Every Fish in the Sea:
Findings Of the First Census of Marine Life

Harvard Class of 1973 40th Reunion
28 September 2013

Representing 2700 colleagues

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The Rockefeller University
Special thanks to Alfred P. Sloan
The First Census of Marine Life

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
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

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
Some reminders about features of the oceans: vast, varied environments

Shores, shelves, continental margins or slopes, abyssal plains, ocean ridges, seamounts, ice oceans, reefs…
Why: Surface crowding by maritime transport

Time lapse tracks of vessels > 300 gross tons, 2009

Busy highways but also areas with few vessels;

3x # of large ships since 1960

Source: US Coast Guard
TAT-8 (20 million bits/second), 8th trans-Atlantic telecom cable, and first to use fiber-optics, is laid. Isaac Asimov attends ceremony.

TAT-14 (3.2 trillion bits/second) is one of ~228 submarine cables with capacity in excess of 5 billion bits/second.

Why: Development of seafloor - telecom cables
Crucial for domestic & int’l communications
Satellites could pick up <10% of capacity if lost
Why: Seafloor crowding by offshore oil & gas
Extensive, complex networks

Gulf of Mexico pipeline network

Source: NOIA
Why:
More uses, more users

Drilling derricks

Beach in Qingdao, China

sushi
Yet oceans still little & unevenly unexplored, mostly near shore, near rich

Number of taxonomically reliable observations per 5 degree cell in biggest biology database, 2013 red many records, dark blue very few.
How to conduct a Census? Different cultures of marine science from near shore to mid-ocean

Source: CoML NaGISA
From polar to equatorial

Source: CoML CAML
Shallow & deep, small & large

Polar sampling

Source: ArcOD
How: A concerto of technologies, in 14 projects

Image: E. Paul Oberlander
Diversity: Kinds of life
Richer

Distribution: Where they live & travel
More connected

Abundance: How much of each kind
More altered
Diversity: Even in Atlantic new macro- and megafauna found

after Garrison, 1993
Diversity: >6000 new species, ~1200 fully described
N. Atlantic deep-sea octopod *Stauroteuthis syrtensis*

Source: CoML MAR-ECO
A new octopus on reef off northeastern Australia

Source: CReefs
Celebes Sea, new “squidworm”

Source: CoML CMarZ, L. Madin
Diversity hard to imagine

Angola Basin: > 800 different copepods, most new to science
Southern Ocean: > 700 different isopods, > 500 new to science
Pages created for species in Encyclopedia of Life with links to other sources; >130,000 marine species have EOL pages
Diversity: Organizing the Known, e.g. “Squat Lobsters”
Decapod crustaceans, near hermit crabs, ~1000 species

A, *Galathea* sp. on bryozoa, eastern Australia.
B, *Babamunida debrae*, Hawaii


Source: Poore et al., 2011
1000 Galatheids or squat lobsters

A, Allogalathea elegans, Taiwan.
B–C, Allogalathea elegans, Vanuatu.

D, Allogalathea babai, Vanuatu.
E, Allogalathea longimana, Philippines.
F, Fennerogalathea chacei, Philippines.

I, Macrothea bouchardi, Mayotte.

Source: Poore et al., 2011
B, *Galathea magnifica*, eastern Australia.
C, *Galathea mauritiana*, Taiwan.


Source: Poore et al. 2011
C, *Eumunida funambulus*, Taiwan.

D, *Eumunida macphersoni*, Taiwan.

Source: Poore et Al., 2011
Total marine species diversity: ~250,000 known, named; ~0.5-2 million more? + microbes!

Why so many yet to know?
The rare, the small
Hard to sample, immensity, 3-d complexity, hard to reach
Few experts – Many taxonomic groups poorly known
Not only astounding richness of diversity but interesting biology

A group of carnivorous sponges abundant & species rich in the deep sea

Source: Pedro Martínez Arbizu – CeDAMar
Unusual longevity

Alaminos Canyon 645, Gulf of Mexico 2200 m
Most common tubeworm at deep sites (> 1000m)
*Escarperia laminata* aged 500-600 years old

Vent & Seep (ChEss) team lead from Southampton
An anaerobic animal, found in deep Mediterranean, the phylum Loricifera, *Nanaloricus cinzia*

No mitochondria

Survivors from an ancient anoxic ecological niche?

Source: Danovaro et al., 2010
Average known diversity in 25 regions

~10,000 known species in average region


>11,000 views
ID of diversity hot spots – Caribbean example

Data from OBIS

60,368 records of 5601 species

Source: CoML Caribe

CENSUS OF MARINE LIFE
Global maps of richness of species diversity

Source: Tittensor et al. (2010). Nature 466: 1098-1101
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

• Comprehensive pre-spill (2010) baseline
• 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 the NNE region near Deepwater Horizon spill

Source: Harte Institute GoMex project
Distribution: The journeys
Trans-ocean travelers: Bluefin tuna, *Thunnus thynnus*

Source: CoML TOPP
Turtles tagged in Costa Rica range through and characterize Eastern Pacific.
Two elephant seals, *Mirounga leonina*, explore seamounts down to 2,300 meters, connecting deep & surface; crabeater seals make tracks close to shore.
Distributions: Journeys of the traveling animals, connecting the oceans, e.g. southern elephant seals, *Mirounga leonina*

Source: CoML TOPP/SEaOS
Fish EZ Pass: Tagging to understand continental shelf migrations

“POST” system; Lines of receivers create coastal “curtains” across shelf

Tagged animal crosses curtain and the occurrence is recorded in receiver
Tagging salmon smolts in British Columbia to learn where salmon die
Tracking salmon in the Columbia River (NW USA-Canada) & north to Alaska

POST acoustic detection line
Trans-Pacific migrations of a bluefin
25,000 nm 600 Days

Commuting tuna connect LA-Tokyo
Summary distributions of top predators: \textit{connectivity} Blue Highways and neighborhoods of the Pacific

Bluefin tuna

Leatherback turtles

White shark

Source: CoML TOPP Project
Animation of movements of 9 species as sea temperature warms and cools. Source: TOPP.
Tigers of the ocean

Extreme site fidelity: White shark

San Francisco

~220 white sharks off N. California

Source: TOPP
Vertical connectivity: Dusk & dawn commutes at the Mid-Atlantic Ridge

Lighter colors show rising of countless animals ~9pm & submergence about 5 am

Source: MAR-ECO
Abundance: A story of alteration
Recreational fishing, Key West, Florida, 1958

Source: CoML HMAP
Abundance:
Recreational fishing, Key West, 2007

Source: CoML HMAP
Large removals began long ago: Early depiction of trawling Mosaic from 5th century, Bizerte, Tunisia. Source: Yacoub, M., Splendors of Tunisian Mosaics, Tunis, 1995, Fig. 115.
Abundance: Decline of large animals

alteration

Source: CoML HMAP, MacKenzie et al.
Destiny of a fish who grows large
Abundance: Losses, especially seafood species, hard to imagine past richness

Auction of bluefin tuna, Skagen, Denmark, 1946
Source: B. McKenzie
Bluefin tuna past and present

1900-1950
Tuna fishing contests in the channel between Sweden and Denmark near Copenhagen!
Globalization of supply: Octopus from Mauretania (NE Atlantic) in Tokyo fish market
Abundance: 3 Oct 2006, a quarter of a billion fish (50,000 tons) gather in the same place


Ocean Acoustic Waveguide Remote Sensing (OAWRS) uses properties of spherical spreading to image schools of fish as far as 150 km from the sound source.
OAWRS 2006 Gulf of Maine and Georges Bank Experiment
Simultaneous National Marine Fisheries Trawl

More than 99% Atlantic Herring
### Abundance/Alteration: 90% drops of 10 groups

Source: CoML FMAP, Lotze et al.

<table>
<thead>
<tr>
<th>Category</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>57</td>
<td></td>
</tr>
<tr>
<td>Reef fish</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Sharks</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Large pelagics</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Deep-sea fish</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Pinnipeds, otters, sirenians</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Whales</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Sea turtles</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Coastal birds</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

*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
Marine microbes: The hidden majority

Diverse: A billion kinds? 20,000 kinds in gulp of seawater

Ubiquitous, connecting all seas

Acantharian, captured off Bermuda

Source: CoML ICOMM, L. Amaral Zettler
Abundance: Filamentous bacteria, *Thioploca*, wove mat size of Greece off Chile

Source: CoML Gallardo
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

Already 1418 citations in Google Scholar

High Abundance Populations

1 billion phylotypes?

Cf 1 million species

1000:1 microbes/species?

Low Abundance Populations

Rare Biosphere
How many microbes live in the Oceans?

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

Microbes may account for 90% of biomass in oceans!
Unexplored ocean: Arctic records in OBIS per 5 degree (left) and 1 degree (right) cell
Source: Ward Appeltans
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
USA needs a “Wet NASA”!

2013 has around 2.7x more records (almost 19 million) compared to 2009, and range of sample depths represented has increased slightly, from 0-10670m in 2009 to 0-10900m. Source: OBIS/Appeltans
Practical benefit from Census: Growing library of “DNA Barcodes” for species identification

Works for fragments, look-alikes, different life stages

From COI gene Mitochondrial DNA

Colored stripes represent thymine, cytosine, adenine, guanine bases

Barcodes: Stoeckle
Images: Clarke-Hopcroft, Hopcroft, Bluhm, Iken
“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
Mislabeled as more expensive or desirable fish

- Mozambique Tilapia sold as “White Tuna”
- Caribbean Spotted Goatfish sold as “Mediterranean Red Mullet”
- White Bass (farmed freshwater fish) sold as “Sea Bass”

Source: Stoeckle & Strauss
Public Engagement: The iconic species of CoML, yetis 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 Edvardsen
Art & Science together
Highlights report available open access
Books for experts and wide audiences

- *Citizens of the Sea: Wondrous Creatures from the Census of Marine Life* edited by Alasdair D. McIntyre (NATIONAL GEOGRAPHIC)
- *The Mortal Sea: Fishing the Atlantic in the Age of Sail* by W. Jeffrey Bolster (W. Jeffrey Bolster)
- *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
National Geographic wall map
Halpin et al.
A bridge between people
Participants, CoML workshop
Sultan Qabus University, Muscat, Oct 2007
CoMLCaribe
Isla de Margarita, Venezuela, June 2004
CoML Southern Africa
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

Susan Poiner, Victor Gallardo, Ian Poiner, Myriam Sibuet, Patricia Miloslavich
Great adventures

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
Mysterious Creatures Found in Antarctica
Feb 19, 2008
SYDNEY, Australia (AP) — Scientists investigating the icy waters of Antarctica said Tuesday they have collected mysterious creatures including giant sea spiders and huge worms in the murky depths. Australian experts taking part in an international program to take a census of marine life in the ocean at the far south of the world collected specimens from up to 6,500 feet beneath the surface, and said many may never have been seen before.


Antarctic census set to reveal new species: scientists
Feb 19, 2008
SYDNEY (AFP) — An international project to document the sea life of Antarctica is likely to reveal new species among the dinner-plate sized sea spiders and other overgrown animals of the deep, scientists said Wednesday.
The family lobster, discovered 300 meter deep in Philippine Sea
Original specimen in Sydney Natural History Museum

Dinochelus ausubeli
Ausubel’s Mighty Claws Lobster

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ORIGINAL: View image source

Catalogue of Life: Annual Checklist 2010. Select an alternate hierarchy from the list above

Archaea +
Bacteria +
Chromista +
Fungi +
Plantae +
Protozoa +
Viruses +
Census Summary 2000-2010
*It can be done*

>2,700 scientists
>80 countries
>540 field expeditions
~US $650 million
>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…
films, paintings, sculptures,
songs…
New protected areas…

Marine Life is:
• richer
• more connected
• more altered
• yet unknown, unexplored

*Highlights available in 11 languages*
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
Voted favorite animal: Blob fish

Found south of Tasmania

Thanks to all who made the Census happen!

www.coml.org

Source: K. Parkingson