CONSORTIUM FOR OCEAN LEADERSHIP Welcomes you

the 2016 Public Policy Forum

SCIENCE AND SOLUTIONS FOR A RESILIENT OCEAN
Climate and the Deep Sea
The Deep Sea: Science and Solutions for a Resilient Ocean

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Sand and measureless mud, and tracts of slime . . (Plato, Phaedo)

A New View

The deep sea as source of some of the greatest species and ecosystem diversity on Earth

A source of scientific wonder, still poorly explored and in critical need of improved stewardship based on scientific understanding and appreciation of its fragility and intrinsic value
Opportunities: the last frontier on Earth

- Polymetallic Sulphides (Cu, Zn, Pb, Ag, Au)
- Cobalt Crusts (Cu, Ni, Co, Ce, Mb)
- Polymetallic Nodules (Ni, Co, Zn, REE)
The key risks: 
I. Fishing & habitat destruction

- Extreme life histories: longevity ~100 yr
- Low productivity
- Seamounts: localized, predictable, aggregated
Trawling on seamounts reduced coral cover by 2 orders of magnitude
Little recovery after 10 years (Althaus et al MEPS 2009)

Deepwater reefs in N Atlantic: up to 200-500 m wide, 35-60 m high, date back >10,000 yr
Growth rates 10% that of warm water corals

Caution: Much of the deep sea exhibits extremely LOW resilience due to
- low productivity
- extreme life histories
- low rates of re-colonization
- adaptation to low rates of disturbance
Global movement to conserve deepwater corals

Growing recognition by governments (US, Norway, Australia, NZ) of the need to protect deep-sea habitats from impacts of trawling

UN General Assembly failed to pass a moratorium on high-seas bottom trawling

2006 Resolution: States & Regional Fishery Management Organizations to regulate high-seas bottom trawling to prevent adverse impacts or prohibit them

The issue is ongoing

*1981 and before; **through May
(pers comm, E Pikitch, Pew, U Miami)
Myth: the deep ocean is too remote and well-buffered from the atmosphere to be significantly affected by climate change

Reality: the deep ocean is warming, acidifying and losing O$_2$

The ocean has absorbed >93% of the heat and 28% of CO$_2$ emissions
Acidification & hypoxia linked
Highest in areas of poor ventilation: North Pacific & Indian Oceans

Coldwater scleractinian corals predominantly in the N Atlantic & SW Pacific, not the N Pacific
Already excluded due to low pH? (Guinotte et al 2006)
Oxygen Minimum Zones (OMZs) form at bathyal depths (100-1000 m) in regions of upwelling (nutrients), old water, absence of ventilation.
Oxygen has declined in the NE Pacific Ocean

Station P - Whitney et al. 2007

1956-2014

British Columbia

Oxygen loss of 0.67 µM/y

Crawford and Pena 2013

Oregon

Bograd et al. 2015

So. Cal. Bight

Bograd et al. 2015
Low oxygen areas are expanding

In the last 50 y there has been a rise in AOU and massive oxygen loss in the tropical and subtropical ocean

At 200 m the area with <70 µM O₂ has increased by 4.5 million km² area

Changes from 1960-74 to 1990-2008

Stramma et al. 2010

DSR I
10 Earth System Models project
widespread oxygen decline at intermediate depths

Bopp et al. 2013
Biogeosciences
Why?

• A warmer ocean holds less O₂
• A warmer ocean is more stratified
  ✓ Intensified thermal stratification
  ✓ Surface freshening at high latitudes
• Reduction in exchange between mixed layer and ocean interior (i.e., reduced ventilation)

Helm et al. 2011
GRL
Impacts of deoxygenation

Dominant pattern (PC 1) for 86 larval fish taxa (proxies for adult spawning stock biomass), 1951-2008: 24 midwater fishes from 8 families loaded highly on PC1
20% decline in midwater O$_2$ since 1990,
63% decline in midwater fish abundance

Is this a regional phenomenon or are these fishes declining wherever O$_2$ is declining?

Mesopelagic fishes $10^{10}$ t in world ocean!
Primary conduit between plankton & higher predators

Richness is positively correlated with deepwater oxygen concentration (p<.05)
How can science assess ecological change in the deep ocean?

A global network of ecological time series based on larval fish, which samples epi- and mesopelagic + demersal fishes

- NOAA-sponsored workshops planned to assemble North American time series, analyze them to assess magnitude and coherence of change. Ecological indicators to be used in ecosystem-based fisheries management and ecosystem assessments
The deep sea as source of some of the greatest species and ecosystem diversity on Earth

The last frontier with vast mineral, energy and living resources.

A source of scientific wonder, still poorly explored and in critical need of improved stewardship based on scientific understanding and appreciation of its fragility and intrinsic value.
DARK, COLD, AND SLOW

Mark Abbott, President and Director
Woods Hole Oceanographic Institution
"I don't know why I don't care about the bottom of the ocean, but I don't."
Deep and Deeper

Average depth of ocean is 3682 m

Mt. Everest (8848 meters above sea level)

Mariana Trench

Challenger Deep 11,035 meters below sea level
The Hadal Zone
The Great Ocean Conveyor
Life is More Complicated
Does the Ocean “Pull” or “Push?”
OSNAP – Monitoring a Changing Ocean
Deep sea responds to surface climate in decades

Signal Arrival Time [years]: 2.5 km depth

Response: ~50 years

Woods Hole Oceanographic Institution
Deep sea response lingers for millennia
Warming of the Deep Ocean
Life at the Bottom of the Ocean

Hadal Ecosystem Studies Program

- Unexpectedly High Food Supply
- Biodiversity Hotpots (>200 species/sample)
- Diverse & different ecosystems w/ depth
- Antiquity / relict fauna in trenches
- Novel adaptations to extreme habitats
- Protein adaptations already impacting biomedical field against diseases

Woods Hole Oceanographic Institution
Drizzle and Storms
Climate Change Impacts on Larval Survival
5 to 7 miles - “Supergiant Amphipod”
Key Messages

- Deep ocean responds to change on decades
  - But upper ocean changes can have shorter impacts
- Connectivity between deep ocean ecosystems can be disrupted
- Deep ocean is now warmer, more acidic, and with less oxygen
- Deep ocean remembers the environment for centuries to millenia
- Observing systems are essential
Acknowledgments

- Stace Beaulieu
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- Susan Humphris
- Lauren Mullineaux
- Larry Madin
- John Toole
- And especially Tim Shank
While NSF is predominantly a “Bottom-Up” driven agency; Strive for community input

Decadal Survey of Ocean Sciences 2015-2025


Lisa Clough
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Sea Change: Science Priorities

- Rates, mechanisms, impacts, etc. ... sea level rise?
- Coastal, estuarine ecosystems and linkages.
- Ocean biogeochemistry & physics ... and climate.
- Biodiversity & resilience of ecosystems, & changes.
- Marine food webs in the coming century.
- Formation and evolution of ocean basins.
- Geohazards (‘quakes, tsunamis, landslides, volc.).

Sea Change: Infrastructure

- Subsea floor biosphere, biogeochem. cycles & life.

- 20 % OOI; - 10 % IODP; - 5 % ARF
- On Operations and Maintenance (O & M)
Deep Ocean is tied with Shelf Seas as highest BO % spending

Informal discussions with other lead PDs at NSF: At least 50% of funding directed to Deep Ocean (especially if >200m)
Sea Change: Science Priorities

• Rates, mechanisms, impacts, etc... sea level rise?
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Sea Change: Infrastructure

• 20 % OOI; 10 % IODP; 5 % ARF
• On Operations and Maintenance (O & M)
January, 2016
(with still more to come)
Figure 3-9 Relative cost versus relevance of the infrastructure presented in Table 3-2 (colors are keyed to the same infrastructure). Ships are clustered into one group for this figure. The asterisk next to manned vehicles and ROVs indicates that costs increase if the costs of necessary support vessels are included.
National Deep Submergence Facility

Alvin
Human Occupied Vehicle
Accommodates:
1 Pilot and 2 Scientific Observers
Depth Capability:
4,500m (14,764 feet)

Jason
Remotely Operated Vehicle
Depth Capability:
6,500m (21,450 feet)

Sentry
Autonomous Underwater Vehicle
Depth Capability:
6,500m (21,450 feet)
A workshop focused on determining how both existing and new technologies can be better deployed to help address critical science questions, as well as how federal agencies, non-profit organizations, commercial operations and academic institutions can better work together to advance our understanding of the deep sea.
Jason upgrade for OOI

Jason and Madea (2-body)

ROPOS (1-body)
The importance of sustained observations, in the right places, for years to come

Observing climate change trends in ocean biogeochemistry: when and where

Existing or planned sites (http://www.oceansites.org)

Number of years required To separate signal from noise

Jensen et al 2016 (NOC)

Global Change Biology
Volume 22, Issue 4, pages 1561-1571, 6 JAN 2016 DOI: 10.1111/gcb.13152
Spatial Scale over which an observatory is relevant (NOTE the absence of measurements in the Deep Ocean)
OOI: Ocean Observatories Initiative: Project Locations & Scope

Four Global high latitude sites
- Station Papa
- Irminger Sea
- Argentine Basin
- Southern Ocean

Two Coastal Arrays
- Endurance Array
- Pioneer Array

Cabled Array
- Meso-scale, Plate Scale network

CyberInfrastructure
- Acquisition, Storage, Processing, and Distribution of Data
OOI Science Themes

- Ocean-Atmosphere Exchange
- Climate Variability, Ocean Circulation, and Ecosystems
- Turbulent Mixing and Biophysical Interactions
- Coastal Ocean Dynamics and Ecosystems
- Fluid-Rock Interactions and the Subseafloor Biosphere
- Plate-scale, Ocean Geodynamics

Additional Focus On

- Ecosystem Health
- Climate Change
- Carbon Cycling
- Ocean Acidification

Reference: OOI Science Prospectus
www.oceanobservatories.org

Figure Credit: Center for Environmental Visualization, UW
Regional Scale Nodes

- Grays Harbor Line
- Portland CyberPOP
- Axial (no science)
- Mid Plate
- Newport Line
- Hydrate Ridge
- Primary Node
- Low Voltage Node
- Node - no science
- Coastal mooring
Regional Scale Nodes

Winch Instrument Package
- Current Meter-T
- CTD Dissolved O2
- Fluorometer OB
- Nitrate
- pH
- Optical Attenuation
- Spectral Irradiance
- PAR
- PCO2
- Digital Still Camera
- Fluorometer - 3W

Float Instrument Package
- Broadband Hydrophone
- CTD-Dissolved O2
- Fluorometer OB
- pH
- VADCP
- Digital Still Camera
- Acoustic Modem
- ADCP-150kHz

Primary Node
- Current Meter
- Pressure Sensor
- Medium Power Junction Box
- Broadband Seismometer
- Hydrophone
- Acoustic Modem
- ADCP
- Low Voltage Node
- Fluorometer
- CTD
- Dissolved Oxygen

Sub-surface Float & Instrument Packages
- Winched Profiler
- Profiler

Winch Package
- Winch Instrument Package

Autonomous Underwater Vehicle
- Current Meter
Measuring the heartbeat of Axial Volcano

~8000 earthquakes in 24 hr period

From
W. Wilcock
UW

5 short-period seismometers
2 broadband seismometers

Data streamed to IRIS
90 repeat users monthly

Navy Testing

April 24, 2015 Eruption

November 16 2014
January 18 2015
March 4
May 24
Predaceous Polynoids
THE HORS D’OEURVE
Animals thriving and competing on a large Sulfide Structure
Pioneer Array

• Multi-platform, multi-scale
• Fixed and mobile assets
• Integrated with regional observing assets

Plueddemann and Trowbridge (WHOI)
Pioneer Array

- Full water column
- Cross-front resolution
- Power-generating buoys
- Multi-function nodes
- AUV docks

Plueddemann and Cook (WHOI)
Argentine Basin Array Operational Status

- 2/3 Patrol Gliders, 0/2 Profiling Gliders are Deployed and Operational.
- Both Flanking Moorings Operational.
- Hybrid Profiler Mooring Operational.
- Some instruments on Global Surface Mooring not working.
Website
http://oceanobservatories.org
Wrap-Up-

- NSF- Science Questions first and foremost
- LOTS of places where Deep Sea fits into input the community has given to NSF
- And Deep Sea research within the portfolio already
- National Deep Submergence Assets to draw on
- OOI data to learn from (and more coming on-line every week)
Focus: Clarion Clipperton Zone (International Waters)
Overview

- World’s demand for minerals is on the rise, including to meet the demands of a Green Economy

- Seafloor Mineral Production may offer many social and environmental advantages for mineral development

- Even so, good environmental management practices are needed
Terrestrial Mining: The Situation

- **Land resources are stretched = increasing economic, social and environmental costs:**
  - moving more rock per tonne of metal;
  - processing more rock per tonne of metal;
  - larger waste rock dumps;
  - increasing tailings disposal & noxious waste;
  - increasing deforestation, soil erosion, etc

- **Increasing land use conflicts**
Minerals for a Green Economy

A single 5 MW Wind Turbine:
- 15 tonnes manganese
- 5 tonnes copper
- 5 tonnes nickel

Wind power requires significantly more metal to produce power than conventional power generation
The Blue Planet

- 70% of our planet is covered by water

- Historical mining activity has focused on the 30% made up by land yet land is rare

- Holistic approach to decision making is needed
Why Go to the Sea?

- World’s demand for metals continues to rise
- Land resources are stretched
- Every human activity impacts on the environment
- What if…?
Social and Environmental Advantages

1. Clean Mineral Processing
2. No Social Displacement
3. No Deforestation
4. High grade
5. Minimal Overburden, Stripping and Waste
6. Reusable Production Infrastructure
Seafloor Production System

Basic Components:

- Production Vessel
  - Operational base
- Riser and Lifting System
  - Pumps material to the surface
- Harvesting Tools
  - Cut/collect material
Main Impacts

Similar for all mineral types:

- **Seafloor:**
  - Material/habitat/animal removal (same for any mining operation)
  - Plumes, Light, Noise/vibration

- **Midwater:**
  - Presence of a riser and occasional passage of equipment

- **Surface:**
  - Lighting, Noise
  - Routine discharges (governed by MARPOL and other regulations)
Environmental Management Goals

- **Maintain** overall biodiversity and ecosystem health and function
- **Reduce, mitigate, and, where possible, prevent** the impacts of mining and pollution that can affect wider habitats and ecosystems
- **Balance** impacts of extractive activities with conservation goals
Example Management Measures

- Employing technologies and methodologies to limit sediment re-suspension during harvesting
- Order and style of extraction
- Establishing set-aside areas
- Fully-enclosed ore delivery systems
- Biodegradable fluids and oils in all subsea equipment

Image courtesy of the International Seabed Authority
Stakeholder Engagement

- Early, transparent and inclusive
  - Multi-stakeholder workshops to develop plans and programs
  - Public hearings
  - Availability of environmental materials
  - Collaborative research
  - Freedom to Publish
Summary

• World’s demand for minerals is on the rise, while land resources are becoming stretched

• Seafloor Mineral Production may offer many social and environmental advantages for mineral development

• Even so, good environmental management practices are needed
Extra Slides Follow
Demand for minerals continues to rise

- Population Growth
- Emerging economies transitioning to industrialised and urbanised societies

World consumption over the next 15 years will exceed all of copper metal ever mined to date.
the 2016 Public Policy Forum

Science and Solutions for a Resilient Ocean

Jeremy Weirich
Senate Appropriations Committee
Climate and the Deep Sea

the 2016 Public Policy Forum

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