

### The Census of Marine Life: A Retrospective

26 January 2021 Virtual Symposium, Consortium for Ocean Leadership

Observing Life in a Changing Ocean:

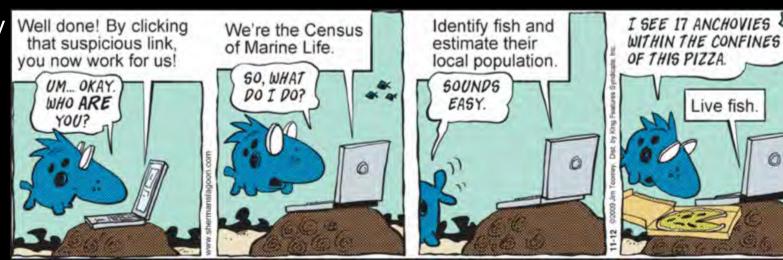
**Exploring a Census of Marine Life Today** 

Representing 2700 colleagues

Jesse H. Ausubel, The Rockefeller University

**Special thanks to Alfred P. Sloan** 

Jim Toomey Sherman's Lagoon



Live fish.



### Voted favorite animal: Blob fish



Found south of Tasmania

"A sense of humor is part of the art of leadership, of getting along with people, of getting things done" – Dwight D. Eisenhower

Source: K. Parkingson

### Nudibranch humor is the rage in 2021





### Leadership by women



Myriam Sibuet (Vice Chair)

Vera Alexander

Linda Amaral-Zettler

Maria Baker

Barbara Block

**Bodil Bluhm** 

Antje Boetius

Angelika Brandt

Ann Bucklin

Lucia Campos

Cedar Chittenden

Marta Coll

Mireille Consalvey

**Darlene Crist** 

Michelle DuRand

Nicole Dubilier

Sylvia Earle

**Brigitte Ebbe** 

Anne Edvardsen

Sara Ellis

Elva Escobar

Carola Espinoza

Tone Falkenhaug

Daphne Fautin

Ruthy Gertwagen

Kristina Gjerde

Sara Hickox

Katrin Iken

Ellen Kenchington

Nancy Knowlton

Brenda Konar

Ksenia Kosobokova

Jo-Ann Leong

Lisa Levin

Mirtha Lewis

Karen Lloyd

Ponnapakkam LokaBharathi

Heike Lotze

Connie Lovejoy

Alison MacDiarmid

Yvette Mallet

Anne Husum Marboe

Lauren McClenahan

Angela Mead

**Anna Metaxas** 

Patricia Miloslavich

Bhavani Narayanaswamy

Isabel Sousa Pinto

Anne Lise Pierrot-Bults

Sasa Raicevich

Eva Ramirez

Tamara Robinson

Sigrid Schiel

Lily Simonsen

Karen Stocks

Cindy Van Dover

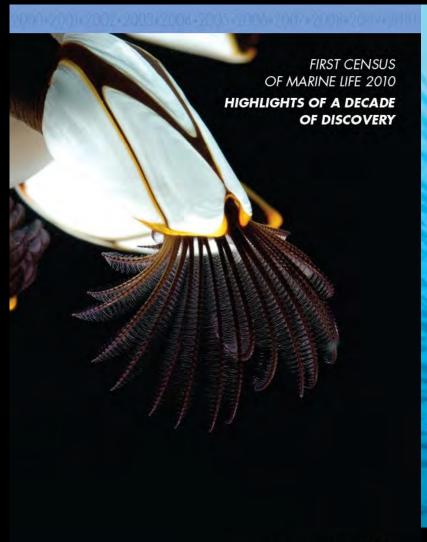
Victoria Wadley

Meryl Williams

Kristen Yarincik

Fan Zheng

### 2010 Highlights report continues to be good summary



FIRST CENSUS OF MARINE LIFE 2010

### HIGHLIGHTS OF A DECADE OF DISCOVERY

#### CONTENTS

Readers may approach this volume, like marine life, at different levels. A sequence of images and blue captions tell the story, as does the black text, and the combination.

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## A decade-long (2000-2010) program to assess and explain the

### diversity, distribution & abundance

of marine life

microbes to mammals in all ocean realms describing the Known, the Unknown, the Unknown, the Unknownble

operated by an International Scientific Steering Committee in cooperation with

SCOR, SCAR, POGO, IOC, FAO/Fisheries and dozens of national and regional agencies Strong commitment to public engagement



## Grand Challenge Questions& program components to address them

- 1) What <u>did</u> live in the oceans? History of Marine Populations
- 2) What <u>does</u> live in the oceans?

  Ocean Realm Field Projects (14)
- 3) What <u>will</u> live in the oceans? Future of Marine Populations
- 4) How to access & visualize data on living marine resources?

  Ocean Biogeographic Information System



### Challenge of different cultures

of marine science from near shore to mid-ocean



Source: CoML NaGISA



### From polar to equatorial



Source: CoML CAML





## How: concerto of technologies, 14 field projects Don't depend on one technology or expedition

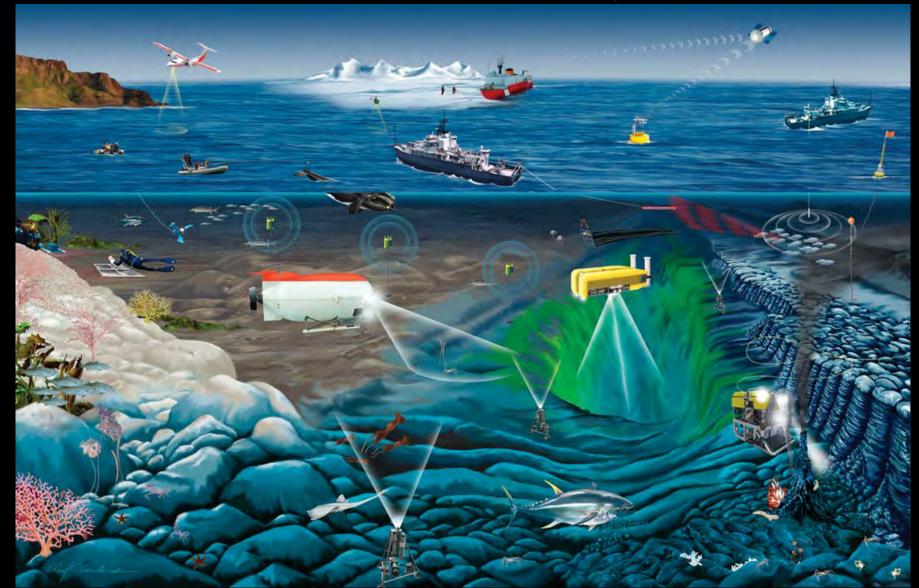


Image: E. Paul Oberlander



### Results

### **Diversity:**

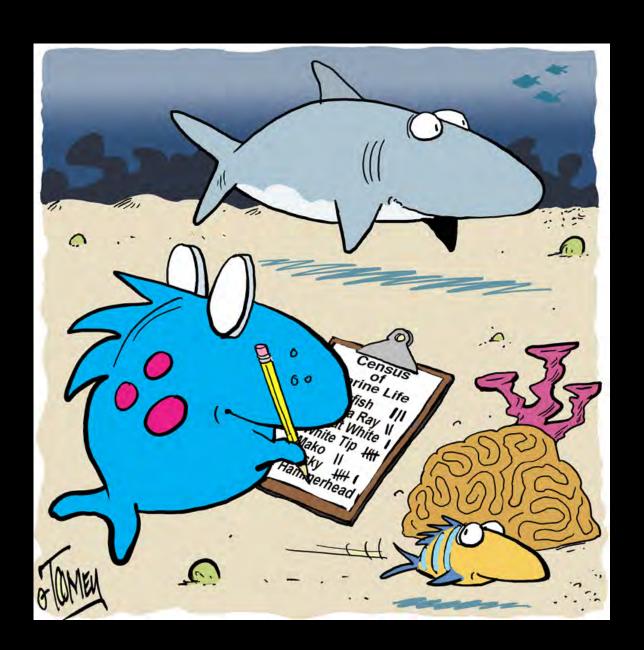
Kinds of life *Richer* 

### **Distribution:**

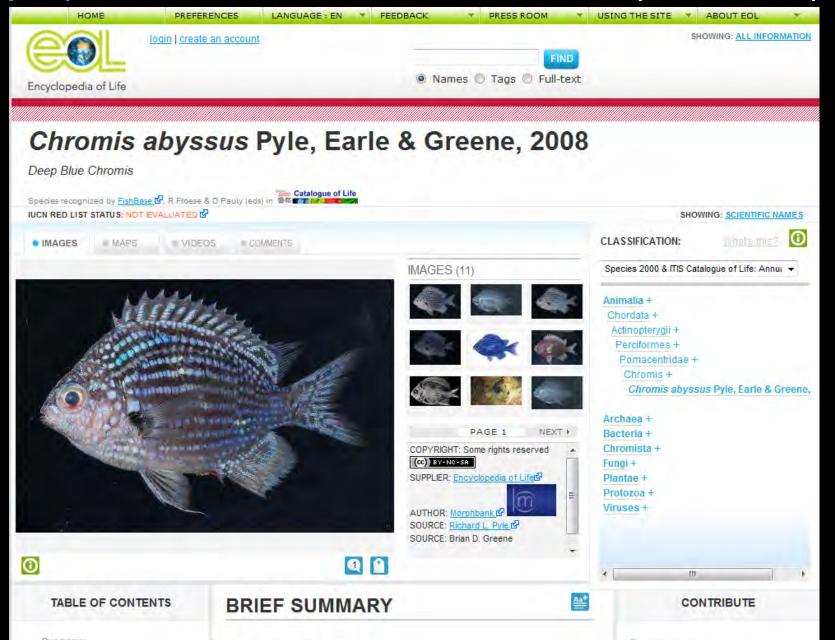
Where they live & travel *More connected* 

### Abundance:

How much of each kind *More altered* 



Diversity: Commitment to traditional & new taxonomy; pages in Encyclopedia of Life; in 2010 >130,000 marine species EOL pages





Particular discoveries: anaerobic animal found in deep Mediterranean, phylum Loricifera, *Nanaloricus cinzia* 

No mitochondria

Survivors from an ancient anoxic ecological niche?



Source: Danovaro et al., 2010



### Many syntheses

Average known diversity in 25 regions

~10,000 known species in average region

Source: Costello et al., 2010, PLoS One.



19% Crustacea

(including crabs, lobsters, shrimp, and barnacles)

17% Mollusca

(including squid, octopuses, clams, snails, and slugs)

12% Pisces

(fish, including sharks)

10% Protists

(unicellular microorganisms)

10% algae and plant-like organisms

7% Annelida (segmented worms)

5% Cnidaria

(including sea anemones, corals, and jellyfish)

3% Platyhelminthes (including flatworms)

3% Echinodermata

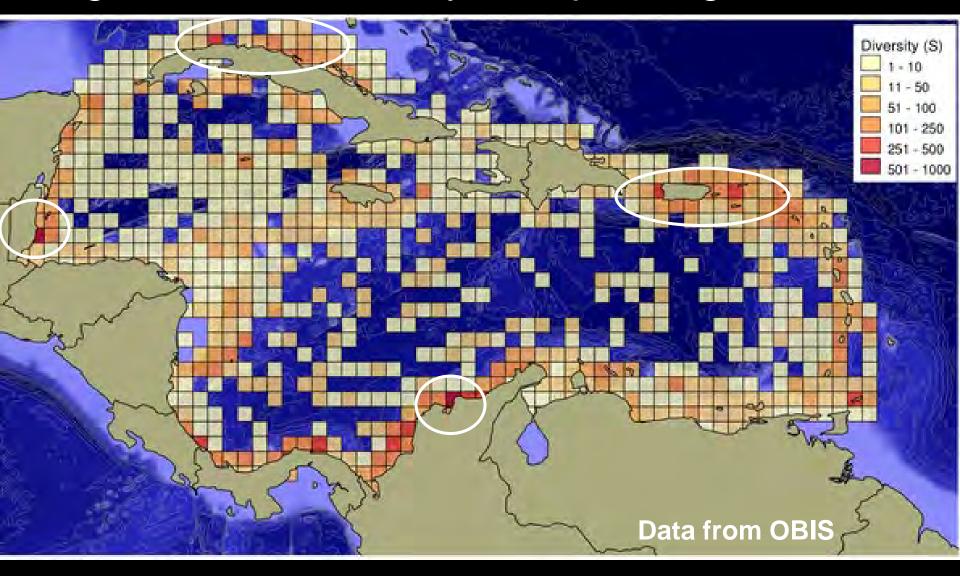
(sea stars, sea urchins, sea cucumbers)

3% Porifera (including sponges)

2% Bryozoa (mat or "moss animals")

1% Tunicata (including sea squirts)

### Regional ID of diversity hot spots, eg Caribbean

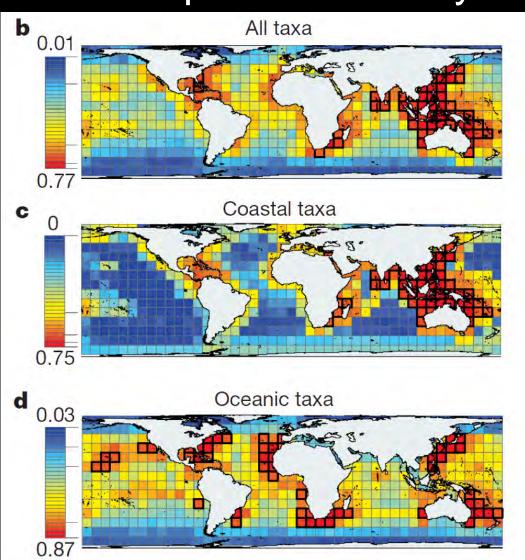






## Global maps of richness of species diversity

### Citation classics



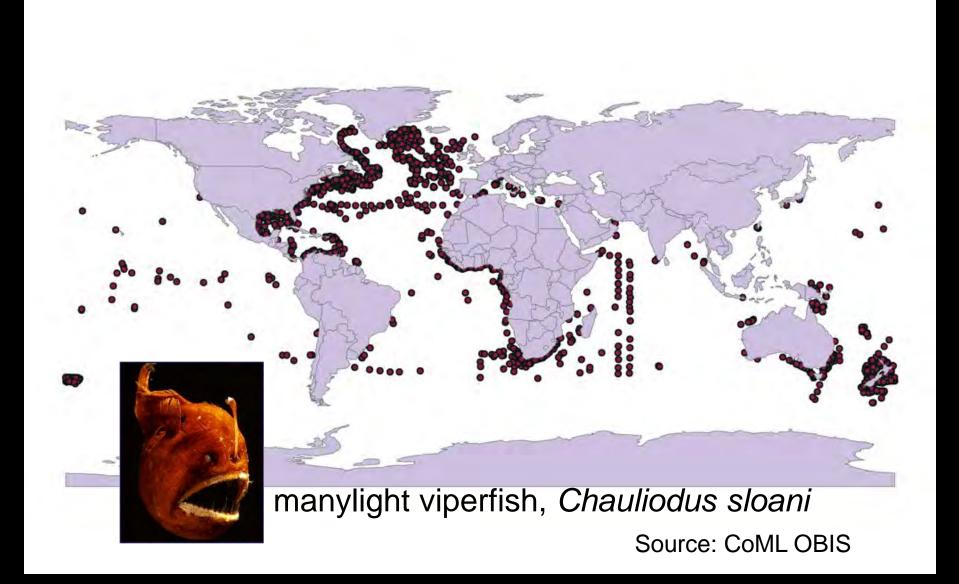
The biodiversity of the Mediterranean Sea: estimates, patterns, and threats Marta Coll ...R Danovaro... PloS one, 2010 cited by 1428

How many species are there on Earth and in the ocean? C Mora, DP Tittensor, S Adl, AGB Simpson, B Worm - PLoS Biol, 2011 cited by 2250

Source: Tittensor et al. (2010). Nature 466: 1098-1101, cited by 997



# Distribution: CoML's Ocean Biogeographical Information System (OBIS) allows global view where species reliably observed



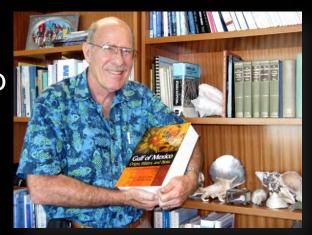


## Distribution: What lives in e.g., the Gulf of Mexico

- Gulf of Mexico
  Origin, Waters, and Biota
  Volume 1, Biodiversity

  Essent by Darryl L. Felder
  and David K. Camp
- Baseline (2010) before Deep Horizon spill (2011)
- 15,419 species
- Compiled by 140 experts from 80 institutions in US, Cuba, Mexico
- Data available through OBIS & http://gulfbase.org/biogomx/biosearch.php

Team leader Wes Tunnell prepared expert report for spill investigation



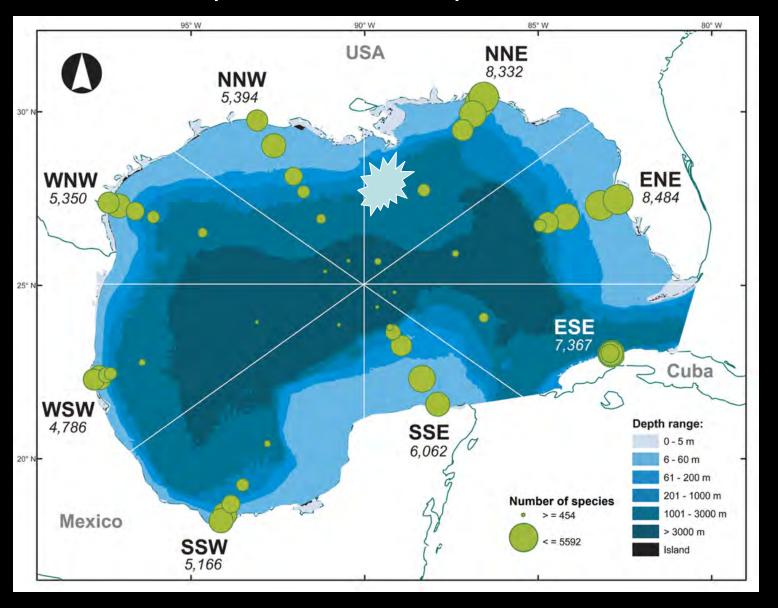
A Decade of Discovery

Source: Tunnell et al., GoMex project



## 8,332 species recorded in NNE region near Deepwater Horizon spill

Source: Harte Institute GoMex project





## Summary distributions of top predators: connectivity Blue Highways and neighborhoods of the Pacific

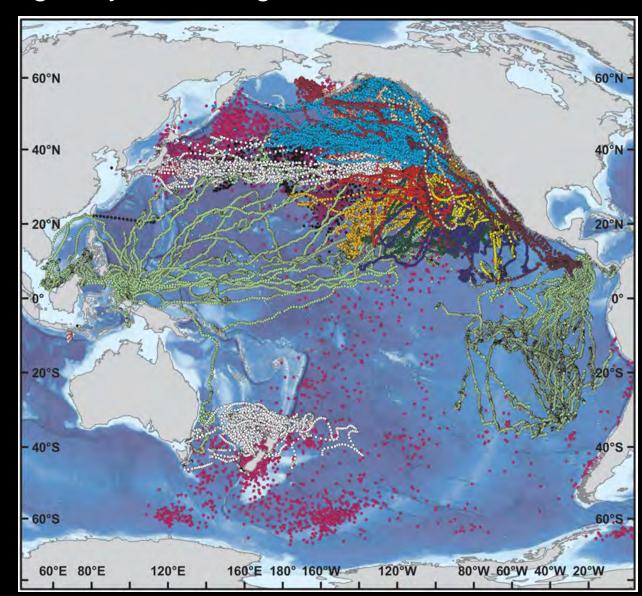
Bluefin tuna

Leatherback turtles

### White shark

Source: CoML TOPP Project

Tracking apex marine predator movements in a dynamic ocean BA Block, ID Jonsen, ...M Wiese...D Costa Nature, 2011 - cited by 1044





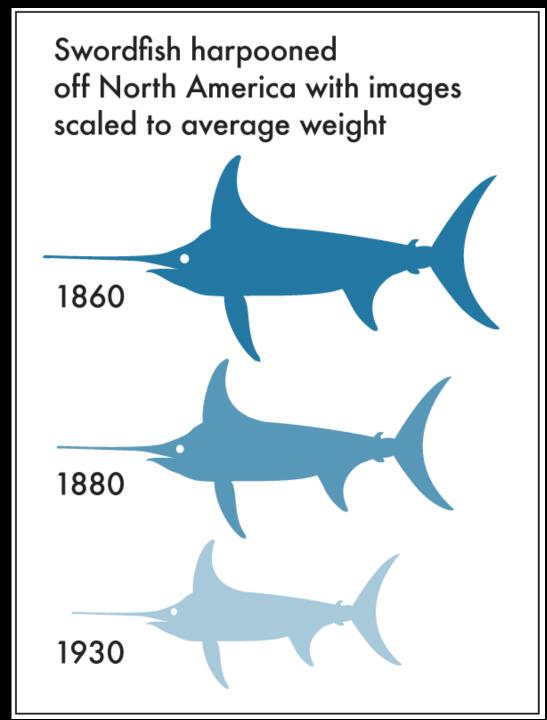
Oceans Past

### Abundance:

Decline of large animals

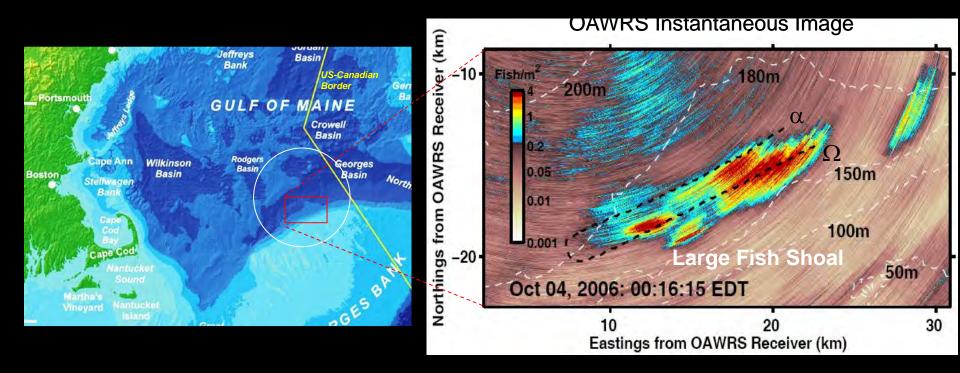
alteration

Source: CoML HMAP, MacKenzie et al.



## Abundance: 3 Oct 2006, a quarter of a billion fish (50,000 tons) gather in same place

Makris, Ratilal, Jagannathan, Gong, Andrews, Bertsatos, Godoe, Nero, "Critical Population Density Triggers Rapid Formation of Vast Oceanic Fish Shoals" *Science* (2009).

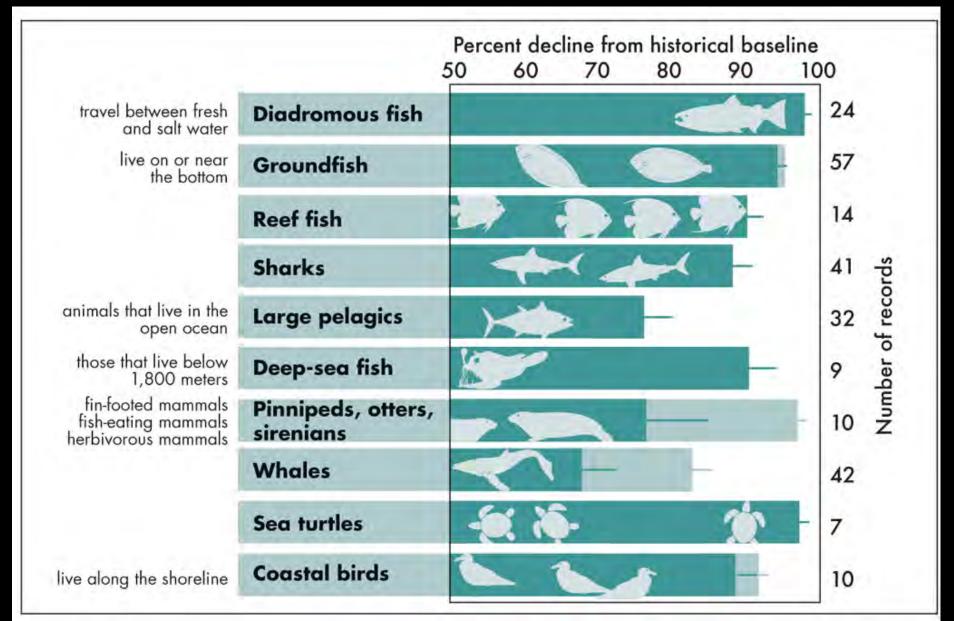


Ocean Acoustic Waveguide Remote Sensing (OAWRS) uses properties of spherical spreading to image schools of fish as far as 150 km from sound source



### Abundance/Alteration: 90% drops of 10 groups

Source: CoML FMAP, Lotze et al.



While direct removal affects sea life most, other factors matter too. Marine debris causes mortality, e.g., of albatross in Northwest Hawaiian Islands



Photos: Susan Middleton



Major discovery: Rare is Common in the oceans

# Microbial diversity in the deep sea and the underexplored "rare

biosphere "Mitchell L. Sogin,
Hilary G. Morrison, Julie A. Huber, David Mark
Welch, Susan M. Huse, Phillip R. Neal, Jesus N
Arrieta, and Gerhard J. Herndl

3703 citations in Google Scholar

High Abundance Populations

1 billion phylotypes?Cf 1 million species1000:1 microbes/species?

Low Abundance Populations

Rare Biosphere

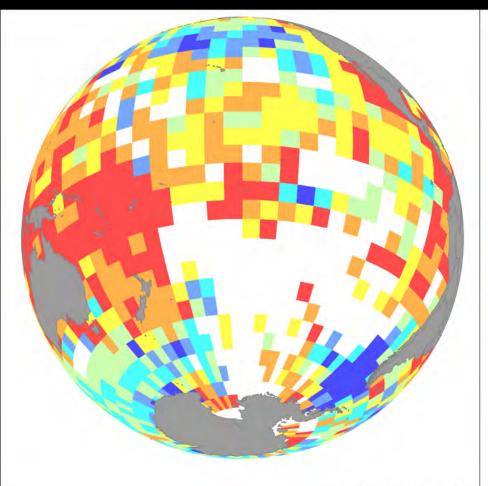


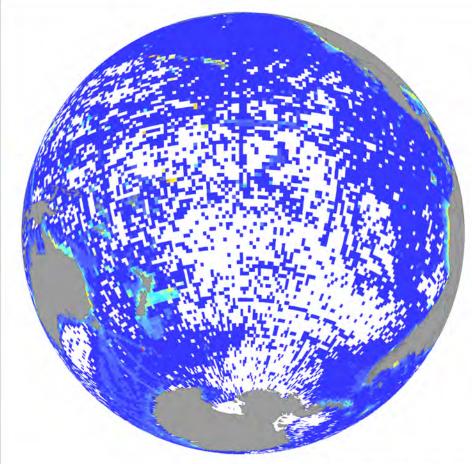
How many microbes live in the Oceans?

10,000,000,000,000,000,000,000,000

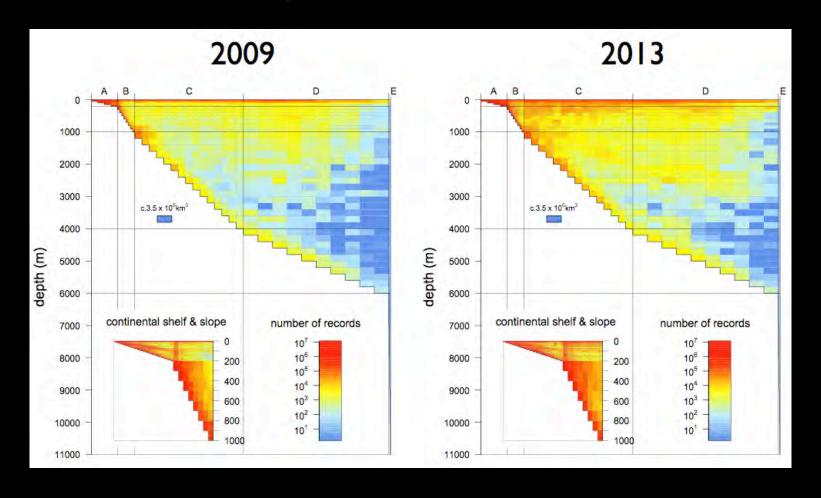
Microbes may account for 90% of biomass in oceans!

# Unexplored ocean: Eastern & Southern Pacific OBIS records per 5 degree (left) & 1 degree (right) cell Source: W. Appeltans



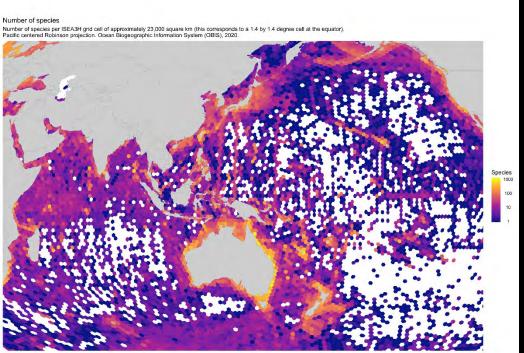


## Known & Unknown Ocean: A slice red = many records, dark blue none



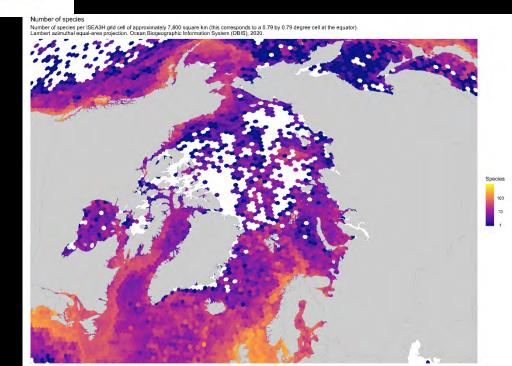
In 2010 OBIS has ~7 million records, in 2021 >64 million from >3800 datasets.

Source: OBIS/Appeltans



OBIS February 2020 species richness and blank spots

Used in IPBES Global biodiversity assessments



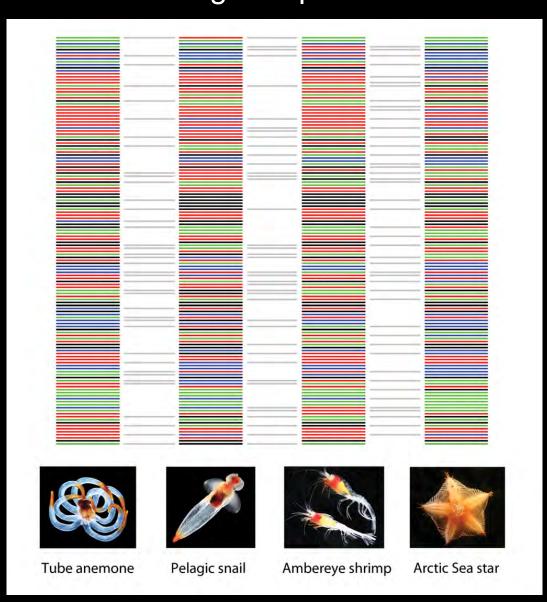


### Census catalyzed global Barcode of Life initiative and led marine barcoding for species identification

Works for fragments, look-alikes, different life stages

Colored stripes represent thymine, cytosine, adenine, guanine bases

Barcodes: Stoeckle Images: Clarke-Hopcroft, Hopcroft, Bluhm, Iken



### Census/Barcoding pioneered Citizen Science: Sushi-gate 2008 - High School students apply DNA barcoding to fish sold in their NYC neighborhood, discover one-quarter is mislabeled



#### Can DNA name this fish?



#### YOUR BUSINESS: Keeping them honest

by Kate Stoeckle & Louisa Strauss

#### High school students track down fish fraud

White (Albacore) Tuna

\$8,50/lb wholesale

fied by their DNA barcodes.

Some fish sold in New York City are

mislabeled as more expensive varieties

Mozambique Tilapia

\$1.70/lb wholesale

longtime contributor to Pacific Fishing, heard a month, we had a full set of samples and important? In most of an exemplary high school student project, in sent them to University of Guelph, Ontario, cases, less expensive which two Trinity School seniors went looking Canada, where graduate student Eugene fish were marketed for an honest fishmonger in New York City. We wanted to know how they did it, in case you the barcode gene region. wanted to do your own investigation into fish fraud. Here is their report:

A new DNA-based identification system shows that fish in New York City (93 percent) of our samples could be identirestaurants and grocery stores are commonly mislabeled

The identification system "scans" the same part of the same gene from every fied by DNA, 13 - or 23 percent - were mislabeled fish are from completely differ-

species and matches it with similar information in a database containing verified gene sequences of tens of thousands of species.

Scanning the gene species is like scanning the barcode to identify a supermarket item. By analogy. the system is called "DNA barcoding."

A commercial laboabout \$25 per sam-

isolate the DNA yourself, which is easy With some help from Kate's dad, who is farmed. a biologist at The Rockefeller University, we collected 60 samples from 14 Manhattan restaurants, fish markets, and grocery stores. We snipped off a tiny bit of each is restricted to the Caribbean. Seven of nine other parts of New York City. 3

alcohol in our kitchen freezer. We recorded the market name of included Acadian redfish from the North each fish and where and when it was Atlantic, slender pinjalo from Southeast purchased, and in most cases took pictures Asia, lavender jobfish from the South Pacifof each sample. We created a project on the ic, Nile perch, a freshwater fish from Africa, Barcode of Life Database (BOLD) Web and Atlantic cod.

and stored the pieces in plastic vials with

Before starting, make an arrangement and instructions on how to use it. with a laboratory that does DNA sequenc- The Smithsonian Institution in Washinging, preferably one that is familiar with ton, D.C., also has sample collection kits and DNA barcoding methods.

small tray with 96 plastic tubes for samples specimens.

is experienced with DNA barcoding.

samples listed as "red snapper" were mis-

labeled. Fish substituted for "red snapper"

Guelph, Ontario, Canada. They sent a spe- in microscopic bits of tissue, so it is very closely related species have similar DNA cially designed collection kit, which is a important to avoid carry-over between barcodes, you may need an expert to help

Wong performed DNA sequencing from as more expensive

fish. You might think you We compared the DNA barcodes of are eating \$20-a-pound samples to the BOLD reference library, "flying fish roe," but you which so far contains about 24,000 are actually eating \$6-abarcodes from 4,500 fish species. Nearly all pound smelt roe.

We are not certain where

the mislabeling occurs, but it seems it is Of the 56 samples that could be identi- not the fishermen doing it, because the

> For example, if a fishing boat arrives at a dock in Florida, it is unlikely that it carries fish from Southeast Asia.

Perhaps the mislabeling occurs somewhere in the middle, when the fish are filleted and no longer

easily identifiable. We think that there should be routine DNA barcode testing of fish to make sure we are getting what we pay for and to make sure that

ple to sequence DNA from a piece of fish. mislabeled. For example, a piece of sushi being sold illegally But the charge would be about \$5 if you labeled as "white tuna" (albacore) matched

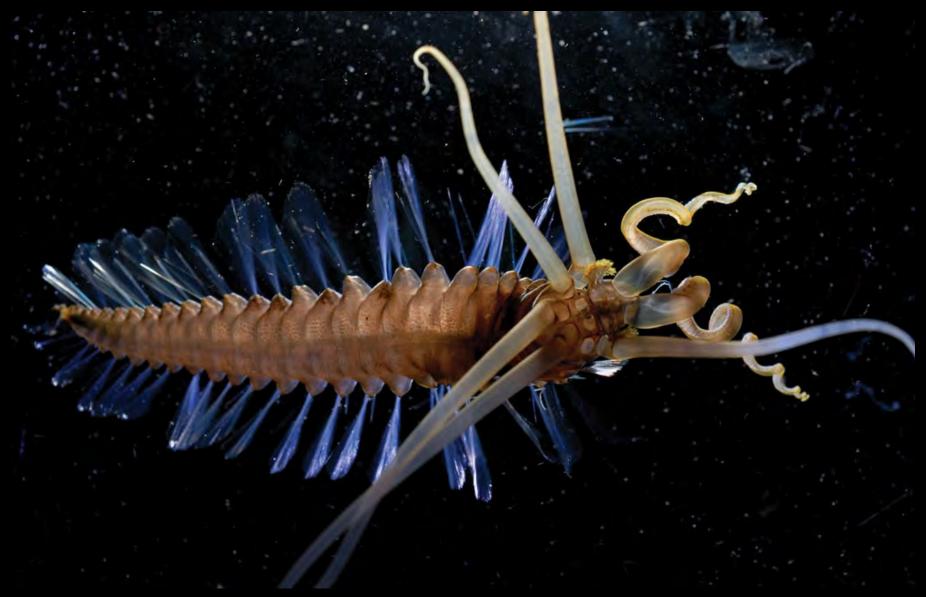
Scientists around the world are cooperatwith the DNA sequence of Mozambique ing in a Census of Marine Life program to tilapia, a freshwater fish that is commonly develop a reference library of barcodes not only for fish but also for scallops, crabs, and A restaurant item listed on the menu as other kinds of seafood. We hope to get our 'Mediterranean red mullet" matched the school interested in doing a larger investi-DNA sequence of spotted goatfish, which gation of fish markets and restaurants in

Once you have your DNA sequences, it is easy to copy and "paste" these into the "Identification Engine" on the Barcode of We worked with the University of The testing method can detect DNA Life Database, However, because some with analyzing the data. 4

34 ☐ PACIFICFISHING ☐ SEPTEMBER 2008 ☐ WWW.PACIFICFISHING.COM



### Strong aesthetic: Celebes Sea, new "squidworm"



Source: CoML CMarZ, L. Madin



### Convergence of art and science

New copepods & isopods from Angola Basin & Southern Ocean





Public Engagement: Iconic species of CoML, yeti crab, *Kiwa hirsuta*, discovered in S. Pacific



Source: CoML CHeSS



## Yeti crab enters popular culture ....on a skate board







Jeweled squid Deep sea cephalopod Photo: David Shale







#### Artist's model





Ornulf Opdahl In his studio on Research vessel G. O. Sars





#### Sculpture Anne B Edvardsen

Mainly I make sculptures inspired by deep sea creatures.. I participated on a science ship in the North Sea where the scientists let me learn about their methods and we discussed our approach to the species. The possibility to handle and study the animals on the ship has followed me since...



https://anne-b-edvardsen.com/works/#mg



### Art & Science together



A. Edvardsen



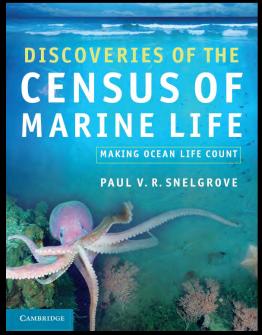
Zombie worm (Osedax roseus)
eating bone of dead whale fallen to seafloor
in Sagami Bay, Japan

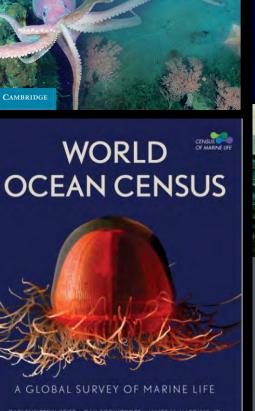


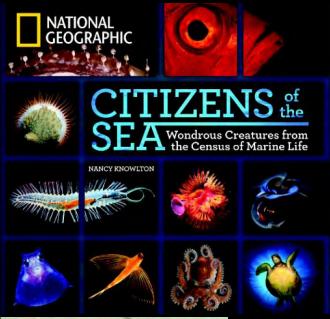
Minister of Agriculture, Forestry and Fisheries Michiko Kano with zombie worm boutonniere



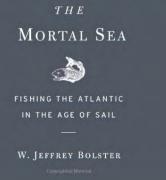
#### Books for experts and wide audiences

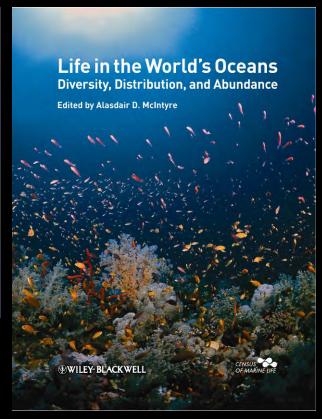












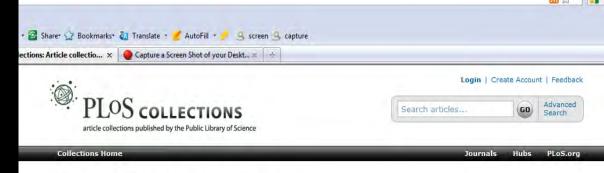
2010 American Publishers prizes for excellence in both earth sciences & physical sciences

2013 Bancroft Prize in American history (Harvard UP)



# Pioneering commitment to Open Access

Technical papers:
CoML pioneers
use of PLoS One
for collections of
papers from a
big science project



#### Census of Marine Life Collections

The Census of Marine Life Collections present research from the Census of Marine Life (CoML), which is a ten-year initiative intended to assess and explain the diversity, distribution, and abundance of marine life in the world's oceans—past, present and future. As with all of our content, all material within collections is published under a Creative Commons Attribution License; hence users can, with attribution, download, print, or reuse in any way either individual articles or entire collections.

Much of the research reported within the articles published in these collections was conducted under the auspices of the Census of Marine Life (CoML)—a project supported by (among others) The Alfred P. Sloan Foundation. The named PLoS editor for each article had sole responsibility for the publication decision on the paper.



Diversity in the Nearshore: The NaGISA Collection



The FMAP Collection



The HMAP Collection



The MarBO Collection



Marine
Biodiversity and
Biogeography Regional
Comparisons of
Global Issues



The TOPP Collection



The POST Collection



Biogeography of Deep-Water Chemosynthetic Ecosystems - The ChEss Collection

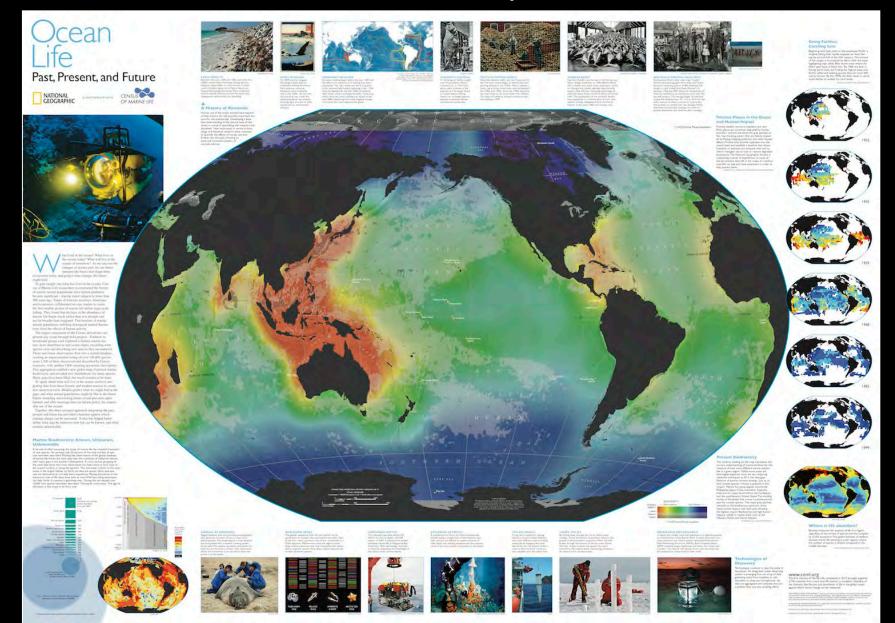
#### Additional articles:

Global Patterns and Predictions of Seafloor Biomass Using Random Forests

Do Meio- and Macrobenthic Nematodes Differ in Community Composition and Body Weight Trends with Depth?

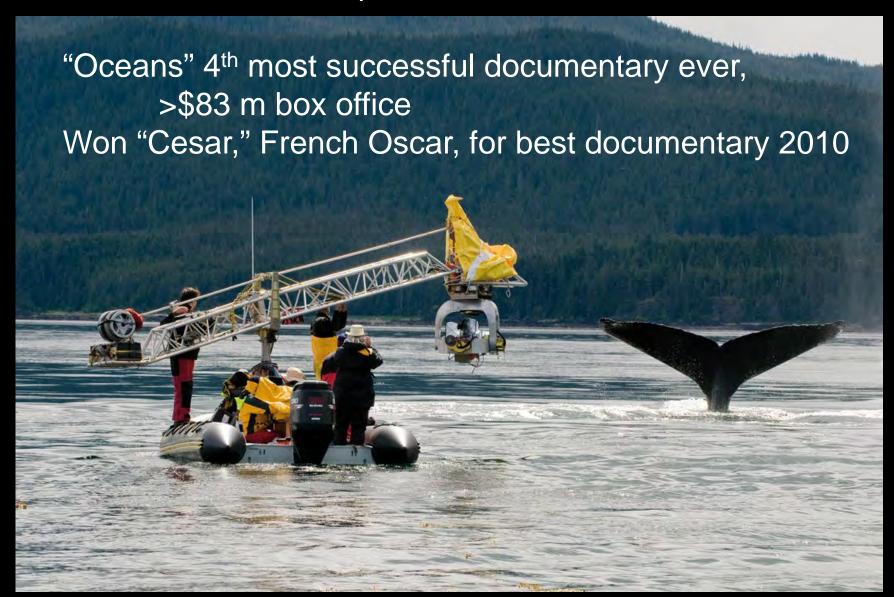
### CENSUS OF MARINE LIFE 2010

#### National Geographic wall map Halpin et al.





### Galatee Films (Jacques Perrin et al.) observes humpback whale off British Columbia





Oceans film by Jacques Perrin Galatee Films, advertised on Paris kiosk





#### A bridge between people Participants, CoML workshop Sultan Qabus University, Muscat, Oct 2007





### CoMLCaribe Isla de Margarita, Venezuela, June 2004





### CoML Southern Africa





### CoML Indian Ocean





### CoML.cn





## The spirit of a ship's crew: a culture of pulling together Marine biology can succeed as Big Science







Great adventures USCG icebreaker Healy

Hidden Ocean Expedition Sampling from ice floes in the Arctic north of Alaska

High-powered rifle In case of polar bears

Ice divers







# Census Summary 2000-2010 It can be done

#### Inputs

- >2,700 scientists
- >80 countries
- >540 field expeditions
- ~US \$650 million
- Outputs
- 2003 baseline report
- Annual reports 2004-2009
- >1,200 new species + 5000 await description
- >130,000 EOL pages for marine species

~35,000 marine species
with DNA barcodes
3,100 publications + books,

maps, videos (as of 10/2010)

films, paintings, sculptures, songs...

Highlights available in 11 languages



#### Outcomes and legacies:

Technologies, protocols

Knowledge, heavily cited papers, OBIS, start of Annual Rev. of Marine Sci.

Globally networked communities, shift to Open Access

Subsequent programs (deep sea, global tagging, Ocean Tracking Network)

Strengthened fields: marine taxonomy; historical marine ecology

More biology in global ocean observing system

Marine protected areas (Mid-Atlantic Ridge, Antarctica)

Enhanced careers, Sloan ocean science fellowships (8/yr)



Ricardo Santos of Seamounts project

#### **Unusual features:**

Sloan Foundation role

- --10-year commitment, \$77 m
- --fast decision-making (<90 days)
- --funds could be spent anywhere Autonomy of steering committee Warm geopolitics in late '90s Integration with Arts & Humanities Commitment to public engagement

Sense of humor