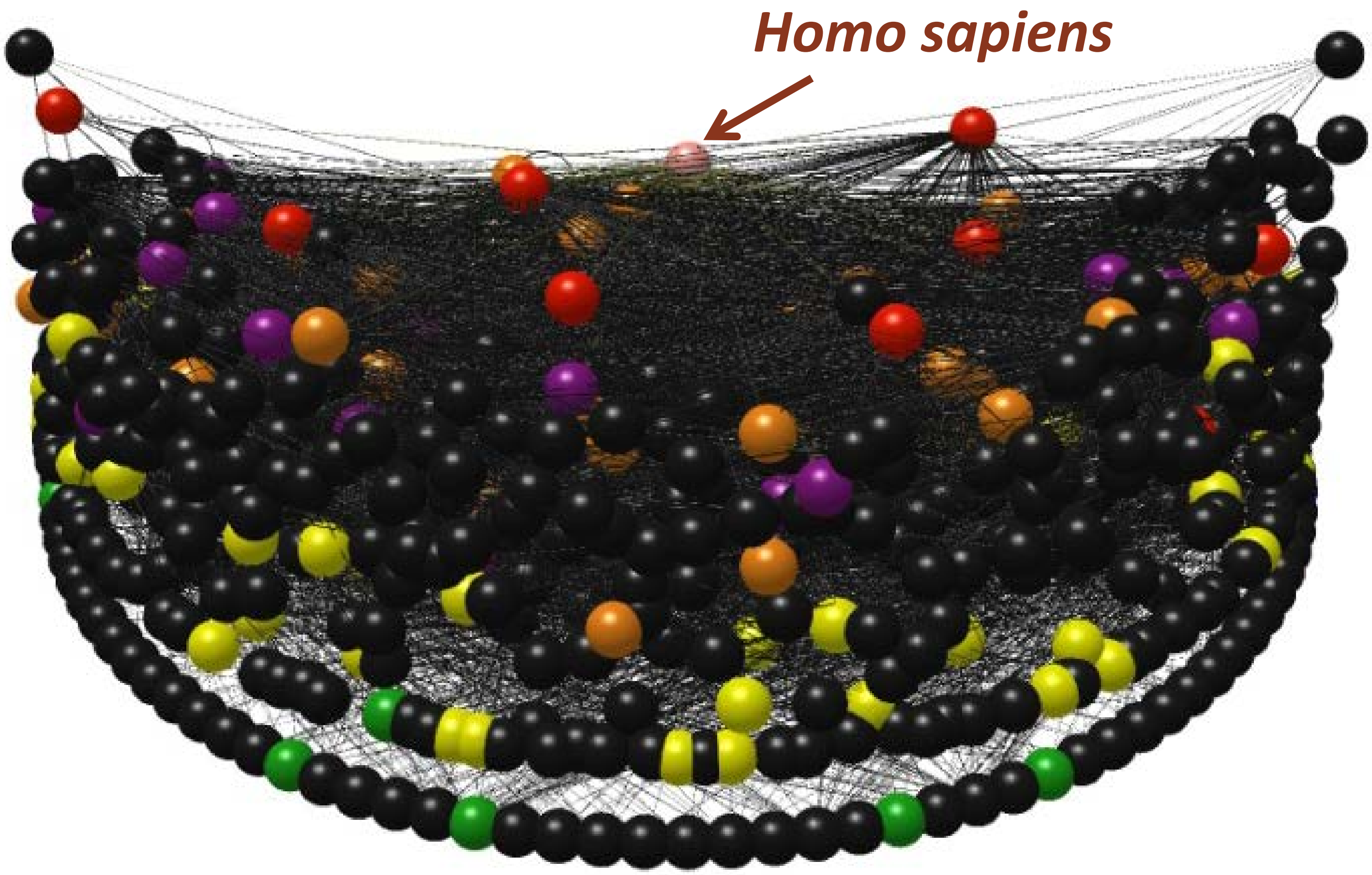


Sanak Nearshore Marine Food Web

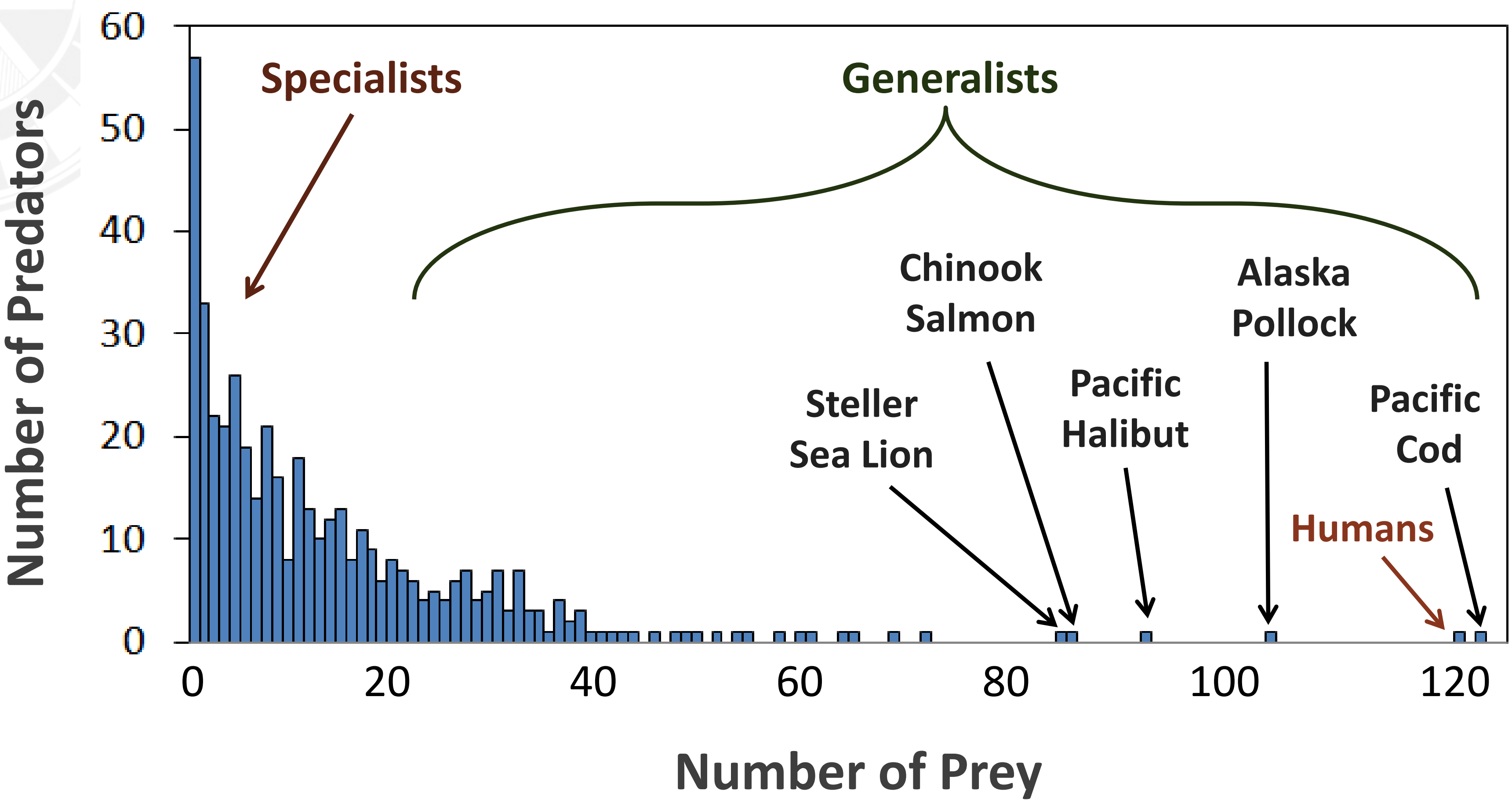


513 taxa, 6774 feeding links, 13 links per species

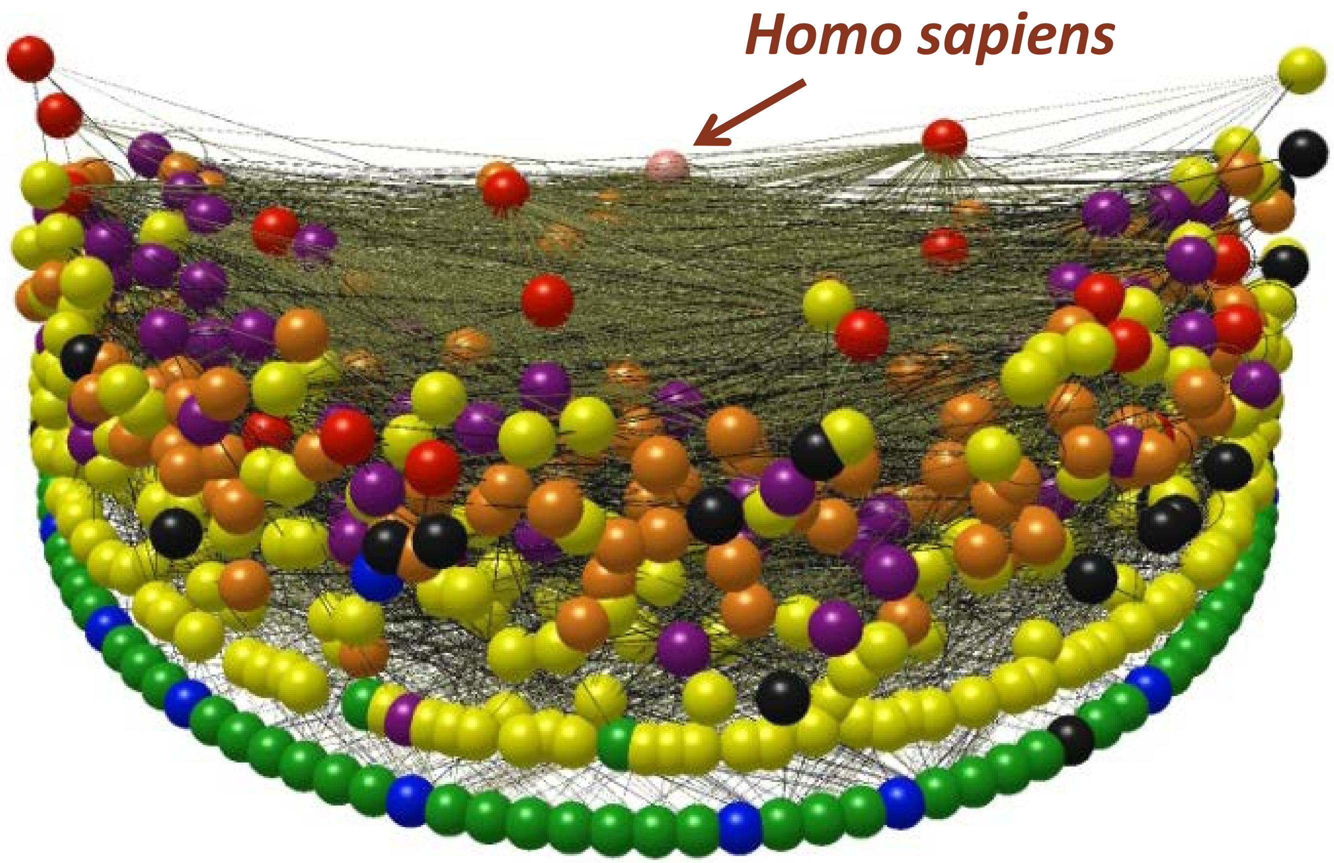
Humans Fed on 122 Taxa (24%)



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?

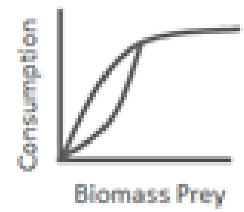
Changes in species biomasses:

- 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



Functional Response

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

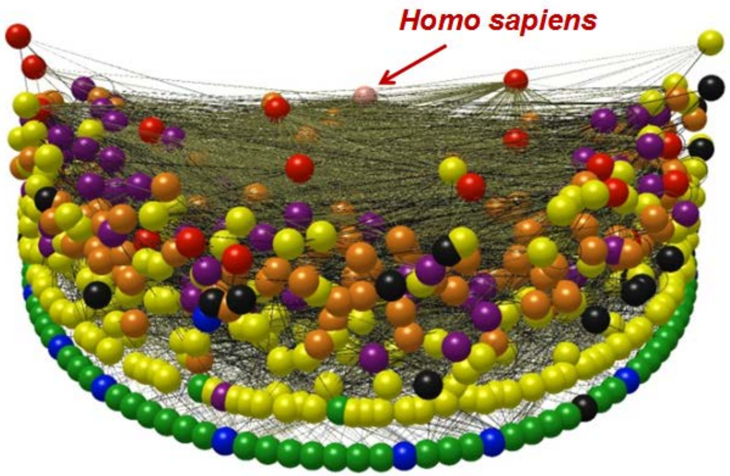
assimilation efficiency

max metabolic-specific ingestion rate

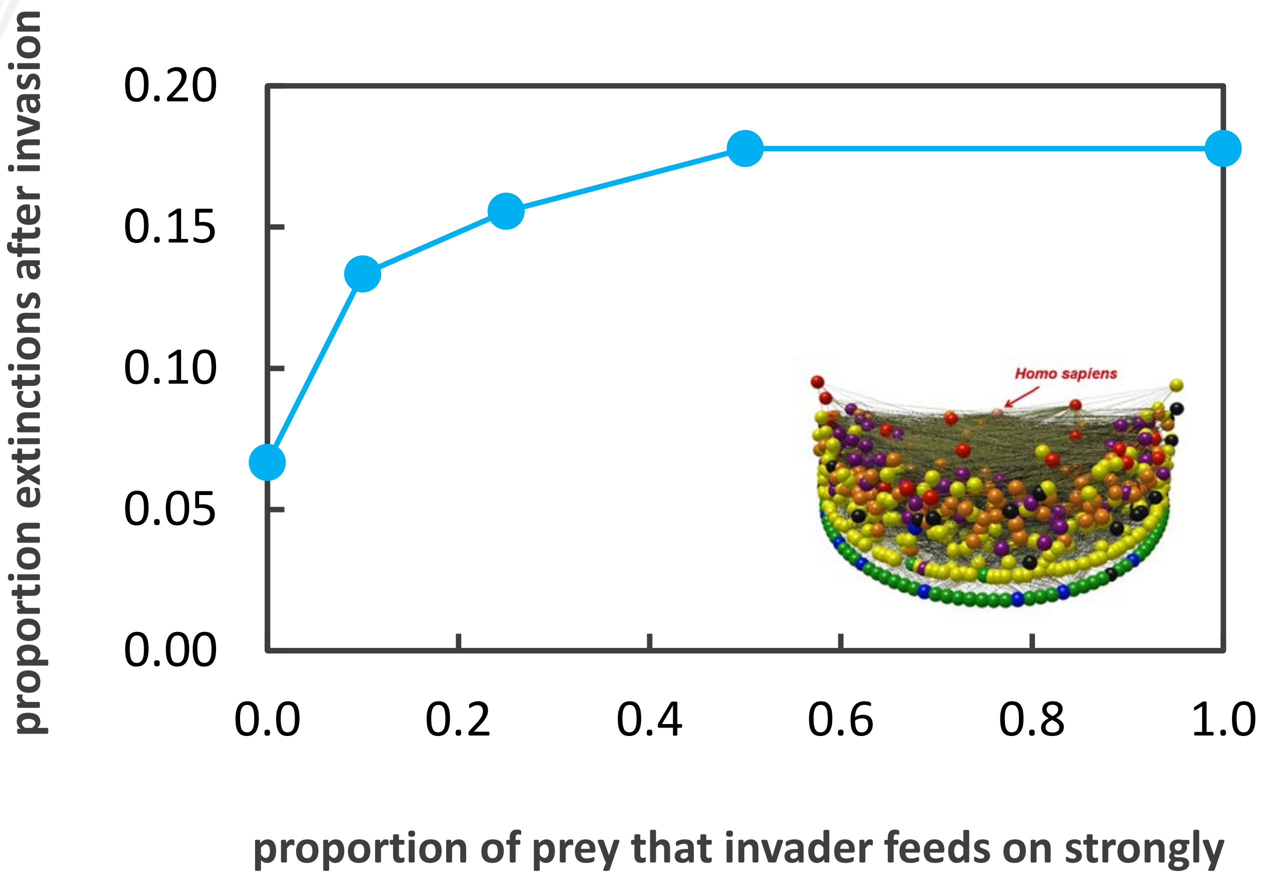
An *in silico* Experiment:

Impact of invasion by human-like taxon on ecological persistence

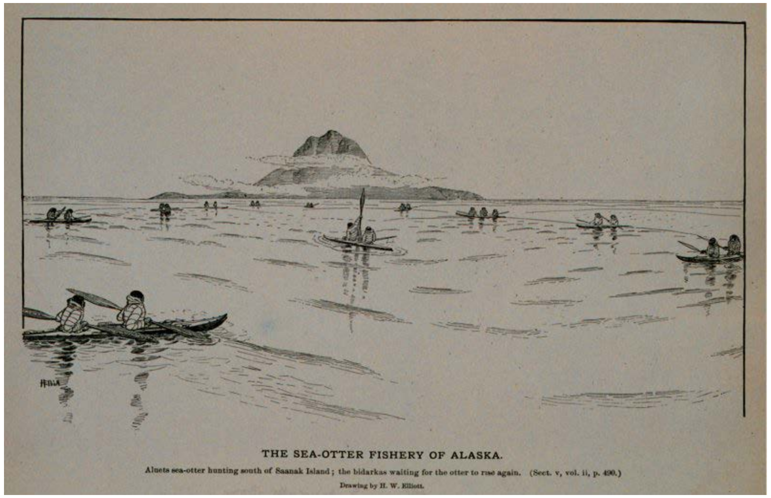
- Create a "zoo" of dynamically persistent model food webs
- Include prey-switching by generalist species
- Invade each web with an omnivorous super-generalist species
- Hunting tech: vary fraction of invader's links that are strong
- How many extinctions follow?



Impact of Human Invader on Extinctions



Sanak Archipelago, Aleutian Islands, Alaska



Aleuts hunting sea otter south of Sanak Island, 1870s (H.W. Elliott)

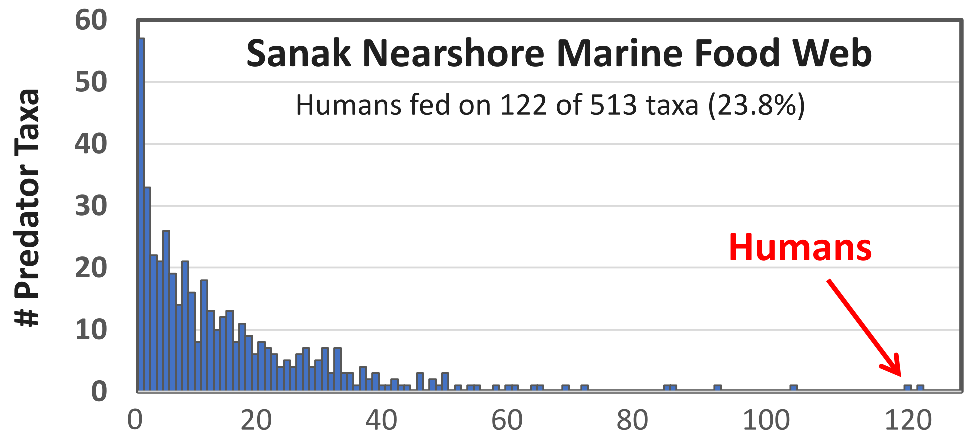
Western Desert of Australia

Martu elder ranger Rita Cutter performing 'right way' fire burn (Photo: Annette Ruzicka)

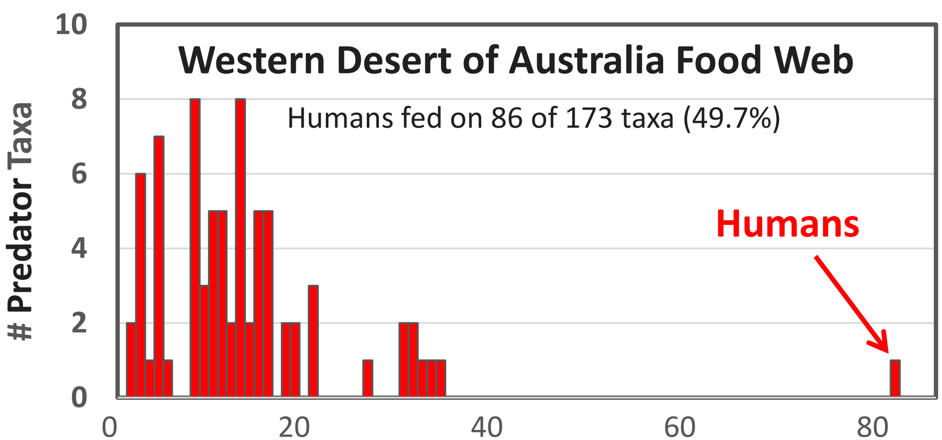
Tagus Estuary, Portugal

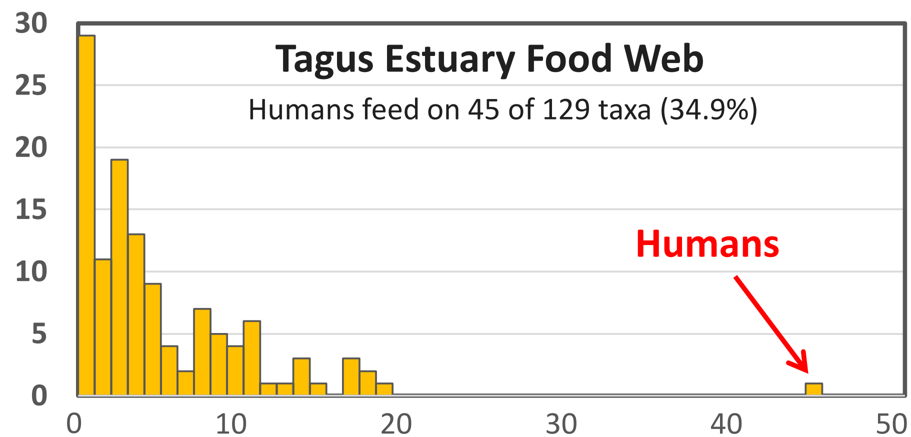
From: *Keeping afloat—Fishing in the Tagus Estuary* (M. Corte-Real, 2017)

Humans are Super-Generalists



Dunne et al. 2016
Scientific Reports



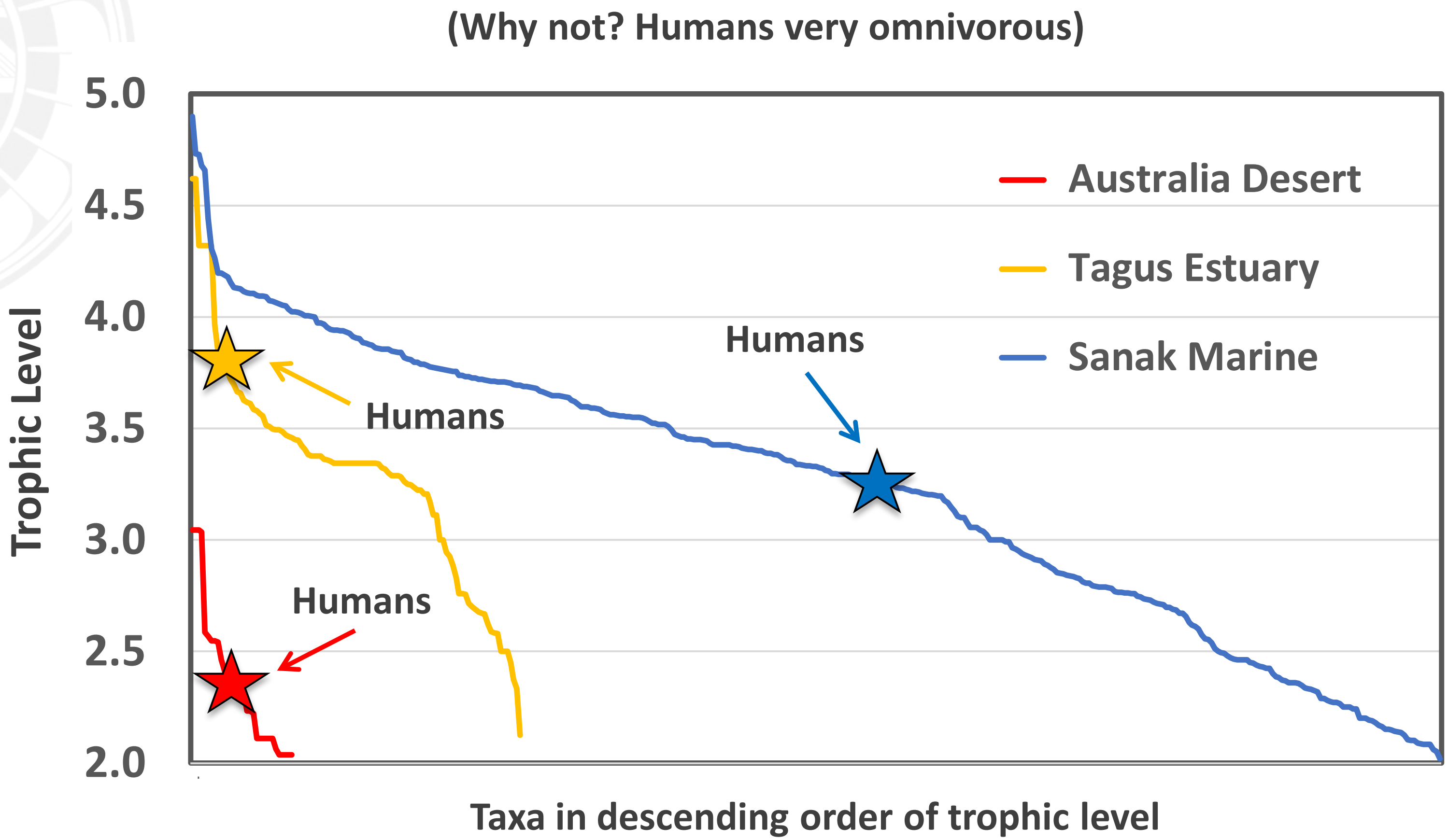


Crabtree *et al.* 2019
Human Ecology

 # Prey Taxa per Predator

Vinagre *et al.*
In review. *MEPS*

Humans NOT at Top of Food Webs

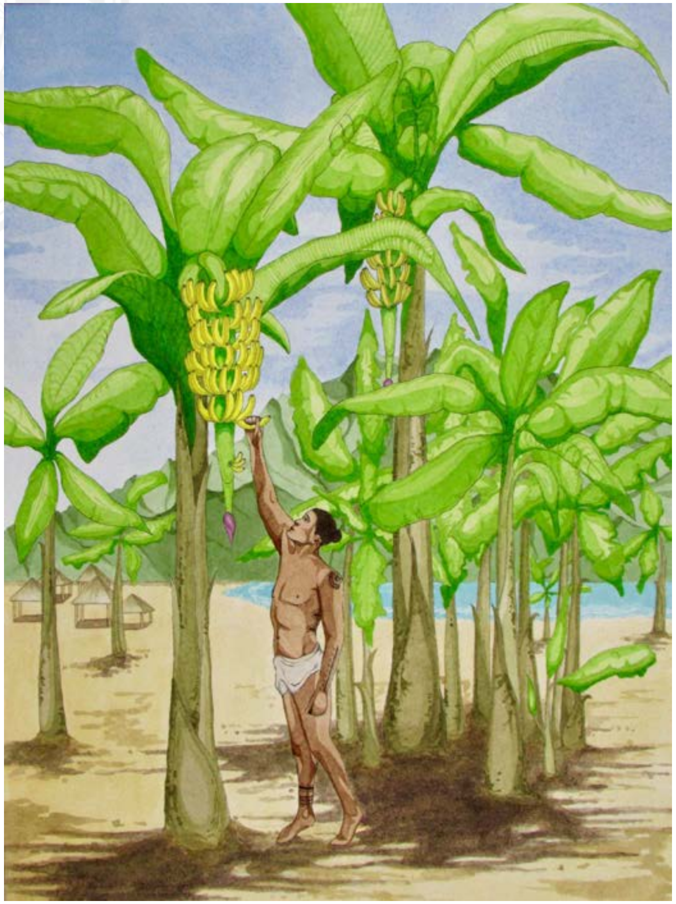


Notes:

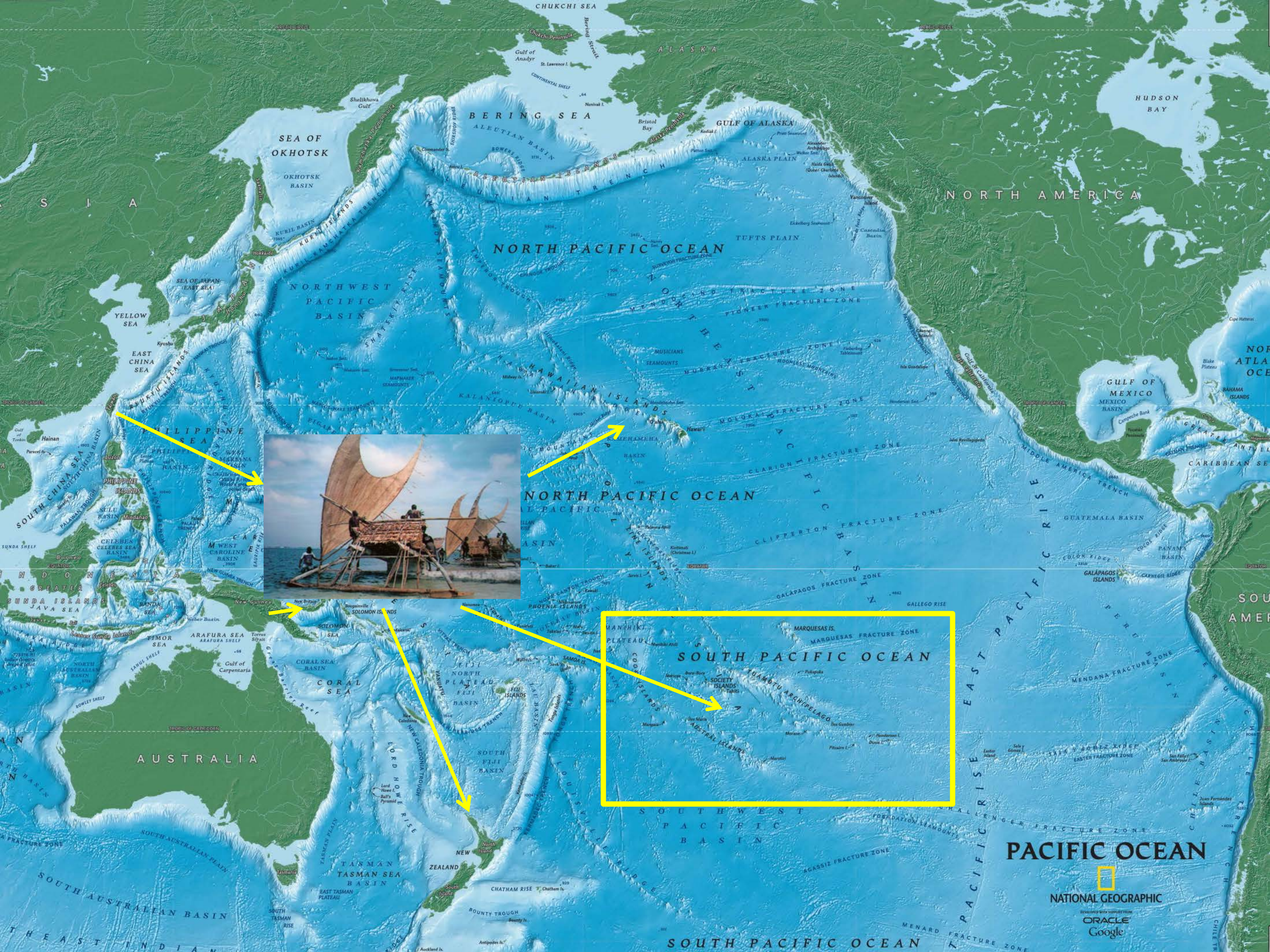
- Taxa with TL > 2 shown
- Primary producers have TL = 1
- Strict herbivores have TL = 2

System	*Human TL*	*Rank*	*TL>2*	*Taxa*
Australia Desert	2.36	13	32	173
Tagus Estuary	3.84	9	103	129
Sanak Marine	3.26	214	389	513

III. Beyond Trophic Interactions



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


CHUKCHI SEA
ALASKA
BERING SEA
SEA OF OKHOTSK
OKHOTSK BASIN
GULF OF ALASKA
ALASKA PLAIN
HUDSON BAY
NORTH AMERICA
ASIA
NORTH PACIFIC OCEAN
TUFTS PLAIN
NORTHWEST PACIFIC BASIN
SEA OF JAPAN (EAST SEA)
YELLOW SEA
EAST CHINA SEA
PHILIPPINE SEA
HAWAIIAN ISLANDS
GULF OF MEXICO
CARIBBEAN SEA
NORTH PACIFIC OCEAN
GUATEMALA BASIN
MARQUESAS IS.
SOUTH PACIFIC OCEAN
SOCIETY ISLANDS
TUAMOTU ARCHIPELAGO
AUSTRAL ISLANDS
EAST PACIFIC RISE
CORAL SEA
AUSTRALIA
TASMAN SEA
NEW ZEALAND
SOUTHWEST PACIFIC BASIN
SOUTH AUSTRALIAN BASIN
SOUTH PACIFIC OCEAN
PACIFIC OCEAN
NATIONAL GEOGRAPHIC
ORACLE
Google







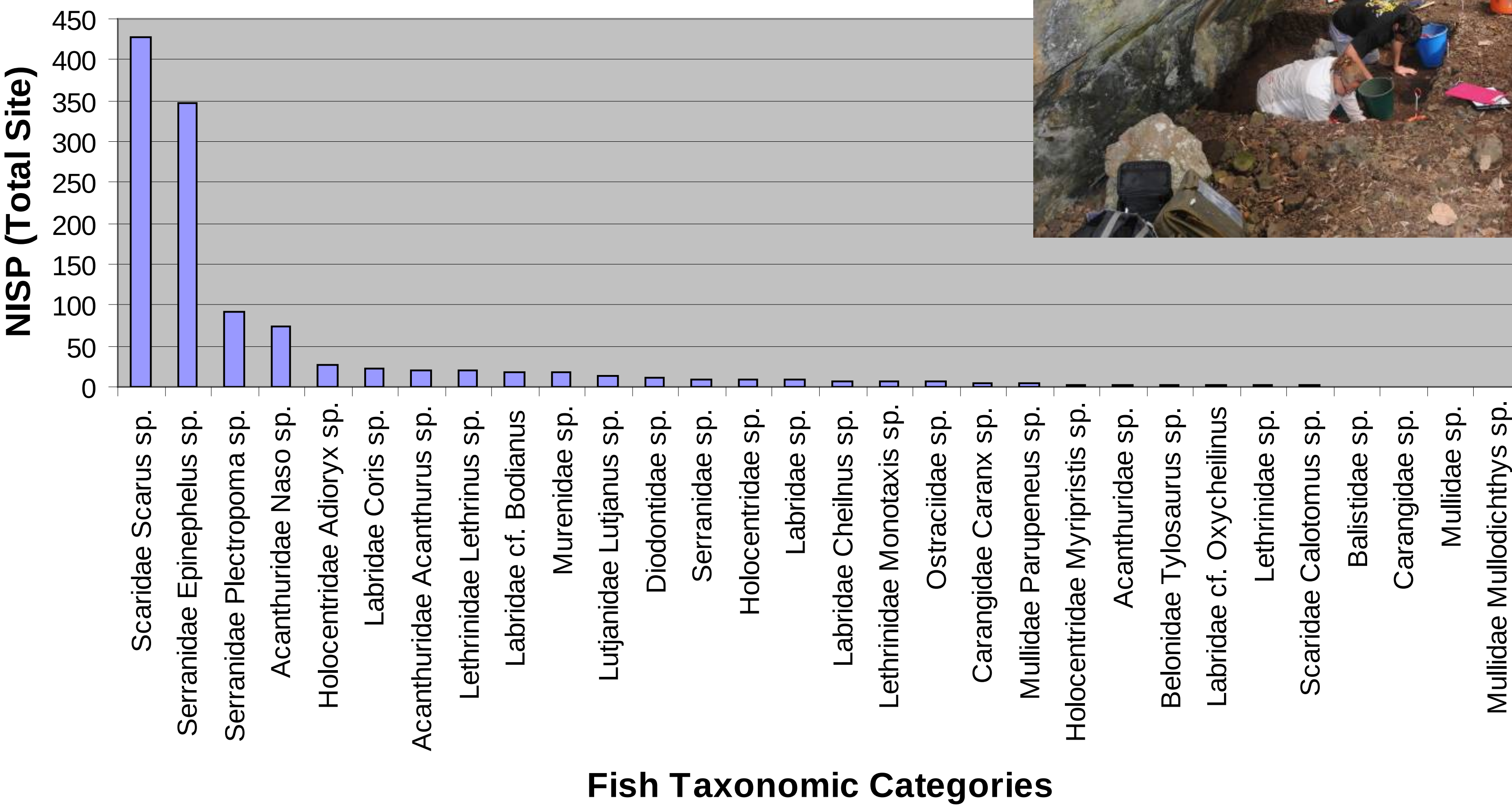




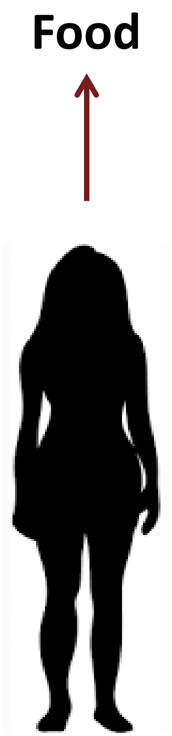




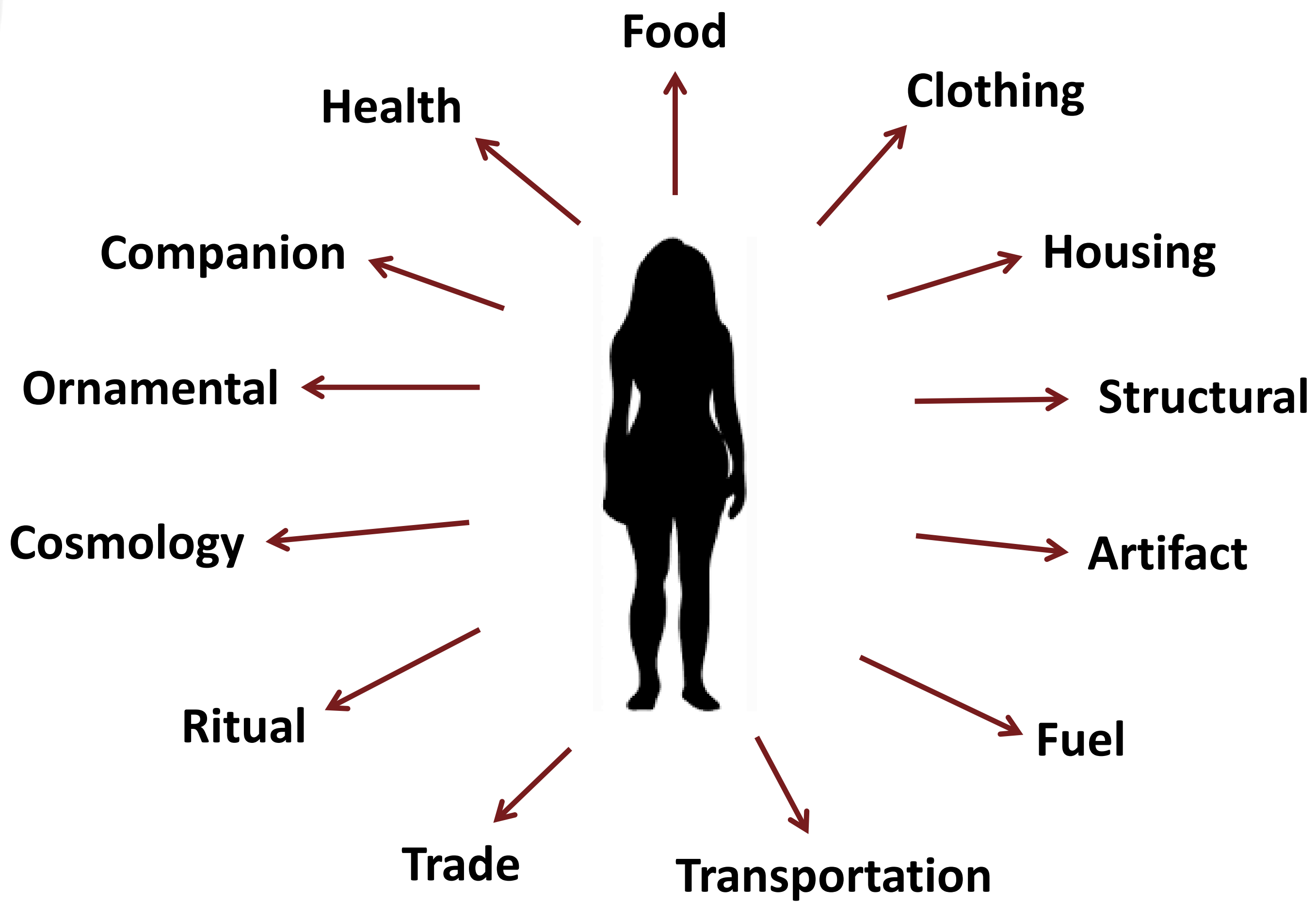

The Nenega-Iti Rockshelter



Human Interactions with Other Species



Human Interactions with Other Species



The ArchaeoEcology Project (TAEP)

How human interactions with biodiversity are shaped by, and have impacts on:

- **Ecology**

  Habitats, species richness, types of taxa, interactions

- **Environment**

  Climate, geography, soils, age

- **Culture**

  Modes of production, social organization, norms & taboos, technology & innovation

Lessons from the Past for Sustainability of the Future

Primary Co-Conspirators: Stefani Crabtree, Spencer Wood

Northwest Coast, North America

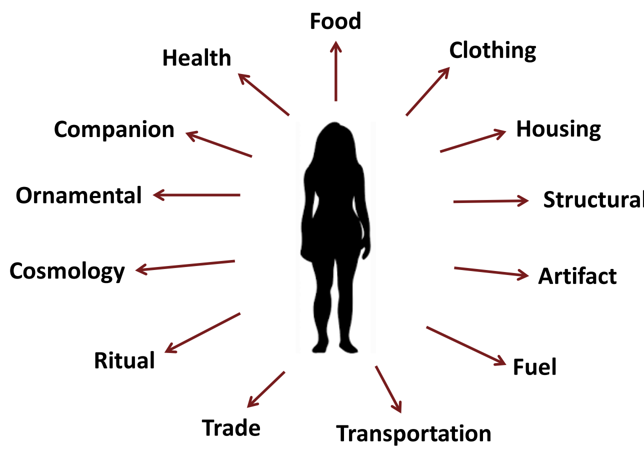
Nuu-chah-nulth people

Western Desert of Australia

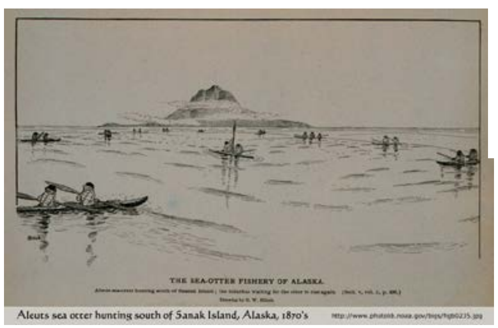
Martu people

North Atlantic Islands

Norse culture



French Polynesia



Polynesians

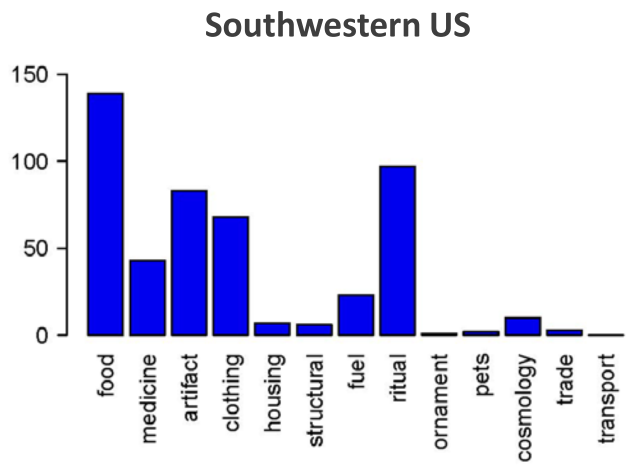
North Central Europe

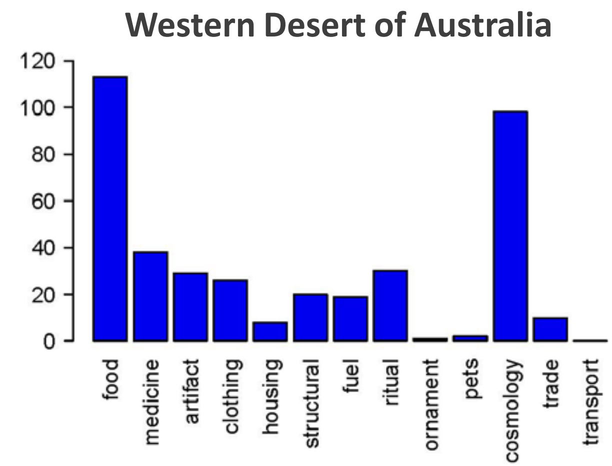
Swifterbant culture

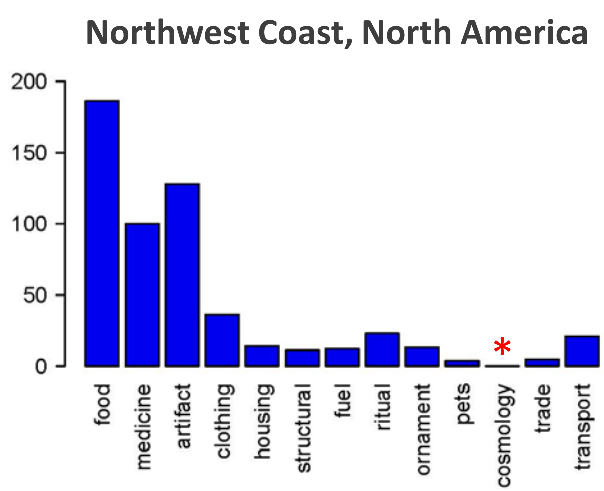
Southwestern United States

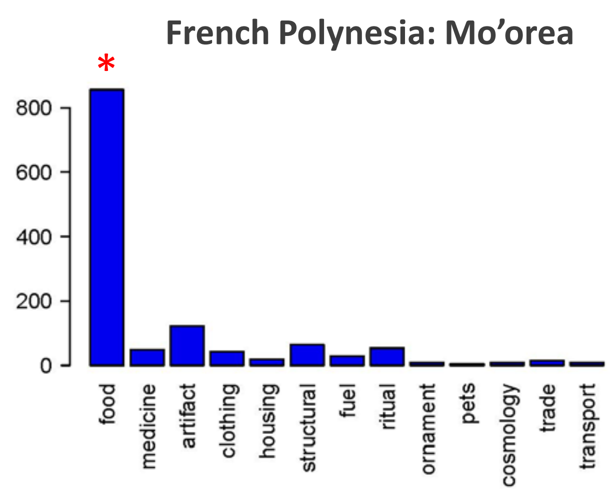
Ancestral Puebloans

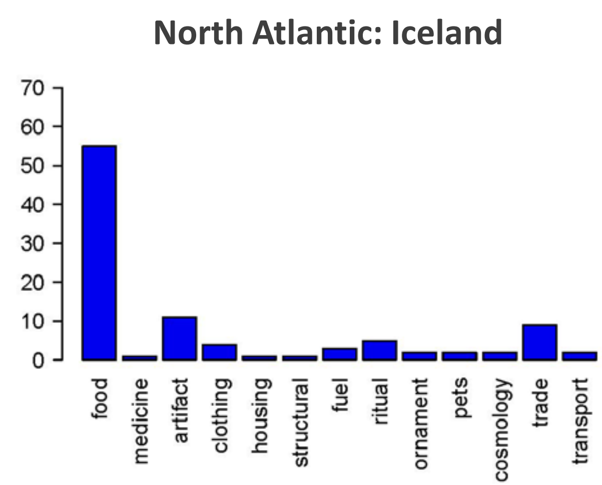
A First Glimpse: Preliminary Use Patterns





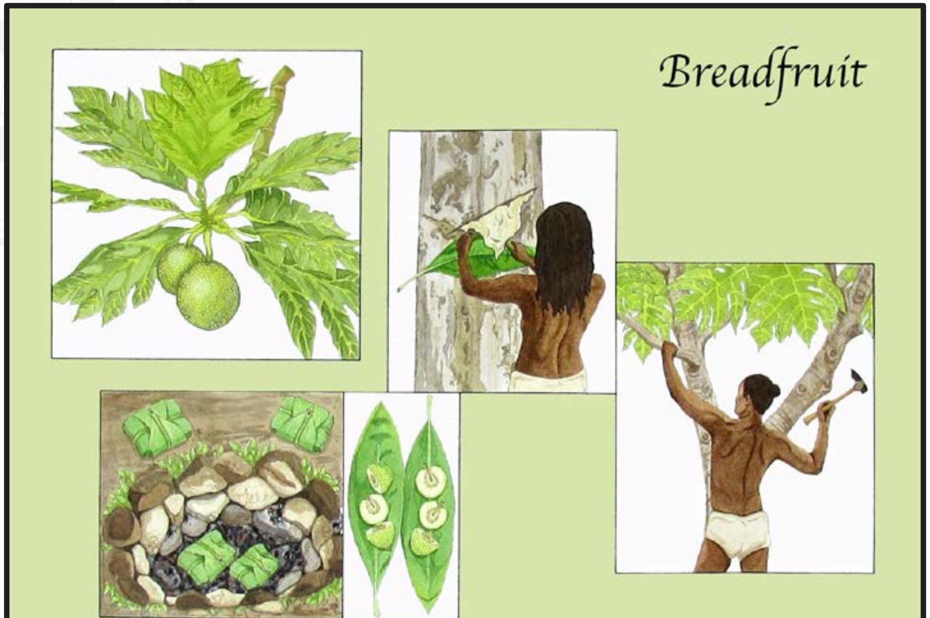






*** Cosmology underestimated in NWC; Food overestimated in Mo’orea**

One Species, Many Uses



Images: Sienna Van Slooten

Breadfruit (Mo'orea, French Polynesia)

Fruit: Steamed, roasted, or fermented for food

Fruit: Pig fodder

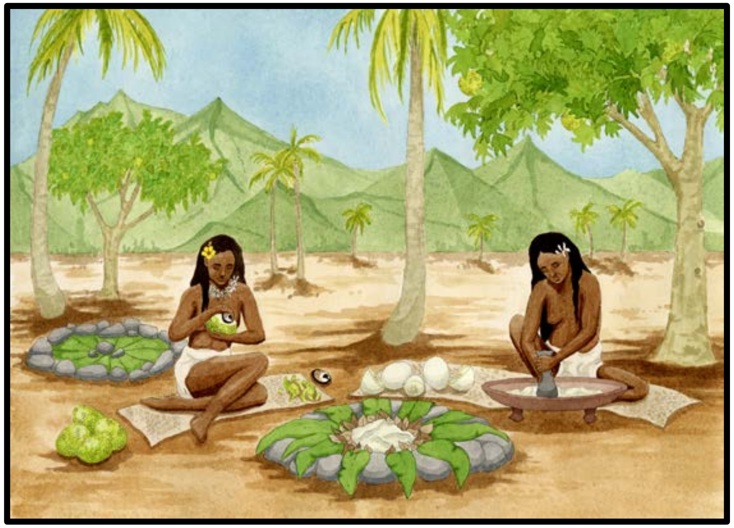
Sap: Caulk canoes, make bird traps, medicines

Wood: House & temple structures, fuel, idols

Bark: Clothing (barkcloth, rapa)

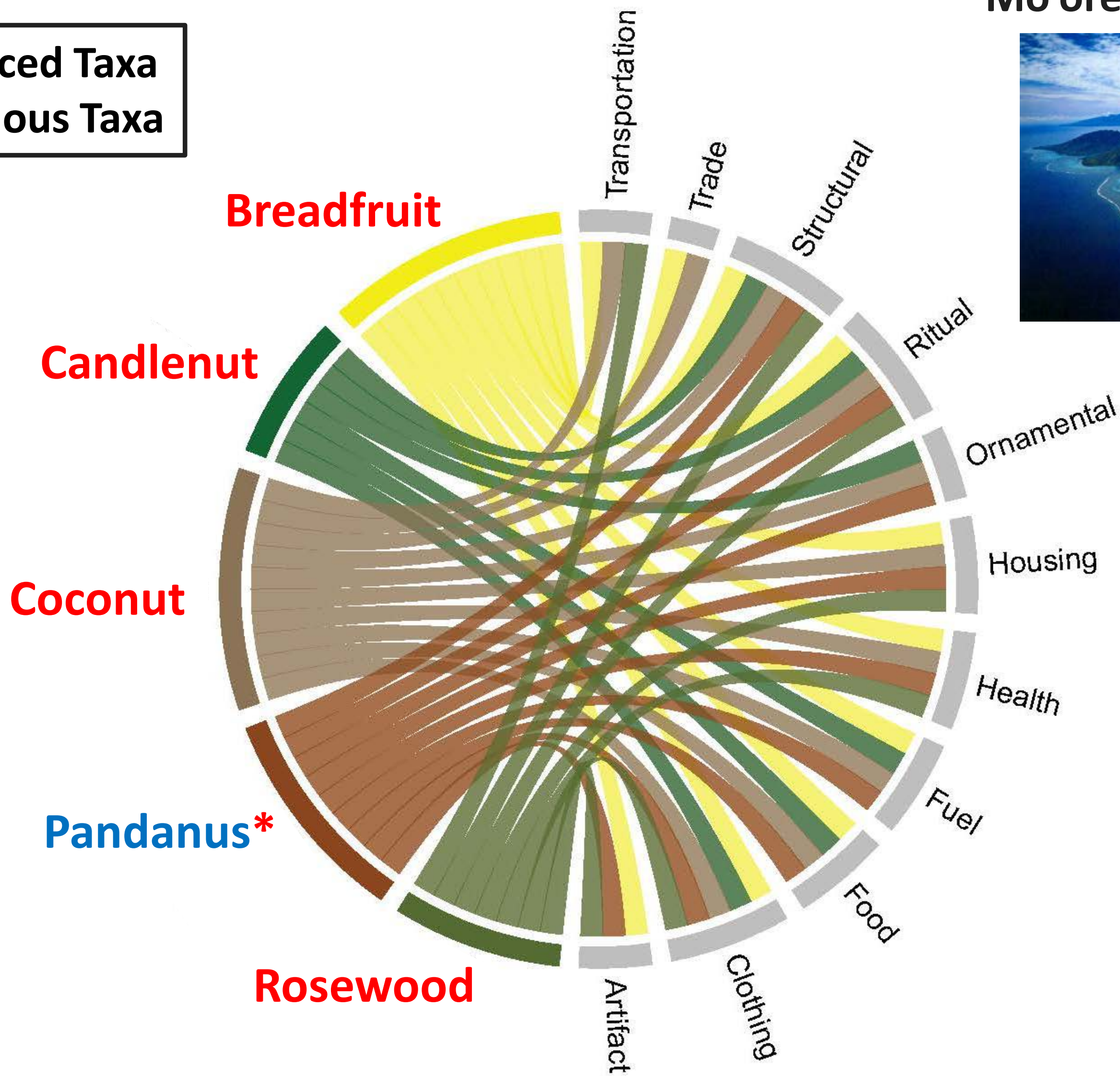
Leaves: Medicines

Fruit & Bark products also use for Trade and Taxation purposes



Top Multi-Use Species

Red: Introduced Taxa
Blue: Indigenous Taxa

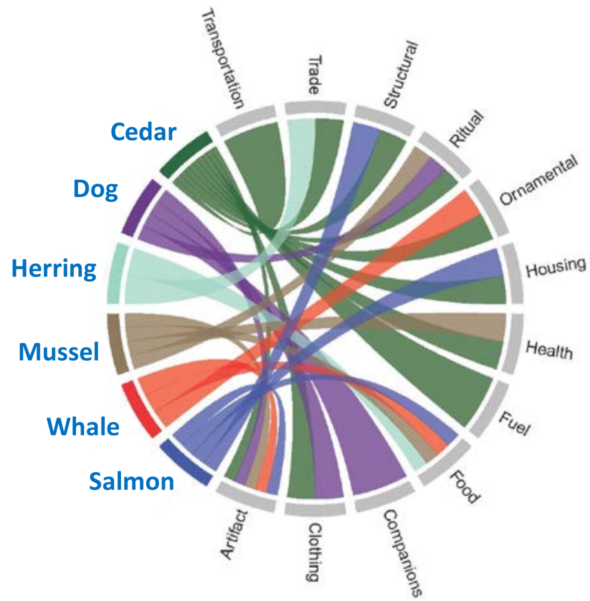


Mo’orea, French Polynesia

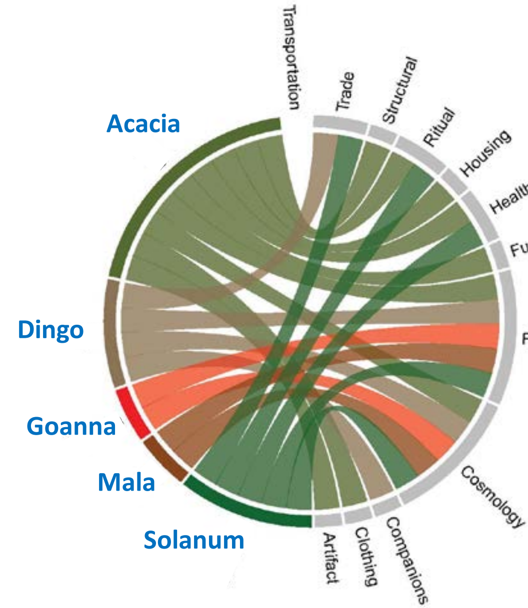
Top Multi-Use Species

Red: Introduced Taxa
Blue: Indigenous Taxa

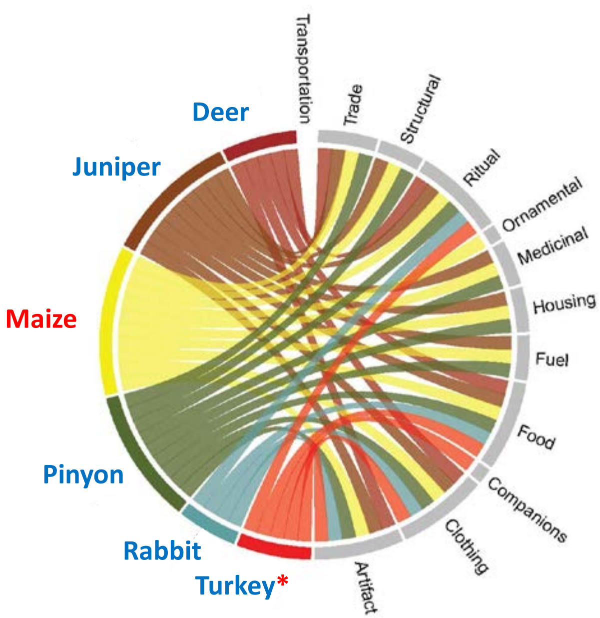
Northwest Coast NA



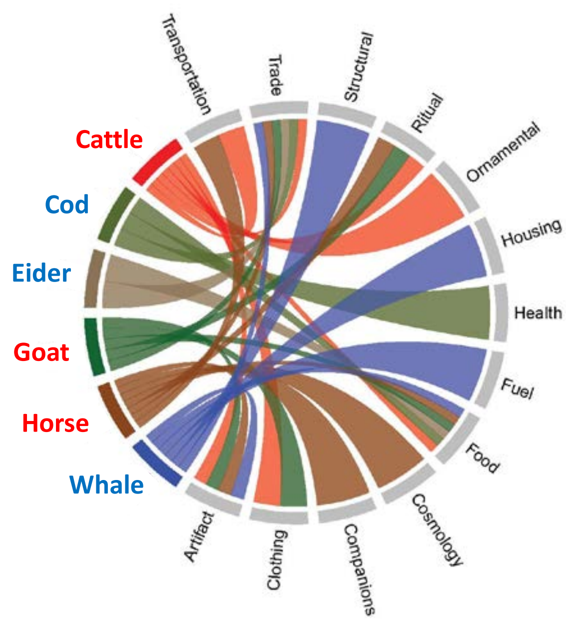
Western Desert of Australia



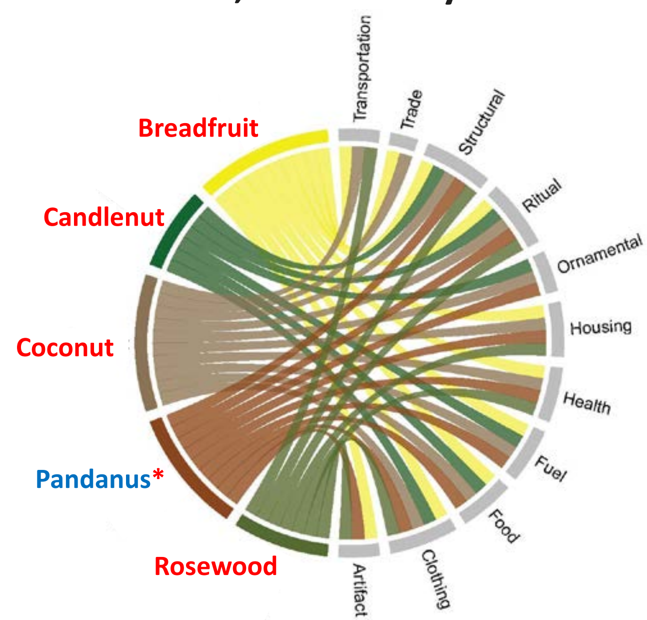
Southwestern US



Iceland

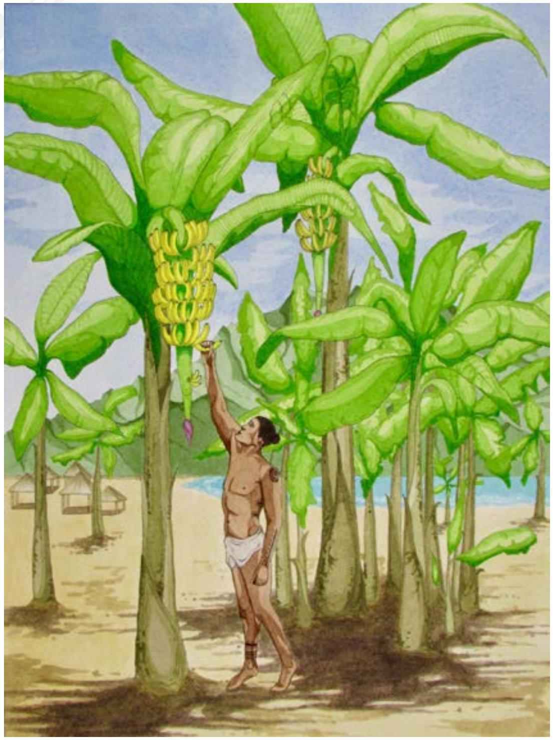


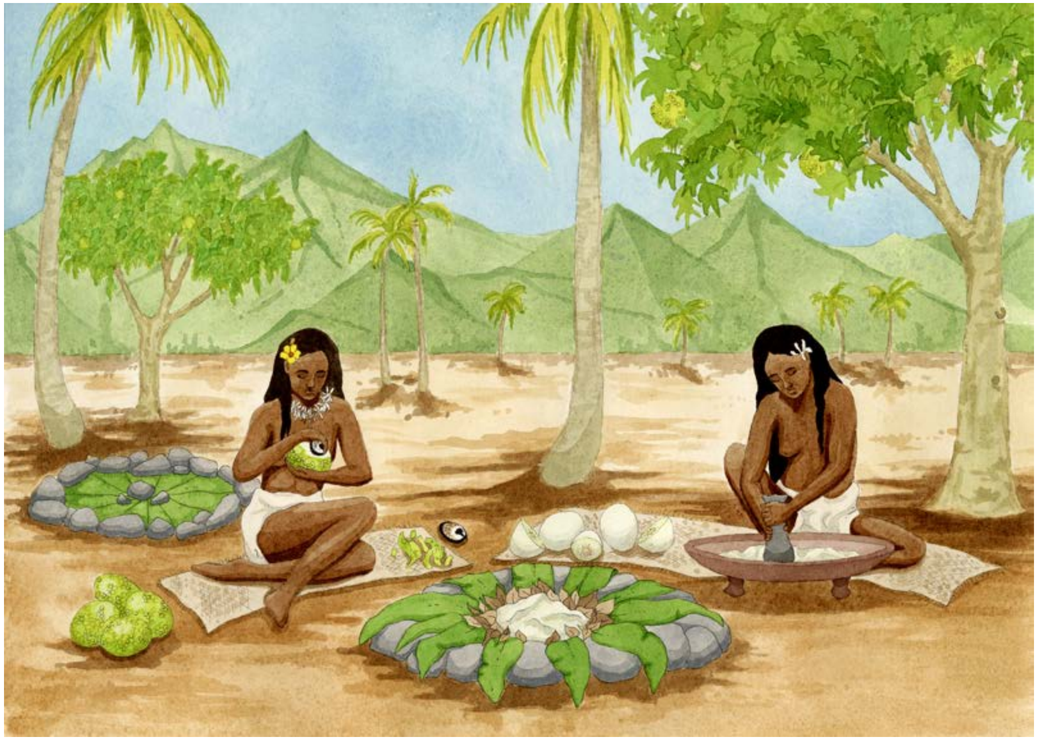
Mo’orea, French Polynesia



Simple vs. Complex Interactions

Human eats banana | **Human eats breadfruit**



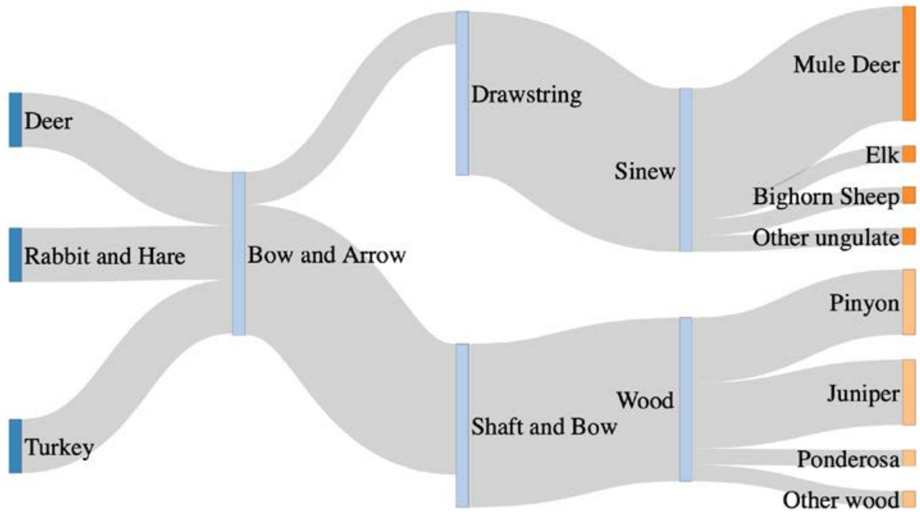


Mo'orea, French Polynesia

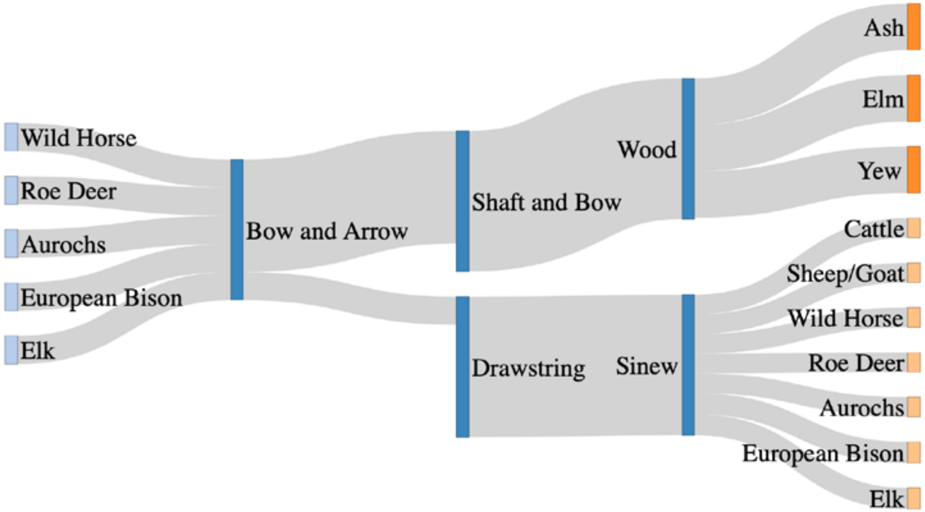
Images: Sienna Van Slooten

Bow & Arrow Technology

Species Hunted ← Tech ← Components ← Material ← Species Used



Ancestral Puebloans, Southwest US



Swifterbant Culture, Neolithic Transition, Northern Central Europe

Human eats berry

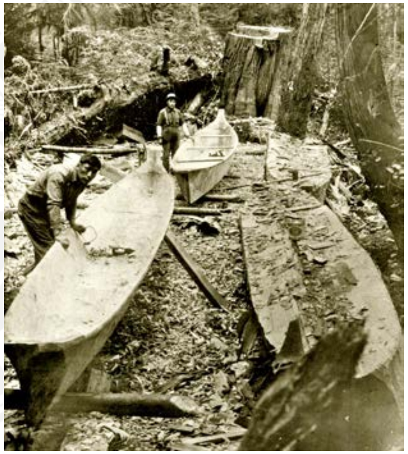
Tlingit women eating thimbleberries

Human eats whale

Nuu-chah-nulth people processing whale

Northwest Coast, North America

Human Eats Whale



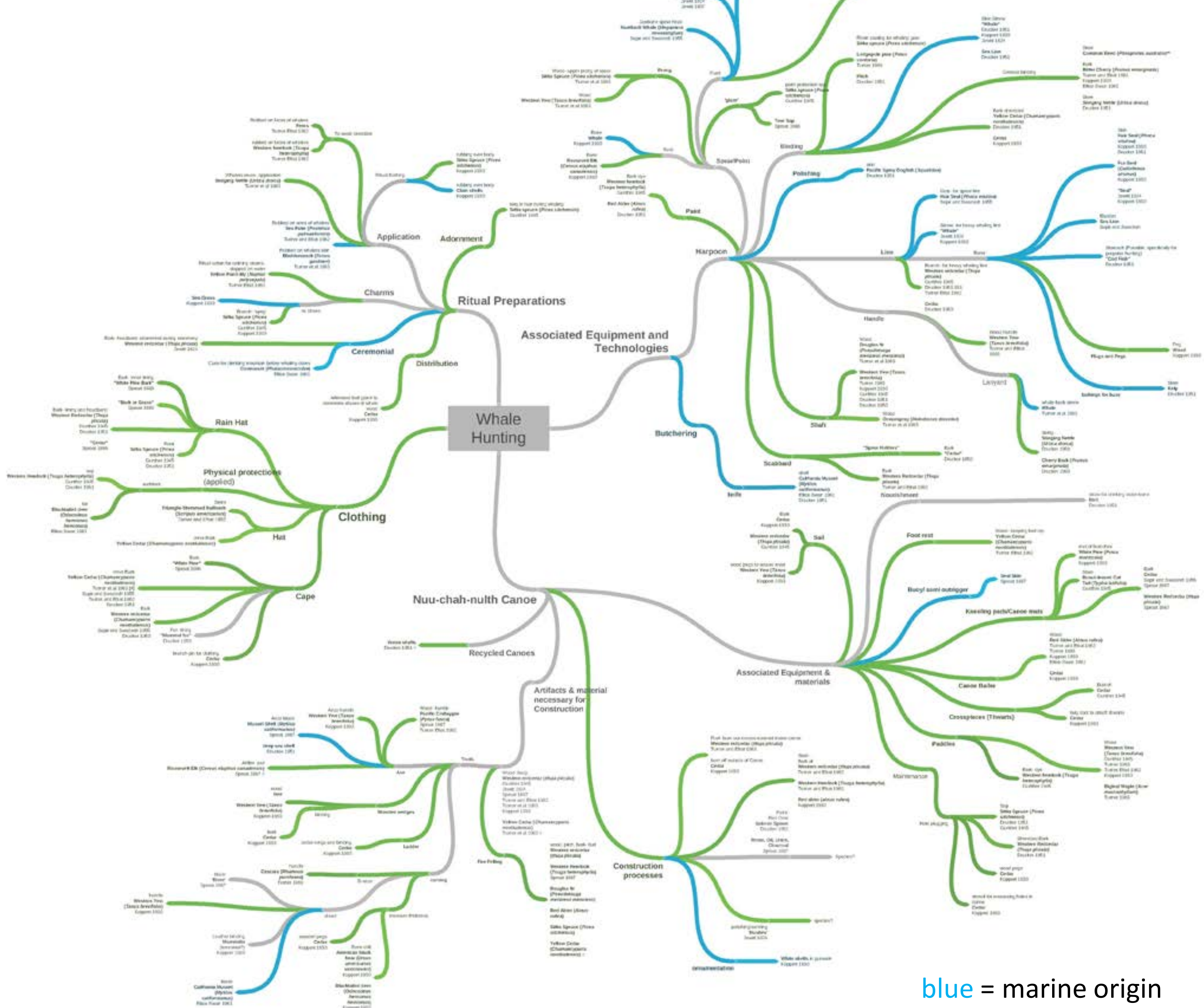
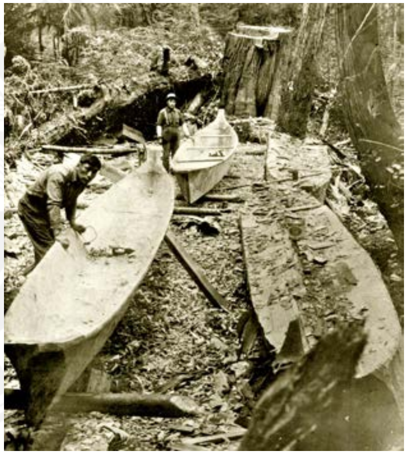


Image: Jacob Earnshaw

blue = marine origin
green = terrestrial origin
grey = mix



Human Eats Whale

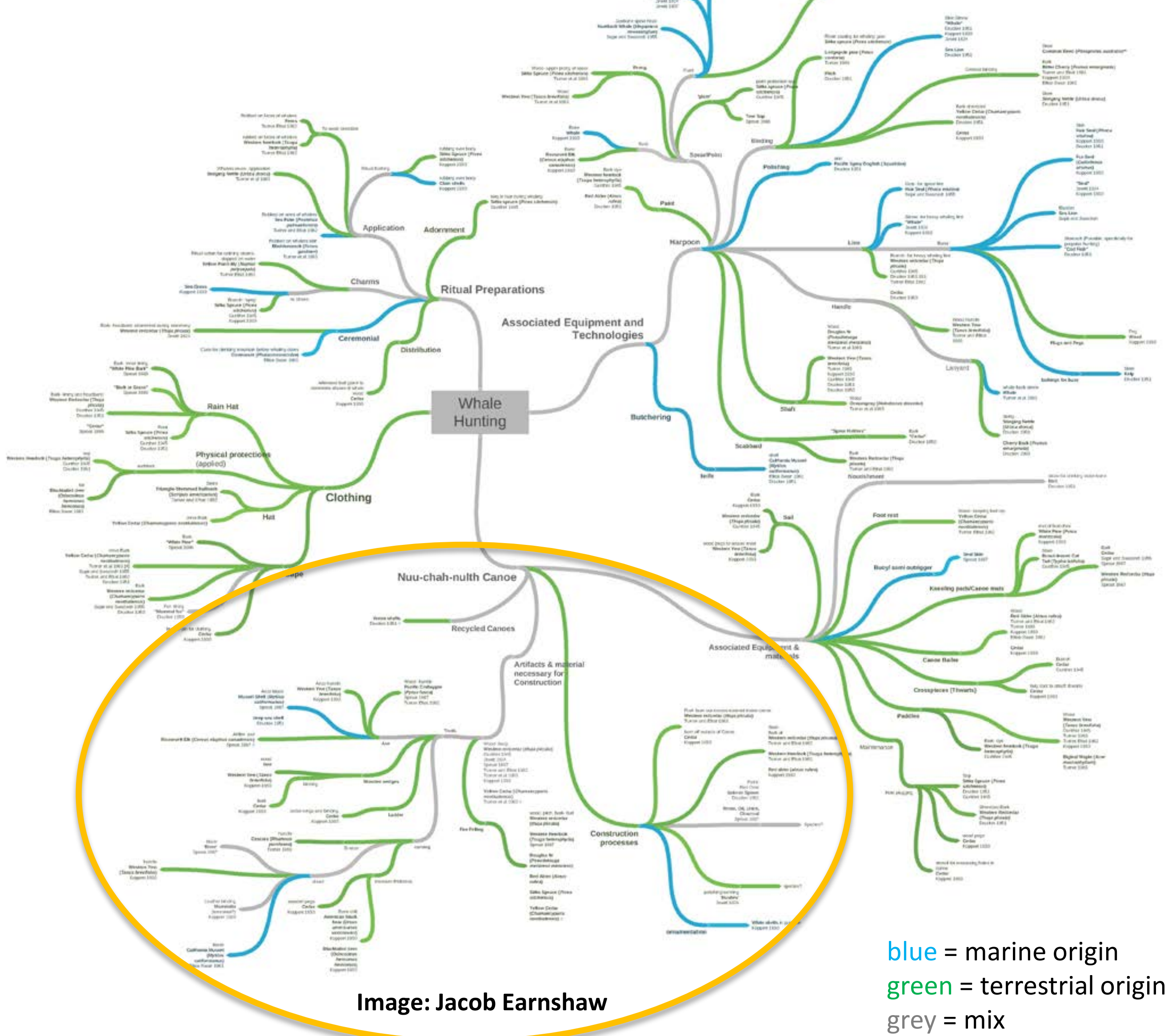


Image: Jacob Earnshaw

blue = marine origin
green = terrestrial origin
grey = mix

Making a Canoe

Animals used:

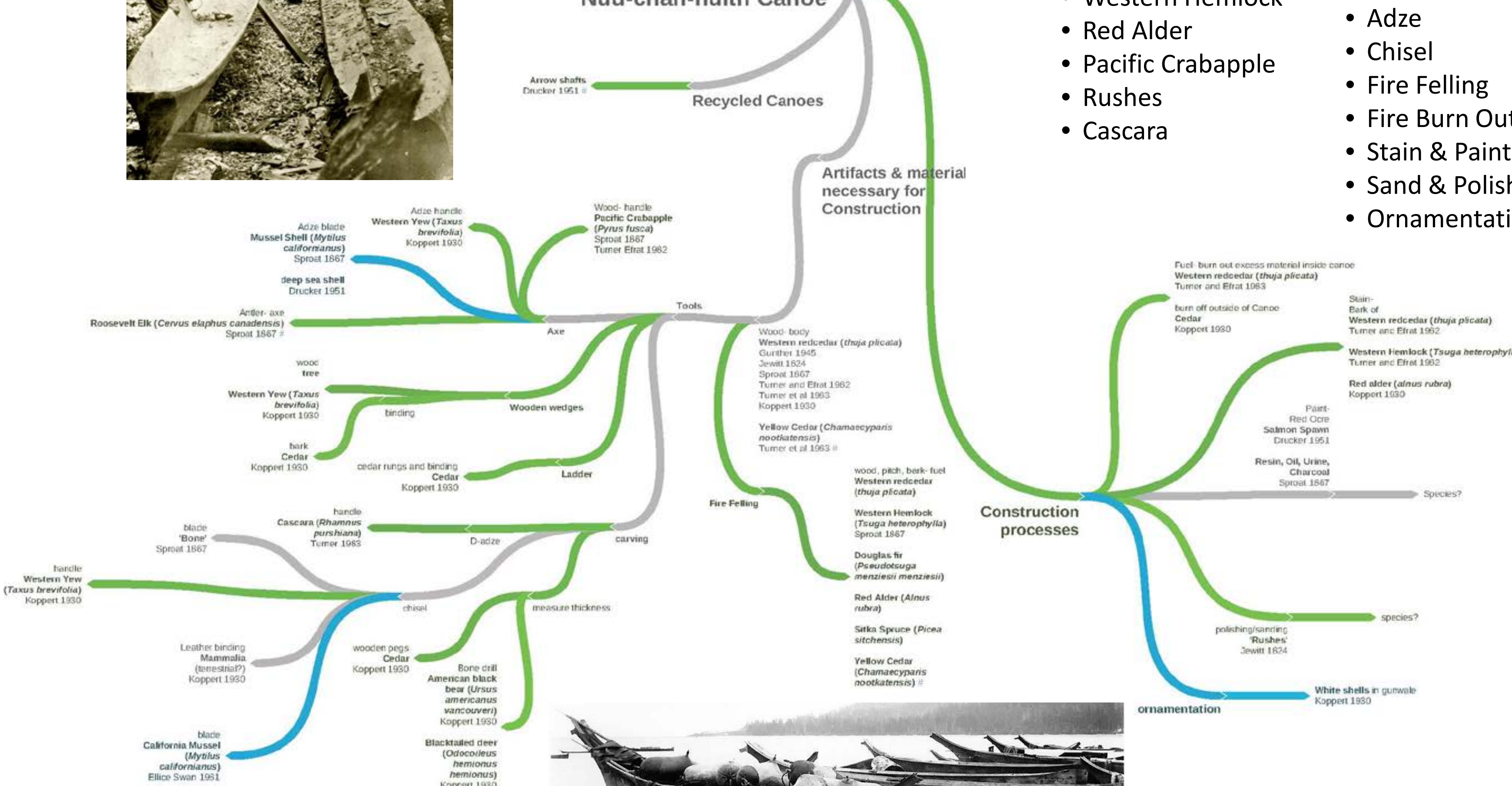
- Mussel
- Roosevelt Elk
- Black Bear
- Black Tailed Deer
- Salmon-spawn
- Mollusk spp.
- Mammal spp.

Plants used:

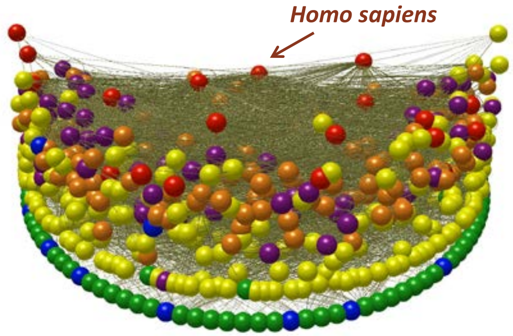
- Western Red Cedar
- Yellow Cedar
- Western Yew
- Douglas Fir
- Sitka Spruce
- Western Hemlock
- Red Alder
- Pacific Crabapple
- Rushes
- Cascara

Tech used:

- Axe
- Wedge
- Ladder
- Adze
- Chisel
- Fire Felling
- Fire Burn Out
- Stain & Paint
- Sand & Polish
- Ornamentation

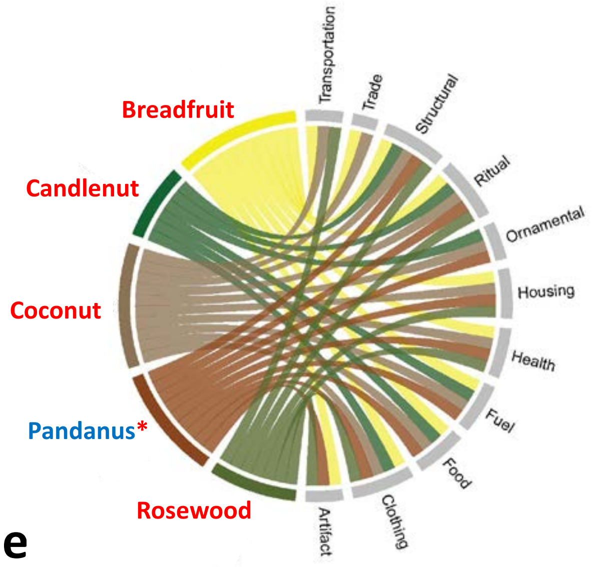


Humans in Food Webs:



- As species go extinct, food webs unravel
- The Great Unraveling: food webs more simplified, more 2° extinctions, less stable to perturbations
- But, humans not just an external, negative "forcing factor"
- Humans are a part of food webs: often super-generalists, highly omnivorous, ~2 degrees of separation, technologists
- Humans NOT at the top of food webs
- Many examples of major negative socio-ecological change
- But also examples of humans as integral and stabilizing parts of persistent socio-ecosystems (Sanak Aleut, Australian Martu)

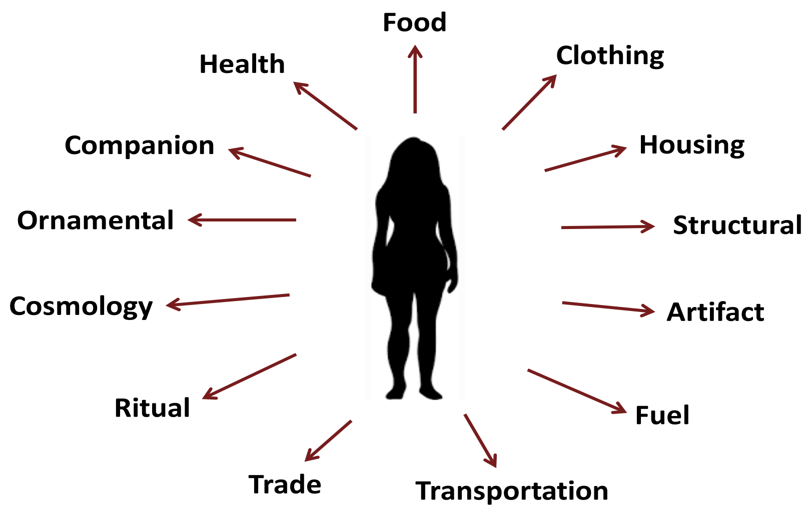
Beyond Food Webs:



- New research agenda: How humans interact with biodiversity through space and time
- First time comprehensive data of this type compile
- Human use patterns in relation to: ecological & environmental context, human culture, modes of production, etc.
- Species often served a variety of uses for pre-industrial humans
- Simple vs. complex interactions: A new way to quantify and compare technology development and use, innovation dynamics
- The search for lessons from the past for sustainability of the future

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



Thanks!

SANTA FE
INSTITUTE

Coalition for
Archaeological
Synthesis

ASU-SFI Center
for Biosocial
Complex Systems

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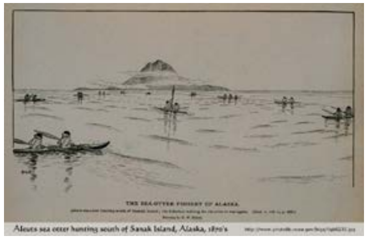
Dieta Hanson



Iain McKechnie,
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Spencer Wood

Stefani Crabtree

Rebecca Bliege-Bird
Stefani Crabtree

Andy Dugmore, Tom Ryan
George Hambrecht

Philip Verhagen