



ISCO Interdisciplinary Science Conference

OIST, Okinawa – Japan  
February 27, 2023

Neil Davies, UC Berkeley  
ndavies@berkeley.edu



## Island Earth

Island Digital Ecosystem Avatars | Infrastructure for Democratic Ecological Actions (IDEAs)



# 1. Island Earth

Context: Science & Society (Polynesia)

People, Ocean, Planet



# Island Earth



Image IBCAO  
© 2013 Cnes/Spot Image  
Image © 2013 TerraMetrics  
Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
51°45'06.70" N 1°15'28.06" W elev -65 m



Eye alt 12084.24 km



x Moorea

© 2013 Cnes/Spot Image

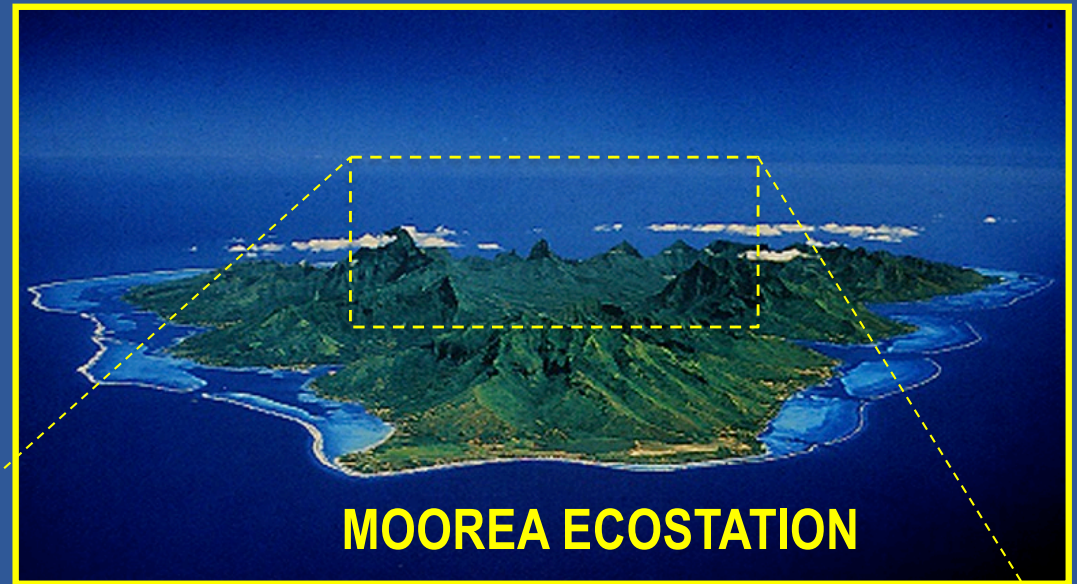
Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
17°32'19.83" S 149°49'46.43" W elev -3062 m



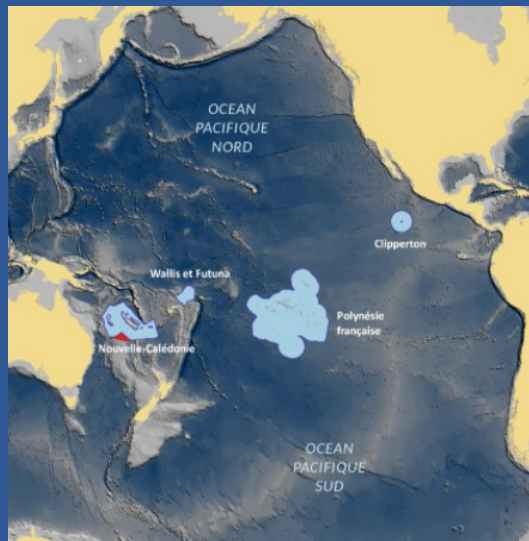
Eye alt 12649.02 km







## French Polynesia



**limitesmaritimes.gouv.fr**  
French national portal of maritime limits







Research, Higher Education, & Innovation Council of French Polynesia



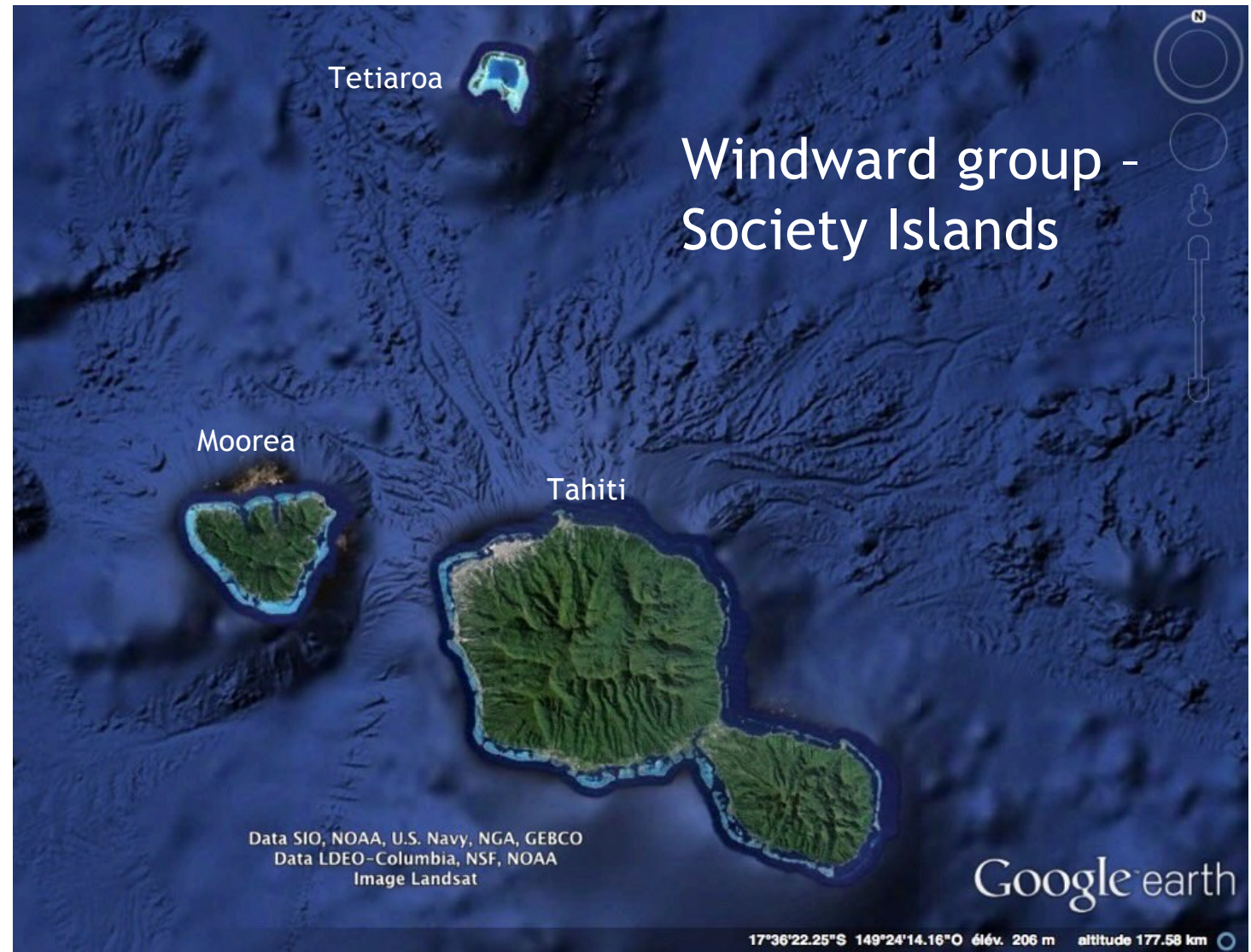






# Scales of Complexity

- **Tetiaroa**
  - pop ~150
  - 6.5 km<sup>2</sup> (land)
  - “flat” atoll
- **Moorea**
  - pop ~17,000
  - 134 km<sup>2</sup>
  - 1,207 m
- **Tahiti**
  - pop ~184,000
  - 1,045 km<sup>2</sup>
  - 2,241 m







**Gump South Pacific  
Research Station**  
*Moorea, French Polynesia*

Established 1985



Berkeley  
UNIVERSITY OF CALIFORNIA

UCSB

UCLA

UC SANTA CRUZ

CSUN.



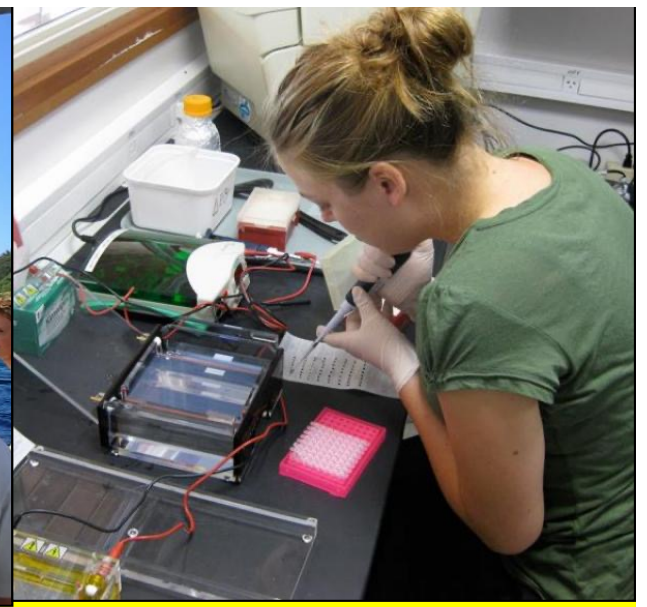
UNIVERSITY  
OF  
CALIFORNIA



## Mission: Research







## Interdisciplinary

Physical/Chemical, Bio/Ecological, Social/Humanities



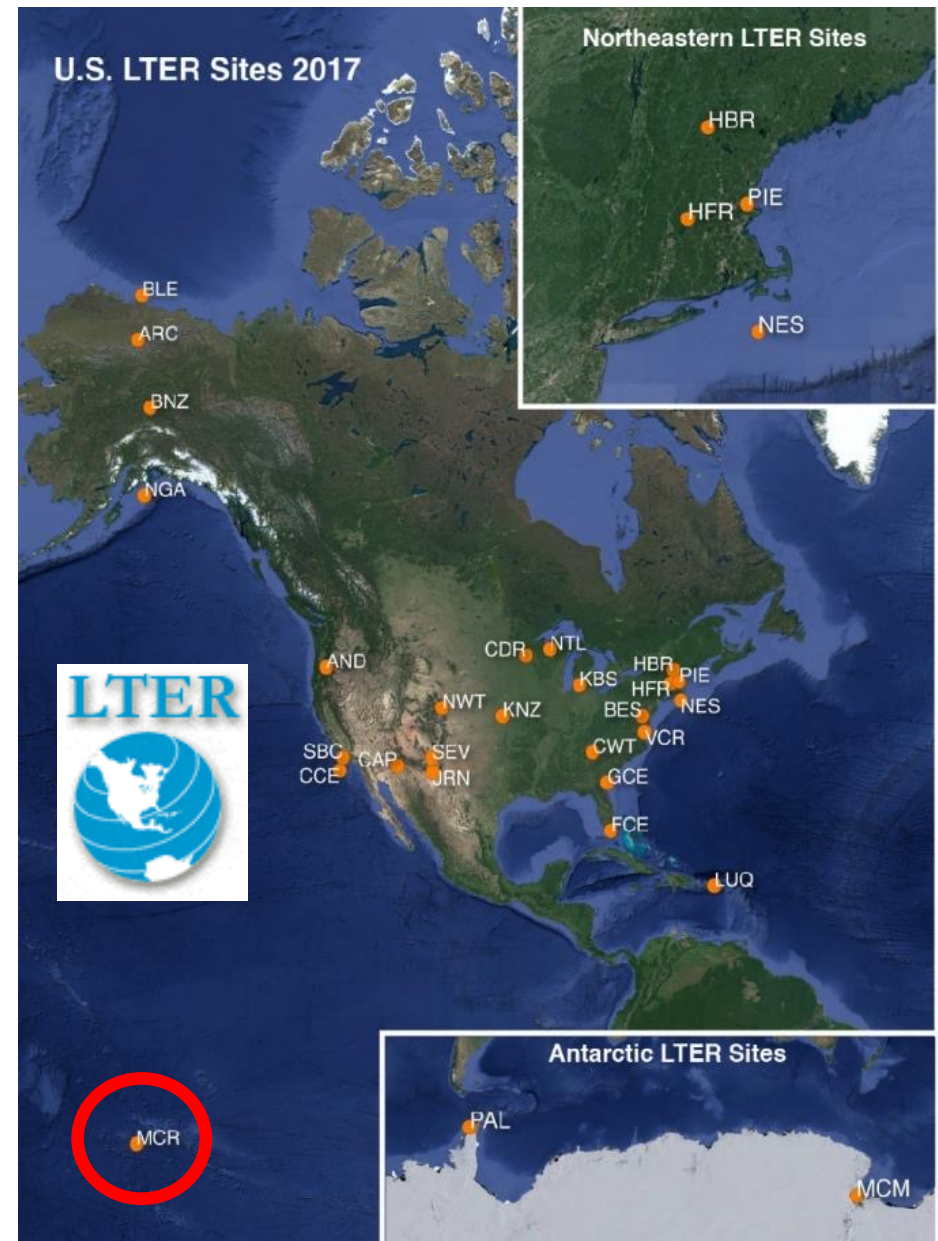




Established 2004  
at Gump Station

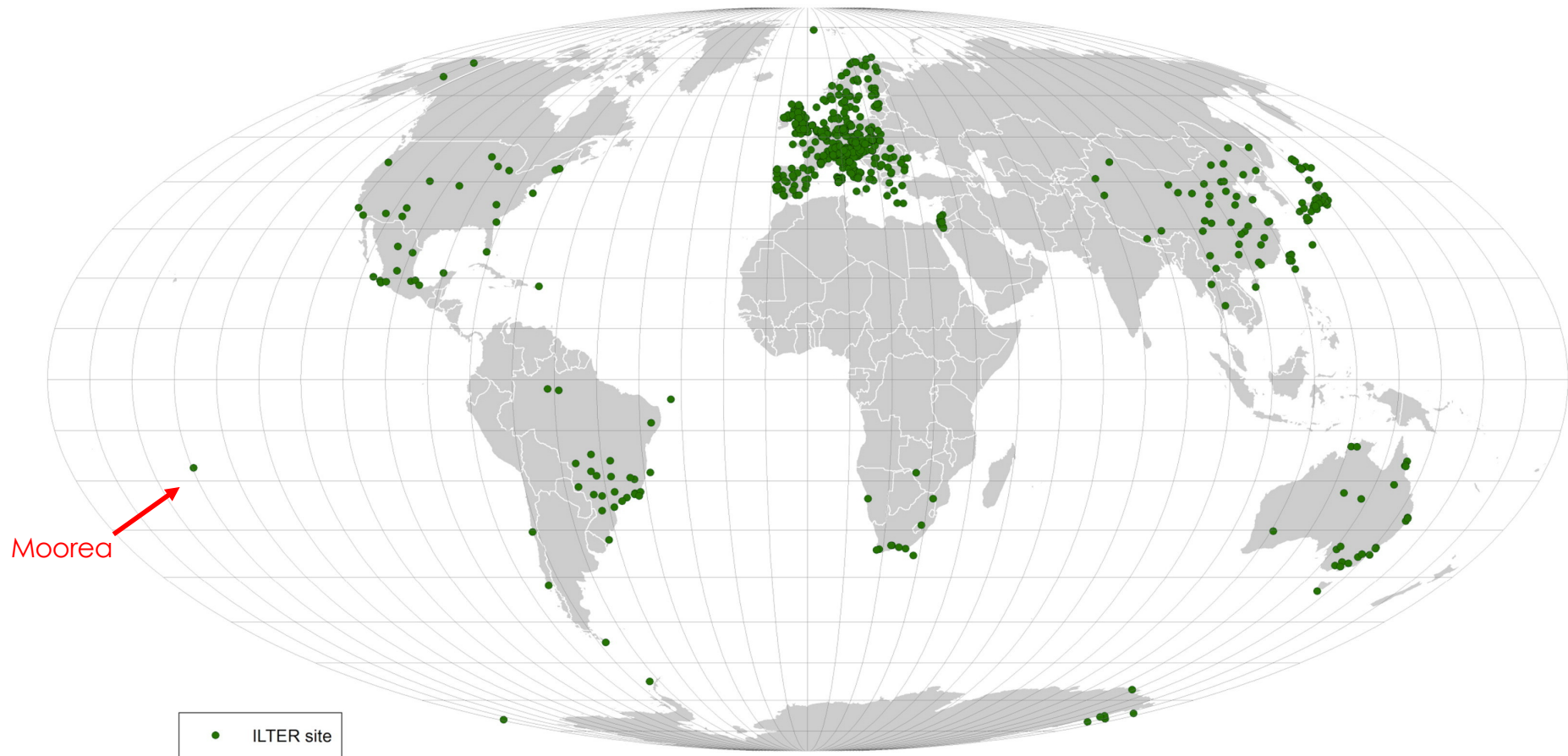


> 2000 researchers at 28 sites  
who apply long-term observation,  
experiments, and modeling to  
understand how ecological  
systems function over decades



# Global Collaboration

## International Long-term Ecological Research Network (ILTER)



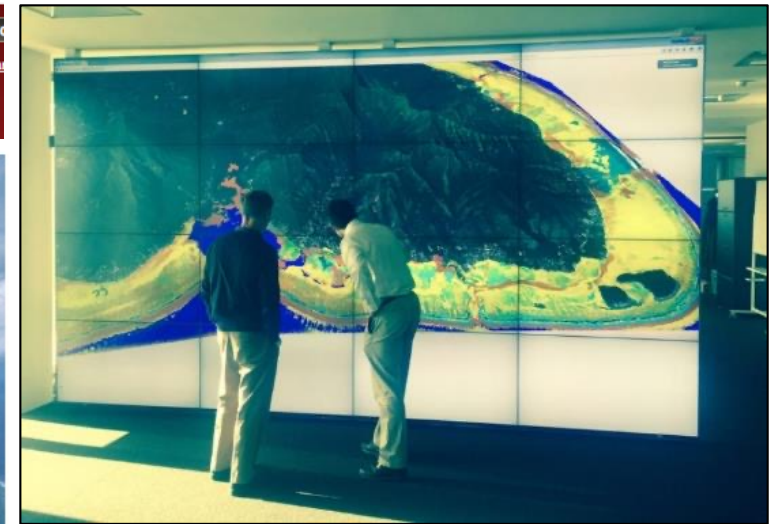
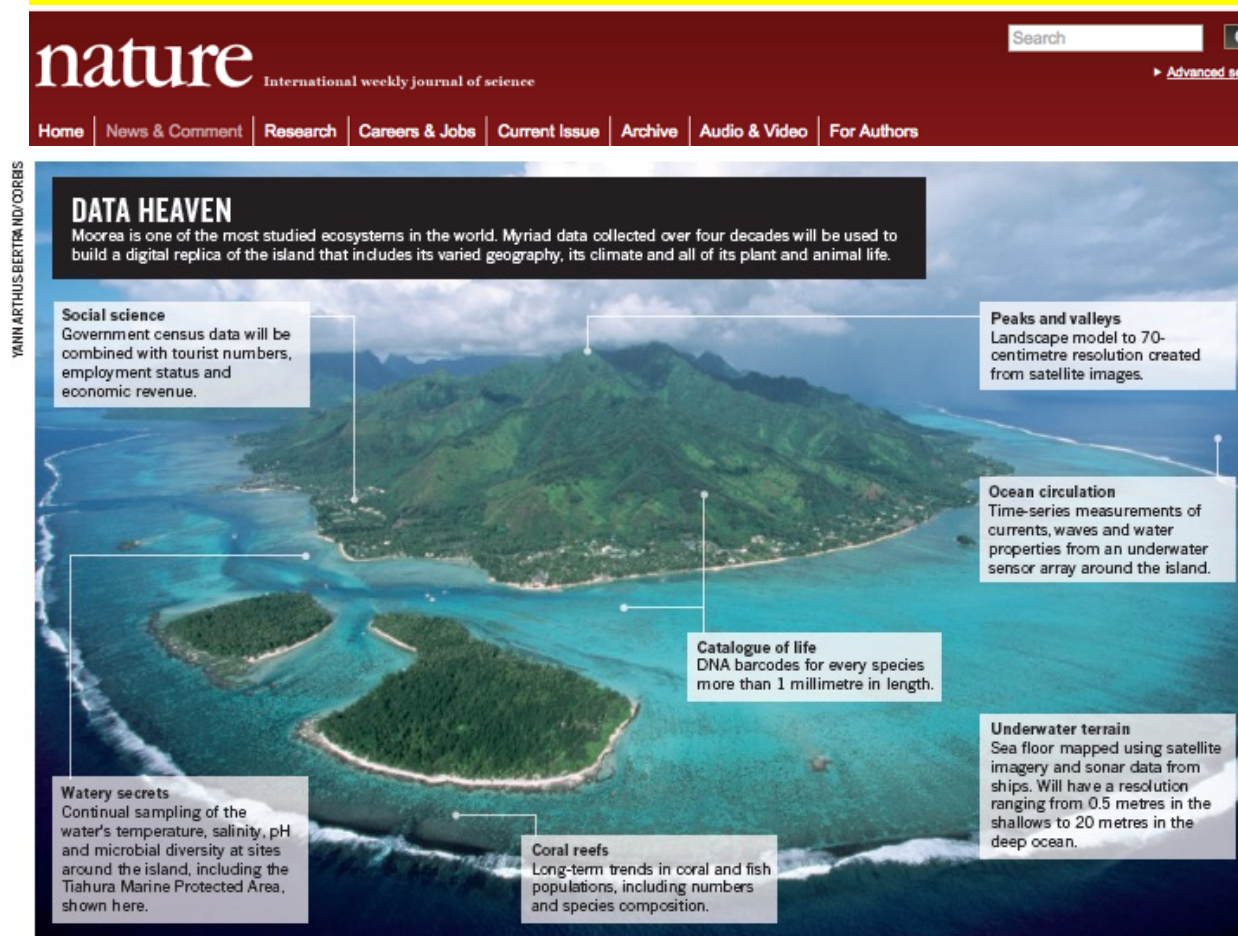
**Sources:** Site information: <https://data.ilter-europe.net/deims/>  
Administrative boundaries: <http://www.gadm.org/>

Datum: WGS 84  
Projection: Mollweide (EPSG: 54009)

© Environment Agency Austria 2017



# Moorea has become a model system for global change & sustainability science



The Moorea IDEA Project is developing climate change scenario forecasting models



Researchers mapping the sea floor around Moorea

## ENVIRONMENT

# Tropical paradise inspires virtual ecology lab

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

Cressey (2015) Tropical paradise inspires virtual ecology lab. *Nature* **517**:255–256.



# Mission: Higher Education



UCLA Marine Biology Quarter  
2014



## Key UC Undergraduate courses taught at the Gump Station

- Fall – UC Berkeley: **Biology & Geomorphology of Tropical Islands**
- Winter/Spring – UC Berkeley: **Island Sustainability** Semester
- Spring – UCLA: **Marine Biology** Quarter
- Summer – UCLA: The **Diversity Project** Summer Course





## Graduate student research training at the Gump Station

NSF Research Experience for Undergraduates (REU) awardees



PhD candidate conducting her dissertation research



PhD candidate and his under-graduate assistant trapping mosquitoes

PhD candidate and her undergraduate assistant with their faculty advisor





## Mission: Outreach & Public Service







## Science-Society Dialogue







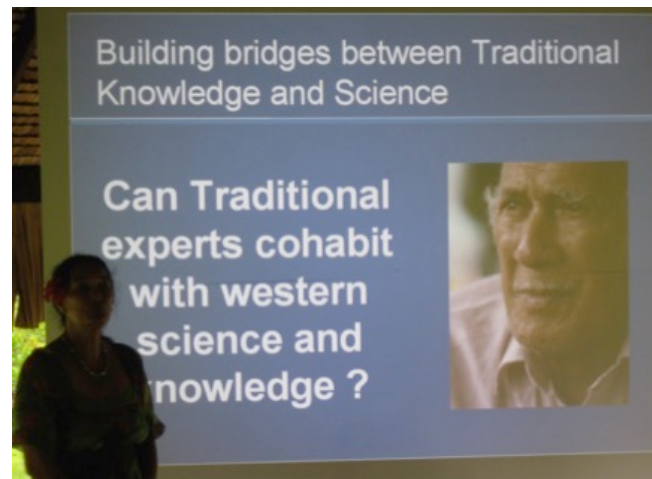
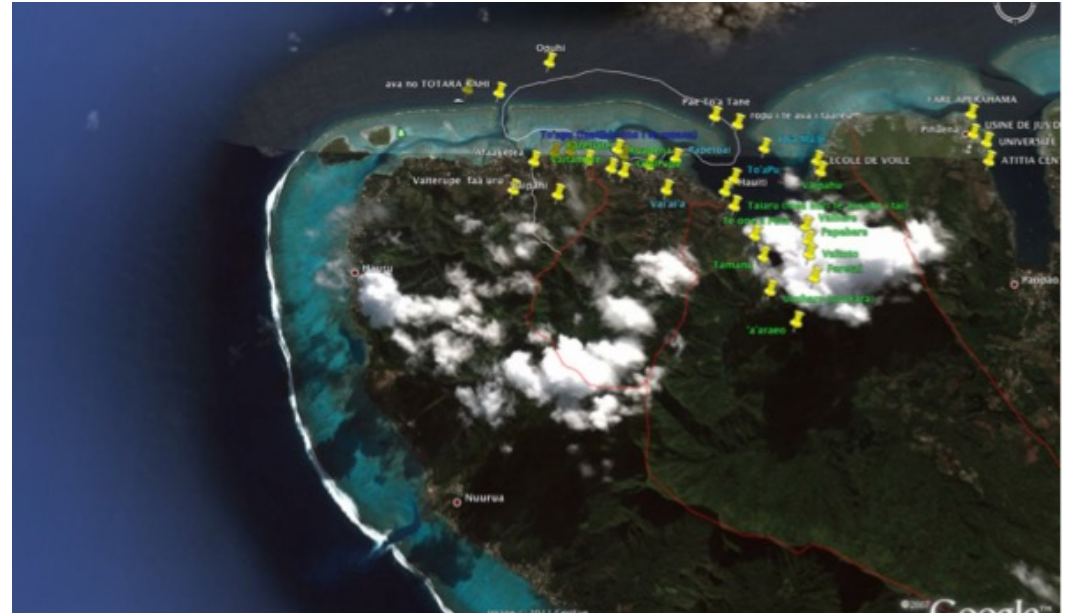
Centre Atitia



Te Pū 'Atiti'a



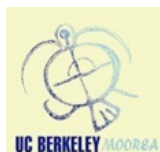
# Local and Indigenous Knowledge







## Outreach: Combining Traditional Knowledge and Scientific Understanding in K12 Education



J. Craig Venter  
INSTITUTE

Gordon and Betty  
MOORE  
FOUNDATION



TWANDA Foundation





**Public Service:** collaboration with FP Dept. Agriculture brought a major pest insect under biological control throughout French Polynesia





## 2. Island Digital Ecosystem Avatars (IDEA) Consortium

Infrastructure for Democratic Ecological Action





# Overview

- Island Ecosystems: Challenges for Sustainability
- Model Systems for Sustainability
- IDEA 1: Island Digital Ecosystem Avatars
- IDEA 2: Infrastructure for Democratic Ecological Action



# Overview

- **Island Ecosystems: Challenges for Sustainability**
- Model Systems for Sustainability
- IDEA 1: Island Digital Ecosystem Avatars
- IDEA 2: Infrastructure for Democratic Ecological Action



# Navigating the Anthropocene

Collective Intelligence | Social-Ecological Foresight



# Island Earth: Societal Challenges

## Sustainability and Environmental Justice



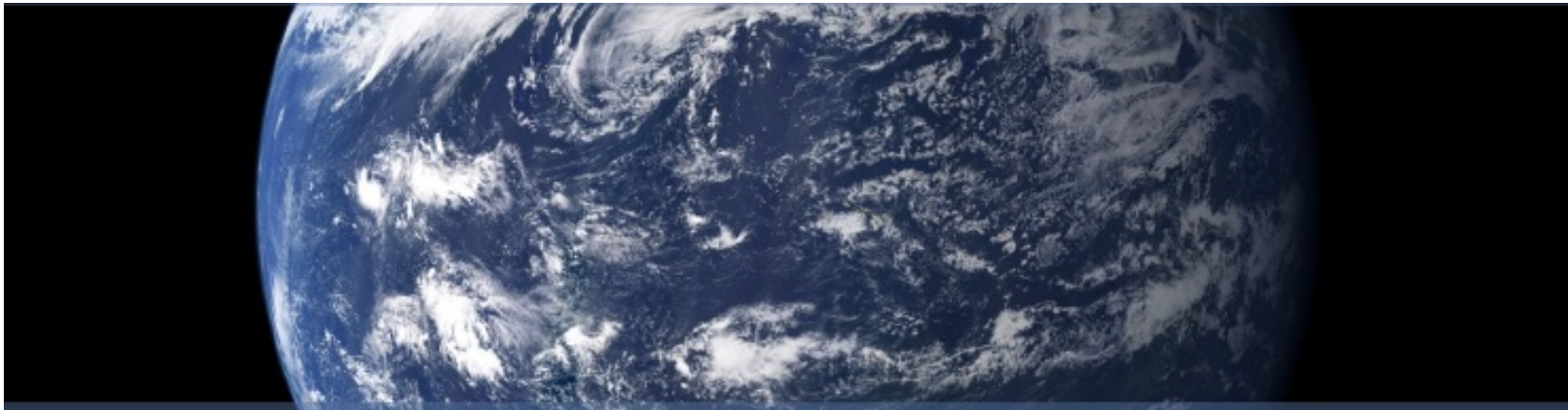
## Economic Equity and Social Justice



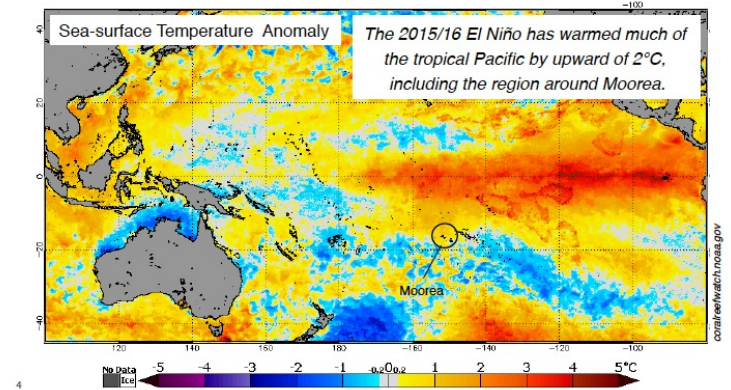


# Island Earth: Scientific Challenges

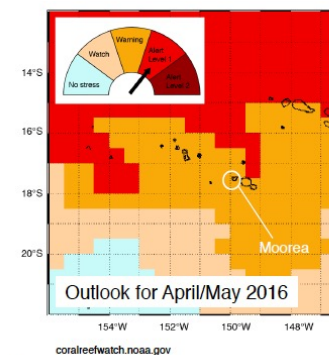
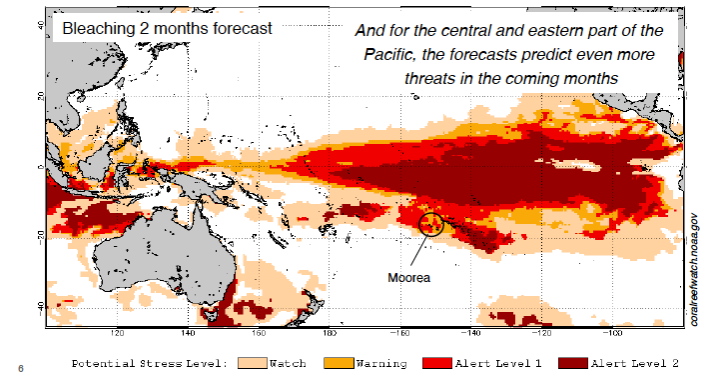
Connecting Large Scale Change to Local Impact...







Coral Bleaching Forecasts April/May 2016



The outlook for this April/May calls for an Alert Level 1/Warning for the area around Moorea, i.e., a high chance for the development of a major bleaching event.



# Future Pacific Ocean: Modeling the World's Largest Biome

Nicolas Gruber & Matthias Münnich

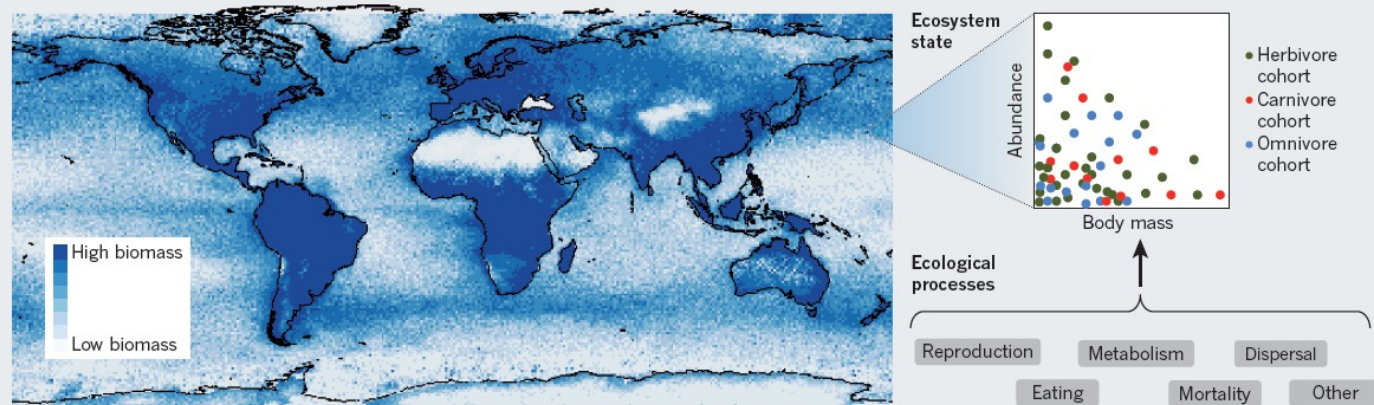
Acknowledgments: Martin Frischknecht

ETH Zürich, Switzerland



## MODEL LIFE

Variation in biomass across the world simulated by the Madingley model for terrestrial and marine ecosystems. Fundamental ecological processes, encoded into simple computational forms, determine the abundance and body mass of organisms (grouped into cohorts for simplicity) and so indicate the state of ecosystems.

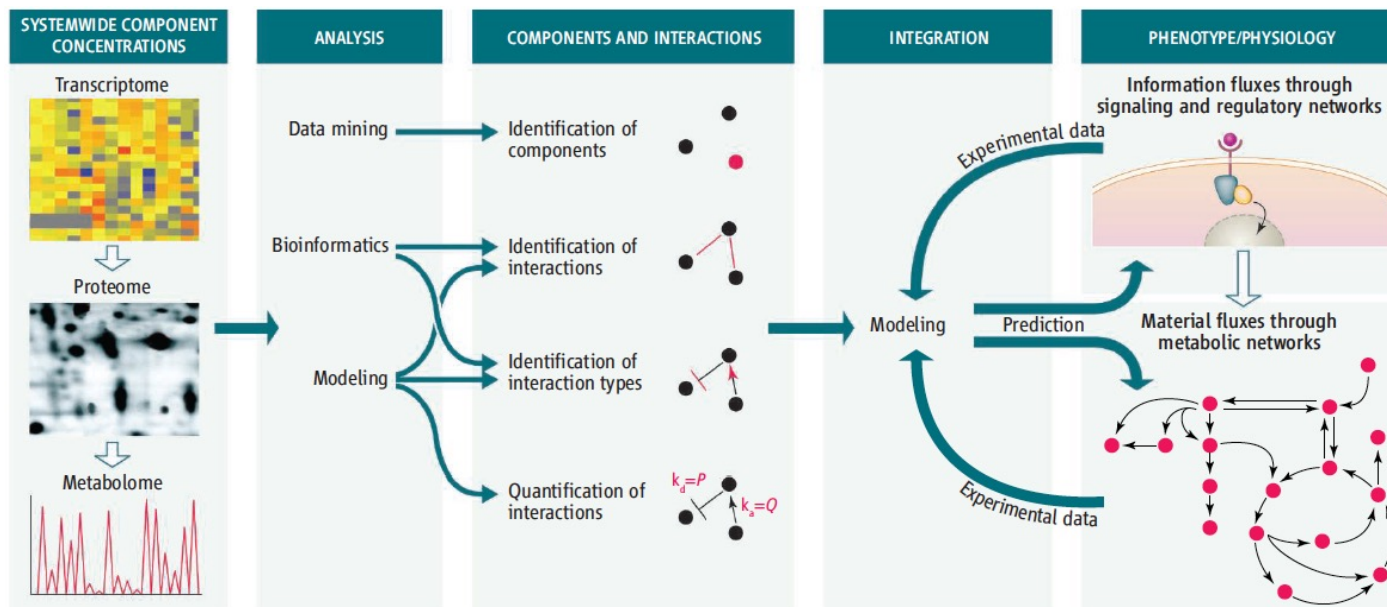


PLANET DOWN



GENOME UP

Purves et al. Ecosystems: Time to model all life on Earth. *Nature* 2013, **493**:295–7.

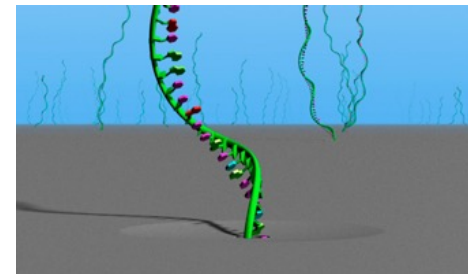
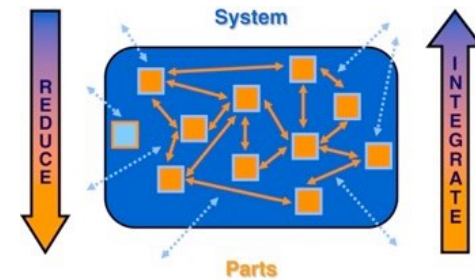


Sauer et al. (2007) Getting Closer to the Whole Picture. *Science* **316**:550–551



# Systems Ecology: Island Earth

A complex problem





# Reduce the Complexity

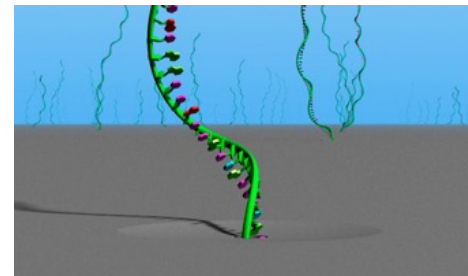
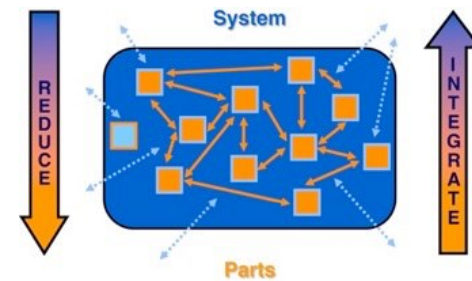
## Model Systems





# Systems Ecology: Moorea Island

A tractable problem







# Overview

- Island Ecosystems: Challenges for Sustainability
- **Model Systems for Sustainability**
- IDEA 1: Island Digital Ecosystem Avatars
- IDEA 2: Infrastructure for Democratic Ecological Action



# How to build a model ecosystem



1D information  
(parts list)

2D information  
(interactions)

3D information  
(spatial)

4D information  
(temporal)



## COMPONENTS AND INTERACTIONS

Identification of  
components



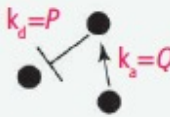
Identification of  
interactions



Identification of  
interaction types



Quantification of  
interactions



Raes & Bork (2008) Molecular eco-systems biology: towards an understanding of community function. Nature Reviews 6:693-699

Sauer et al. (2007) Getting Closer to the Whole Picture. Science 316, 550

moorea

# BIOCODE



*A library of genetic markers and digital identifiers for every species of animal, plant, and fungus on the island of Moorea, this first comprehensive inventory of all non-microbial life in a complex tropical ecosystem will provide a unique platform for the international research community to advance scientific understanding and for local resource managers to improve conservation outcomes.*



# Model Ecosystems Roadmap



1D information  
(parts list)

2D information  
(interactions)

3D information  
(spatial)

4D information  
(temporal)



## COMPONENTS AND INTERACTIONS

Identification of  
components



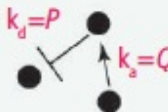
Identification of  
interactions



Identification of  
interaction types



Quantification of  
interactions



Raes & Bork (2008) Molecular eco-systems biology: towards an understanding of community function. Nature Reviews 6:693-699

Sauer et al. (2007) Getting Closer to the Whole Picture. Science 316, 550

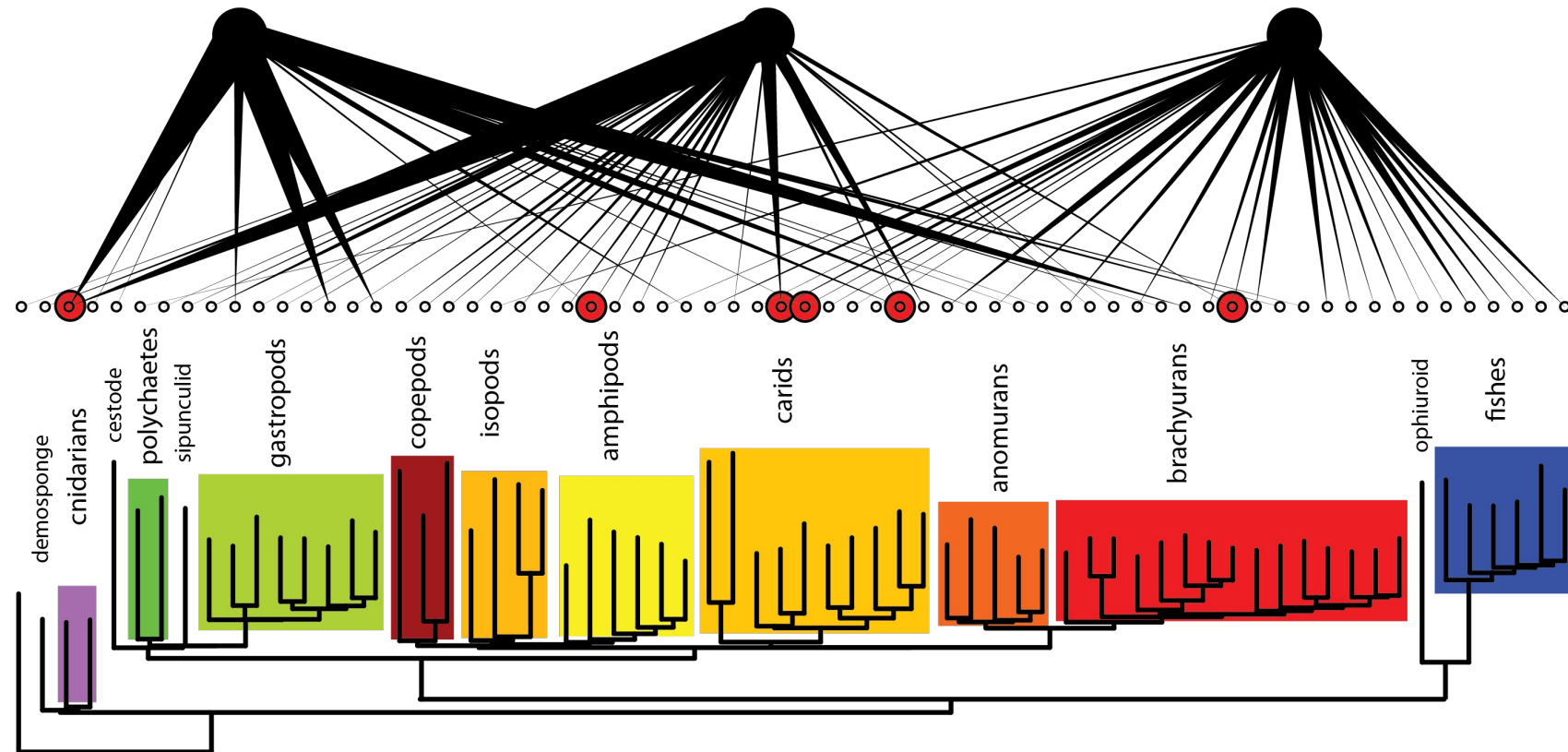
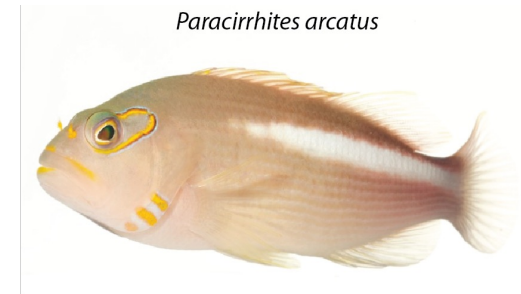
*Caracanthus maculatus*



*Neocirrhites armatus*



*Paracirrhites arcatus*



thickness corresponds to % of total diet  
(only prey >1% of diet represented)

● shared species in diets

Moorea Interactome (e.g., Food webs)



Metabarcoding dietary analysis of coral dwelling predatory fish demonstrates the minor contribution of coral mutualists to their highly partitioned, generalist diet



## A genomic network to monitor Earth

We propose that a network of genomic observatories should be established to take the planet's 'biological pulse'. We invite participants to assist in the shaping of this network (see [genomicobservatories.org](http://genomicobservatories.org)).

DNA sequences are becoming core components of Earth-monitoring systems, and data output is soaring from genomics and other observing technologies. But sequence data alone are of limited value without the context of time and location.

Genomic observatories would integrate genomic information with environmental, socio-ecological and other biological data. Sequencing model ecosystems would accelerate ecological understanding.

Despite reduced sequencing costs, genomic studies are still expensive to analyse and interpret, and the expense of field collection of DNA samples remains incompressible.

Genomic observatories would consolidate these efforts.

These observatories must be supported by field stations, marine labs, museums, standard organizations, research networks and sequencing centres. They should be established at existing scientifically important sites.

**Neil Davies** *Gump South Pacific Research Station, University of California Berkeley, Moorea, French Polynesia.*

**Dawn Field** *Centre for Ecology and Hydrology, Wallingford; and University of Oxford, UK.*  
[dfield@ceh.ac.uk](mailto:dfield@ceh.ac.uk)

**The Genomic Observatories Network** (see [go.nature.com/rcusv3](http://go.nature.com/rcusv3) for a list of co-authors).



**genomic**  
observatories



Davies et al. *GigaScience* 2012, 1:5  
<http://www.gigasciencejournal.com/content/1/1/5>

**GIGA**<sup>n</sup>  
SCIENCE

### REVIEW

### Open Access

## A call for an international network of genomic observatories (GOs)

Neil Davies<sup>1,2</sup>, Chris Meyer<sup>3</sup>, Jack A Gilbert<sup>4,5</sup>, Linda Amaral-Zettler<sup>6</sup>, John Deck<sup>1</sup>, Mesude Bick<sup>7</sup>, Philippe Rocca-Serra<sup>8</sup>, Susanna Assunta-Sansone<sup>8</sup>, Kathy Willis<sup>2</sup> and Dawn Field<sup>2,7,8\*</sup>

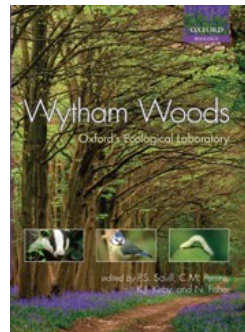
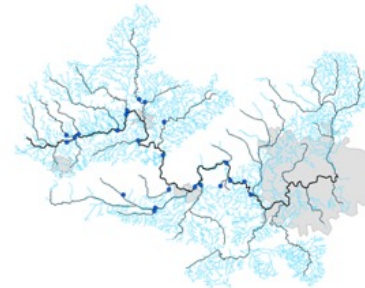
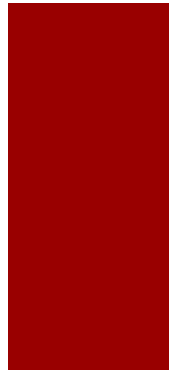
### Abstract

We are entering a new era in genomics—that of large-scale, place-based, highly contextualized genomic research. Here we review this emerging paradigm shift and suggest that sites of utmost scientific importance be expanded into 'Genomic Observatories' (GOs). Investment in GOs should focus on the digital characterization of whole ecosystems, from all-taxa biotic inventories to time-series 'omics studies. The foundational layer of biodiversity—genetic variation—would thus be mainstreamed into Earth Observation systems enabling predictive modelling of biodiversity dynamics and resultant impacts on ecosystem services.

**Keywords:** Ecogenomics, Earth observation, Biodiversity, Ecosystems, Biocode, Genomic observatory, DNA

# Observations across scales of biological organization

- open and closed systems





### Moorea Ocean Sampling Day (20 June, 2012)

The island Moorea (French Polynesia) combines the two research stations: CRILOBE. The Moorea Ecological first actions (after the inauguration).

Like Rothera (Antarctica) we have the same weather conditions: calm, a pod of dolphins were started our OSD adventure. filtering voyage on the 5<sup>th</sup> of June.

### Ocean Sampling Day- Faxaflói, Iceland – Mat

Viggó Thór Marteinsson, Eyjólfur Rey

Sampling was performed in Faxaflói Reykjanes and Snæfellsnes. A small Long: 22° 07,50' V) to the bay at 1 replicate samples from one sampling cleaned bucket. Three water sample Sterivex filters (Millipore). Filtering time other three with total filtration time of °C in individual zip-lock bags.

Additional site information:

Air temperature: 12°C

Water temperature surface: 9,6 °C

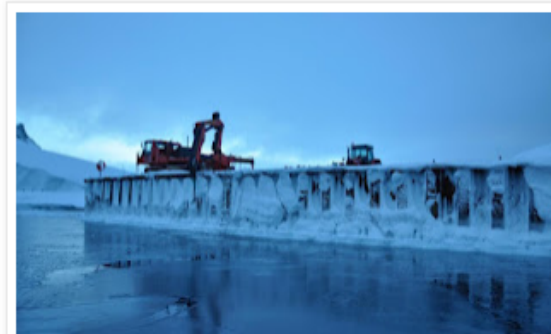
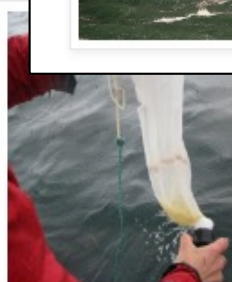
Salinity 3,5%

### Ocean Sampling Day - Summer solstice 2012-06-20 – Roscoff

Sampling was performed at the SOMLIT-Astan long-term observatory site (48° 46' 40 N, 3° 56' 15 W) at 10:30 local time during the 2012 summer solstice. Water was collected from a depth of 1 meter using a Niskin bottle. Water samples were transported to the lab in an acid cleaned plastic bottle within 15 minutes and filtered. Within 30 minutes, 4 replicates of 1 liter were filtered for metagenomic analyses using the Sterivex 0.22µm filters. Filters were sealed and immediately frozen at -80 °C in individual zip-lock bags.

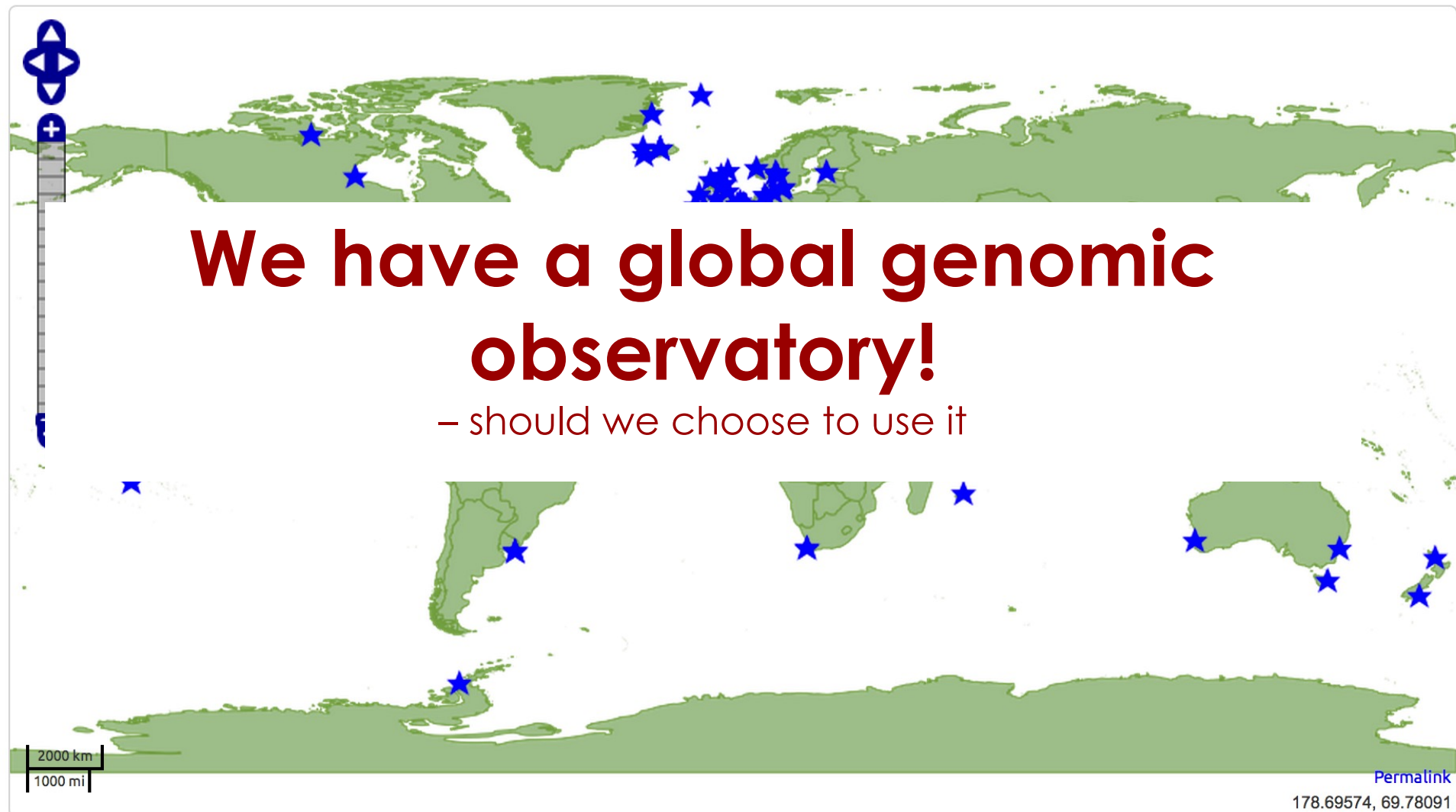
### Ocean Sampling Day – Rothera

Rothera is a British Antarctic Survey research station, located on Adelaide Island on the Antarctic Peninsula at 67° South [http://www.antarctica.ac.uk/living\\_and\\_working/research\\_stations/rothera](http://www.antarctica.ac.uk/living_and_working/research_stations/rothera). The plan was to get out and sample on our Winter Solstice (20th June), which for most of OSD partners was the Summer Solstice. Unfortunately sea ice and wind were against us and we didn't manage to get out to sample until the 31st of July. The sea ice formed the week before the Solstice and was too thick to get one of our RIBs (Rigid Inflatable Boat) through, but too thin to walk on. The ice then thickened up and we were able to go for short walks and even dive through it near to the shore; however it was too dangerous to go too far offshore and get to our sampling sites. The winds picked up towards the middle of July and blew the sea ice out – but the winds remained too high to launch the boats, sometimes even blowing the ice back in. This continued for a few weeks until finally we had a window where there was an area of open water leading toward the sample site and no wind! The Rothera Oceanographic and Biological Time Series (RaTS) has been running since 1997 and continues year round – collecting data through weekly water sampling and CTD events. <http://www.antarctica.ac.uk/staff-profiles/webpace/mmm/RaTS/RaTS.html>



• • • Map of OSD Participant sites

June 21<sup>st</sup> 2014 >180 sites





# OBOB

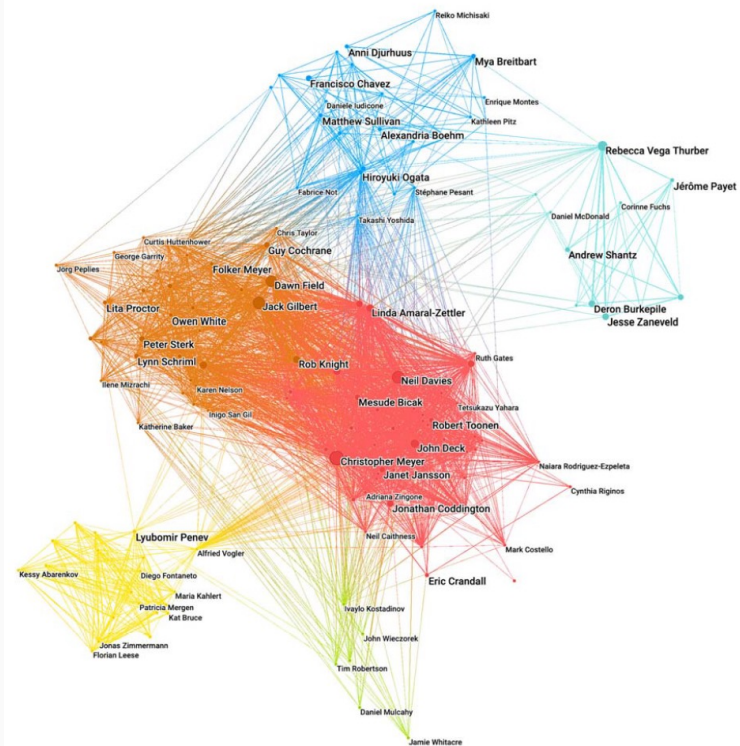
## OCEAN BIOMOLECULAR OBSERVING NETWORK



**2021  
2030** United Nations Decade  
of Ocean Science  
for Sustainable Development

The Ocean Biomolecular Observing Network is an endorsed [#UNOceanDecade](#) programme that will monitor, research & understand ocean life by analyzing biomolecules.

The first list of Endorsed Decade Actions was announced on 3 June 2021. [Click here to find out more.](#)



GOBON

Home About BONs EBVs EESVs Indicators Resources Members Search...



Omic BON



# Model Ecosystems Roadmap



1D information  
(parts list)

2D information  
(interactions)

3D information  
(spatial)

4D information  
(temporal)



## COMPONENTS AND INTERACTIONS

Identification of  
components



Identification of  
interactions



Identification of  
interaction types

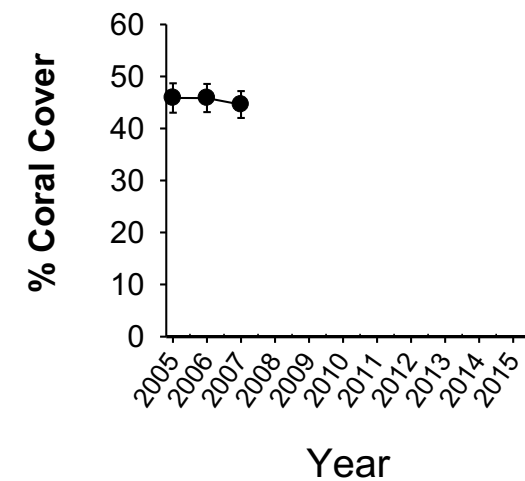
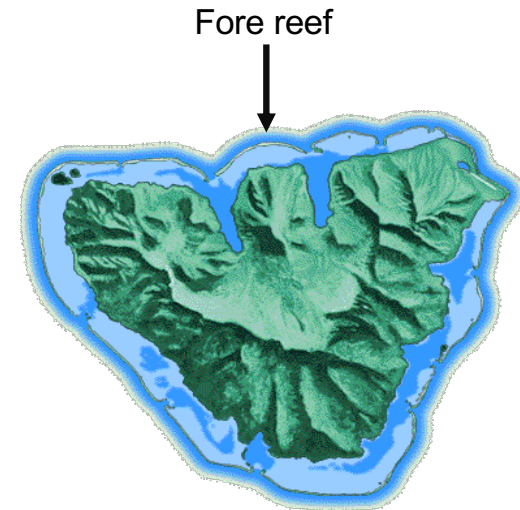


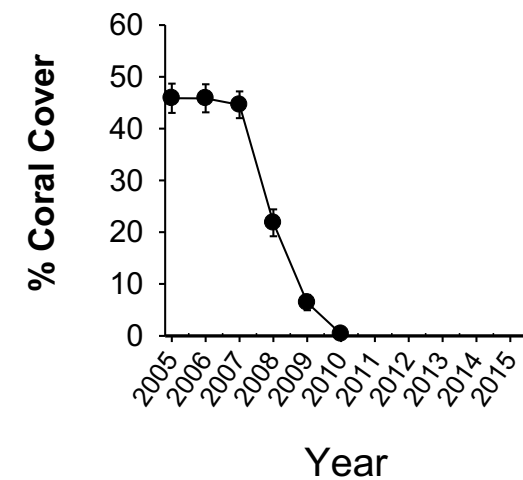
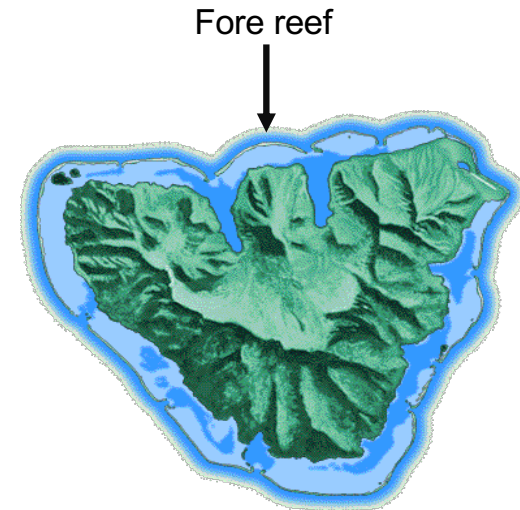
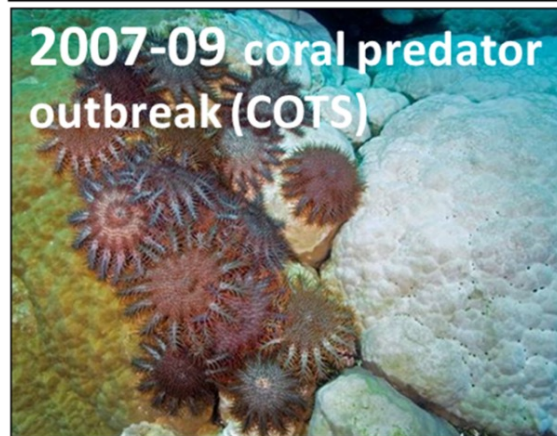
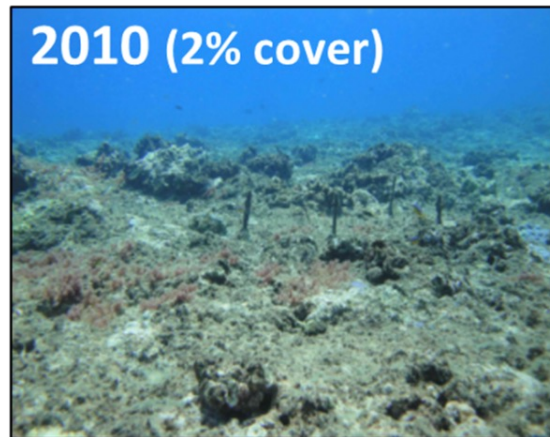
Quantification of  
interactions





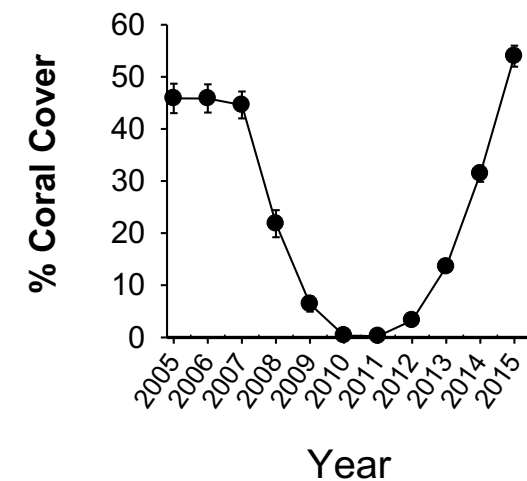
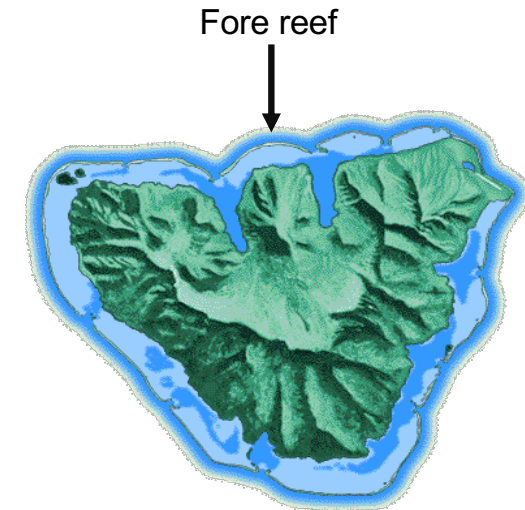
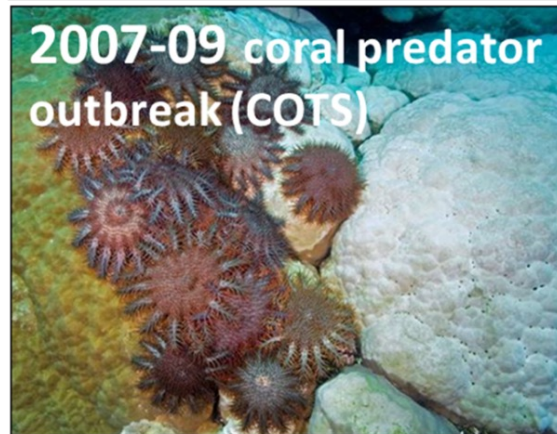
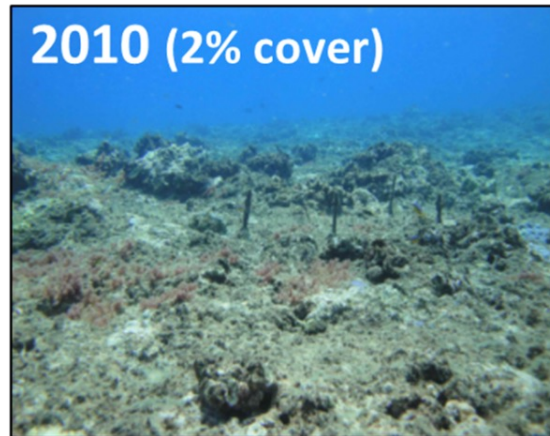
# Understanding Resilience of Corals: Time Series





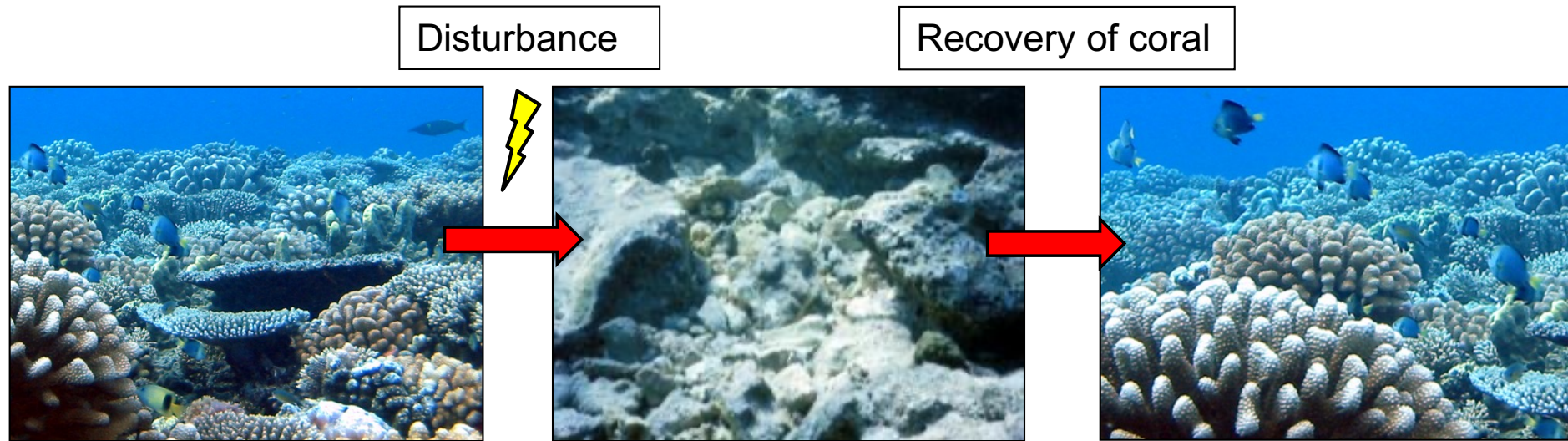


# Very high resilience of corals on the fore reef

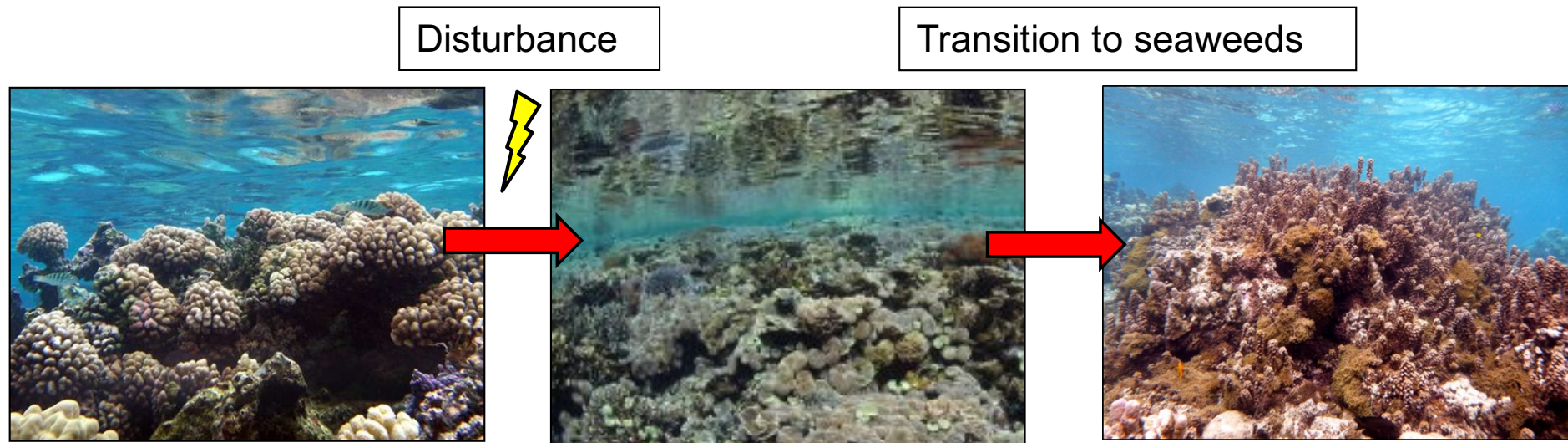




**Until recently, coral reefs have been able to recover (resilient)**



***Now, many coral reefs do not recover & often become seaweed beds***  
Seaweeds prevent corals from returning





# Coral reefs under increasing stress from **local** as well as **global** change

*Both sources lower resilience*

Fishing Pressure



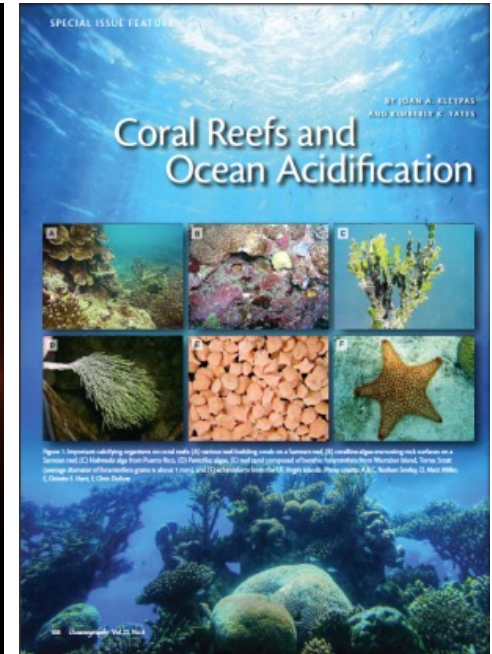
Nutrient Pollution



Ocean Warming

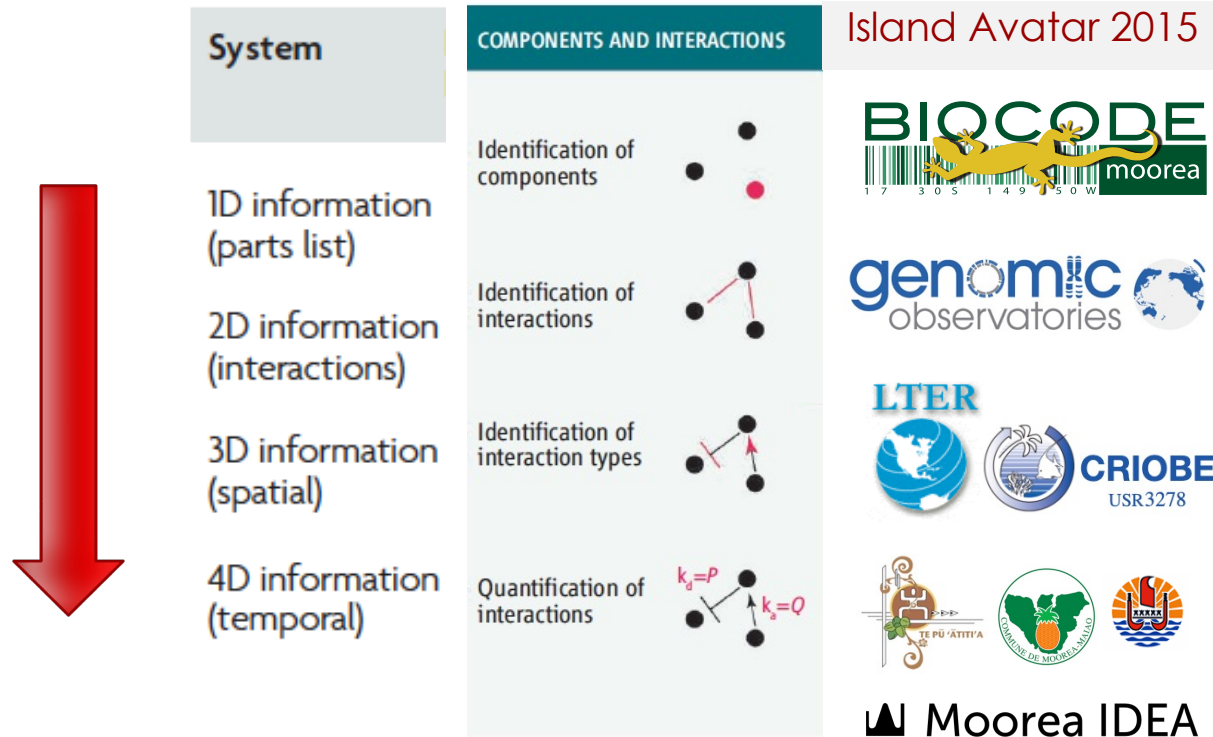


Ocean Acidification



**Need deeper understanding of the social-ecological system to maintain resilience & the societal benefits coral reefs provide**

# Community Decision-Support



Raes & Bork (2008) Molecular eco-systems biology: towards an understanding of community function. *Nature Reviews* 6:693-699

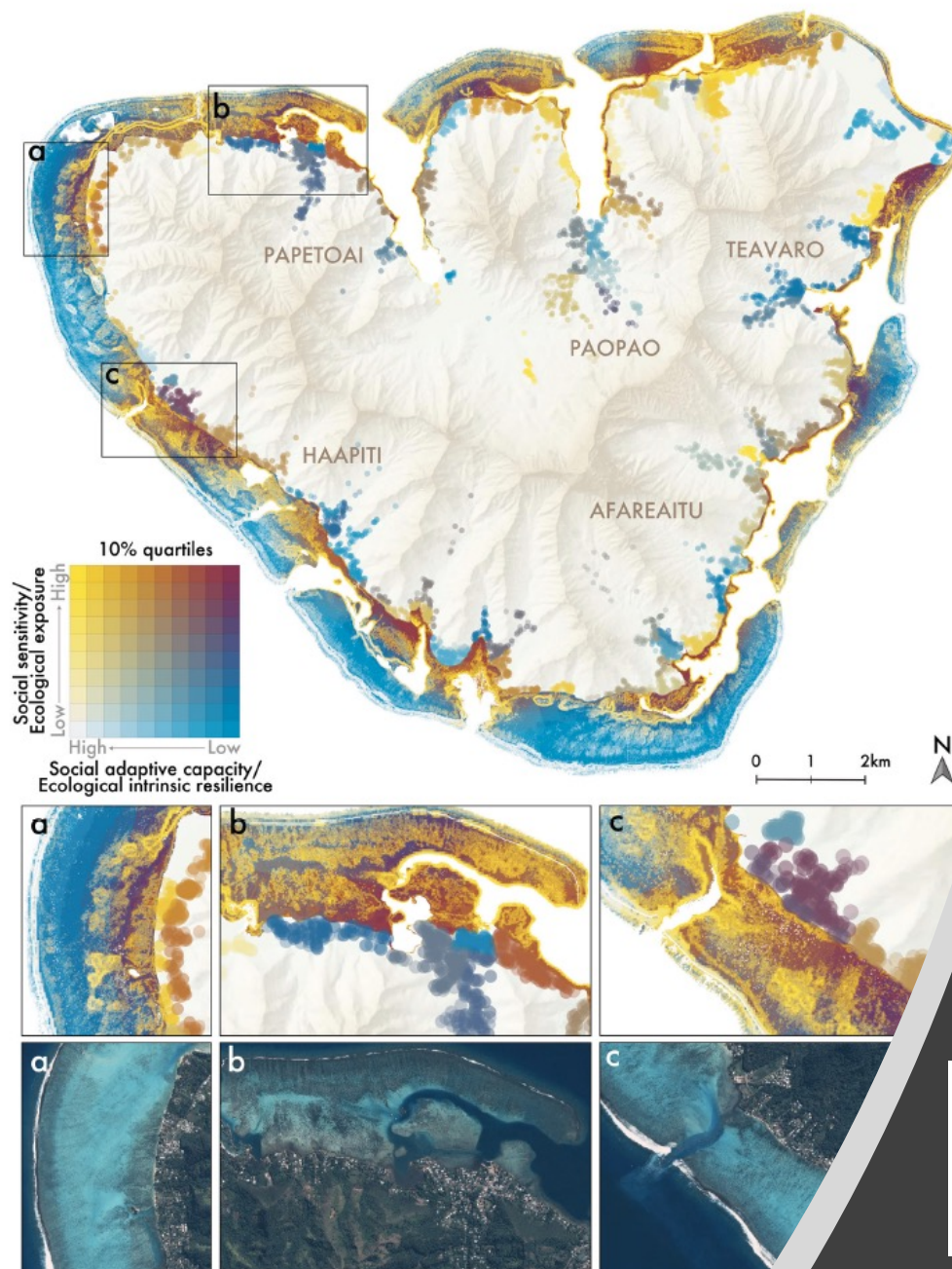
Sauer et al. (2007) Getting Closer to the Whole Picture. *Science* 316, 550

The screenshot shows the Nature journal website. The article title is "Tropical paradise inspires virtual ecology lab" by Daniel Cressey, dated 14 January 2015. The article abstract states: "Digital version of Moorea will provide a way to experiment with an entire ecosystem." The article is categorized under "DATA HEAVEN" and "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." The article includes several images and labels: "Peaks and valleys", "Ocean circulation", "Catalogue of life", "Underwater terrain", "Coral reefs", and "Watery secrets".

A paradise on Earth could soon become the first ecosystem in the world to be replicated in digital form in painstaking detail, from the genes of its plants and animals to the geography of its landscape.

An international team is preparing to create a digital avatar of the Pacific island of Moorea, which lies off the coast of Tahiti and is part of French Polynesia. Moorea is already one of the most studied islands in the world; the team plans to turn those data into a virtual lab that would allow scientists to test and generate hypotheses about the impact of human activities.





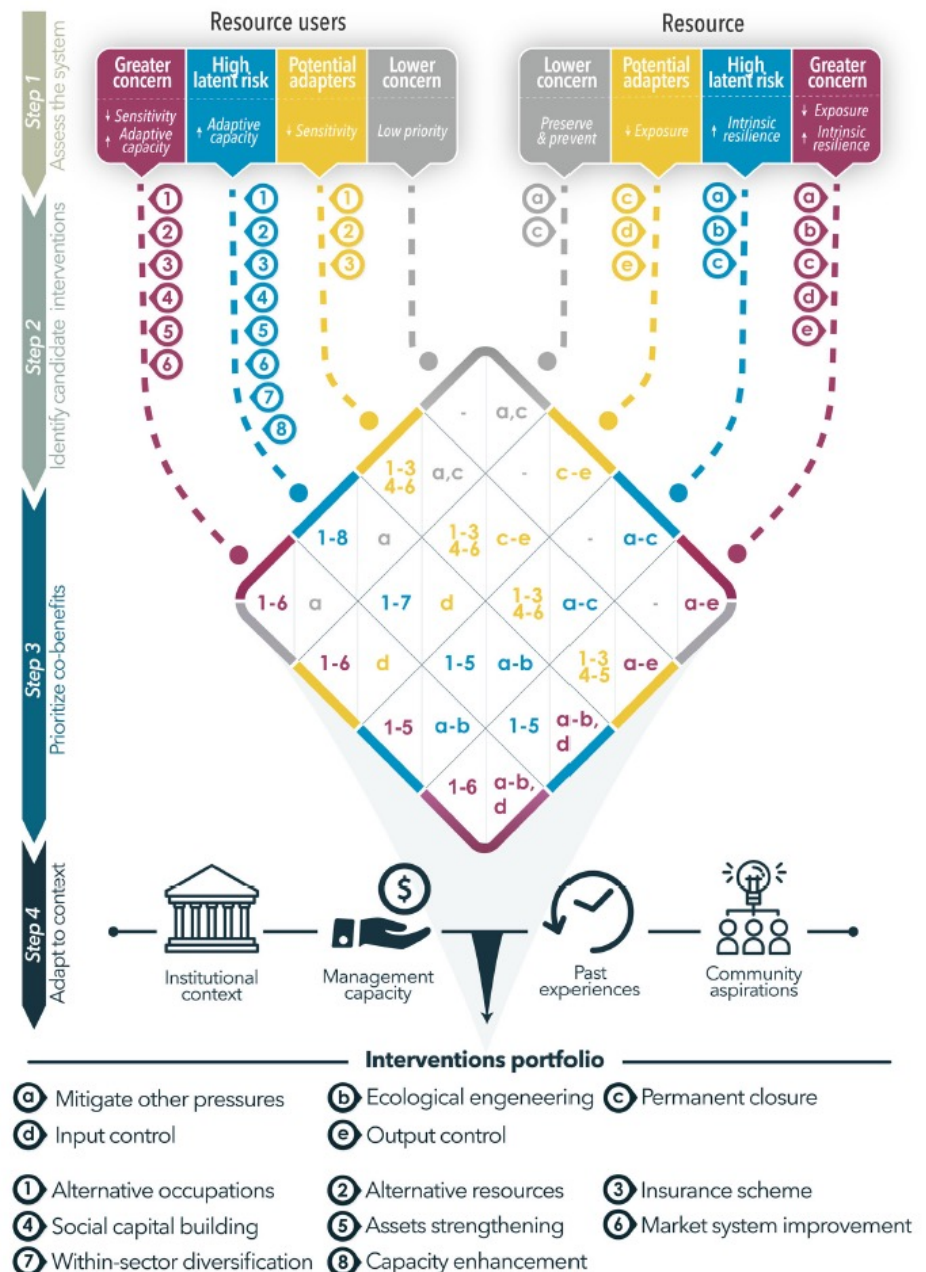
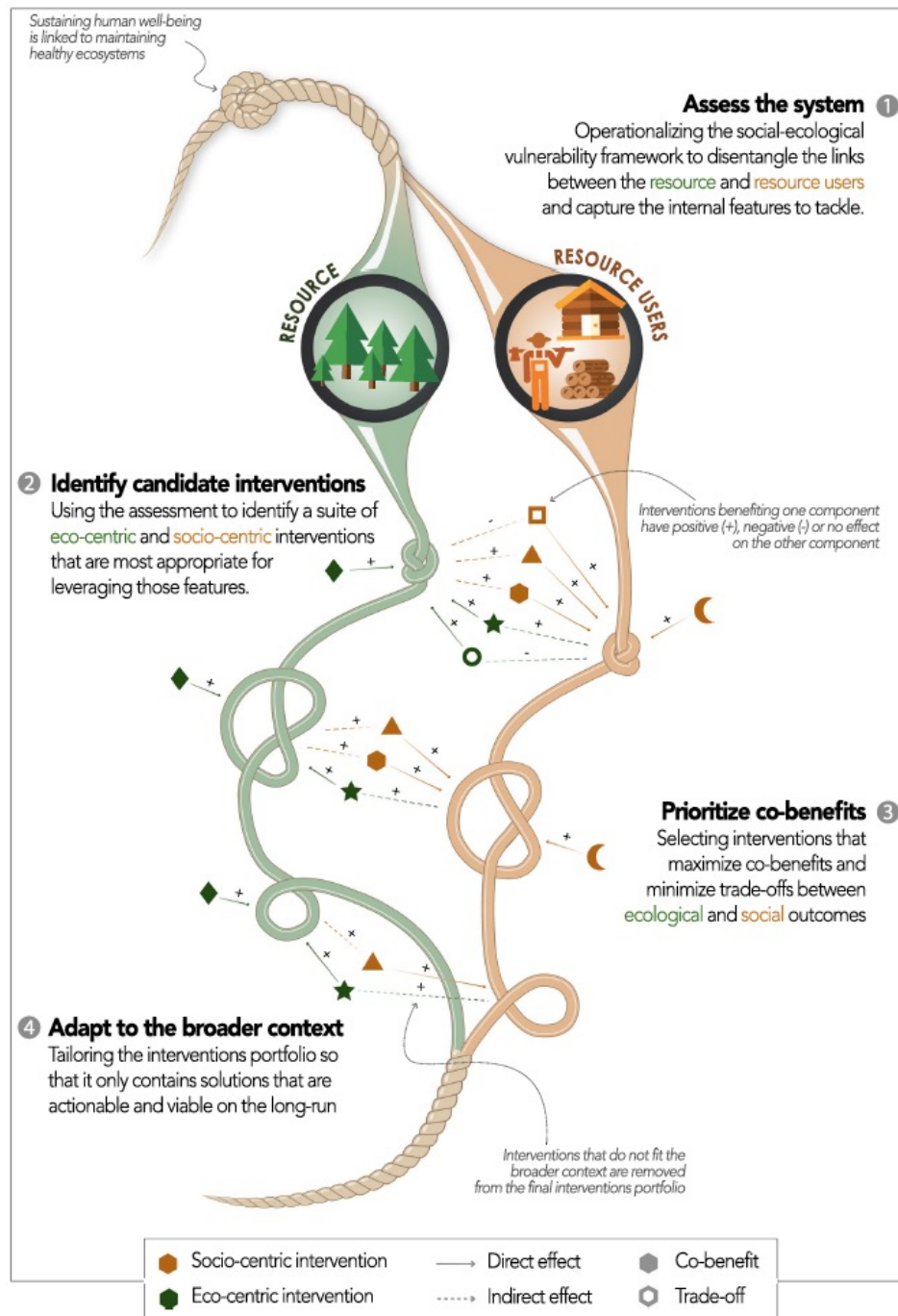
**FIGURE 4** Assessment of the coral reef fishery of Moorea, French Polynesia, using spatially explicit vulnerability (Step 1). Since households mostly depend on resource located on adjacent reefs for provision fishing, combinations of social and ecological vulnerability profiles are spatially linked. Insets highlight specific portfolio of interventions (Figure 3; see Supporting Information Appendix C and Figure S1 for approach)

# Social-Ecological Foresight

**Operationalizing vulnerability for social–ecological integration in conservation and natural resource management**

Lauric Thiault<sup>1,2,3,4</sup> | Stefan Gelcich<sup>4</sup> | Nadine Marshall<sup>5</sup> | Paul Marshall<sup>6,7</sup> |  
Frédérique Chlous<sup>3</sup> | Joachim Claudet<sup>1,2</sup>

Thiault L, Gelcich S, Marshall N, Marshall P, Chlous F, Claudet J.  
Conservation Letters. 2020; 13:e12677. <https://doi.org/10.1111/conl.12677>







# Overview

- Island Ecosystems: Challenges for Sustainability
- Model Systems for Sustainability
- **IDEA 1: Island Digital Ecosystem Avatars**
- IDEA 2: Infrastructure for Democratic Ecological Action



# Moorea IDEA *Island Digital Ecosystem Avatar*

IDEA-1 Workshop @ ETH Zurich, November 2013

Organized by Matthias Troyer

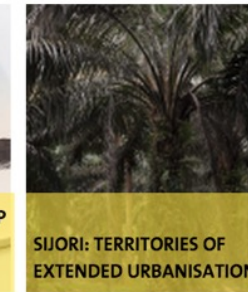
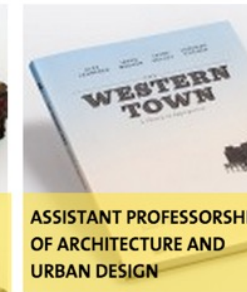
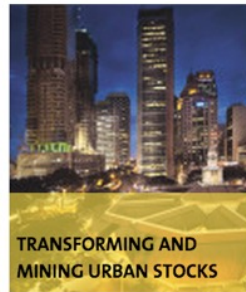
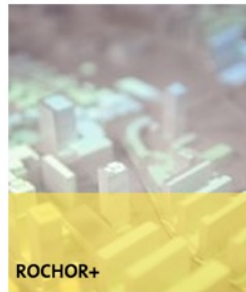
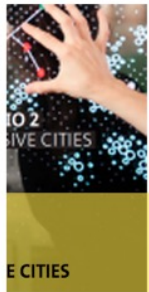




RESEARCH

MODULES

PROJECTS



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# THE QUANTIFIED COMMUNITY

A collection of big data to inform New York City and cities around the world and allow Hudson Yards to continue to optimize, innovate, and enhance the user experience.

Read More

URBAN MODELING  
SMALL ISLANDS “SMART CITIES”





# Systems Approach to Complex Diseases and the Emergence of Proactive P4 Medicine



Lee Hood, President  
Institute for Systems Biology, Seattle

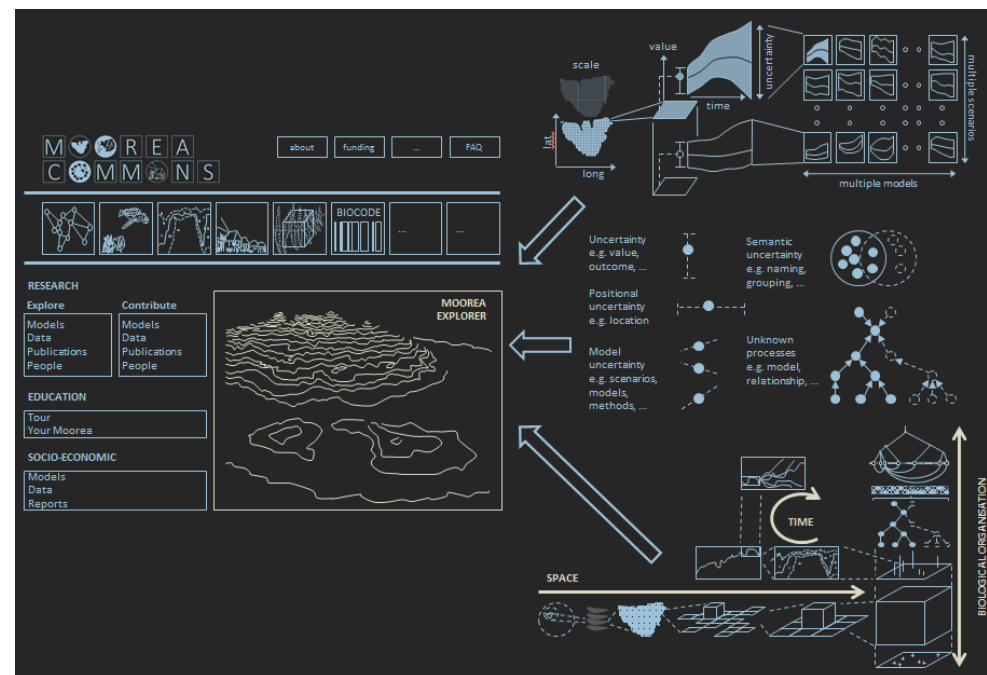


# Island Avatars

- **An open-science initiative in systems ecology**



- **Mission:** to build use-oriented simulations (avatars) of entire social-ecological systems
- **Challenge:** to model links and feedbacks between climate, environment, biodiversity, and human activities



Steering Committee members from:

ETH zürich



Berkeley  
UNIVERSITY OF CALIFORNIA

UCSB






COMMENTARY

Open Access

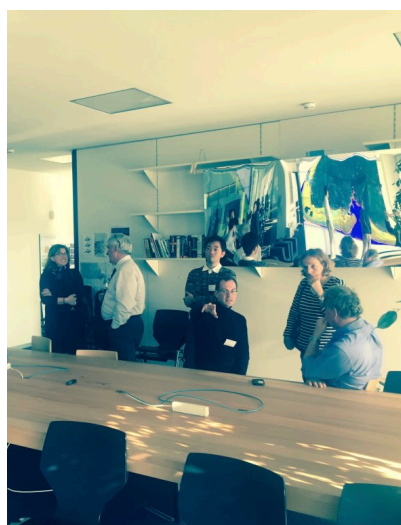
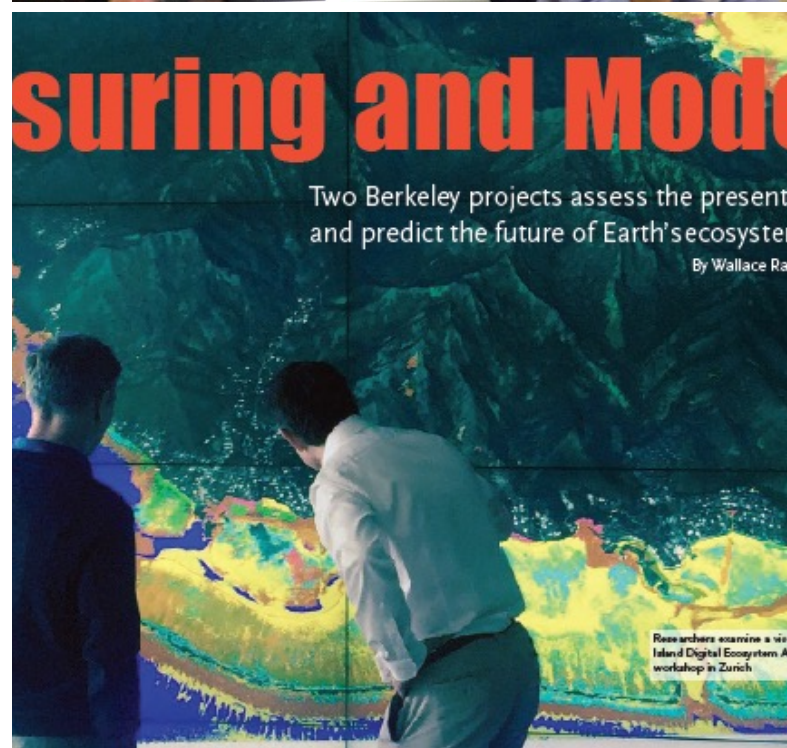


# Simulating social-ecological systems: the Island Digital Ecosystem Avatars (IDEA) consortium

Neil Davies<sup>1,2,3\*</sup> , Dawn Field<sup>2</sup>, David Gavaghan<sup>4</sup>, Sally J. Holbrook<sup>5</sup>, Serge Planes<sup>6</sup>, Matthias Troyer<sup>7\*</sup>, Michael Bonsall<sup>2</sup>, Joachim Claudet<sup>6</sup>, George Roderick<sup>8</sup>, Russell J. Schmitt<sup>5</sup>, Linda Amaral Zettler<sup>9</sup>, Véronique Berteaux<sup>6</sup>, Hervé C. Bossin<sup>10</sup>, Charlotte Cabasse<sup>3</sup>, Antoine Collin<sup>11</sup>, John Deck<sup>12</sup>, Tony Dell<sup>13</sup>, Jennifer Dunne<sup>14</sup>, Ruth Gates<sup>15</sup>, Mike Harfoot<sup>16</sup>, James L. Hench<sup>17</sup>, Marania Hopuare<sup>18</sup>, Patrick Kirch<sup>19</sup>, Georgios Kotoulas<sup>20</sup>, Alex Kosenkov<sup>7</sup>, Alex Kusenko<sup>21</sup>, James J. Leichter<sup>22</sup>, Hunter Lenihan<sup>23</sup>, Antonios Magoulas<sup>20</sup>, Neo Martinez<sup>24,25</sup>, Chris Meyer<sup>26</sup>, Benoit Stoll<sup>18</sup>, Billie Swalla<sup>27</sup>, Daniel M. Tartakovsky<sup>28</sup>, Hinano Teavai Murphy<sup>29</sup>, Slava Turyshev<sup>30,31</sup>, Fernanda Valdvinos<sup>24</sup>, Rich Williams<sup>32</sup>, Spencer Wood<sup>33</sup> and IDEA Consortium<sup>34,35</sup>

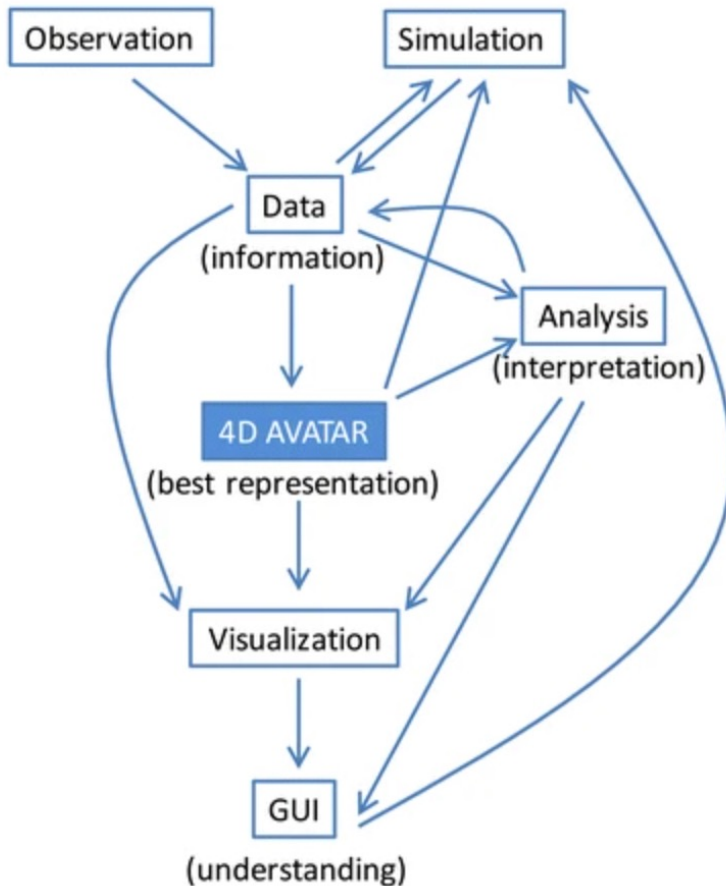
## Abstract

Systems biology promises to revolutionize medicine, yet human wellbeing is also inherently linked to healthy societies and environments (sustainability). The IDEA Consortium is a systems ecology open science initiative to conduct the basic scientific research needed to build use-oriented simulations (avatars) of entire social-ecological systems. Islands are the most scientifically tractable places for these studies and we begin with one of the best known: Moorea, French Polynesia. The Moorea IDEA will be a sustainability simulator modeling links and feedbacks between climate, environment, biodiversity, and human activities across a coupled marine–terrestrial landscape. As a model system, the resulting knowledge and tools will improve our ability to predict human and natural change.





# Framework



## WORKING GROUP

## TASK

### 1. Data Science

Integrating diverse data sources, coupling models, visualizing information

### 2. Physical Modeling

Oceanic / atmospheric forcing, physical-chemical properties and fluxes

### 3. Genes to Ecosystems

Biodiversity dynamics, evolutionary processes, ecological interactions

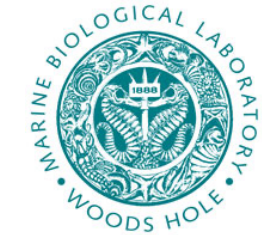
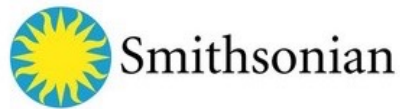
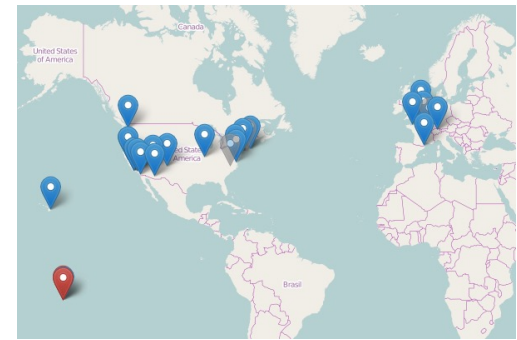
### 4. Social-Ecological Systems

Coupling past, present, future ecosystems to human activities

### 5. Simulations, Synthesis, and Service

Use-oriented avatar for data exploration, scenario-based planning, education

# IDEA Consortium (2016)







# PACIFIC TRANSECT COLLABORATIVE

Established 2020



## Oahu

Elevation: 1,220 m  
Area: 1,545 km<sup>2</sup>  
Population: 953,207

## Palmyra Atoll

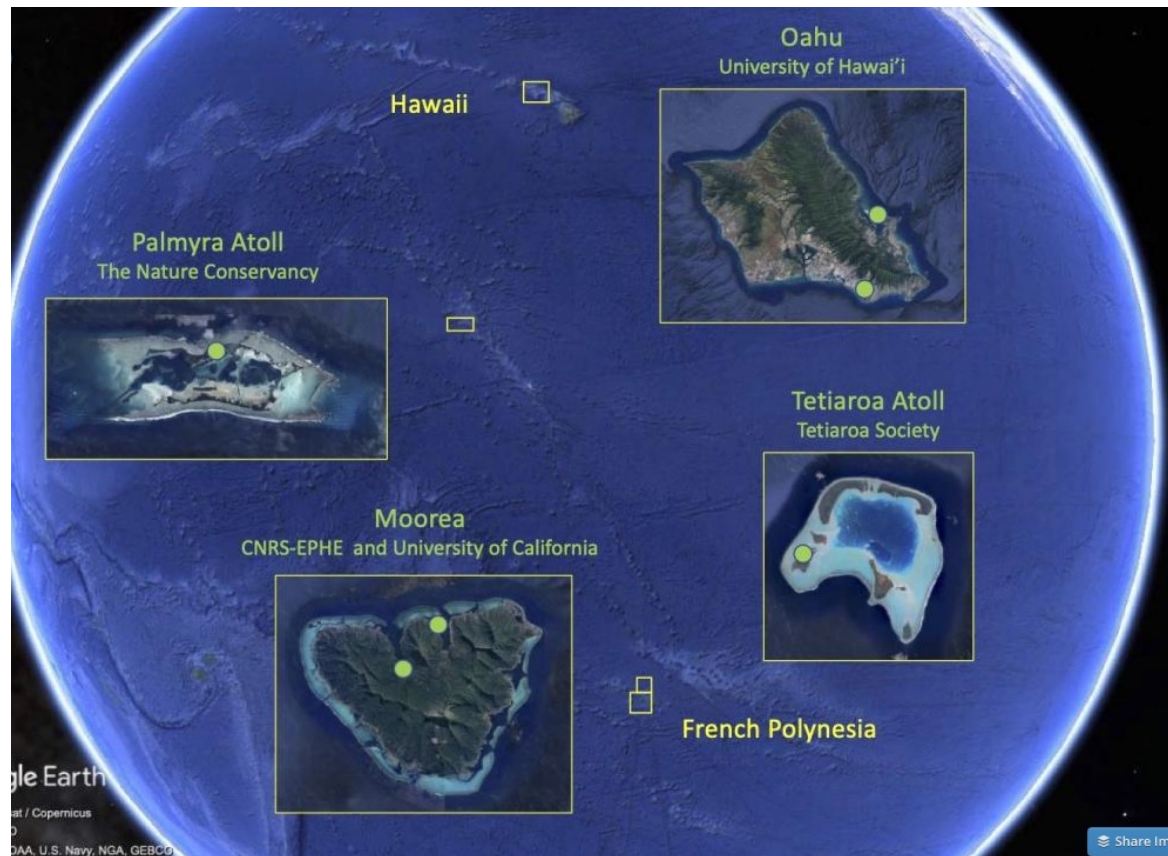
Elevation: 2 m  
Area: 12 km<sup>2</sup>  
Population: 2-20

## Tetiaroa Atoll

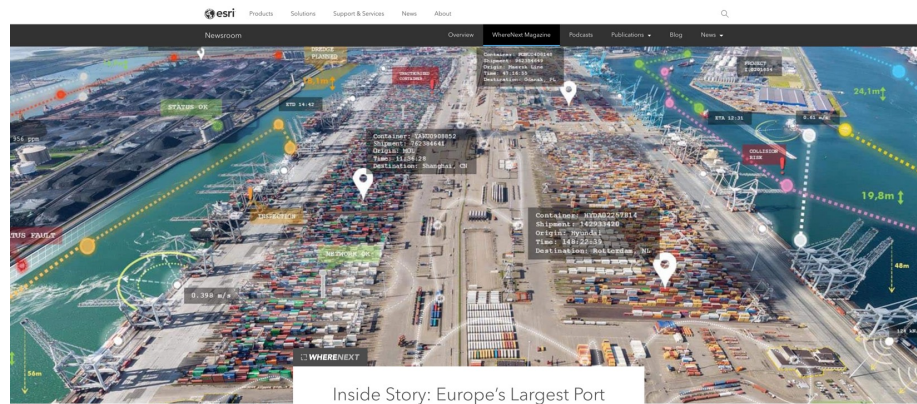
Elevation: 4 m  
Area: 6 km<sup>2</sup>  
Population: 210

## Moorea

Elevation: 1,207 m  
Area: 134 km<sup>2</sup>  
Population: 17,200







Inside Story: Europe's Largest Port Prepares for Autonomous Ships



# Digital Twins

- Medicine
- Industry
- Urban planning





# What is a Digital Twin?



Digital Framework Task Group,  
Centre for Digital Built Britain

The Gemini Principles  
2018

**“A digital twin is a realistic digital representation of assets, processes or systems in the built or natural environment.”**

INTRODUCTION

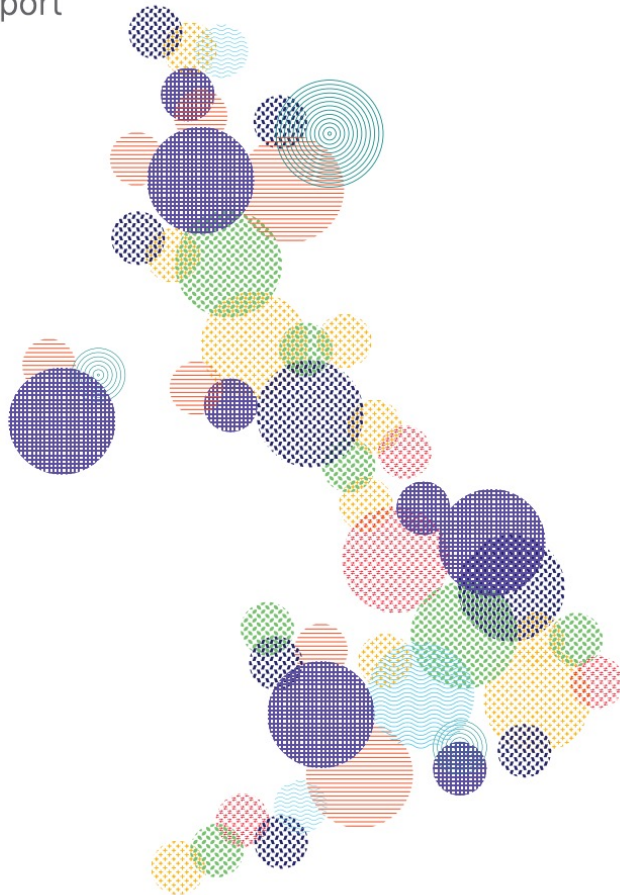
TOWARDS A WEB OF DIGITAL TWINS

- Digital Twin is **“a model of a system that evolves together with the system over time”** (Wright & Davidson 2020 Adv. Model and Simul. In Eng. Sci.).

<https://theodi.org/article/digital-twins-user-research/>

# The approach to delivering a National Digital Twin for the United Kingdom

Summary report



## Island Twin

- **‘federations’ of digital twins** joined together via securely shared data.



# European Digital Twin of the Ocean

- “The ocean is still largely a great mystery for humankind. That is why **Europe is building a digital twin of the ocean.** [...]”
- It will make ocean knowledge open-access, available to citizens, scientists and policymakers around the world. It will be a platform for global cooperation.”

**Ursula von der Leyen**  
**European Commission President**  
One Ocean Summit , Feb 2022



# Foundational Research Gaps and Future Directions for Digital Twins

SH

- About
- Description
- Committee
- Sponsors
- Past Events
- Contact

A National Academies of Sciences, Engineering, and Medicine-appointed ad hoc committee will identify needs and opportunities to advance the mathematical, statistical, and computational foundations of digital twins in applications across science, medicine, engineering, and society.

View recordings of the project's information-gathering workshops on digital twins in the [Biomedical Sciences](#) (January 30); [Atmospheric, Climate, and Sustainability Sciences](#) (February 1-2); and [Engineering](#) (February 7 and 9).

## Opportunities and Challenges for Digital Twins in Biomedical Sciences - A Workshop

SHARE f t in



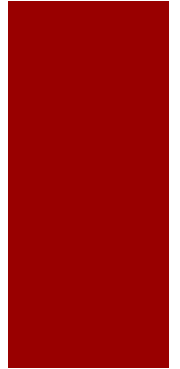
## Digital Twins in Atmospheric, Climate, and Sustainability Science - A Workshop

SHARE f t in





# Caveat Avatar



- **Place** is an emergent property of interconnected physical, biological, socio-economic systems ~ a **Shared Identity**
- **Social-Ecological Systems** can be chaotic, and/or the rules of the system are only partially visible
- **Island avatars are not clones (twins)**; they are multiple, competing hypotheses
- They improve with more evidence but remain **scientifically fallible**
- **Vigilance needed:** risk of human bias (manipulation) in what data are collected (fabricated), which models are developed, and how predictions and uncertainty are presented



# Curation Challenge

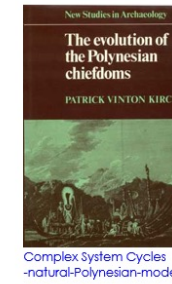
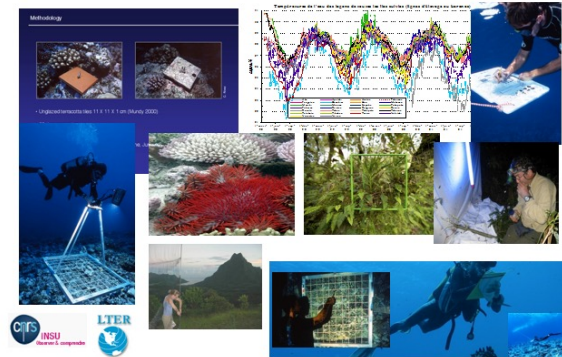
- **Digital predictions** are composed of **data + models**
  - Place-based data – diverse types/sources
  - Scientific models – diverse scales/quality
- **Scenario-based planning** for public policy requires curation of underlying evidence in the public interest
- **Foresight commons?** Curate admissible evidence through:
  - Place-based data institutions at nested levels of governance under democratic control
  - Coordination of tools and best-practice for interoperability across places and scales



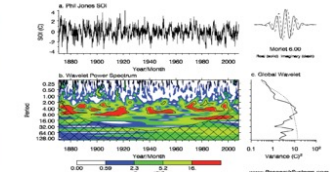
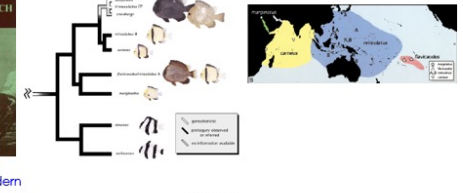
## Environmental Observatory



## Ecological Observatory

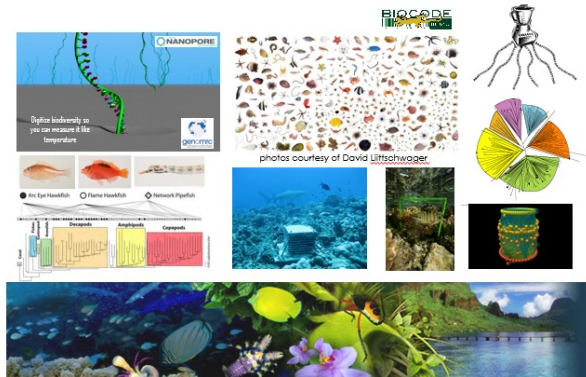


## Biological and Social Lineages Geological and Climatic History

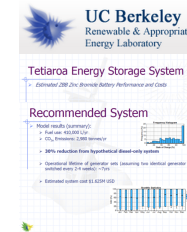
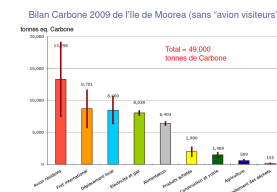


## Genomic Observatory

genomic observatories



## Socio-Economic Observatory

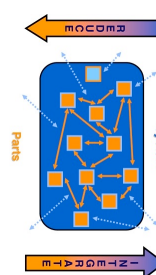
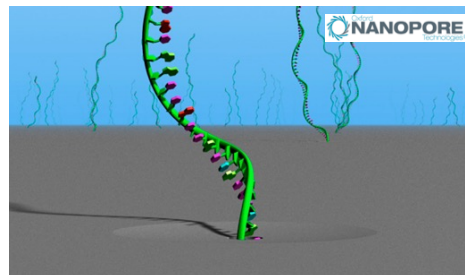


Dépense énergétique globale de l'île de Moorea =  
~ 20 millions de litres de pétrole importés par an  
=  
~ 1,3 milliards de francs CFP ~\$15 million dépensés par an

# Integration Challenge

genomic STANDARDS consortium

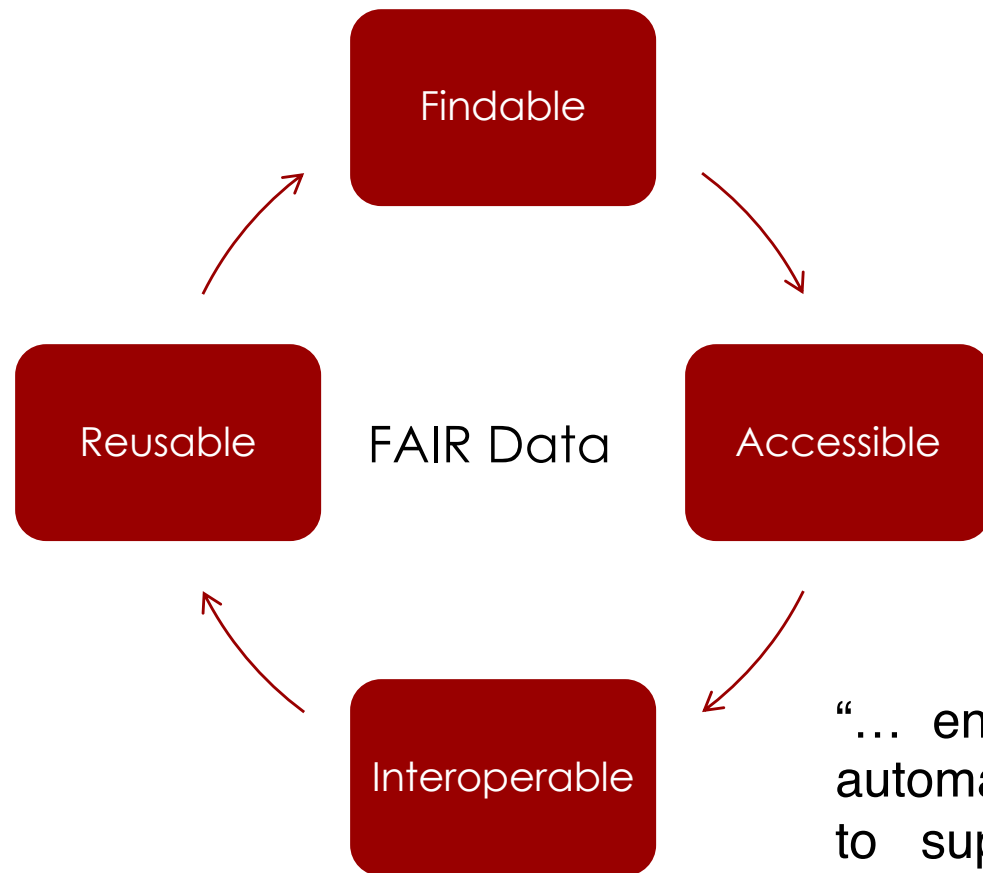
genomic observatories



GEO GROUP ON EARTH OBSERVATIONS



# Open Science Cyber-Infrastructure



“... enhancing the ability of machines to automatically find and use data, in addition to supporting its reuse by individuals”  
(Wilkinson et al. 2016)



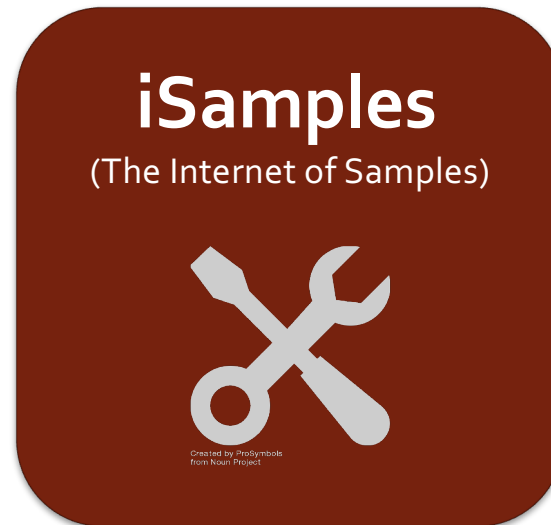
# Futuromics – In Situ Sampling



Funded by the US National Science Foundation

**Maximize the  
Value of  
Today's  
Samples  
for  
Tomorrow's  
Science**

Technology

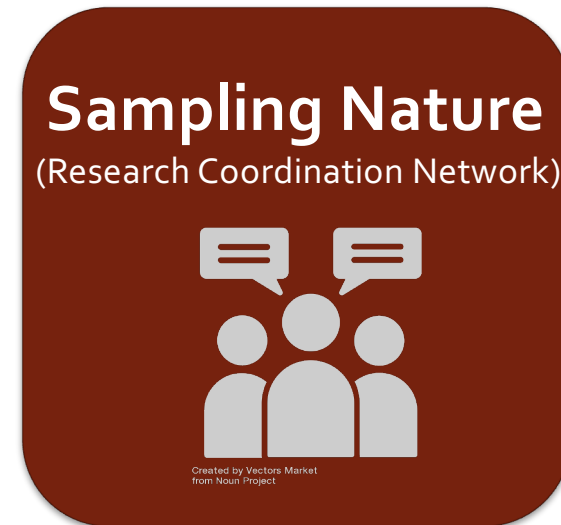


- Develop cyberinfrastructure

NSF OAC-2004839

**Sampling Nature**  
(Research Coordination Network)

Community



- Provide scientific vision
- Develop & promote best practices & standards
- Overcome social barriers

NSF DBI-2129268

See: Davies, N., et al. (2021). "Internet of Samples (iSamples): Toward an interdisciplinary cyberinfrastructure for material samples." *Gigascience* 10(5):giabo28.





# THE FAIR ISLAND PROJECT

Optimizing policies to enable FAIR data



Funded by the US National Science Foundation



**Toward a Foresight Commons:** how to integrate data-centric FAIR principles with ethical, legal, social aspects of people-centric CARE principles for Indigenous data governance



# Overview

- Island Ecosystems: Challenges for Sustainability
- Model Systems for Sustainability
- IDEA 1: Island Digital Ecosystem Avatars
- **IDEA 2: Infrastructure for Democratic Ecological Action**



# Einstein (1949)



“we should be on our guard not to overestimate science and scientific methods when it is a question of human problems;

and we should not assume that experts are the only ones who have a right to express themselves on questions affecting the organization of society.”

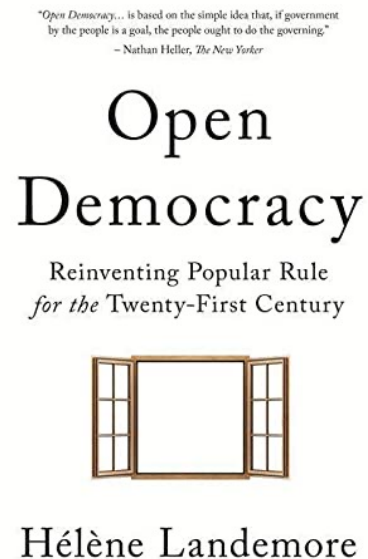
# THE OCEAN DECADE

The Science We Need for the Ocean We Want

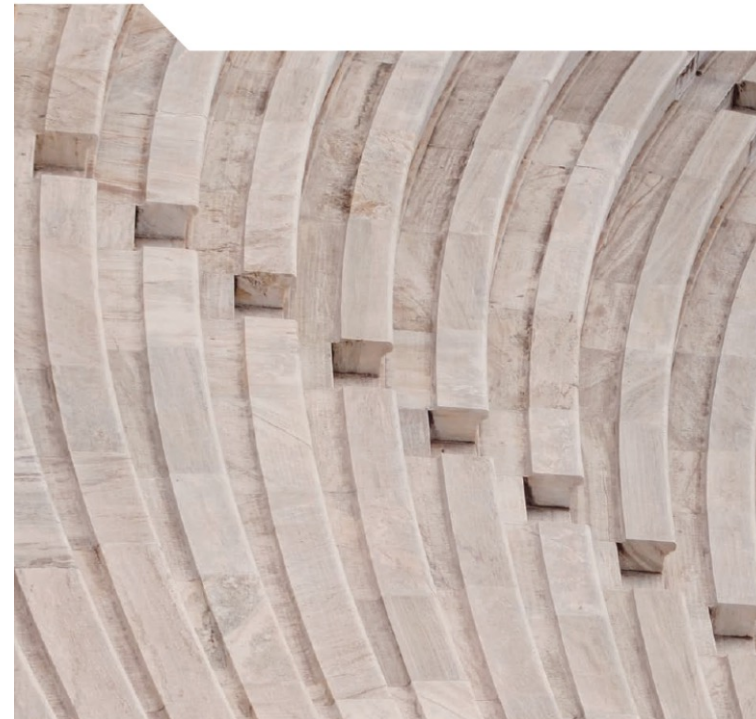
- But **what** do we want?
  - What future state do we need science to help us reach?
- And **who** is "we"?
  - How should we decide who represents us?
  - What happens when "we" disagree?



# New Democratic Thinking



**Cognitive diversity** and **democratic reasoning**: ordinary people are the experts when it comes to questions affecting the organization of society for the common good





# Democracy Next

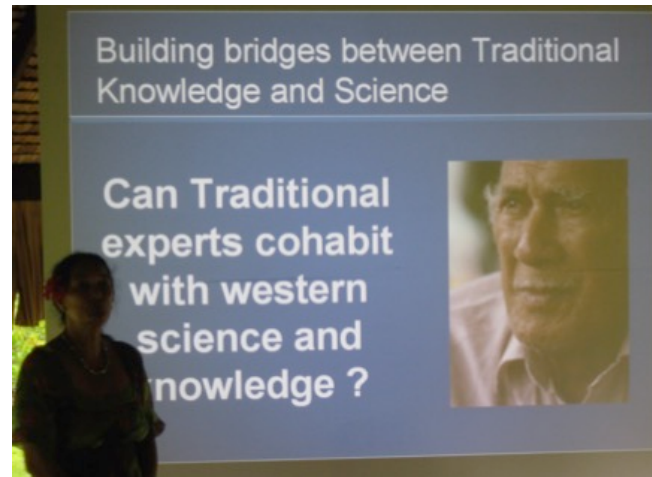
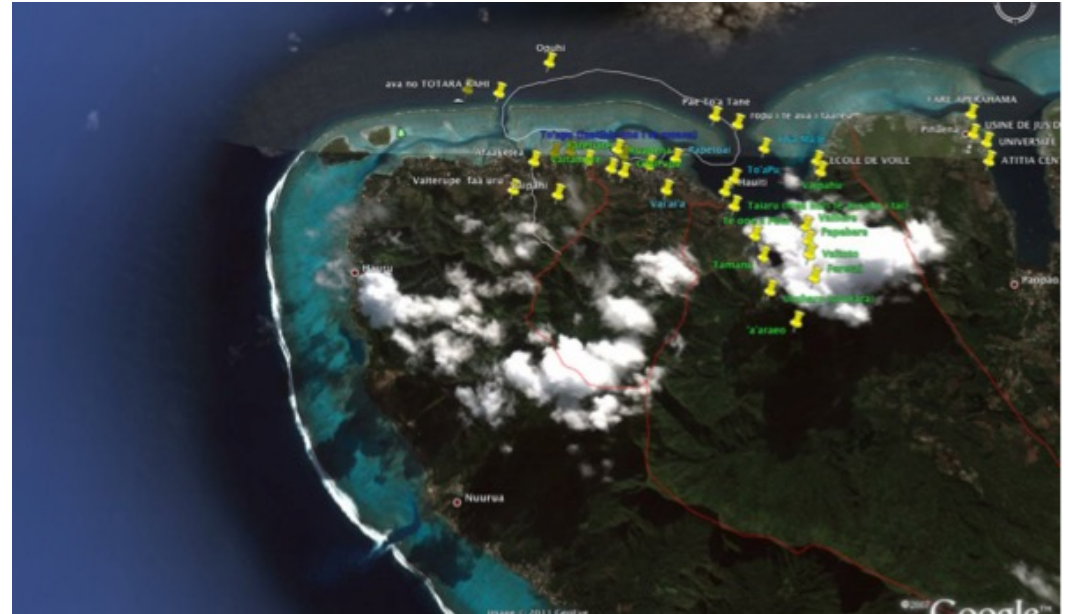
1. Giving people agency and dignity through ***participation***;
2. Distributing equal political power through *representation by lot* (***sortition***), and
3. Channeling collective wisdom and enabling people to find common ground through ***deliberation***.

<https://demnext.org/>

Foresight commons and digital avatars could help curate and communicate **admissible evidence** for citizens assemblies to deliberate over



# New Science-Community-Policy Dialogues



# New Legal Thinking

236

ARTICLE

*International Data Privacy Law*, 2019, Vol. 9,

## Bottom-up data Trusts: disturbing the ‘one size fits all’ approach to data governance

Sylvie Delacroix\* and Neil D. Lawrence\*\*

## Data trusts: international perspectives on the development of data institutions

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**WORKING PAPER 2**

**28 JANUARY 2021**



Data  
Trusts  
Initiative



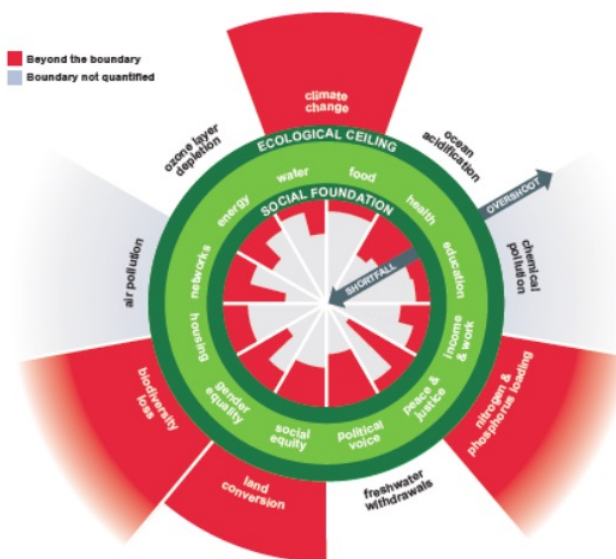
# New Economic Thinking

## Global

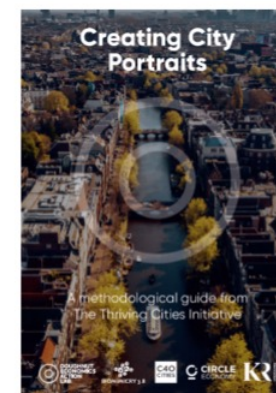
**Figure 1** The Doughnut of social and planetary boundaries



**Figure 2** Transgressing both sides of the Doughnut's boundaries



## Local



## Creating Island Portraits



Finding an **ecologically safe and socially just** space in which **humanity can thrive** (Doughnut Economics, Kate Raworth)

# New Financial Thinking


Multi-dimensional accounting:  
**Balance optimization vs resilience**

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Marcus M. Dapp  
Dirk Helbing  
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## Finance 4.0—Towards a Socio-Ecological Finance System A Participatory Framework to Promote Sustainability

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Thank you, merci, mauruuru roa !

