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
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

Every other mollusc
Nudibranchs

https://twitter.com/spissatella/status/1351470537550262274?s=12
Leadership by women

<table>
<thead>
<tr>
<th>Myriam Sibuet (Vice Chair)</th>
<th>Elva Escobar</th>
<th>Yvette Mallet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vera Alexander</td>
<td>Carola Espinoza</td>
<td>Anne Husum Marboe</td>
</tr>
<tr>
<td>Linda Amaral-Zettler</td>
<td>Tone Falkenhaust</td>
<td>Lauren McClenanah</td>
</tr>
<tr>
<td>Maria Baker</td>
<td>Daphne Fautin</td>
<td>Angela Mead</td>
</tr>
<tr>
<td>Barbara Block</td>
<td>Ruthy Gertwagen</td>
<td>Anna Metaxas</td>
</tr>
<tr>
<td>Bodil Bluhm</td>
<td>Kristina Gjerde</td>
<td>Patricia Miloslavich</td>
</tr>
<tr>
<td>Antje Boetius</td>
<td>Sara Hickox</td>
<td>Bhavani Narayanaswamy</td>
</tr>
<tr>
<td>Angelika Brandt</td>
<td>Katrin Iken</td>
<td>Isabel Sousa Pinto</td>
</tr>
<tr>
<td>Ann Bucklin</td>
<td>Ellen Kenchington</td>
<td>Anne Lise Pierrot-Bults</td>
</tr>
<tr>
<td>Lucia Campos</td>
<td>Nancy Knowlton</td>
<td>Sasa Raicevich</td>
</tr>
<tr>
<td>Cedar Chittenden</td>
<td>Brenda Konar</td>
<td>Eva Ramirez</td>
</tr>
<tr>
<td>Marta Coll</td>
<td>Ksenia Kosobokova</td>
<td>Tamara Robinson</td>
</tr>
<tr>
<td>Mireille Consalvey</td>
<td>Jo-Ann Leong</td>
<td>Sigrid Schiel</td>
</tr>
<tr>
<td>Darlene Crist</td>
<td>Lisa Levin</td>
<td>Lily Simonsen</td>
</tr>
<tr>
<td>Michelle DuRand</td>
<td>Mirtha Lewis</td>
<td>Karen Stocks</td>
</tr>
<tr>
<td>Nicole Dubilier</td>
<td>Karen Lloyd</td>
<td>Cindy Van Dover</td>
</tr>
<tr>
<td>Sylvia Earle</td>
<td>Ponnappakam LokaBharathi</td>
<td>Victoria Wadley</td>
</tr>
<tr>
<td>Brigitte Ebbe</td>
<td>Heike Lotze</td>
<td>Meryl Williams</td>
</tr>
<tr>
<td>Anne Edwardsen</td>
<td>Connie Lovejoy</td>
<td>Kristen Yarincik</td>
</tr>
<tr>
<td>Sara Ellis</td>
<td>Alison MacDiarmid</td>
<td>Fan Zheng</td>
</tr>
</tbody>
</table>
2010 Highlights report continues to be good summary
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 Unknowable 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 did live in the oceans?*
   History of Marine Populations

2) *What does live in the oceans?*
   Ocean Realm Field Projects (14)

3) *What will 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
Polar sampling

Shallow & deep, small & large

Source: ArcOD
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.
Regional ID of diversity hot spots, eg Caribbean

60,368 records of 5601 species

Source: CoML Caribe

Data from OBIS
Global maps of richness of species diversity

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?

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

manylight viperfish, *Chauliodus sloani*

Source: CoML OBIS
Distribution: What lives in e.g., the Gulf of Mexico

- 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

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
Abundance: Decline of large animals

Source: CoML HMAP, MacKenzie et al.
**Abundance:** 3 Oct 2006, a quarter of a billion fish (50,000 tons) gather in same place


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.

<table>
<thead>
<tr>
<th>Habitats</th>
<th>Percent decline from historical baseline</th>
<th>Number of records</th>
</tr>
</thead>
<tbody>
<tr>
<td>travel between fresh and salt water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundfish</td>
<td>90</td>
<td>57</td>
</tr>
<tr>
<td>Reef fish</td>
<td>80</td>
<td>14</td>
</tr>
<tr>
<td>Sharks</td>
<td>70</td>
<td>41</td>
</tr>
<tr>
<td>Large pelagics</td>
<td>60</td>
<td>32</td>
</tr>
<tr>
<td>Diadromous fish</td>
<td>50</td>
<td>24</td>
</tr>
<tr>
<td>animals that live in the open ocean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep-sea fish</td>
<td>90</td>
<td>9</td>
</tr>
<tr>
<td>Pinnipeds, otters, sirenians</td>
<td>80</td>
<td>10</td>
</tr>
<tr>
<td>Those that live below 1,800 meters</td>
<td>70</td>
<td>42</td>
</tr>
<tr>
<td>Whales</td>
<td>60</td>
<td>7</td>
</tr>
<tr>
<td>Those that live below 1,800 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea turtles</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>fin-footed mammals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal birds</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Fish-eating mammals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbivorous mammals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Live along the shoreline</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 M. Arrieta, and Gerhard J. Herndl

3703 citations in Google Scholar

High Abundance Populations

Low Abundance Populations

1 billion phylotypes?
Cf 1 million species
1000:1 microbes/species?

Rare Biosphere
How many microbes live in the Oceans?

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

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

Used in IPBES

Global biodiversity assessments

species richness and blank spots
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

Tube anemone  Pelagic snail  Ambereye shrimp  Arctic Sea star
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?

Research report by students Kate Stoeckle and Louisa Strauss published in Pacific Fishing September 2008
Strong aesthetic: Celebes Sea, new “squidworm”
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
Jeweled squid portrayed by fabric artist Judith Wagstrom.
Water color artist
Ornulf Opdahl,
Aboard Mid-Atlantic expedition
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
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

Discovery of the Census of Marine Life: Making Ocean Life Count
Paul V. R. Snelgrove
Cambridge

Citizens of the Sea: Wondrous Creatures from the Census of Marine Life
Nancy Knowlton
Cambridge

World Ocean Census
Darlene Treu Crist, Gail Scowcroft, James M. Harding, Jr.
Cambridge

The Mortal Sea: Fishing the Atlantic in the Age of Sail
W. Jeffrey Bolster
Cambridge

Life in the World’s Oceans: Diversity, Distribution, and Abundance
Edited by Alasdair D. McIntyre
Wiley-Blackwell

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
Ocean Life
Past, Present, and Future

National Geographic wall map
Halpin et al.
Galatee Films (Jacques Perrin et al.) observes humpback whale off British Columbia

“Oceans” 4th most successful documentary ever, >$83 m box office
Won “Cesar,” French Oscar, for best documentary 2010
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

Bijoux
Seychelles
Griffiths
South Africa

Armah
Ghana

Mgaya
Tanzania

van den Berghe
MASDEA

Sardinha
Angola

Griffiths
South 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
Census awarded 2011 prize for contributions to harmony of nature and humanity
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
Chile-led expedition to Antarctica

Elephant seals
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)

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

Ricardo Santos of Seamounts project