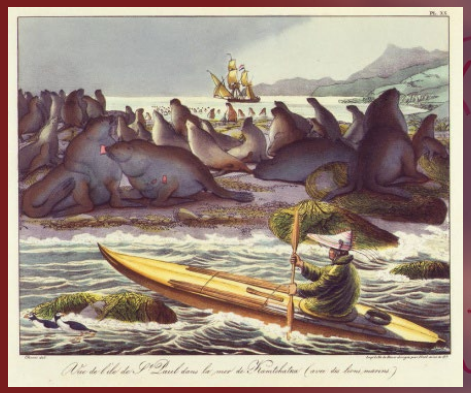
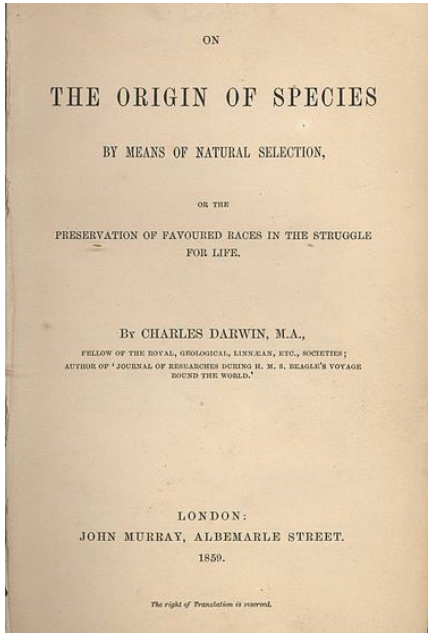
ArchaeoEcological Networks:

A Framework for Exploring How Humans Interact with Biodiversity through Space & Time

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.

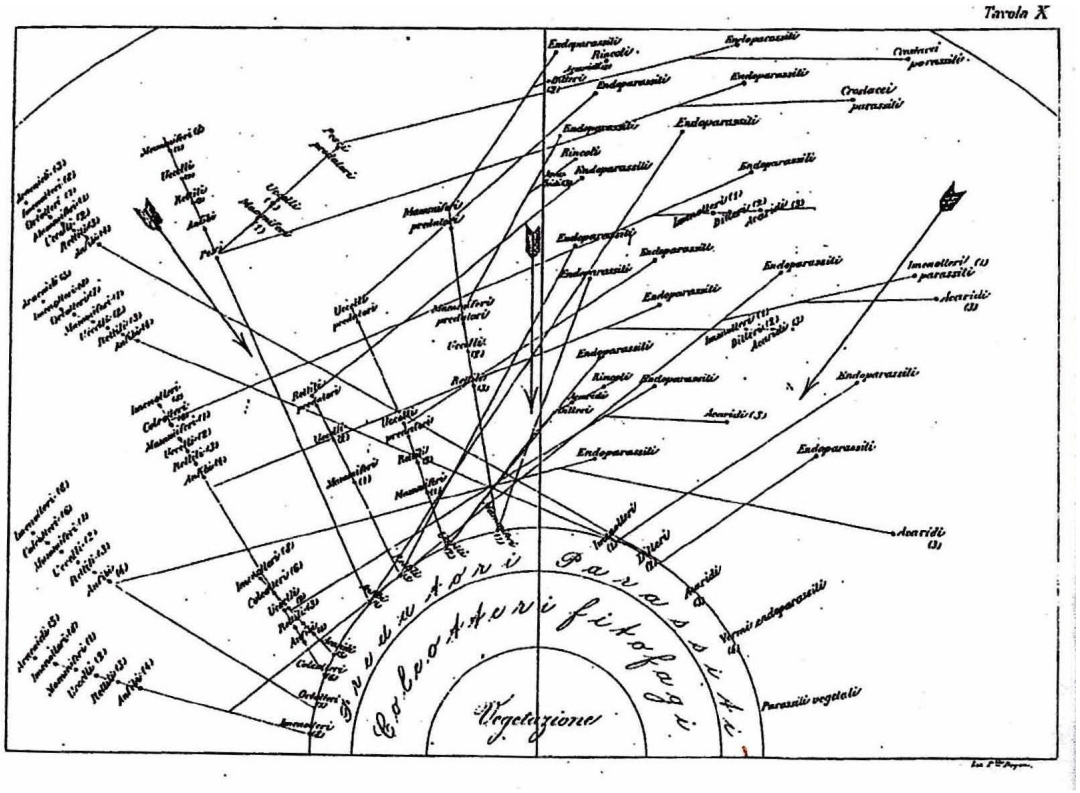
By CHARLES DARWIN, M.A.,

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

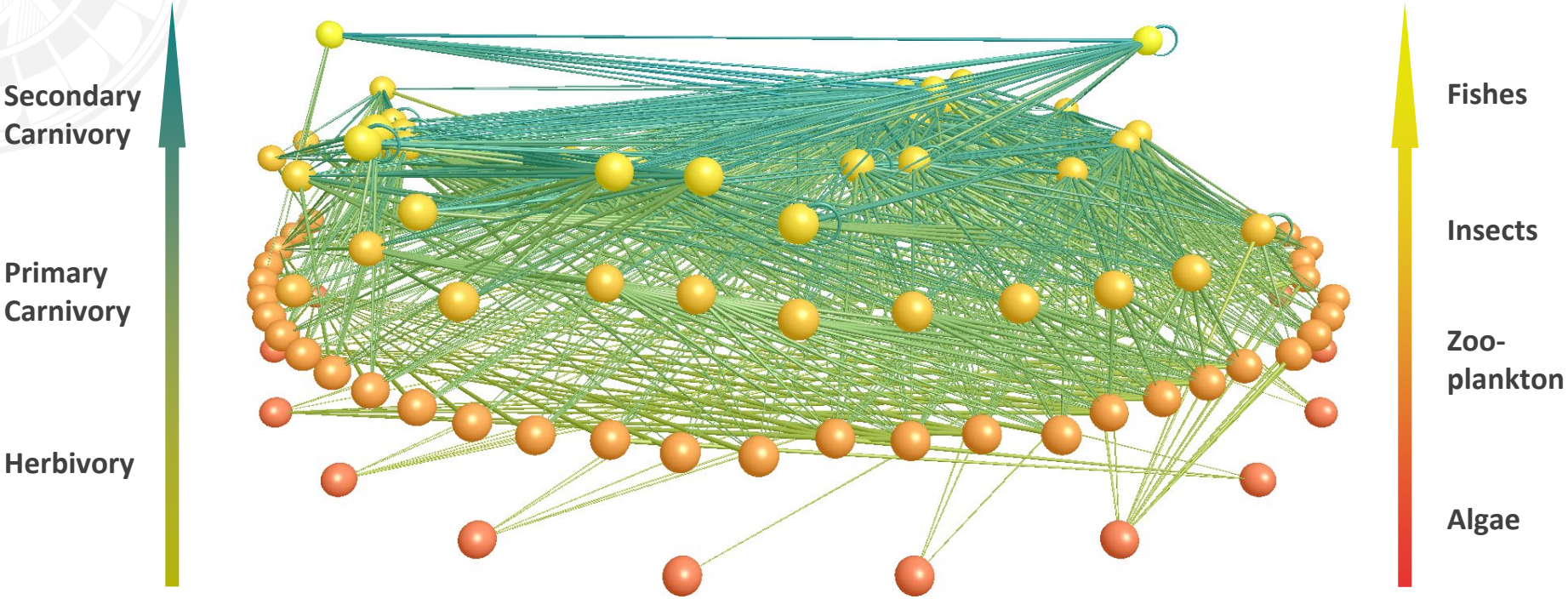


15 taxa:

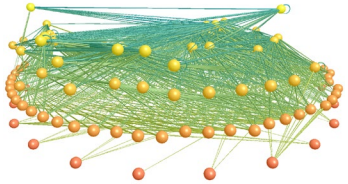
Plants
Parasitic plants
Worms
Amphibians
Reptiles
Fish
Birds
Mammals
Crustaceans
Spiders
Insects

On the equilibrium of living beings by means of reciprocal destruction
Atti della Reale Accademia delle Scienze di Torino

Little Rock Lake, Wisconsin

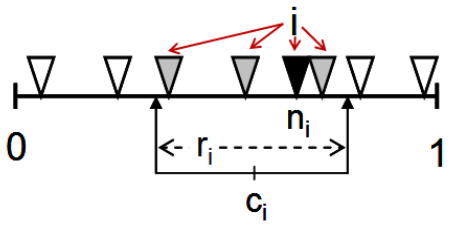


Martinez. 1991. *Ecological Monographs.*
Artifacts or attributes? Effects of resolution on the Little Rock Lake food web.



- **Ecological Network Structure**

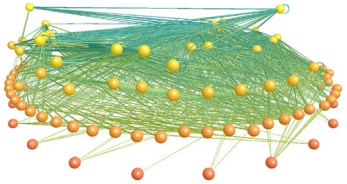
The Niche Model



Nature 2000

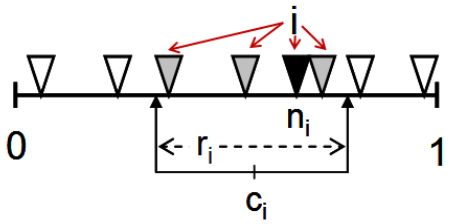
Simple rules yield complex food webs

Richard J. Williams & Neo D. Martinez



- **Ecological Network Structure**

The Niche Model



Nature 2000

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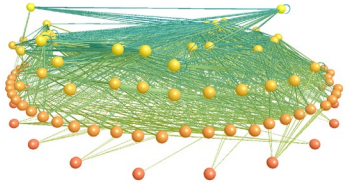
- **Complex Trophic Dynamics**

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

LETTER

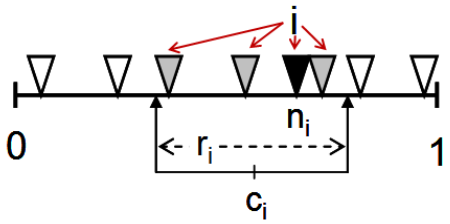
Mechanistic theory and modelling of complex food-web dynamics in Lake Constance

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]

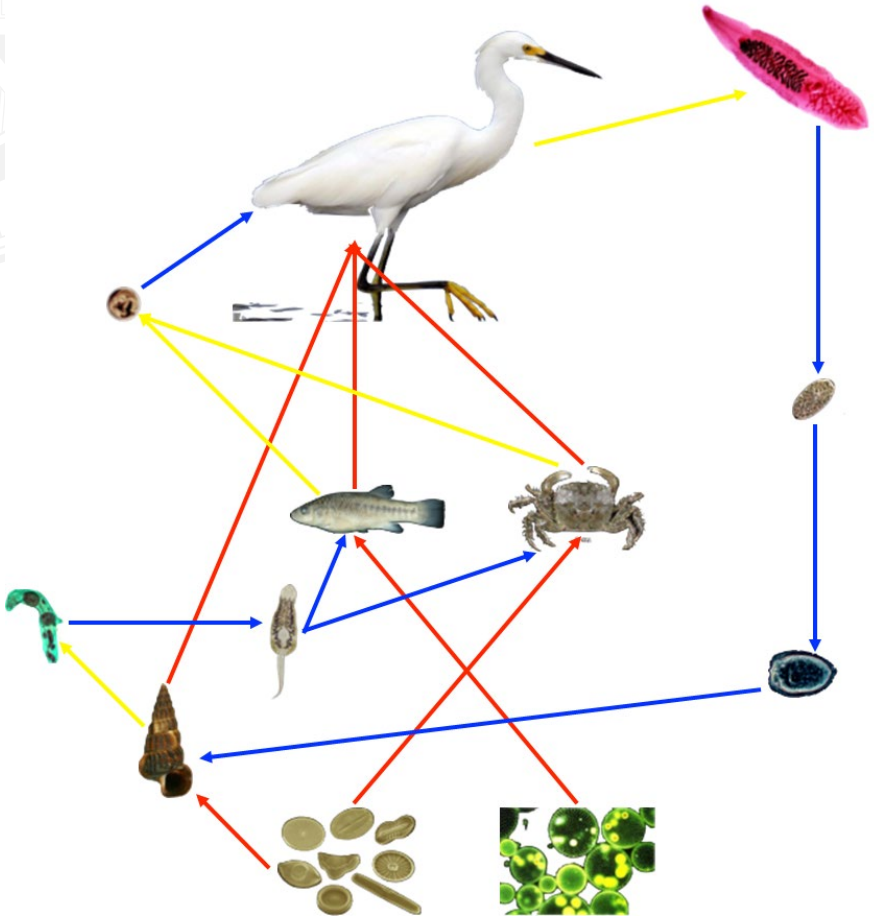
Ecology Letters, (2006) 9: 1228–1236 doi: 10.1111/j.1461-0248.2006.00978.x

LETTER

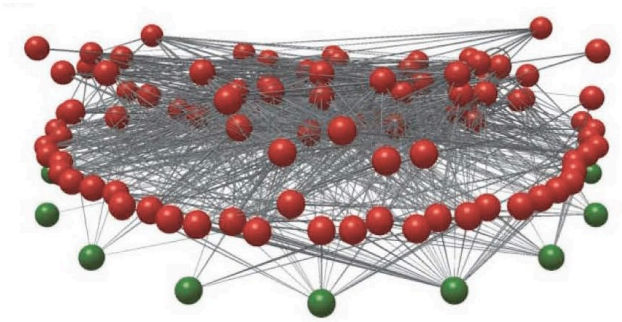
Allometric scaling enhances stability in complex food webs

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

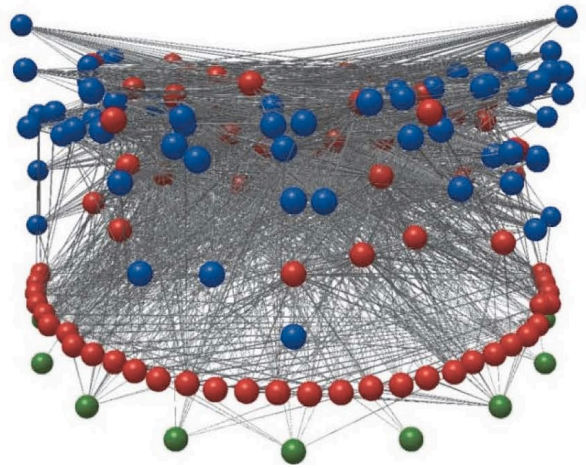
PARASITES



Food Web without Parasites



Food Web with Parasites



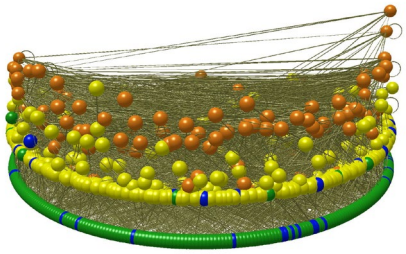
DEEP TIME

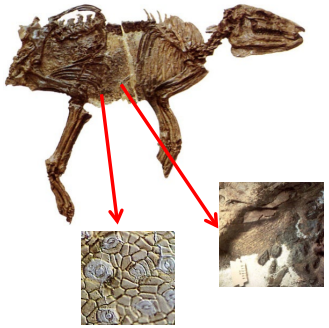
Geologic Time Scale

PHANEROZOIC	CENOZOIC	QUATERNARY	0	HOLOCENE
				PLEISTOCENE
		TERTIARY NEOGENE	1.65	PLIOCENE
				MIOCENE
		TERTIARY 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)

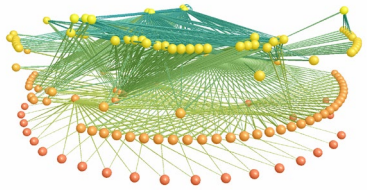
Messel Shale (48 Ma)

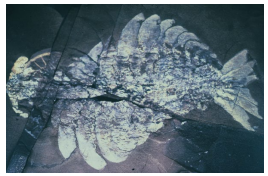




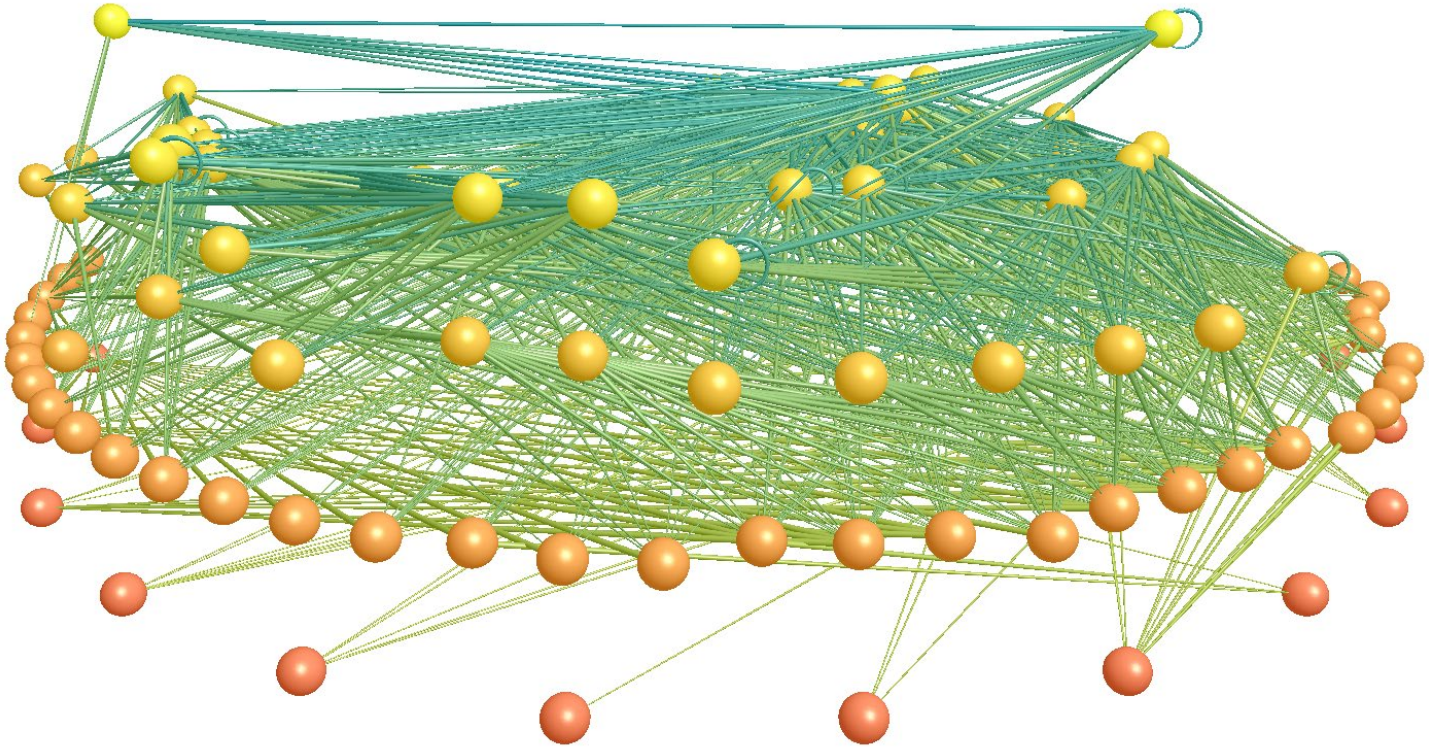
Burgess Shale (505 Ma)

Chengjiang Shale (520 Ma)





What about *Homo sapiens?*



Using ecological networks to:

I. Assess human impacts on ecosystems
II. Understand human roles in ecosystems
III. Investigate aspects of ecological sustainability

I. Human Impacts on Ecological Networks

Adriatic Sea Region

Egypt

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

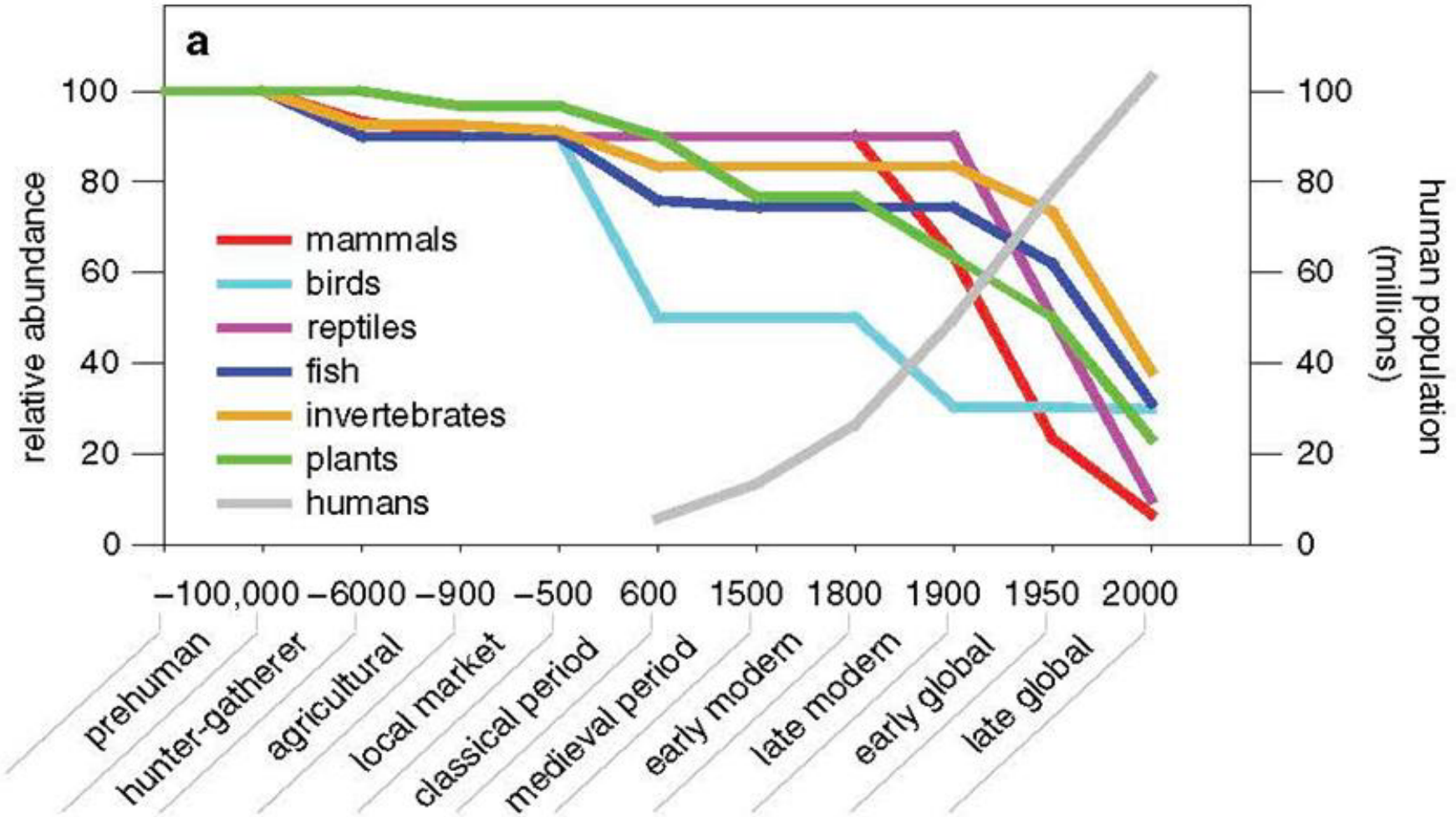
ECOSYSTEMS

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

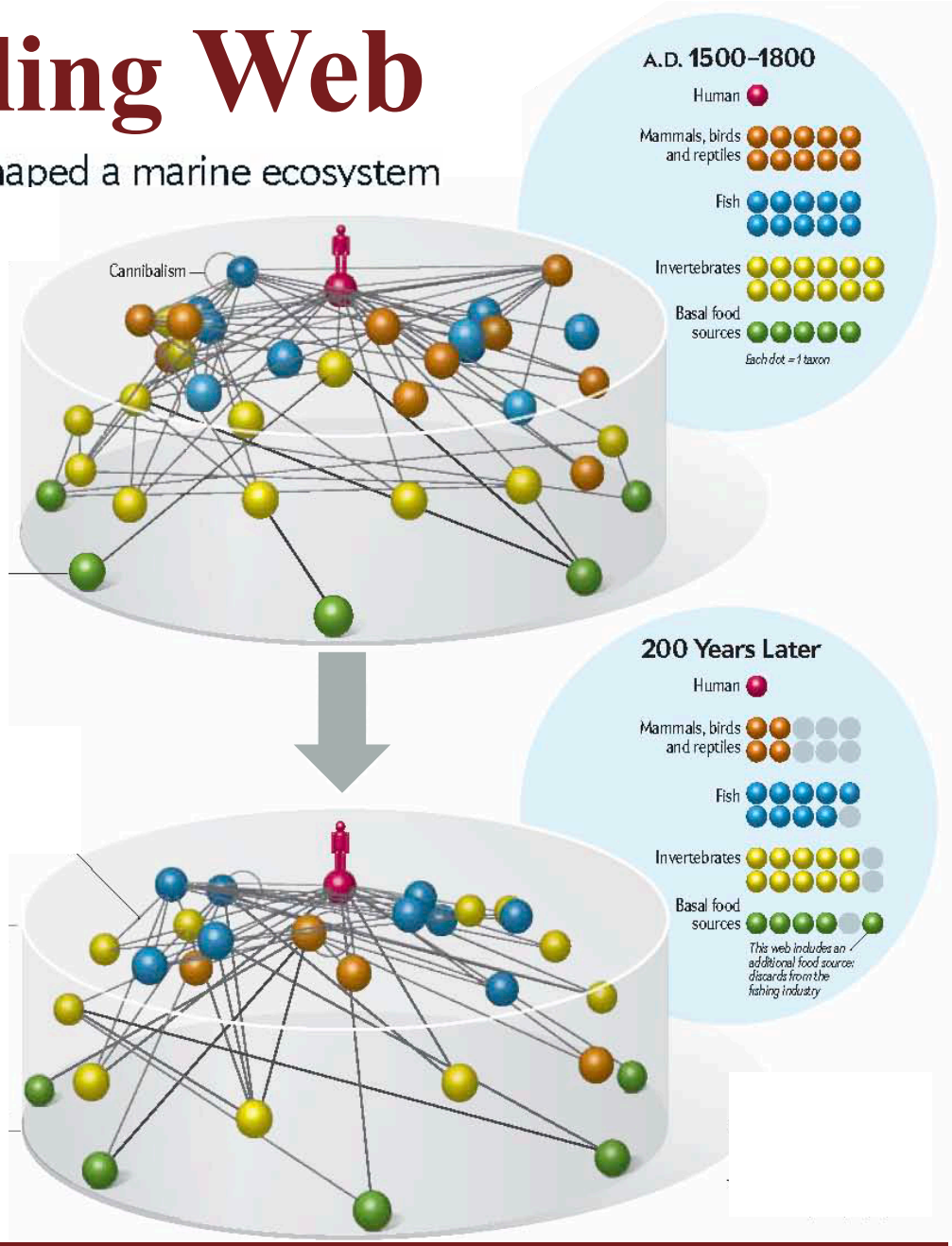
How human exploitation has reshaped a marine ecosystem

Early Modern

25% Taxa ⬇

Robustness ⬇

Late Global



Scientific American 2012

PNAS

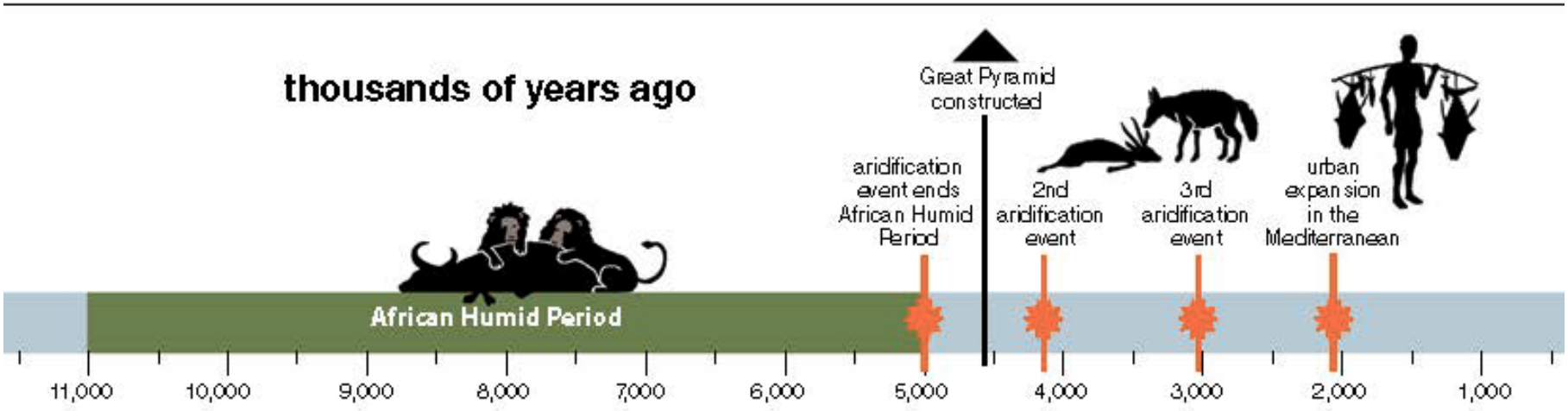
Collapse of an ecological network in Ancient Egypt

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

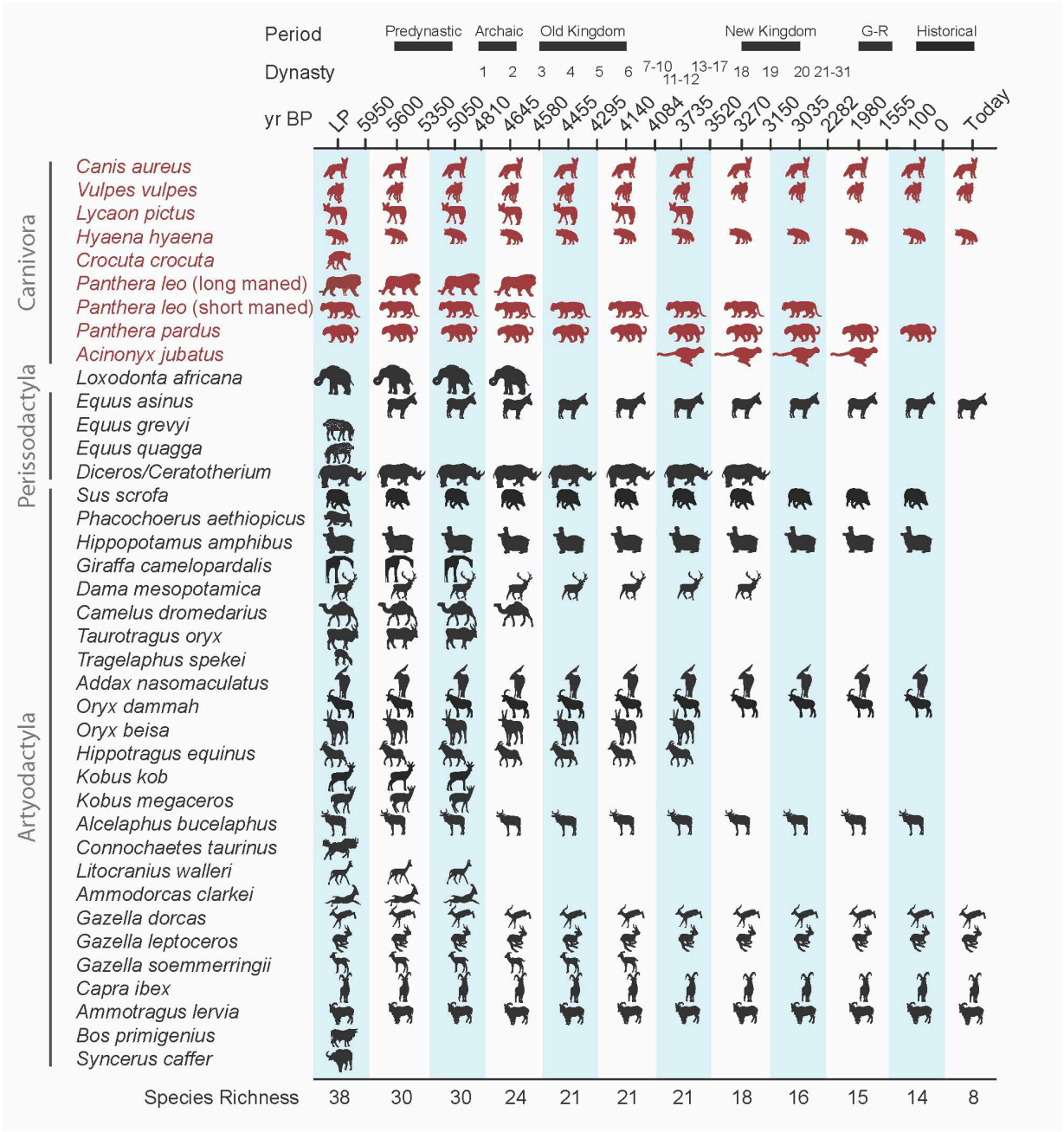
Edited by Justin S. Brashares, University of California, Berkeley, CA, and accepted by the Editorial Board August 11, 2014 (received for review May 8, 2014)

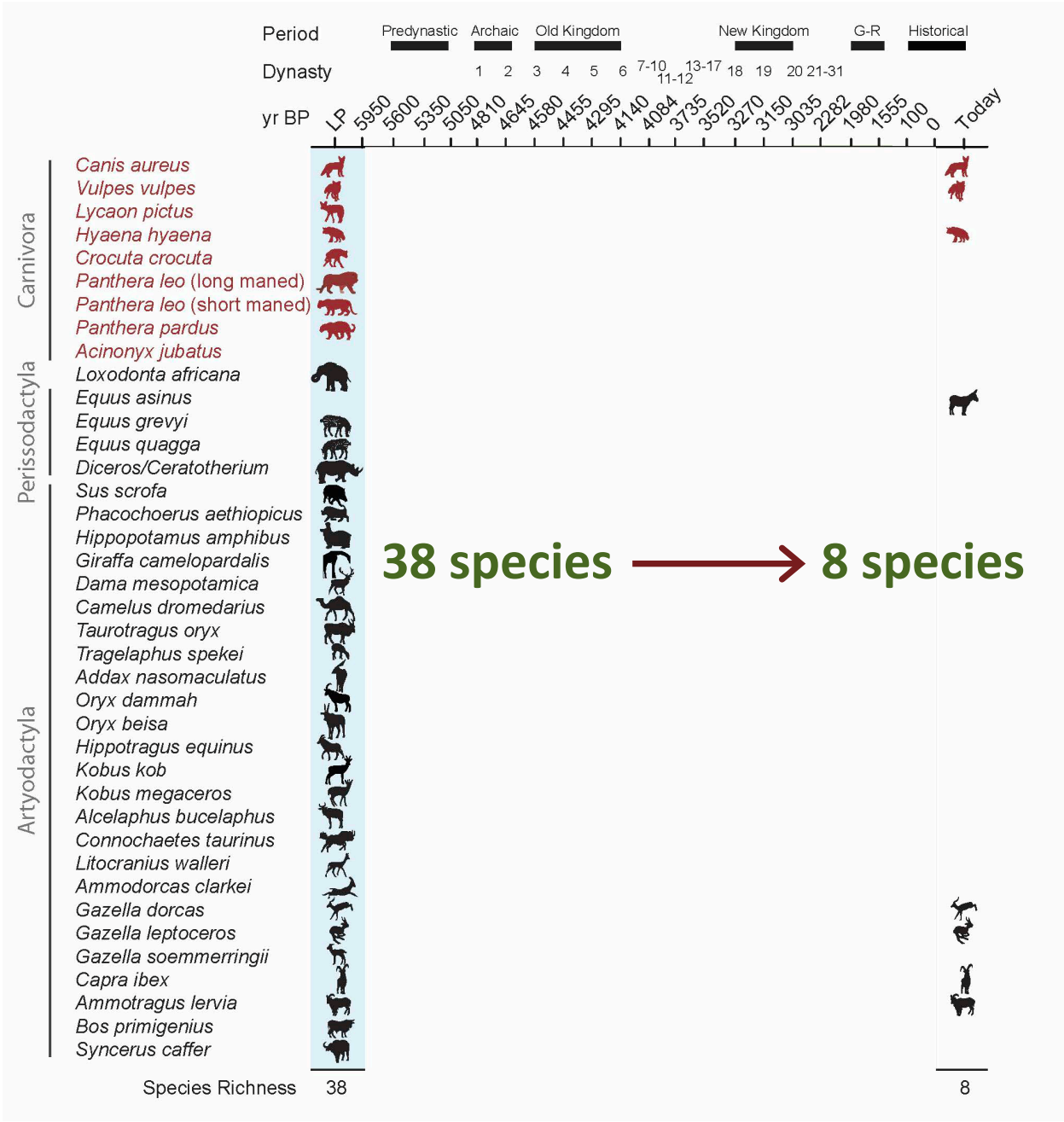
Timeline of Egypt



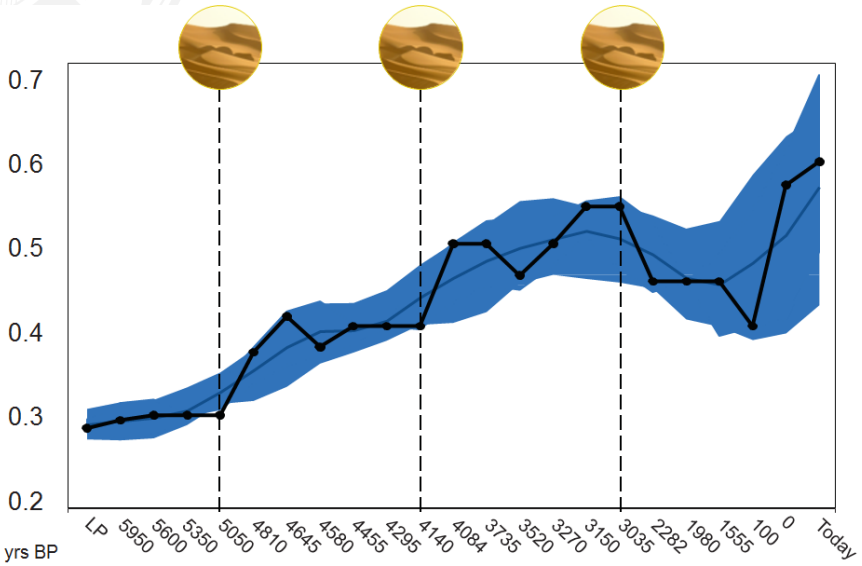
Hierakonpolis Palette: 5150 yrs old

Panel from Tutankhamun's Painted Box: 3000 yrs old

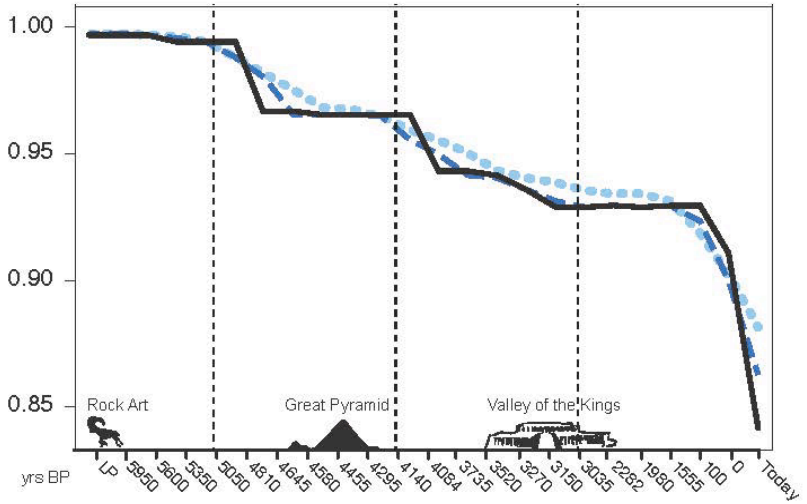

Period
Predynastic
Archaic
Old Kingdom
New Kingdom
G-R
Historical
Dynasty
1 2 3 4 5 6 7-10 11-12 13-17 18 19 20 21-31
yr BP
LP 5950 5600 5350 5050 4810 4645 4580 4455 4295 4140 4084 3735 3520 3270 3150 3035 2282 1980 1555 100 0 Today
Carnivora
Perissodactyla
Artyodactyla
Canis aureus
Vulpes vulpes
Lycaon 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


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
38 species
8 species
Species Richness
38
8

Increasing Predator-Prey Ratio Through Time



Fewer Dynamically Stable Food Webs Through Time

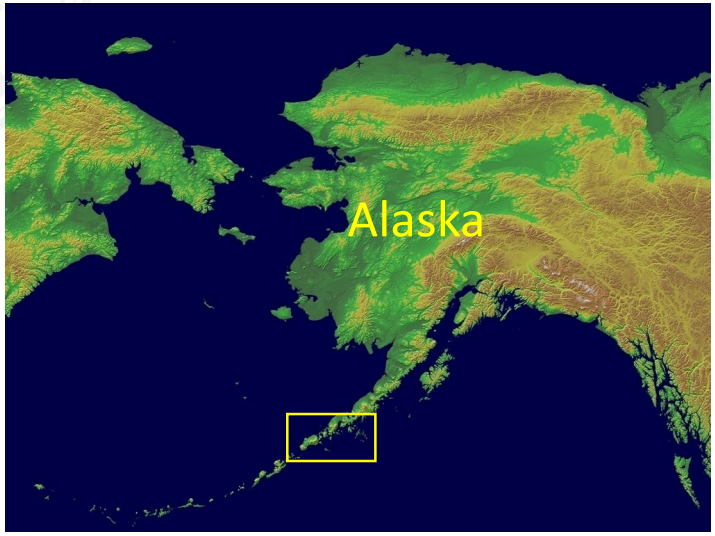


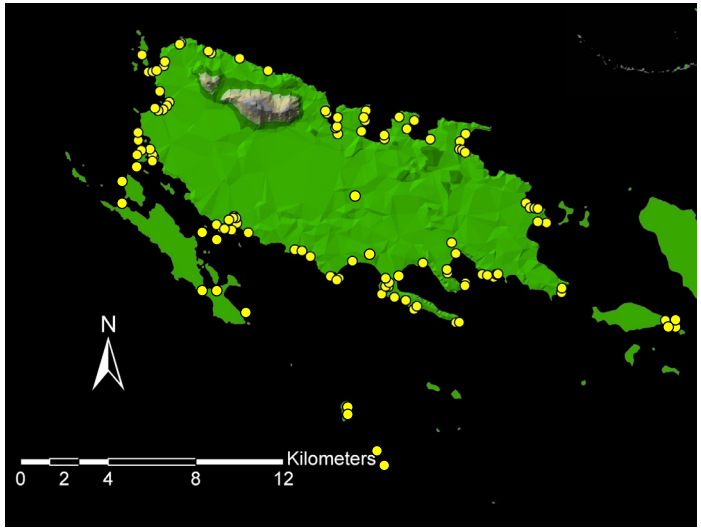
II. Human Roles in Food Webs

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?

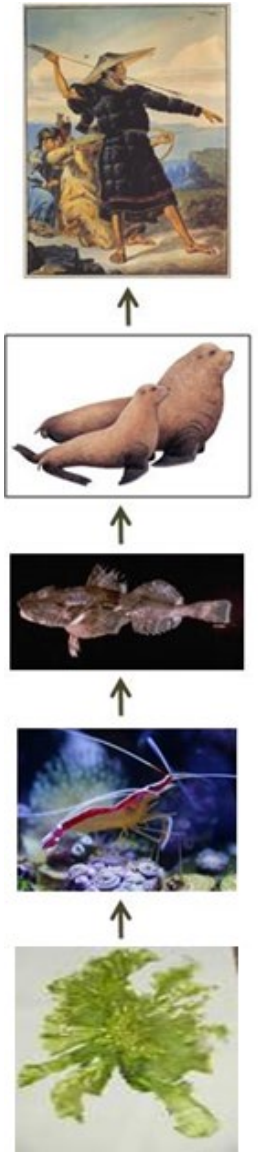
The Sanak Archipelago



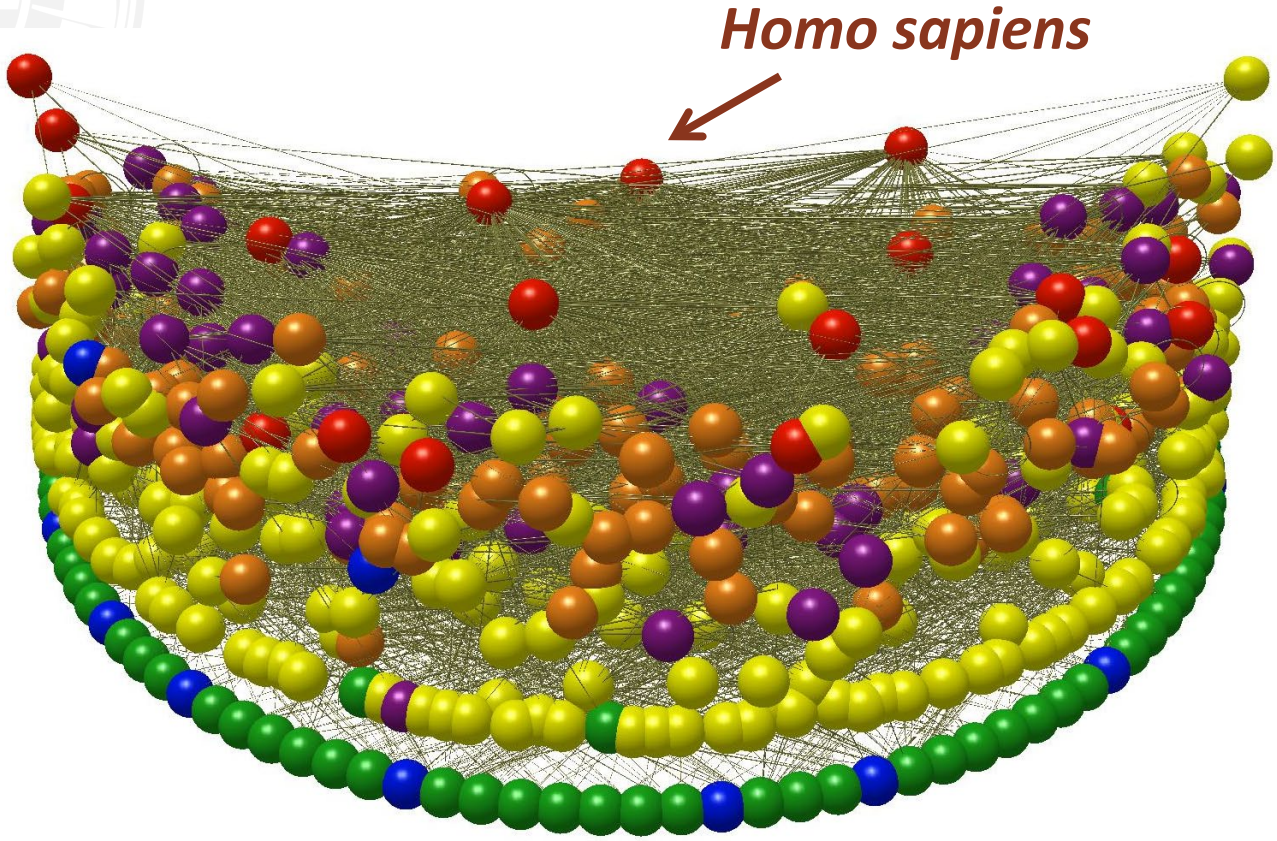


- Far-eastern end of Aleutian archipelago
- Ice-free for 16,000 yrs
- 6,000 yr human record, 128 known sites
- Integrate archeological, ecological & climatic data

Human Trophic Roles: Network Structure



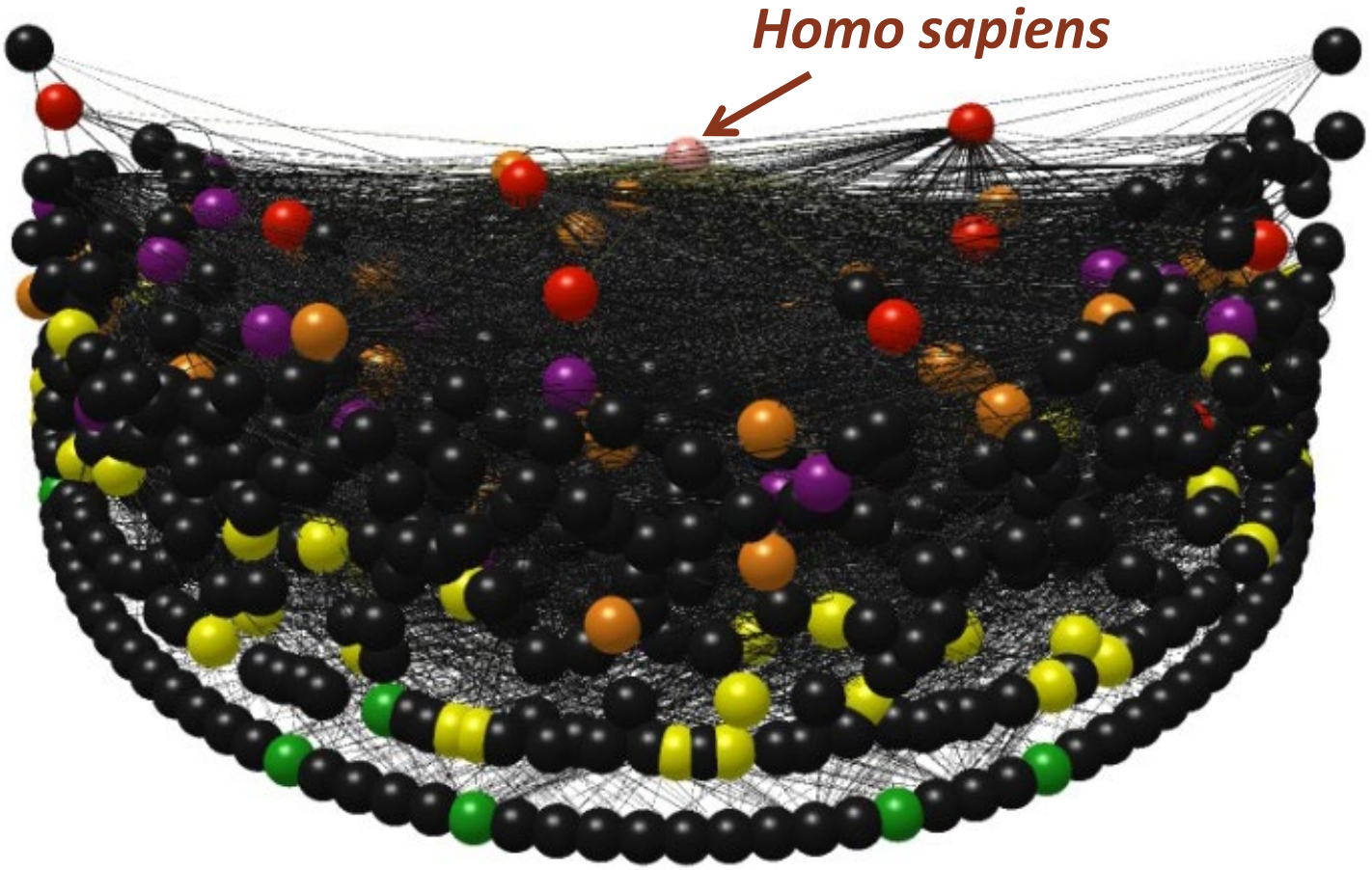
Sanak Nearshore Marine Food Web



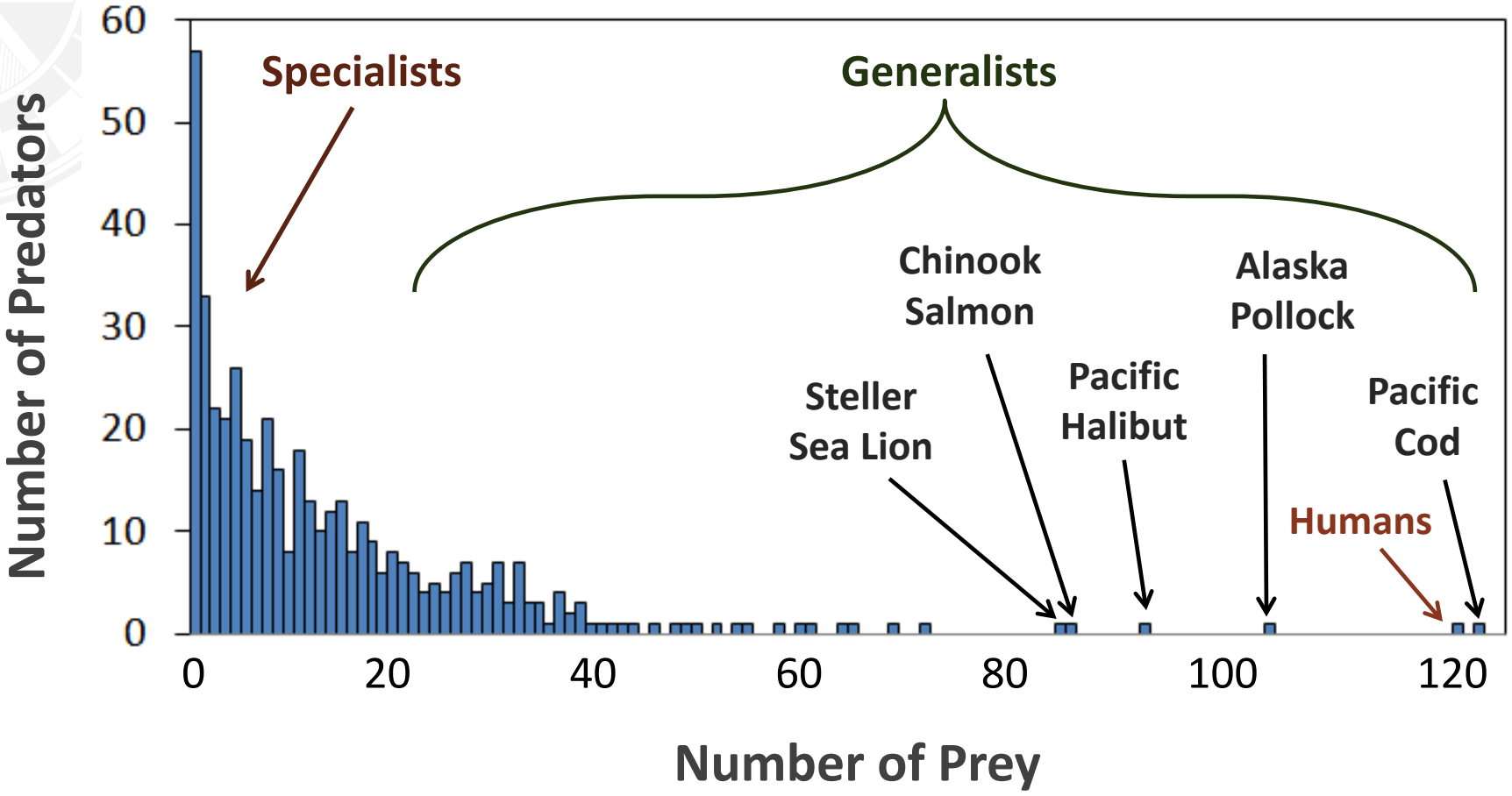
- Birds (64)
- Mammals (21)
- Fish (139)
- Invertebrates (222)
- Algae (54)
- Misc (13)

513 taxa, 6774 feeding links, 13 links per species

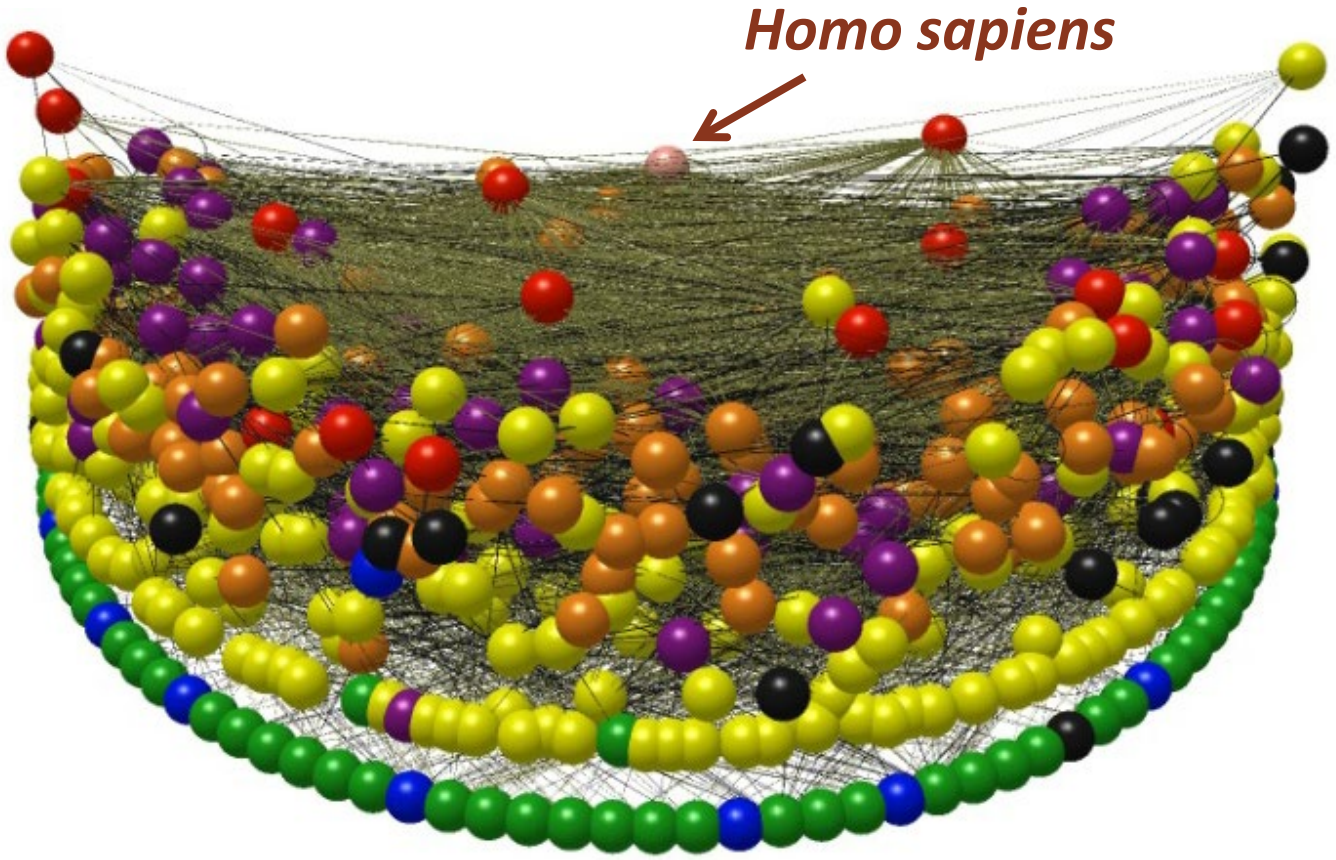
Humans Fed on 122 Taxa (24%)



How Many Prey?



96% of Marine Species Within 2 Links of Humans



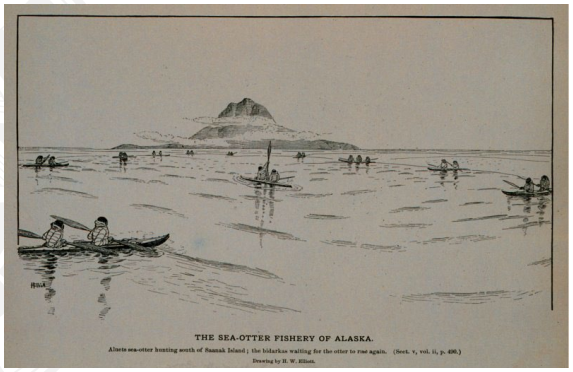
491 of 513 species

Sanak Aleut Roles:

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

Full Food Webs with Humans

Sanak Archipelago, Aleutian Islands, Alaska



Aleuts hunting sea otters near Sanak, 1870s (H.W. Elliott)

Western Desert of Australia

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

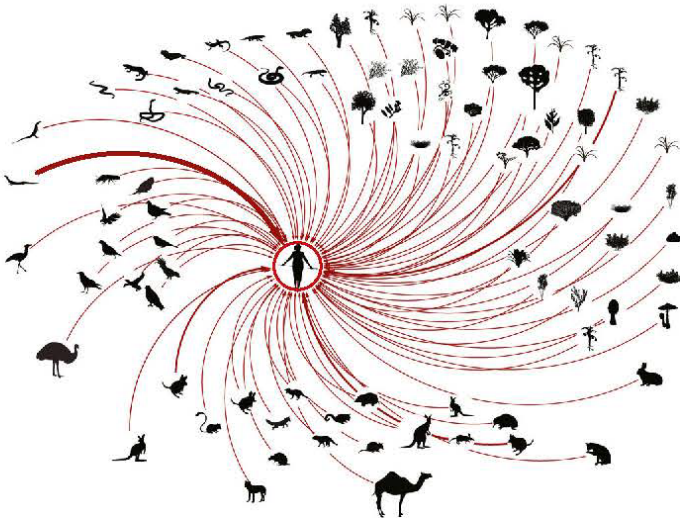
Tagus Estuary, Portugal

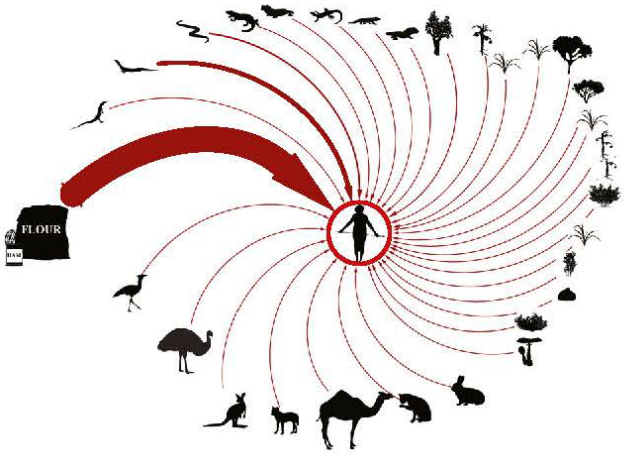
***Keeping afloat-Fishing in the Tagus Estuary* (M. Corte-Real, 2017)**

Martu Diet Before & After Removal From Homelands

(Western Desert of Australia, 1960s to 1980s)

Nomadic Period: 86 taxa → **Contemporary Period: 31 taxa**



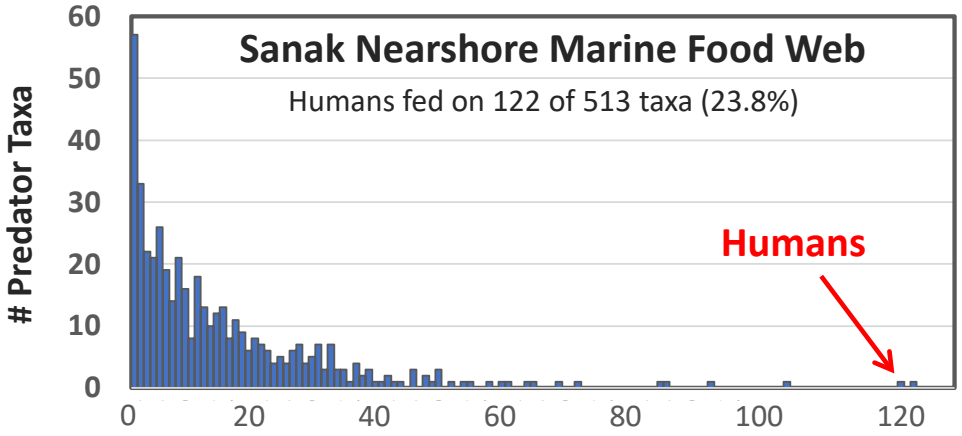


Crabtree *et al.* 2019 *Human Ecology*

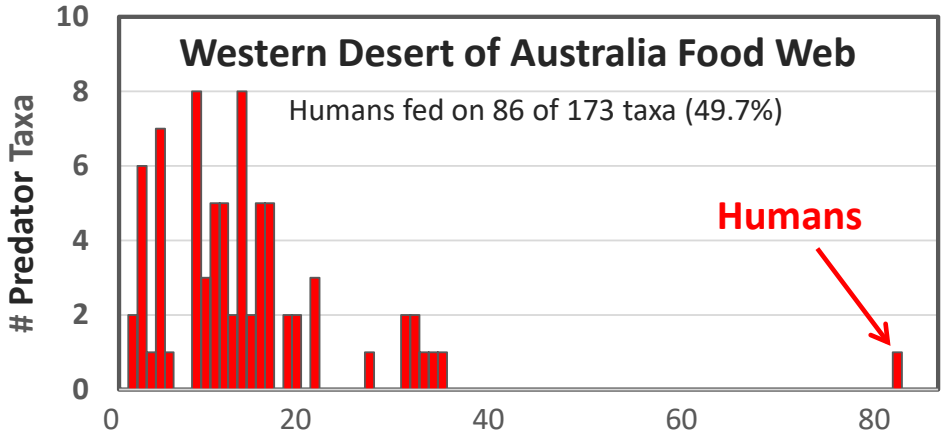
Impacts of removing nomadic human foragers/burners:

- **Simplification of food web**
- **10 species of small mammals extinct**
- **14 mammal, 3 bird, 2 reptile species threatened**
- **Invasive species common: camels, cats, foxes, donkeys**

Humans are Super-Generalists

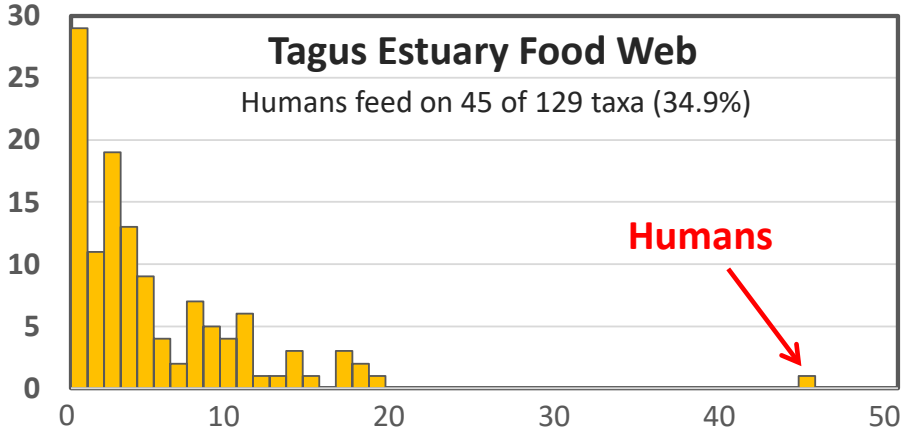


Dunne et al. 2016
Scientific Reports



Crabtree *et al.* 2019
Human Ecology

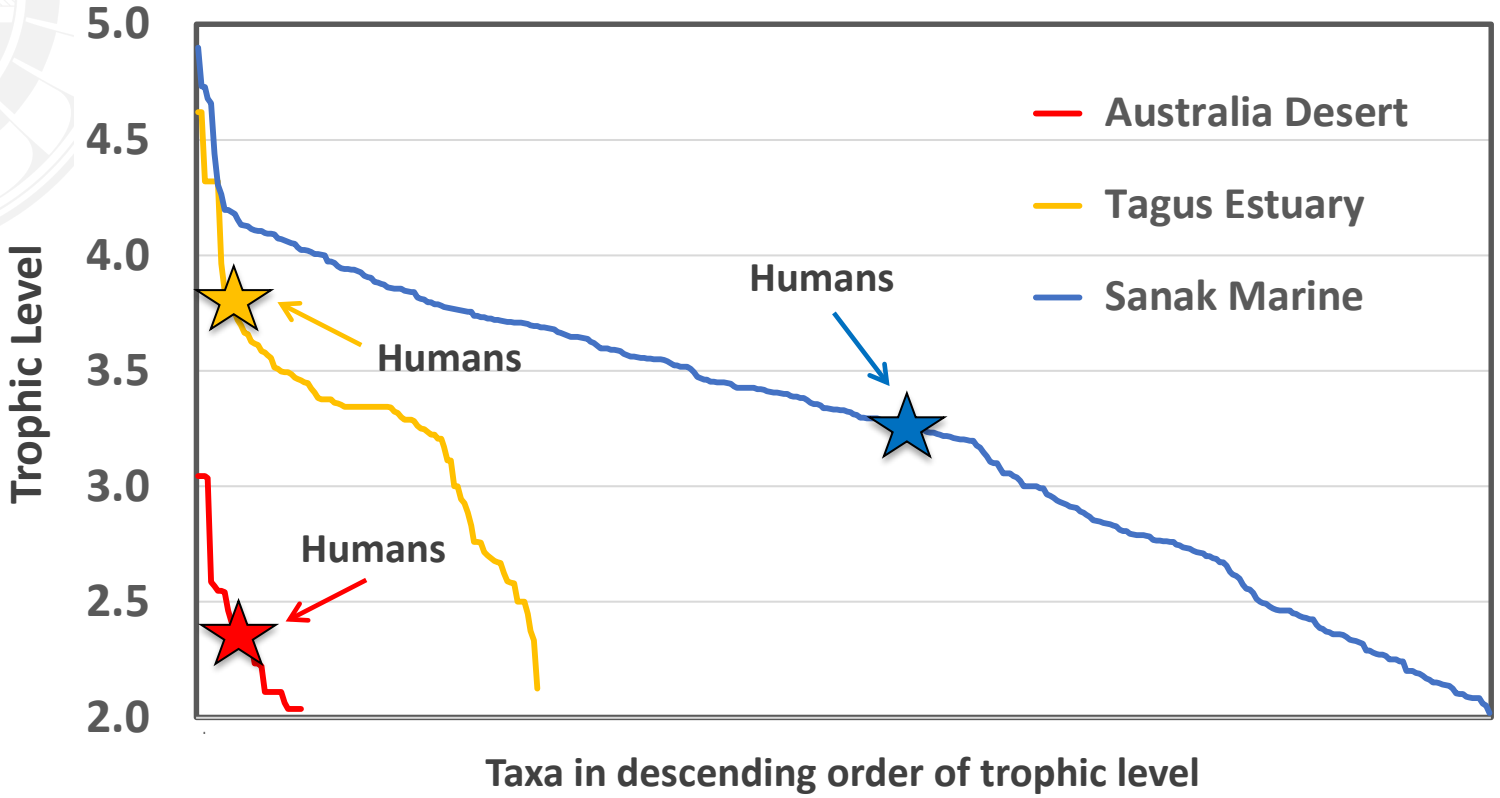
 # Prey Taxa per Predator



Vinagre *et al. 2019*
Marine Ecol Progress Series

Humans NOT at Top of Food Webs

(Why not? Humans very omnivorous)

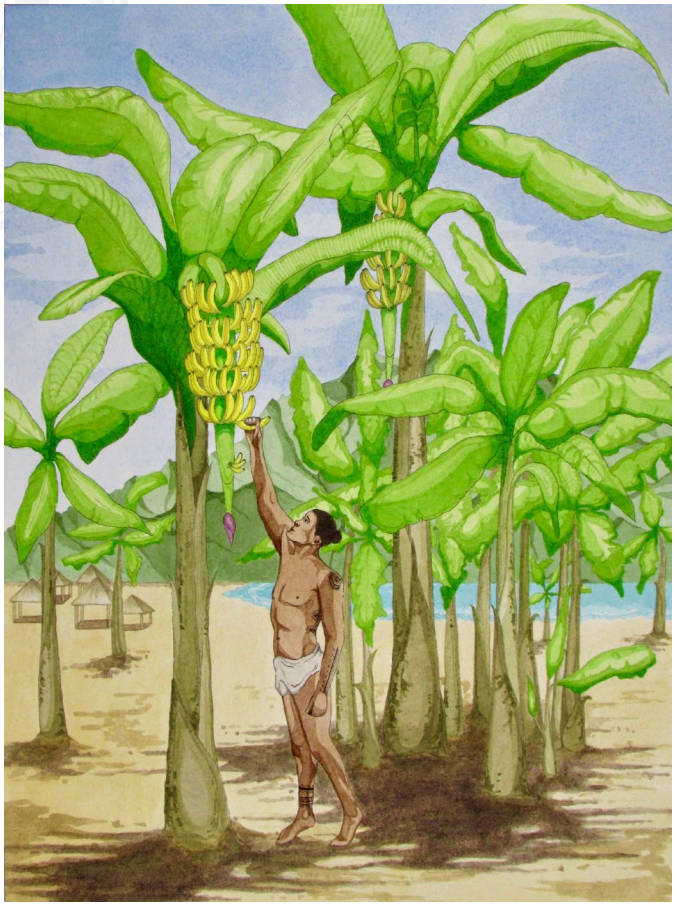


Notes:

- 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. ArchaeoEcological Networks



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

PACIFIC OCEAN

NATIONAL GEOGRAPHIC

DEVELOPED WITH SUPPORT FROM ORACLE Google



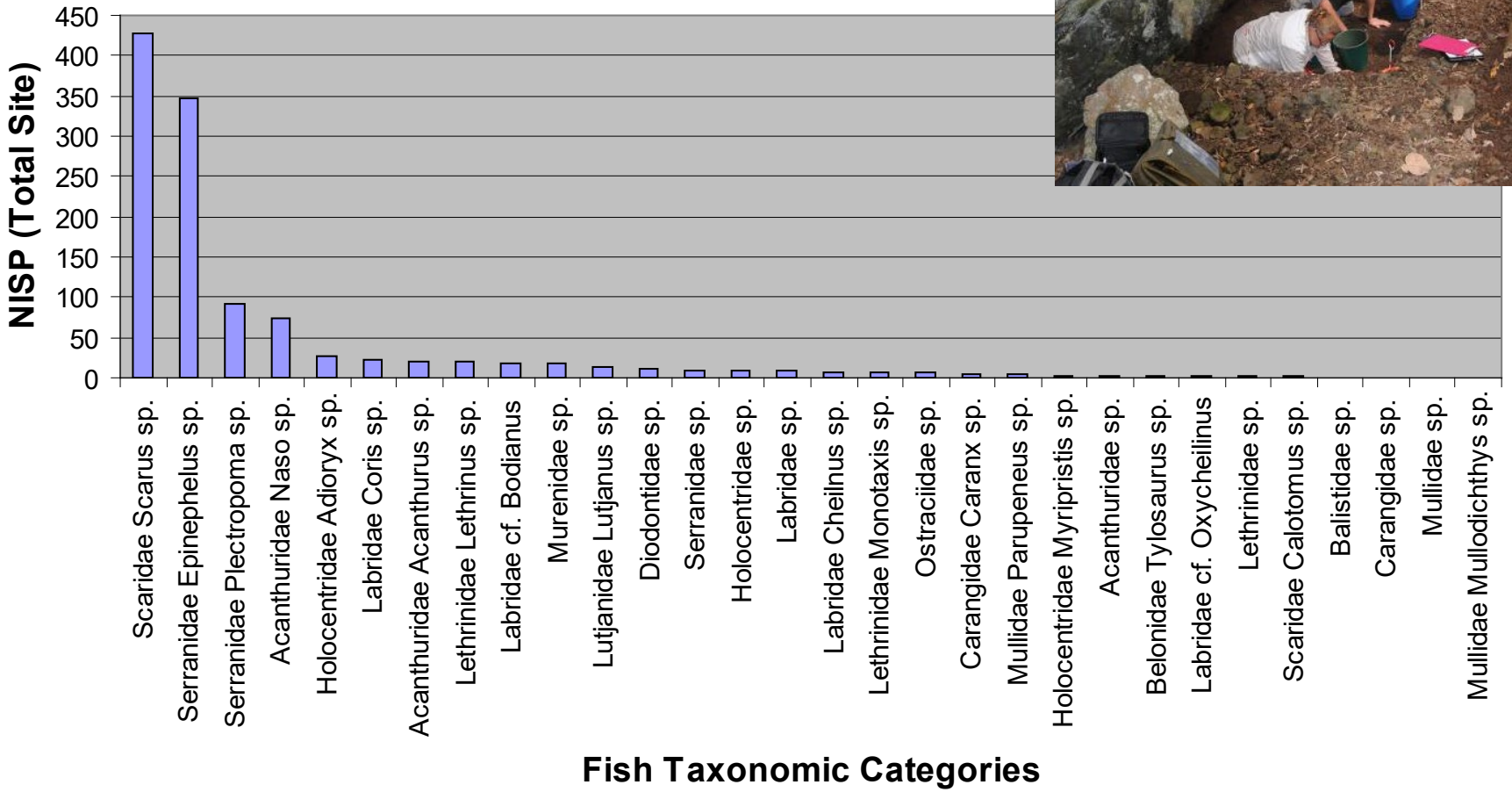






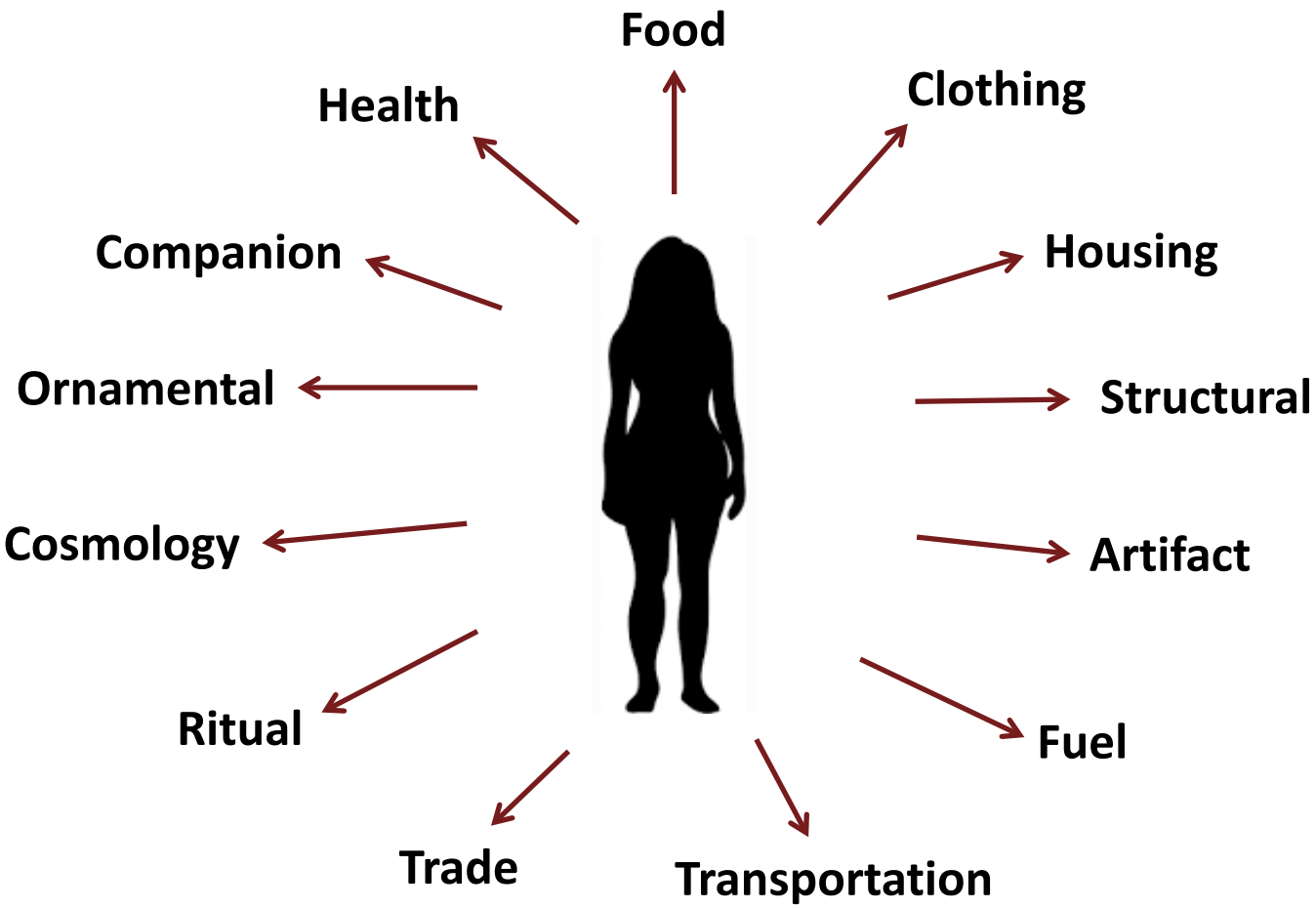


The Nenega-Iti Rockshelter



Human Interactions with Other Species

Human Interactions with Other Species



The ArchaeoEcology Project

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, Jenny Kahn

Northwest Coast, North America

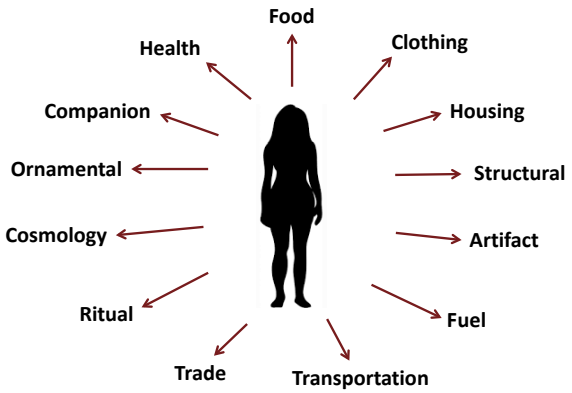
Nuu-chah-nulth people

Western Desert of Australia

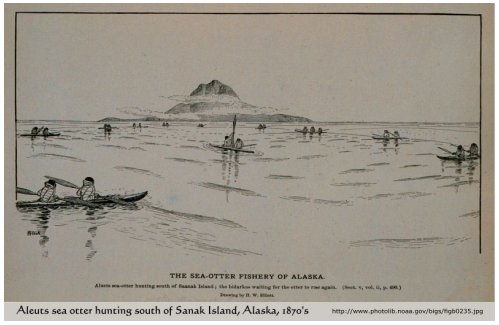
Martu people

North Atlantic Islands

Norse culture



French Polynesia



Polynesians

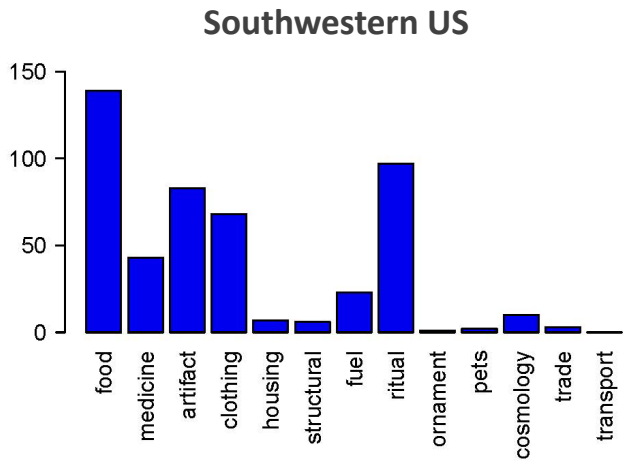
North Central Europe

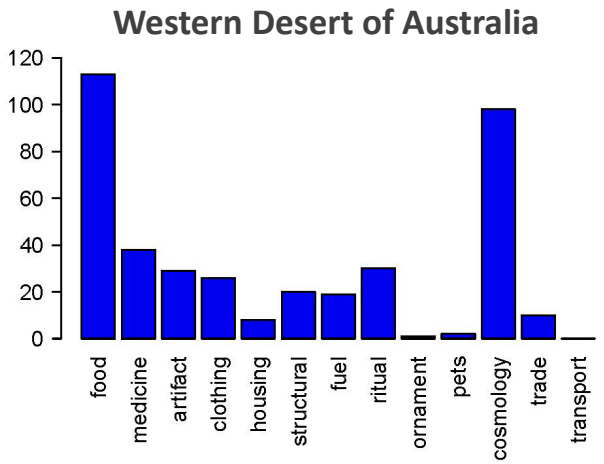
Swifterbant culture

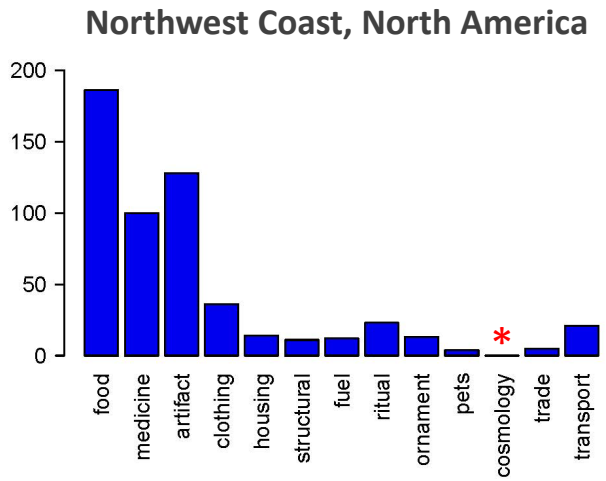
Southwestern United States

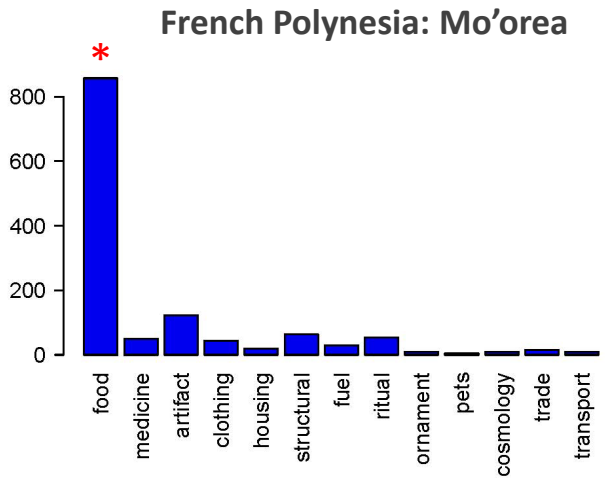
Ancestral Puebloans

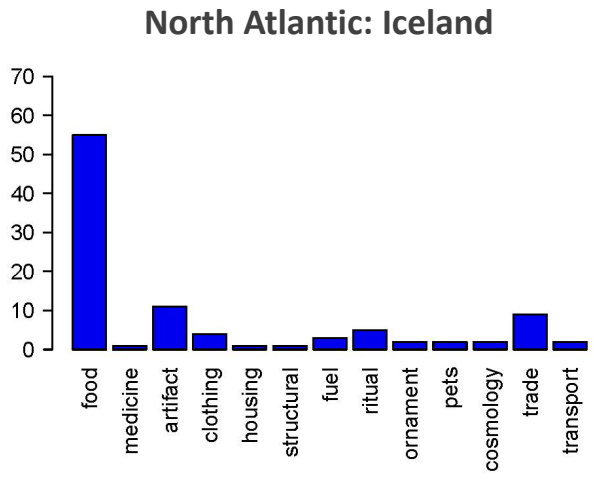
I. Use Patterns







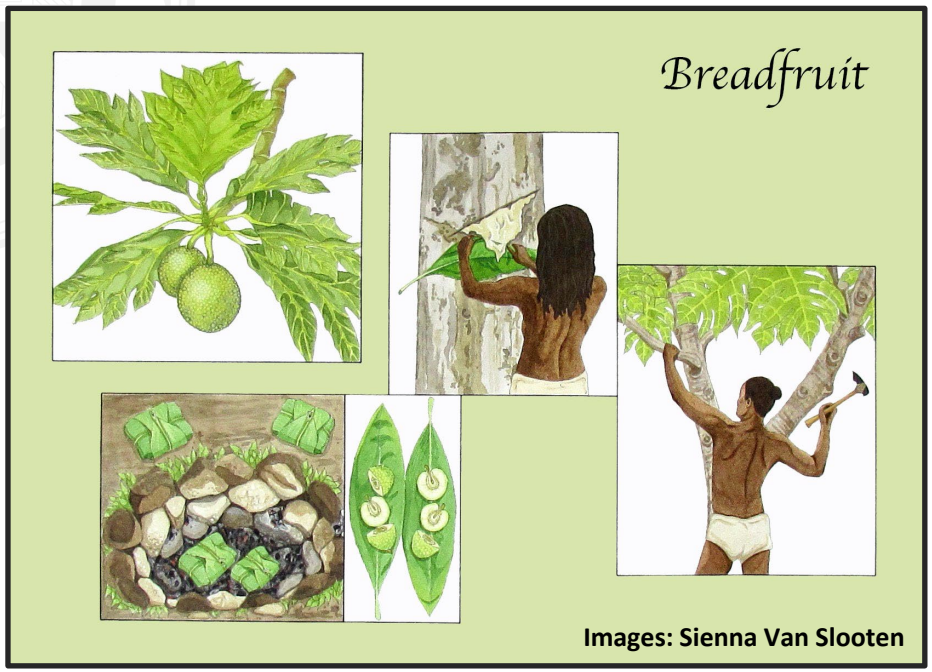




Figures: Stefani Crabtree

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

II. One Species, Many Uses



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)

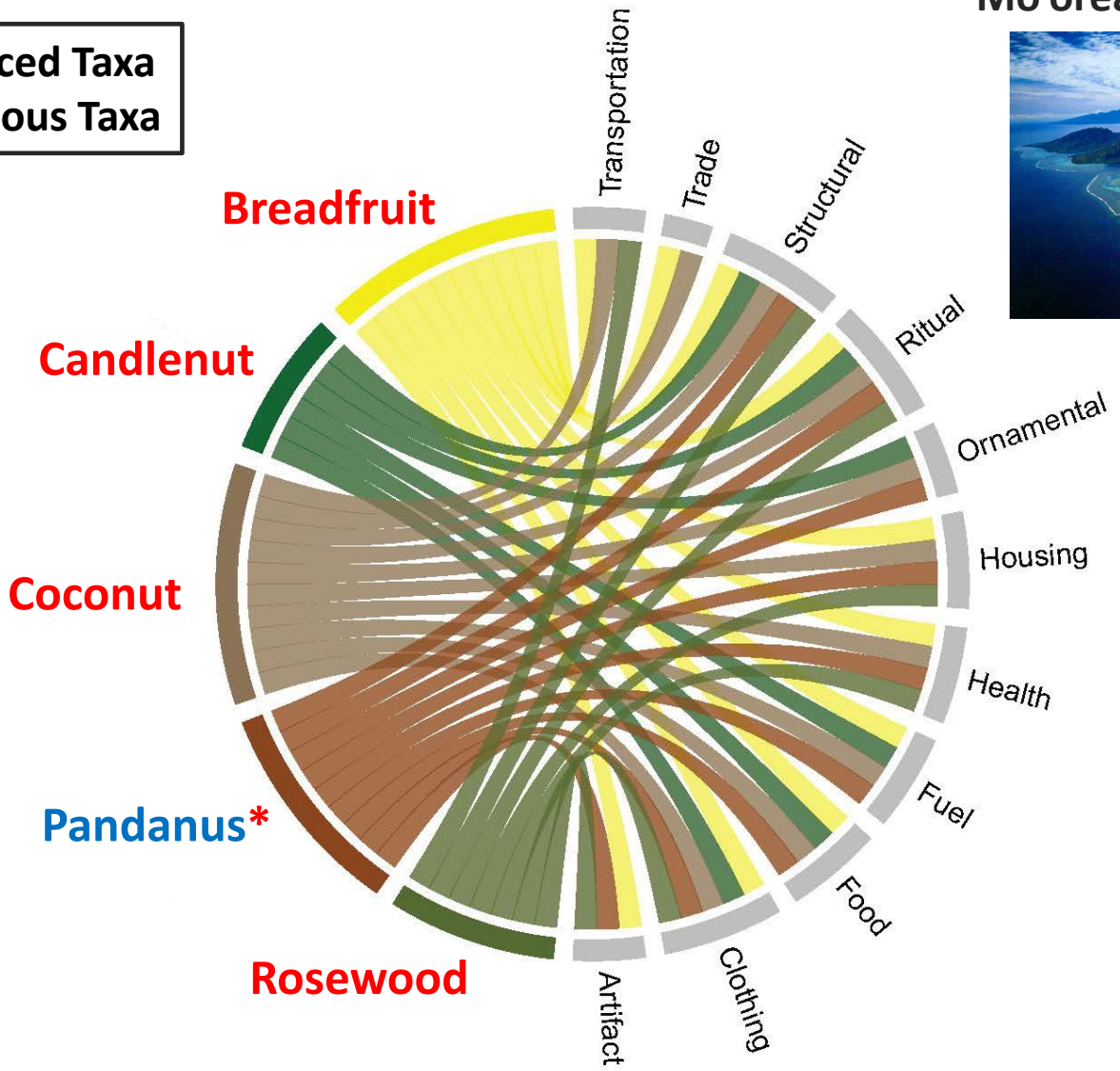
Leaves: Medicines

Fruit & Bark products also use for Trade and Taxation purposes

Top Multi-Use Species

Red: Introduced Taxa
Blue: Indigenous Taxa

Mo'orea, French Polynesia

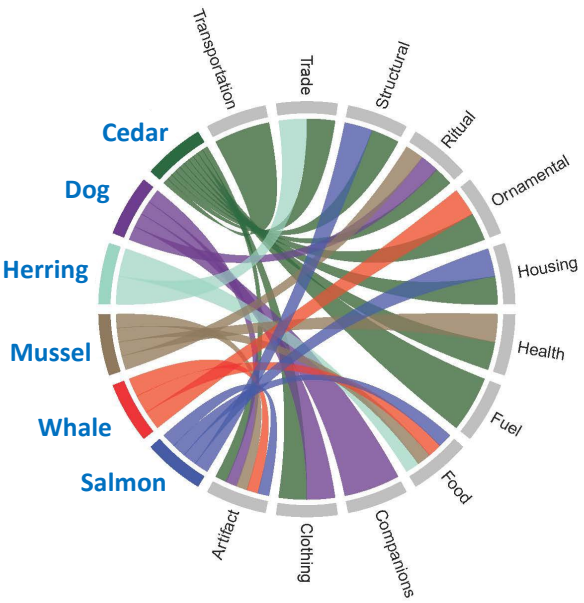


Top Multi-Use Species

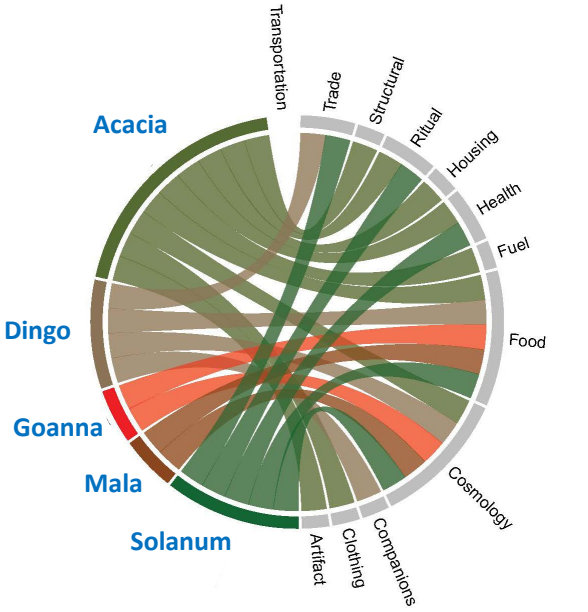
Red: Introduced Taxa
Blue: Indigenous Taxa

Figures: Stefani Crabtree

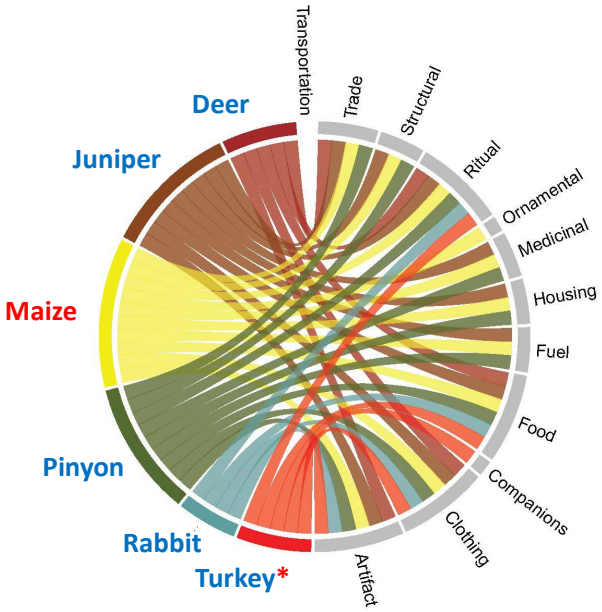
Northwest Coast NA



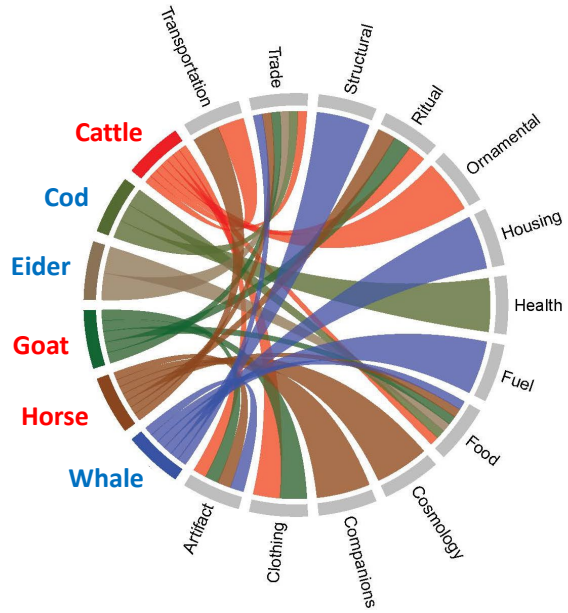
Western Desert of Australia



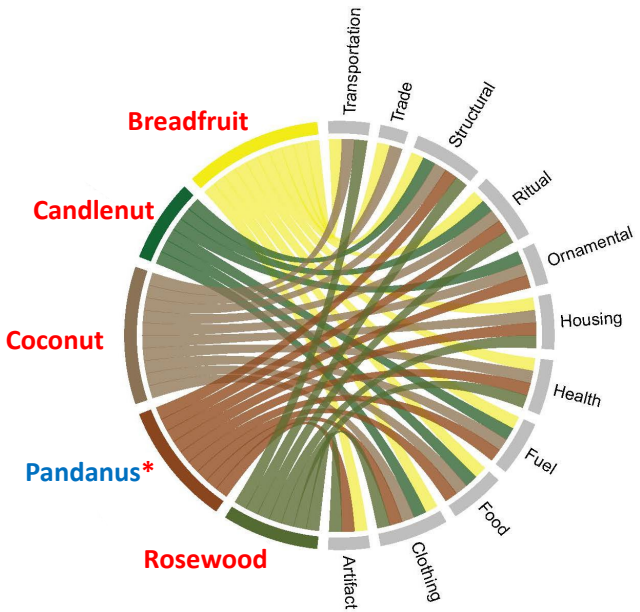
Southwestern US



Iceland



Mo'orea, French Polynesia



III. Simple vs. Complex Interactions

Human eats banana

Human eats breadfruit

Mo'orea, French Polynesia

Images: Sienna Van Slooten

Human eats berry

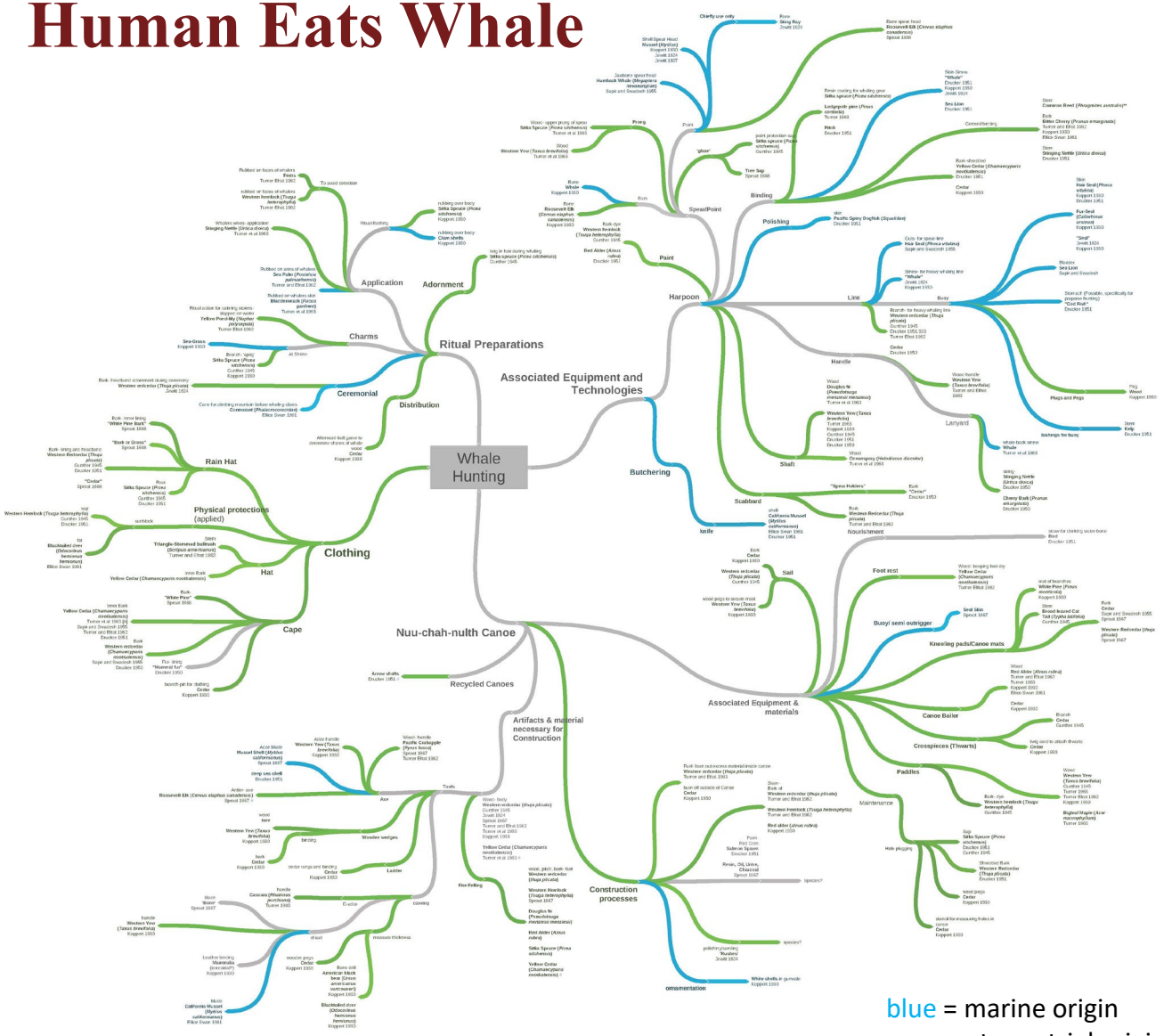
Tlingit women eating thimbleberries

Human eats whale

Nuu-chah-nulth people processing whale

Northwest Coast, North America

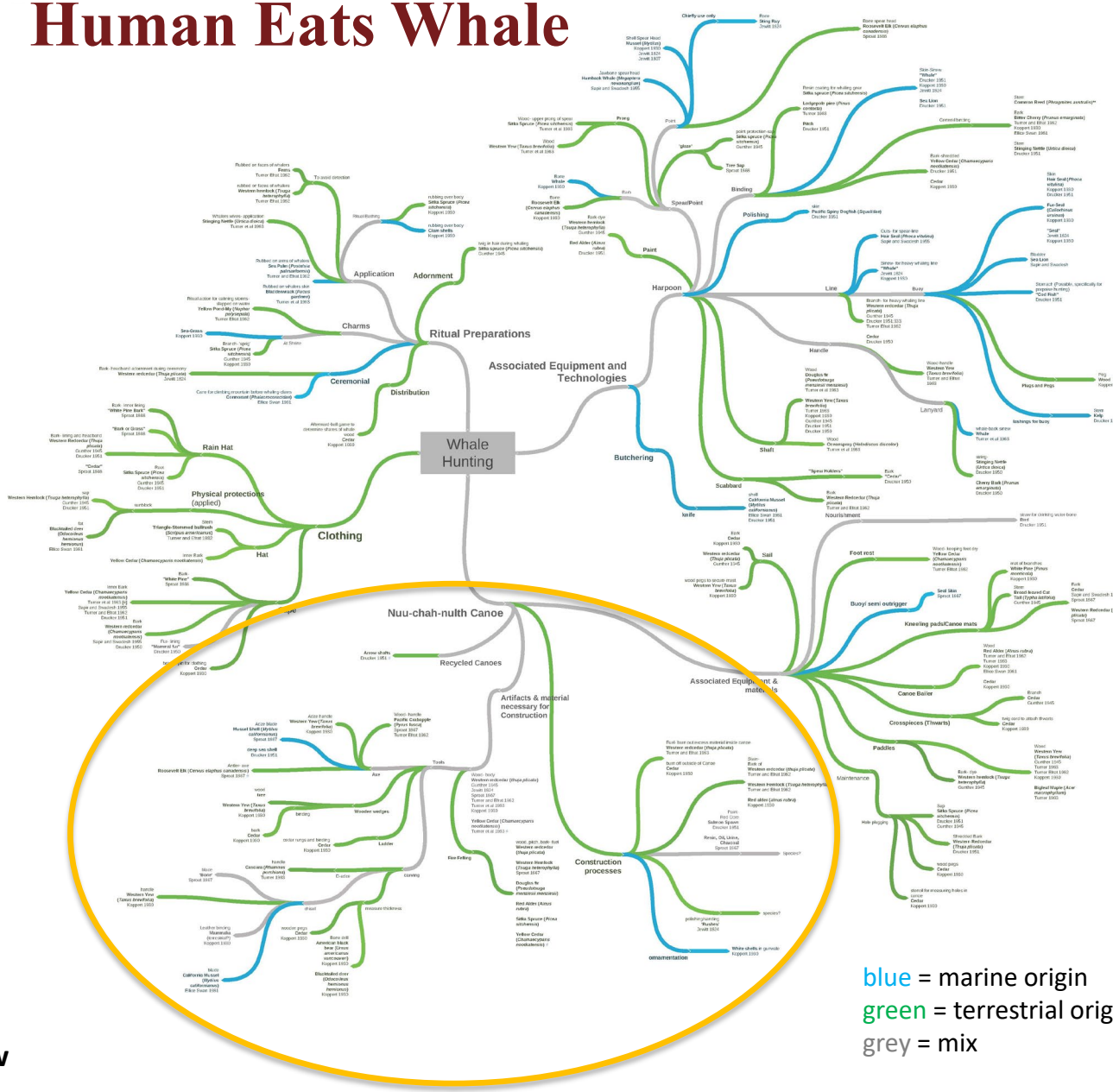
Human Eats Whale



blue = marine origin
green = terrestrial origin
grey = mix

Data & Figure: Jacob Earnshaw

Human Eats Whale



blue = marine origin
green = terrestrial origin
grey = mix

Data & Figure: Jacob Earnshaw

Making a Canoe

Animals used:

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

Plants used:

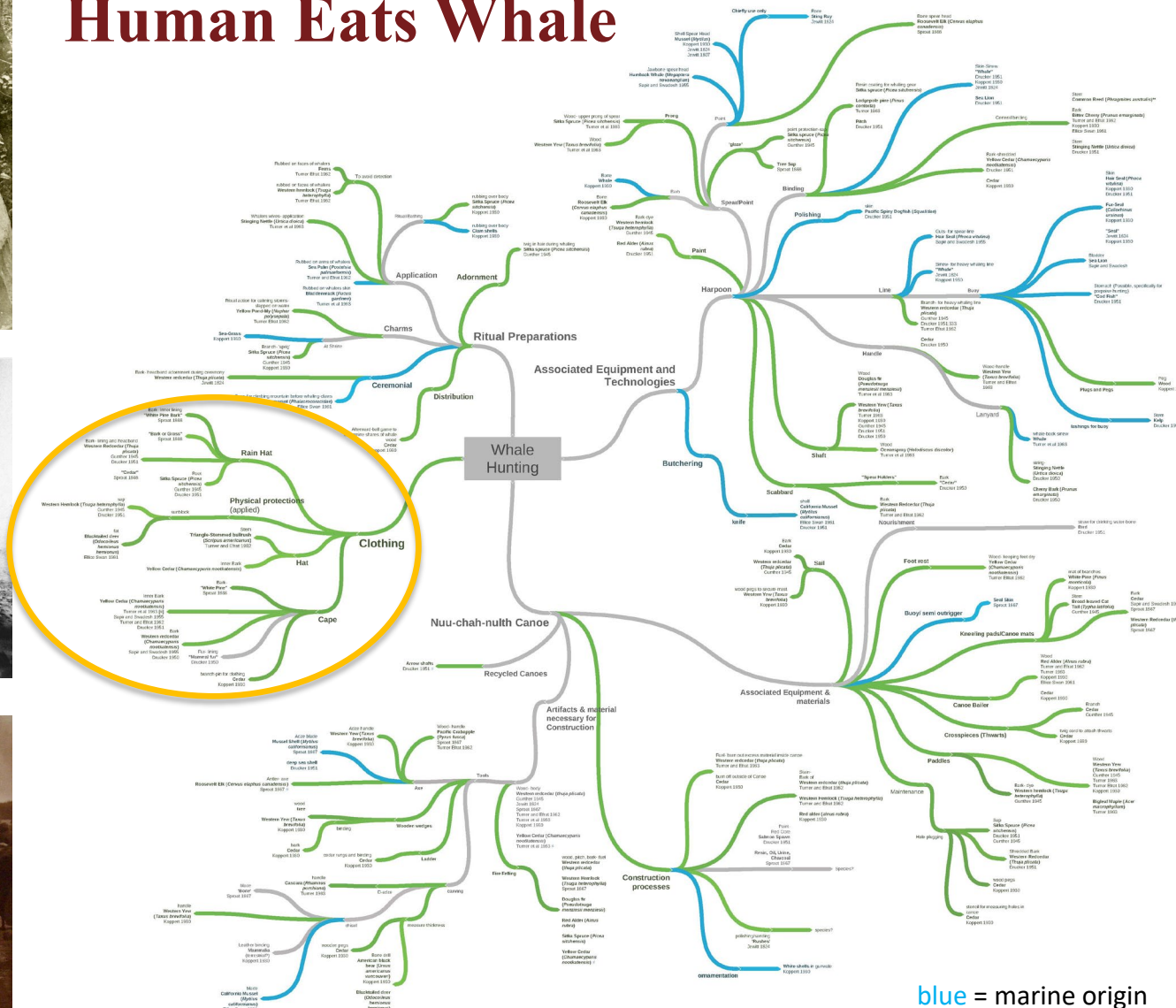
- Western Red Cedar
- Yellow Cedar
- Western Yew
- Douglas Fir
- Sitka Spruce
- Western Hemlock
- Red Alder
- Pacific Crabapple
- Rushes
- Cascara

Tech used:

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

Data & Figure: Jacob Earnshaw

Human Eats Whale



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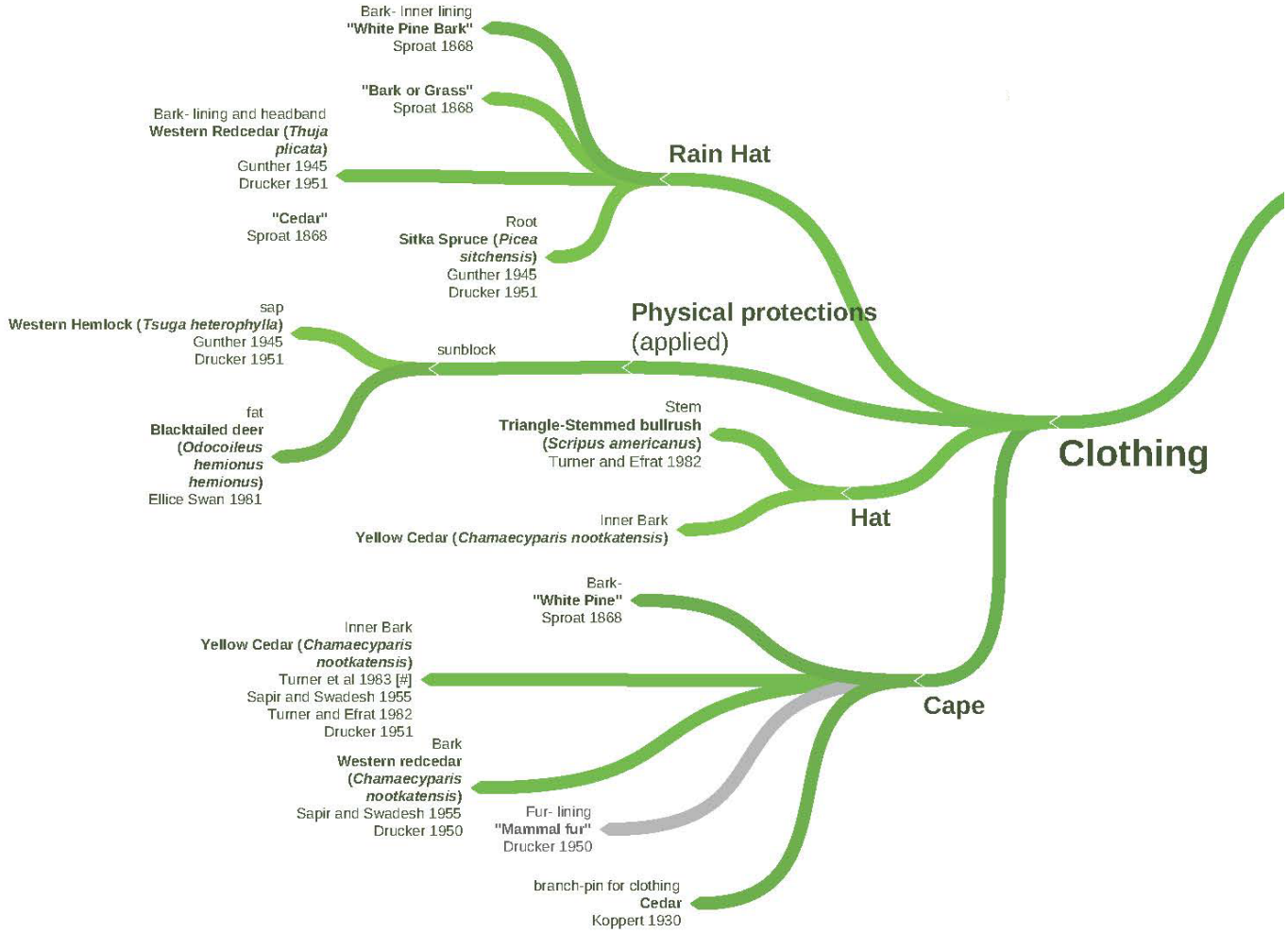
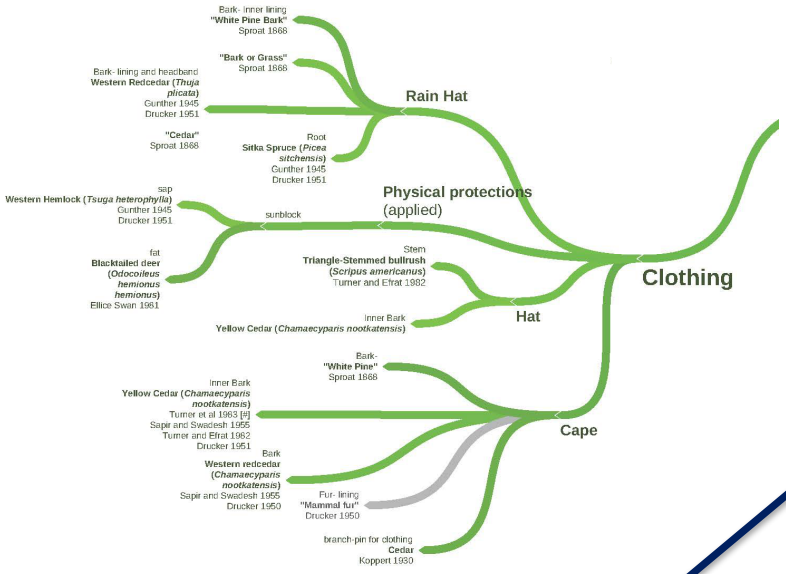
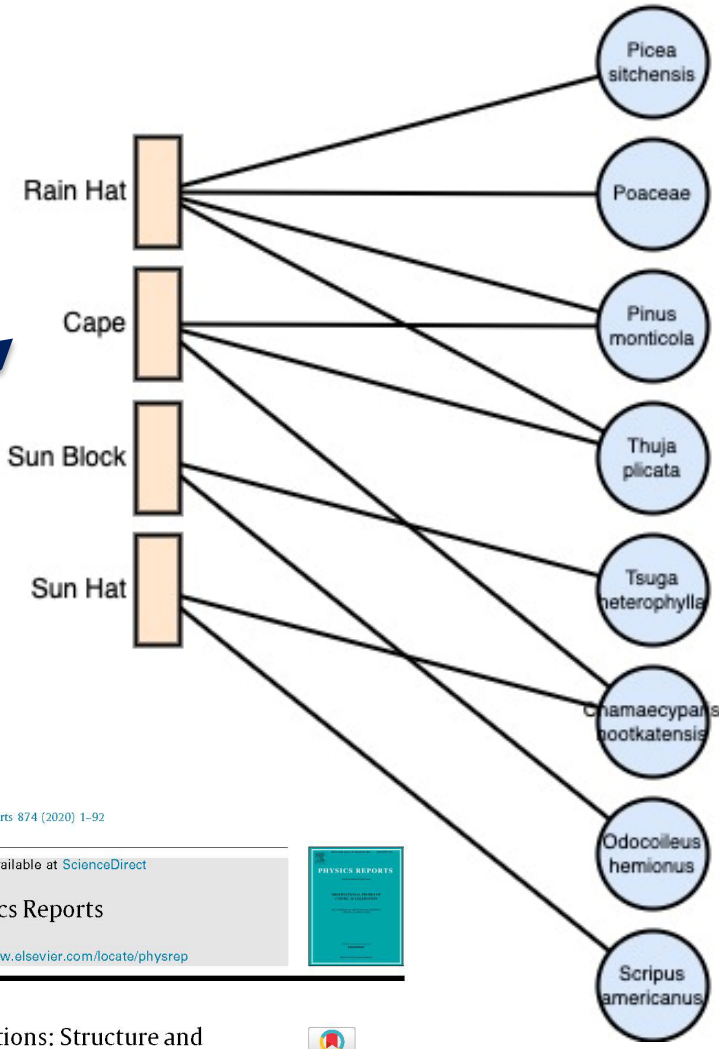
Data & Figure: Jacob Earnshaw

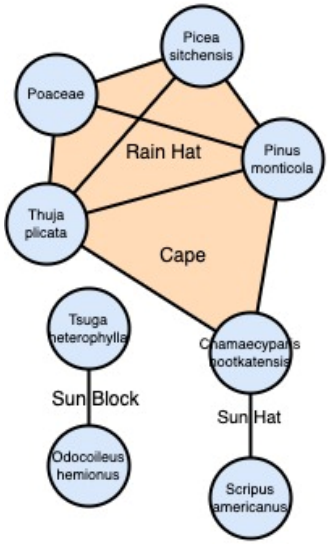

Clothing
Rain Hat
Bark- Inner lining
"White Pine Bark"
Sproat 1868
"Bark or Grass"
Sproat 1868
Bark- lining and headband
Western Redcedar (Thuja plicata)
Gunther 1945
Drucker 1951
"Cedar"
Sproat 1868
Root
Sitka Spruce (Picea sitchensis)
Gunther 1945
Drucker 1951
Physical protections (applied)
sap
Western Hemlock (Tsuga heterophylla)
Gunther 1945
Drucker 1951
sunblock
fat
Blacktailed deer (Odocoileus hemionus hemionus)
Ellice Swan 1981
Hat
Stem
Triangle-Stemmed bullrush (Scripus americanus)
Turner and Efrat 1982
Inner Bark
Yellow Cedar (Chamaecyparis nootkatensis)
Cape
Bark-
"White Pine"
Sproat 1868
Inner Bark
Yellow Cedar (Chamaecyparis nootkatensis)
Turner et al 1983 [#]
Sapir and Swadesh 1955
Turner and Efrat 1982
Drucker 1951
Bark
Western redcedar (Chamaecyparis nootkatensis)
Sapir and Swadesh 1955
Drucker 1950
Fur- lining
"Mammal fur"
Drucker 1950
branch-pin for clothing
Cedar
Koppert 1930



Bipartite Facet Representation



Simplicial Complex



Physics Reports 874 (2020) 1–92

Contents lists available at ScienceDirect

Physics Reports

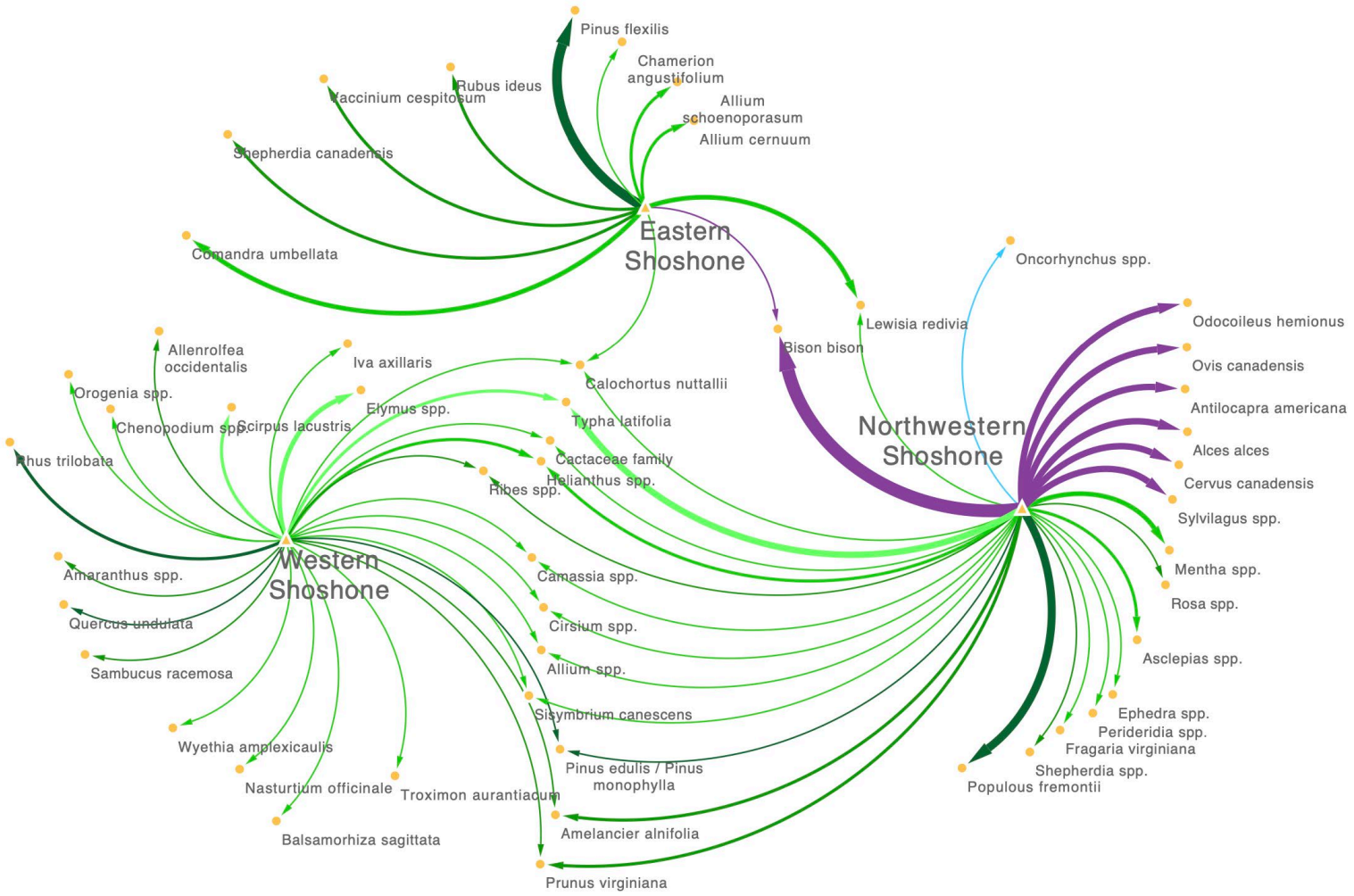
journal homepage: www.elsevier.com/locate/physrep

Networks beyond pairwise interactions: Structure and dynamics

Federico Battiston [a,*], Giulia Cencetti [b], Iacopo Iacopini [c,d], Vito Latora [c,e,f,g], Maxime Lucas [h,i,j], Alice Patania [k], Jean-Gabriel Young [l], Giovanni Petri [m,n]

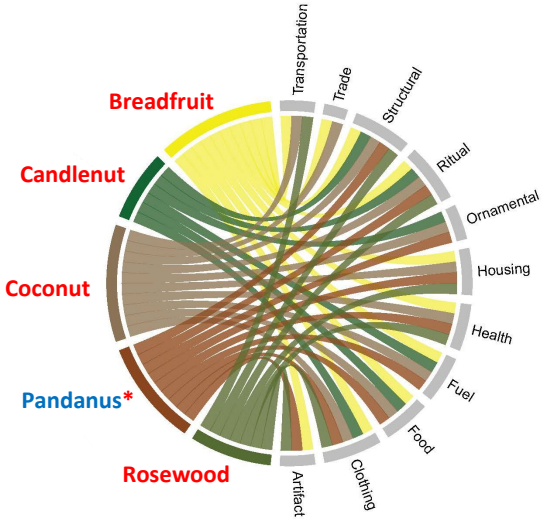
Figures: Spencer Wood

New Datasets Being Compiled



Data & Figure: Patrick Kelly (USU)

ArchaeoEcological Networks:



- Research agenda: How humans interact with biodiversity through space and time
- First time comprehensive data of this type compiled/analyzed
- Human interaction 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

SCIENTIFIC REPORTS

OPEN

The roles and impacts of human hunter-gatherers in North Pacific marine food webs

Received: 16 July 2015
Accepted: 19 January 2016

Jennifer A. Dunne[1], Herbert Maschner[2], Matthew W. Betts[3], Nancy Huntly[4], Roly Russell[5], Richard J. Williams[6] & Spencer A. Wood[7,8]

2016

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applied sciences

MDPI

Article

Reconstructing Human-Centered Interaction Networks of the Swifterbant Culture in the Dutch Wetlands: An Example from the ArchaeoEcology Project

Philip Verhagen [1,*], Stefani A. Crabtree [2,3], Hans Peeters [4] and Daan Raemaekers [4]

2021

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

ELSEVIER

Reconstructing Ancestral Pueblo food webs in the southwestern United States

Stefani A. Crabtree [a, *], Lydia J.S. Vaughn [b], Nathan T. Crabtree [c]

2017

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frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 25 February 2022
doi: 10.3389/fevo.2021.750351

Social and Ecological Factors Affect Long-Term Resilience of Voyaging Canoes in Pre-contact Eastern Polynesia: A Multiproxy Approach From the ArchaeoEcology Project

Jennifer G. Kahn[1], Abigail Buffington[1], Claudia Escue[1] and Stefani A. Crabtree[2,3]*

2022

Human Ecology
https://doi.org/10.1007/s10745-019-0053-z

CrossMark

Subsistence Transitions and the Simplification of Ecological Networks in the Western Desert of Australia

Stefani A. Crabtree [1,2,3] · Douglas W. Bird [1] · Rebecca Bliege Bird [1]

2019

Global Environmental Change 78 (2023) 102597

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

ELSEVIER

Check for updates

Why are sustainable practices often elusive? The role of information flow in the management of networked human-environment interactions

Stefani A. Crabtree [a,*], Jennifer G. Kahn [b], Rowan Jackson [c], Spencer A. Wood [d], Iain McKechnie [e], Philip Verhagen [f], Jacob Earnshaw [e], Patrick V. Kirch [g], Jennifer A. Dunne [h], Andrew J Dugmore [c,i]

2023

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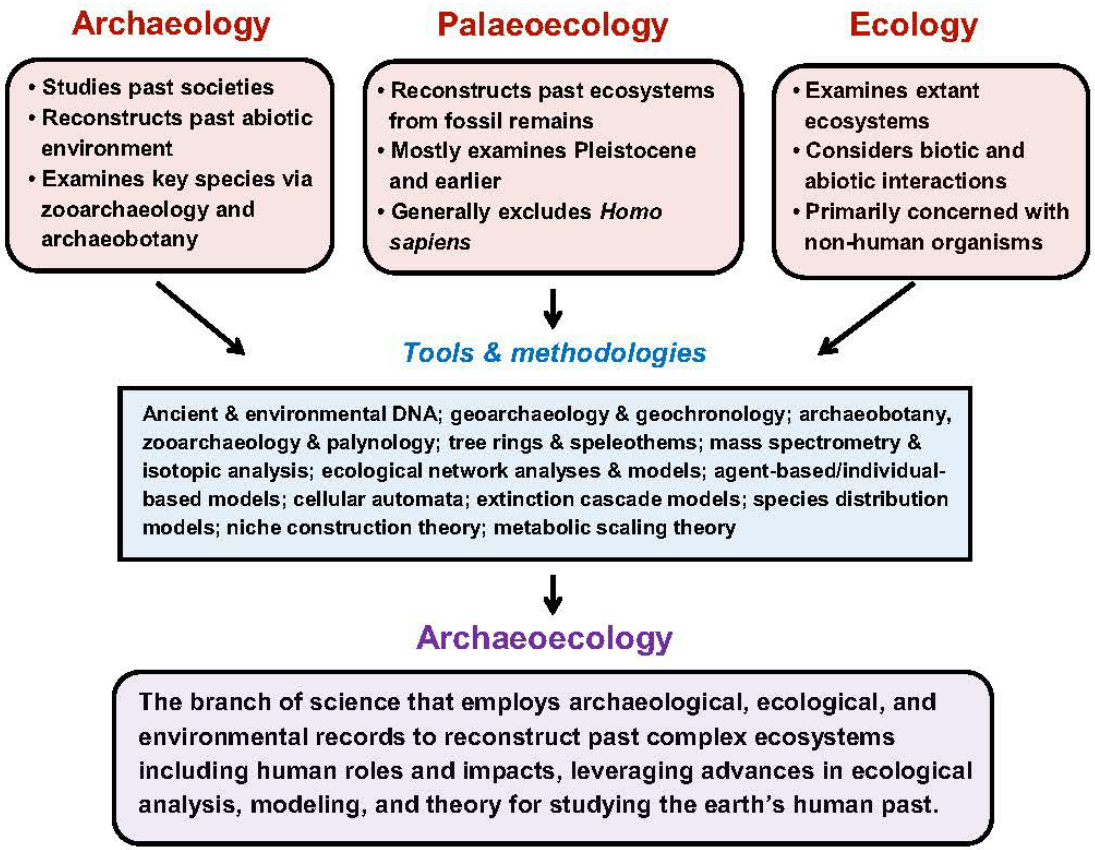
Trends in
Ecology & Evolution

Opinion

Towards a science of archaeoecology

Stefani A. Crabtree[1,2,3,4,5,*] and Jennifer A. Dunne[3,*]

2022



Thanks!

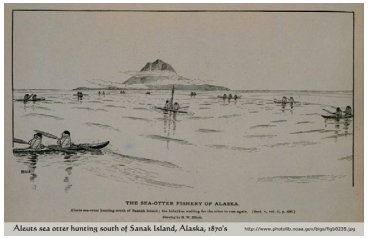
SANTA FE INSTITUTE

NSF

Coalition for Archaeological Synthesis

ASU-SFI Center for Biosocial Complex Systems

Jenny Kahn, Pat Kirch, Spencer Wood, Dieta Hanson



Iain McKechnie, Jacob Earnshaw, Spencer Wood

Stefani Crabtree

Stefani Crabtree Rebecca Bliege-Bird

Andy Dugmore, George Hambrecht, Richard Bankoff

Philip Verhagen