POST 2010 FUNDING MATRIX / EXISTING ASSETS

Project	Brief Description of Project	Management Application / Societal Benefit	Specific Application to Agency Mandates / Federal Acts	Est. Yearly Cost	Funds Secured Post 2010	Previous Agency Funding
ArcOD	Inventories biodiversity in the Arctic sea ice, water column and sea floor from the shallow shelves to the deep basins.	Program will improve understanding of climate change, sea-level rise, and sea ice loss. ArcOD will also provide information to understand biodiversity adaptation to climate change and ocean acidification. Provide information on the implementation of Law of the Sea Treaty. Contributes information on conservation and management of protected species (MMPA and ESA) and commercial fisheries (MSA). Provides information to assist in the siting and regulation (NEPA) of off-shore oil and gas exploration and development. Through instrumentation capitalizes on marine mammals as ocean observatories to provide information to implement MMPA and IOOS.	NOAA , FWS, State Department, MMC, MMS	$$$	▲	NOAA NSF
CAML	Survey the cold Southern Ocean surrounding Antarctica in an attempt to understand the biological diversity of this unique and poorly understood environment.	Contributes information on conservation and management of protected species (MMPA and ESA) the implementation of international treaties (IWC & CAMLAR) and commercial fisheries (MSA). Programs will improve understanding of climate change, sea-level rise, and sea ice loss. CAML will also provide information to understand biodiversity adaptation to climate change and ocean acidification. Provide information on current systems and ecosystem structure and function. Provides information to support decisions within the IWC and CAMLAR.	NOAA , FWS, State Department, MMC	$$$		
CeDAMar	A deep-sea project to document species diversity of abyssal plains to increase understanding of the historical causes and ecological factors regulating biodiversity and global change.	Supports the mission of ocean exploration, provides information to assist in the designation of marine protected areas. Resource and Mineral exploration; seabed mining. Can provide information on marine debris.	NOAA , FWS, State Department, MMS	$$$$$		
CenSeam	A global study of seamount ecosystems, to determine their role in the biogeography, biodiversity, productivity, and evolution of marine organisms, and to evaluate the effects of human exploitation. Samples seamounts in global oceans at depths <2000m; ID factors that drive community	Provides information for the implementation of Law of the Sea Treaty and other UN resolution related to the conservation and management of seamounts and designation of marine protected areas. Contributes information on conservation and management of protected species (MMPA and ESA) and commercial fisheries (MSA). Provides information to meet MSA requirements for the international conservation and management of seamounts.	NOAA , FWS, State Department, MMS, MMC	$$$$$	▲	NSF

	composition on seamounts and how they are similar/different to other deep-sea habitats	Supports the mission of ocean exploration, provides information to assist in the understanding of seamounts and their ecosystems and biodiversity.				
ChEss	A global study of the biogeography of deep-water chemosynthetic ecosystems (hydrothermal vents, cold seeps, whale falls) and the processes that drive them.	Provides information on resource and mineral exploration that can assist in management of seabed mining.	NOAA, MMS	$$$$$	▲ *	NOAA NSF MMS NASA
CMarZ	A global, taxonomically comprehensive biodiversity assessment of animal plankton using emerging technologies in DNA analysis.	Identifies new species and provides important information on stock structure for already identified species that is vital to management under the MMPA, ESA, and MSA. Contributes valuable information to DNA barcoding. Provides information to predict changes in biodiversity associated with changes in climate change , temperature changes, and regime shifts—changes in distribution and abundance of plankton have a ripple effect throughout the ecosystem that affects decisions on climate change and ecosystem management.	NOAA, FWS	$$$		NOAA NSF
CoMARGE	An integrated effort to document and explain biodiversity patterns on gradient-dominated continental margins, including the potential interactions among their variety of habitats and ecosystems. Samples benthic habitats of the deep continental margins (200-4000 m depth), including cold-seeps, oxygen minimum zones, submarine canyons and cold water corals (best sampled in Atlantic Ocean)	Programs will improve understanding of climate change and sea-level rise. COMARGE will also provide information to understand biodiversity adaptation to climate change and ocean acidification. Provide information on the implementation of Law of the Sea Treaty. Contributes information on conservation and management of protected species (MMPA and ESA) and commercial fisheries (MSA). Provides information to assist in the siting and regulation (NEPA) of off-shore oil and gas exploration and development and renewable ocean energy projects. Provides information on the accumulation of gas hydrates—important to future management. Provides information on resource and mineral exploration that can assist in management of seabed mining.	NOAA , FWS, State Department, MMC, MMS	$$$$$	▲	NSF MMS
CReefs	An international cooperative effort to increase tropical taxonomic expertise, conduct a taxonomically diversified global census of coral reef ecosystems, and improve access to and unify coral reef ecosystem information scattered throughout the globe.	Programs will improve understanding of climate change and sea-level rise. CReefs will also provide information to understand biodiversity adaptation to climate change and the effects of ocean acidification on coral reef communities. Contributes information on habitat use and prey availability for the conservation and management of protected species (MMPA and ESA) and commercial fisheries (MSA). Provides information to assist in the siting (NEPA) and management of Marine Protected Areas and marine monuments. Provides information on pharmaceuticals and medicines. Provides information to manage tourism and control trade in precious corals and tropical fish.	NOAA , FWS, MMC, MMS	$$$		USGS NBII NOAA NPS USF&WS

		Provide information on reef development, structure, and changes over time that is important to conservation and management.				
GoMA	A project to identify and collect the biological knowledge necessary for ecosystem-based management in a large marine environment	Programs will improve understanding of climate change and sea-level rise. GoMA will also provide information to understand biodiversity adaptation to ecosystem changes caused by commercial fishing. Contributes information on habitat use and prey availability for the conservation and management of protected species (MMPA and ESA) and commercial fisheries (MSA). Provides information to assist in the development of NEPA documents to manage commercial fisheries. Provided information to conserve and manage Marine Protected Areas and national marine sanctuaries. Helps provide information to further ecosystem approaches to management, under the MSA. Provides end to end ecosystem-base management and modeling to predict ecosystem changes over time Provides critical information to assess risk management for coastal communities (i.e. coastal inundation projections).	NOAA , FWS, MMC, and Fishery Management Councils	$$		NOAA ONR
ICoMM	An international project to use emerging technology to survey marine microbe diversity and to build a cyberinfrastructure to index and organize what is known about microbes, the world's smallest organisms, which account for 90 percent of biomass in oceans	Provides information on pharmaceuticals and medicines. Provides information on sewage contamination that assists in human health decisions and water quality management. Through satellite observation of ocean color can provide information on species richness. Provides information on bacterial changes that respond to changes in temperature and acidity cause by global climate change. Provides information on bacteria that catalyze and produce methane and even involve bacteria in the generation of electricity.	NOAA , EPA, DOE	$$$		NSF NASA EPA NIH
MAR-ECO	An international exploratory study of the macrofauna of the northern mid-Atlantic Ocean including the processes that control their distribution and community structures in the waters around the Mid-Atlantic Ridge.	MAR-ECO will provide information to understand biodiversity adaptation to ecosystem changes caused by commercial fishing. Contributes information on habitat use and prey availability for the conservation and management of protected species (MMPA and ESA) and commercial fisheries (MSA). Provides information to assist in the development of NEPA documents to manage domestic and international commercial fisheries. Helps provide information to further ecosystem approaches to management, under the MSA management of marine resources.	NOAA , FWS, MMC, State Department , Fishery Management Councils, Regional Fishery Management Organizations	$$$$$	▲ *	NOAA NSF
NaGISA	An international collaborative effort to inventory and monitor biodiversity in the narrow inshore zone (encompassing tidal and intertidal zones) of the world's oceans at depths of less than 20	NaGISA will improve understanding of and provide baseline data for long-term monitoring of climate change and sea-level rise; provide information to understand biodiversity adaptation to climate change and ocean acidification. Contributes information on conservation and management of protected species (MMPA and ESA) and commercial	NOAA, FWS, MMC, MMS, EPA, Department of Education, State Department	$	▲	Sea Grant MMS NSF

	meters	fisheries (MSA). Provides information to assist in the siting and regulation (NEPA) of near-shore renewable ocean energy projects. Provides information on the impacts of pollution and the distribution and identification of invasive species in the near-shore environment and assists in the conservation and management of nearshore ecosystem (CZMA). Provides data on the recovery of ecosystems to storms. Successfully mobilizes community involvement and promotes education, especially in developing countries.				
POST	A program to develop and promote the application of new electronic tagging technology to study usage of marine environments and migration routes of Pacific Salmon and other marine species.	POST will improve understanding of and provide baseline data for long-term monitoring of habitat use. Contributes information on conservation and management of protected marine species (MMPA and ESA) and commercial fisheries (MSA). POST provides fish stock and other marine species tracking; information on natural fish stock health and survival; management measures for salmon and other fisheries. Provides information to assist in the siting and regulation (NEPA) of near-shore renewable ocean energy projects and management of existing hydroelectric dams.	NOAA , FWS, MMC, MMS, Department of Energy, Bonneville Power Administration	$$$	▲	USACE Have partnered with the following without receiving any direct funding: NOAA
TOPP	A program using electronic tagging technologies to study migration patterns of large open-ocean animals and the oceanographic factors controlling these patterns.	TOPP will improve understanding of and provide baseline data for long-term monitoring of habitat use. Contributes information on conservation and management of protected species (MMPA and ESA) and commercial fisheries (MSA). TOPP can identify ocean hot spots key for conservation; migration patterns; mitigation measures for bycatch. Information can be used to establish Marine Protected Areas and seasonal closures to reduce bycatch. Further helps to identify habitat use, prey consumption, and combine this information with chemical and physical ocean parameters. Provides information to assist in the siting and regulation (NEPA) of near-shore renewable ocean energy projects. Contributes information that can be integrated into the ocean observing system and climate and weather models.	NOAA , FWS, MMC, MMS, Department of Defense	$$$		Sea Grant NOAA ONR NSF
FMAP	Describes and synthesizes globally changing patterns of species abundance, distribution, and diversity, and to model the effects of fishing, climate change and other key variables on those patterns. This work is done across ocean realms and with an emphasis on understanding past changes and predicting future scenarios.	FMAP has the potential to provide critical predictions about changes in biodiversity caused by climate change; ocean acidification; resource exploitation; changes in prey availability and habitat use; and loss of top predators among other issues.	NOAA , FWS, MMC, MMS, Regional Fishery Management Councils	$		
HMAP	It is an interdisciplinary (history, ecology, paleo-ecology) research	HMAP provides historical baselines that highlights changes in abundance, documents and evaluates global	NOAA , FWS, MMC, EPA,	$	▲	NOAA EPA

	program that uses historical and environmental archives to examine the changes in marine communities over the past 500-1000 years. The goals of HMAP are to examine the ecological impacts of large-scale harvesting, long-term changes in stock abundance, and the role of marine resources in historical development.	consumption patterns, establishes targets for recovery. HMAP can provide information to assist future predictions and in the development of conservation and management measures for commercially exploited species.	Regional Fishery Management Councils			Sea Grant NSF
iOBIS	Global database of biogeographic information; CoML project data and various national datasets	International OBIS provides information about the distribution of marine species, habitat use, which can be used to develop risk assessment models and environmental impact analyses to implement mandates under the MMPA, ESA, MSA, Marine Sanctuaries Act, and NEPA. Can also provide information to assist in the site identification of renewable energy projects, oil and gas exploration, and military readiness activities.	NOAA , FWS, MMC, MMS, USGS, DOD, DOE, USCG	$$	▲	NOPP NSF ONR
OBIS-USA	U.S. implementation of iOBIS hosted by the National Biological Information Infrastructure (USGS); Database of U.S. biogeographic information - U.S. CoML project data and various regional and national datasets	OBIS-USA provides information about the distribution of marine species and will link to IOOS and physical/chemical data as the system is completed. Assists in understanding relationships between species and their environments. Can be used in forecasting and developing risk assessment models and environmental impact analyses to implement mandates under the MMPA, ESA, MSA, Marine Sanctuaries Act and NEPA. Can also provide information to assist in the siting of renewable energy projects, oil and gas exploration, and military readiness activities.	NOAA , FWS, MMC, MMS, USGS, DOD, DOE, USCG	$$	▲	USGS
OTN	A global research network that would meld the telemetry technologies of CoML projects POST and TOPP with the Global Ocean Observing System	See descriptions for POST and TOPP	NOAA , FWS, MMC, MMS	$$$$	▲	
Marine DNA Barcoding		Information can be used to identify specific species of fish, could assist in implementation of seafood safety, country of origin, and control of trade.	NOAA, NMFS, OER	$$$		

$ Minimal Cost
$$ Low Cost
$$$ Moderate Cost
$$$$ High Cost
$$$$$ Very High Cost

(see appendix for breakdown of costs)

▲ No Funds Secured
▲ Limited Funds Secured
▲ Funds Secured

*** Please not that these projects specifically noted that they DO NOT HAVE network or program office funding post 2010**

Appendix

Project	Number of Participants	Ship-time (types and locations)	Cost of technology used	Number and Size of Study Sites	
ArcOD	Small	Some large vessels	High cost	Few, but large size	$$$
CAML	Small	Some large vessels	High cost	Few, but large size	$$$
CeDAMar	Large	Extensive, remote local	Extremely high cost	Few, but large size	$$$$$
CenSeam	Moderate	Extensive, remote local	Extremely high cost	Many and large size	$$$$$
ChEss	Large	Extensive, remote local	Extremely high cost	Many, but small size	$$$$$
CMarZ	Small	Some small vessels	High cost	Few, and small size	$$$
COMARGE	Large	Some large vessels	Extremely high cost	Many and large size	$$$$$
CReefs	Moderate	Extensive, remote local	High cost	Many and large size	$$$
GoMA	Moderate	Some large vessels	Moderate cost	Few, but large size	$$
ICoMM	Small	None	Extremely high cost	Few, and small size	$$$
MAR-ECO	Large	Some large vessels	High cost	Few, but large size	$$$$$
NaGISA	Large	None	Low cost	Many, but small size	$
POST	Small	Some small vessels	High cost	Few, and small size	$$$
TOPP	Moderate	Some small vessels	Moderate cost	Few, and small size	$$$
FMAP	Small	None	Low cost	Few, and small size	$
HMAP	Moderate	None	Low cost	Many, but small size	$
OBIS	Small	None	High cost	Few, and small size	$$
OTN	Moderate	Some small vessels	Extremely high cost	Many and large size	$$$$
DNA Barcoding	Small	None	High cost	Few, and small size	$$$

Global **O**cean **Ma**pping **P**roject (**GOMaP**): publications and abstracts

Vogt, P.R**.,** Jung, W.Y. and Nagel, D., 2000, GOMaP: A matchless resolution to start the new millennium, EOS, 81, 254,258.

Vogt, P.R., 2000, Endorsement of global ocean mapping project (Meetings Report), EOS, 81, 498.

Carron, M. J., Vogt, P.R**.** and Jung, W.Y., 2001, A proposed international long-term project to systematically map the world's ocean floors from beach to trench: GOMaP (Global Ocean Mapping Program), Inter. Hydr. Rev., 2, 49-55.

Vogt, P.R**.,** Carron, M., Jung, W.Y. and Macnab, R., 2001, The Global Ocean Mapping Project (GOMaP) and UNCLOS: Optimizing Article 76 surveys for re-use as components in the construction of a global bathymetric model. http://ww/gmat.unsw.edu.au/ablos/ablos_01papers.htm, 15 p.

Vogt, P.R. (POC), 2002, http://mp-www.nrl.navy.mil/marine_physics_branch/gomap/htm (or…/php). GOMaP (Global Ocean Mapping Project)

Cormier, M.-H., De Moustier, C., Hall, J.K., Mayer, L.A., Monahan, D., and Vogt, P.R., 2004, The Global Ocean Mapping Project (GOMaP): Promoting international collaboration for a systematic, high-resolution mapping of the world's oceans (Abs.), Int. Geol. Cong., 32(2), 986.

Vogt, P.R., and Cormier, M.H., 2008, Proposed systematic mapping of the world seafloor from beach to trench: *GOMaP* (Global Ocean Mapping Project (Abs.), Int. Geol. Congr., 33, Abs.1342341.

Monahan, D., Vogt, P.R., and Cormier, M.H., 2008, GOMaP: A Proposal for Completely Charting the World Ocean Floors (Abs.), Eos, Trans. AGU 89(53), Fall Meet. Suppl., Abs. OS51C-1266.

International Hydrographic Review, 2(3), 49-55, 2001

GOMaP (Global Ocean Mapping Program): *A Proposed International Long-Term Project to Systematically Map the World's Ocean Floors From Beach to Trench.*

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Abstract

At the 1999 Spring American Geophysical Union meeting, the concept of a long-term (20-30 year) international, systematic effort to map the entire world seafloor from beach to trench (GOMaP = Global Ocean Mapping Program) was first presented to the earth science community. A Forum article followed in Eos (P. Vogt, W-Y. Jung, and D. Nagel, Eos, AGU, v. 81, p.254, 258) in June 2000. About 40 experts and stakeholders, representing mostly US government, academia and industry, assembled in Bay St. Louis, MS 12-14 June 2000, endorsing GOMaP as important and technically feasible with current technology and existing vessels (Meetings Report, Eos, v. 81, p.498, 2000; NRL Tech Memo, in preparation).

The goal of GOMaP would be to map the ocean floors with at least 100 percent coverage sidescan and swath bathymetry and perform whatever other data collection could be carried out simultaneously (e.g., subbottom profiling, magnetics, gravity, physical oceanography and meteorology). Minimum standards for data accuracy, pixel navigation, and resolution would need to be established before GOMaP is launched.

Spatial resolutions for GOMaP sidescan sonar imagery should be 200 m or better in the deep sea. This is comparable to what has been achieved by the Shuttle Imaging Radar over the terrestrial earth, the MAGELLAN radar mapping of Venus, the MARS GLOBAL SURVEYOR and other probes on Mars, and the GALILEO mission to the moons of Jupiter. The spatial resolution for swath bathymetry is slightly less than for sidescan. Both bathymetry and sidescan resolutions improve sharply with decreasing water depths, particularly for the 10 percent of the world ocean less than 500 m deep. The decrease of swath width with water depth implies that over 600 ship years are required to map waters 25-500 m deep, compared to just approximately 200 ship years for the deep ocean (500 m and greater). Better pixel navigation accuracy suggests hull-mounted systems (9-16 kHz for deep water, and 30 kHz or higher for shelf waters) may be superior to towed systems, although improvements in towed system navigation instrumentation may mitigate this difference in the future. Seafloor mapping with air-deployed hyperspectral and laser bathymetric scanning may be required to replace or supplement shipborne mapping in clear waters less than 50 m deep.

At the GOMaP workshop, the following areas were proposed as candidate "pilot" GOMaP areas: 1) The Gulf of Mexico [Good opportunities to utilize US Gulf Coast assets and to demonstrate international cooperation]; 2) The Juan de Fuca plate [A nearly complete "ocean floor in miniature," a chance for US-Canadian cooperation and to support the NEPTUNE project]; 3) an area in the Southern Ocean with exceptional scientific interest but with very sparse data coverage; 4) the EEZ of a willing, small coastal state, as a demonstration; and 5) the Black Sea [A great opportunity for international cooperation and geological and archeological significance].

Introduction

The end of the 20th century was a period of exciting mapping projects in our solar system. Unfortunately, the century closed with Earth being one of the most poorly mapped objects in the solar system. As demonstrated by Figure 1, much of the world's ocean bottoms have not been surveyed.

At the 1999 Spring American Geophysical Union meeting, the concept of a long-term (20-30 year) international, systematic effort to map the entire world seafloor from beach to trench (GOMaP = Global Ocean Mapping Program) was first proposed to the Earth science community. A Forum article followed in Eos (P. Vogt, W-Y. Jung, and D. Nagel, Eos, AGU, v. 81, p.254, 258) in June 2000. About 40 experts and stakeholders, representing mostly US government, academia and industry, as well as representatives from Canada and the United Kingdom, assembled in Bay St. Louis, MS 12-14 June 2000. This group endorsed GOMaP as important and technically feasible with current technology and existing vessels (Meetings Report, Eos, v. 81, p.498, 2000).

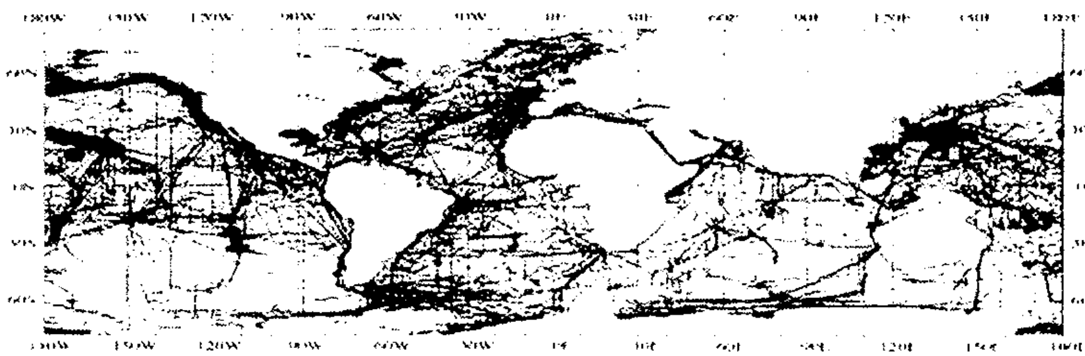

Figure 1. Inhomogeneous world seafloor database: Ship tracks for 1980-1999 period, courtesy of the National Geophysical Data Center. Tracks for surveys using sidescan sonar and/or swath bathymetry are a small subset of tracks shown here. Note: Actual width of tracks is much smaller than shown in this figure.

This presentation will summarize the efforts to define the GOMaP, set standards, establish a loose organizational structure for information and data sharing, and discuss the issues involved in estimating the effort required to undertake and accomplish such a large task.

The strategic goal of GOMaP is to systematically map the world ocean floor with at least 100 percent coverage of sidescan imagery and swath bathymetry and to perform whatever other data collection that can be carried out simultaneously. Minimum standards for data accuracy, pixel navigation, and resolution will need to be established before GOMaP is launched.

Why a GOMaP?

It should be easy to argue that detailed maps of the Earth's topography are at least, in the short term, as important to those who inhabit the Earth as maps of extraterrestrial bodies. Can any direct benefit, other than an intellectual exercise, be gained by doing so? We believe so. For example, precise knowledge of the seafloor topography would have direct benefits for improved assessments of geologic resources, finfish and shellfish habitat mapping, geologic risk assessments (for example, submarine landslides, earthquake fault activity, tsunamis, and submarine volcanism), navigation hazards, and bottom boundary conditions for dynamic oceanographic and meteorological models that are used in the prediction of long-term global change.

What are the technical issues?

Just what does it mean to completely map the world's ocean floor? A good example of 100 percent swath coverage can be shown by the data collected during a Naval Research Laboratory survey in part of the extinct Aegir Ridge rift valley and its adjacent rift mountain summits (Figure 2A). These data, resolving features with wavelengths of approximately 200 m, and the corresponding side-scan sonar image (Figure 2B), resolving wavelengths on the order of 10-20 m, capture the topography and sediment characteristics of the debris flows and turbidites that have spilled onto the rift valley. The Navy GEOSAT and ERS-1 microwave altimetric mapping programs allowed us to estimate the bathymetry from the gravity field (Figure 2C) on a global scale at full wavelengths of 20,000-30,000 m (Sandwell and Smith, 1997). To illustrate the magnitude of the proposed effort, the region illustrated in Figure 2A-C is less than 1/3000 percent of the total ocean floor. Figure 2D is the Clementine solar-illuminated image of part of the Schroedinger lunar crater, with an area of the same dimensions as in images A-C. The central swath (20-40 m pixel resolution) is comparable in resolution to a 12-kHz ocean-floor sidescan image at a 500-1000 m depth range, while outer areas of the image have spatial resolution comparable to that of 12-kHz sonar in the deep (~7 km) ocean.

The spatial resolution for swath bathymetry is slightly less than for sidescan. Bathymetry and sidescan resolutions improve sharply with decreasing water depths, particularly for the 10 percent of the world ocean less than 500 m deep. The decrease of swath width with water depth (Figure 3) leads one to

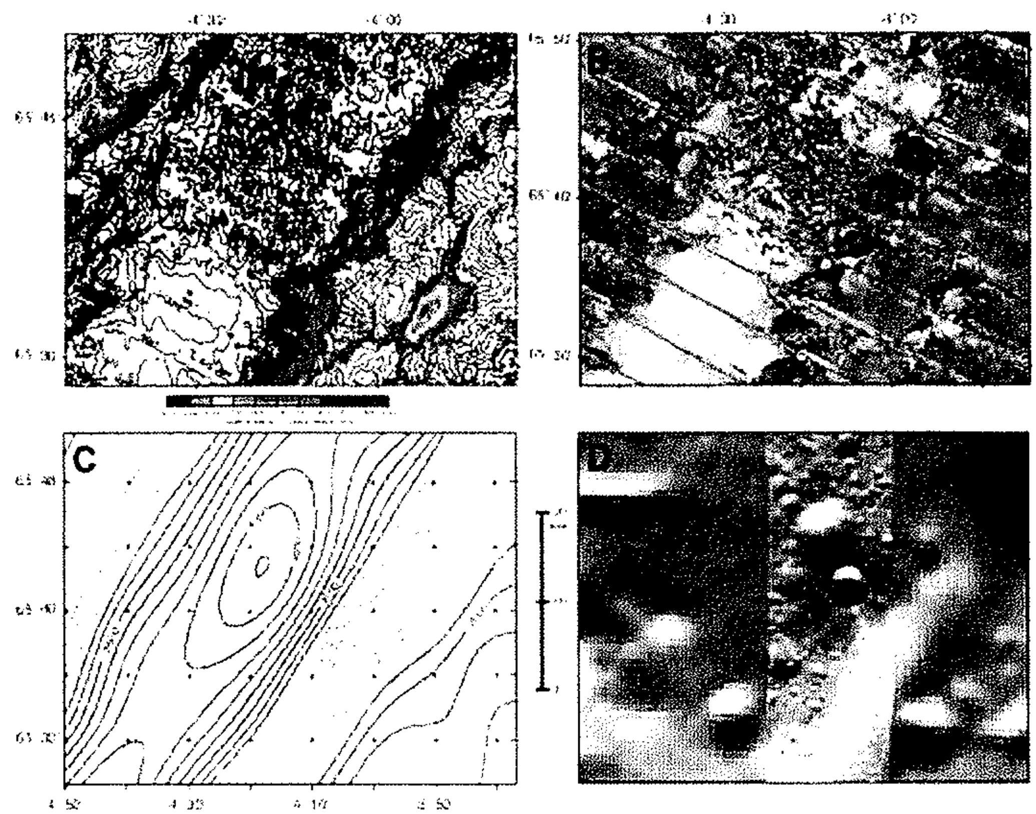

Figure 2. A) 16-KHz multibeam (HYDROSWEEP) bathymetry for part of the extinct Aegir Ridge rift valley, Norway Basin (NRL data). B)11-12 kHz SeaMARC II sidescan sonar image of same area. Darker shades indicate stronger returns (NRL data). C) ERS-1/GEOSAT-derived predicted bathymetry for same area (Sandwell and Smith, 1997). D) *Clementine* solar-illuminated image of part of Schroedinger lunar crater, with area of same dimensions as in images A-C. The central swath (20-40 m pixel resolution) is comparable in resolution to a 12-kHz ocean-floor sidescan image at 500-1000 m depth range, while outer areas of the image have spatial resolution comparable to that of 12-kHz sonar in the deep (~7 km) ocean. (P. Vogt, W-Y. Jung, and D. Nagel, Eos, AGU, v. 81, p. 258)

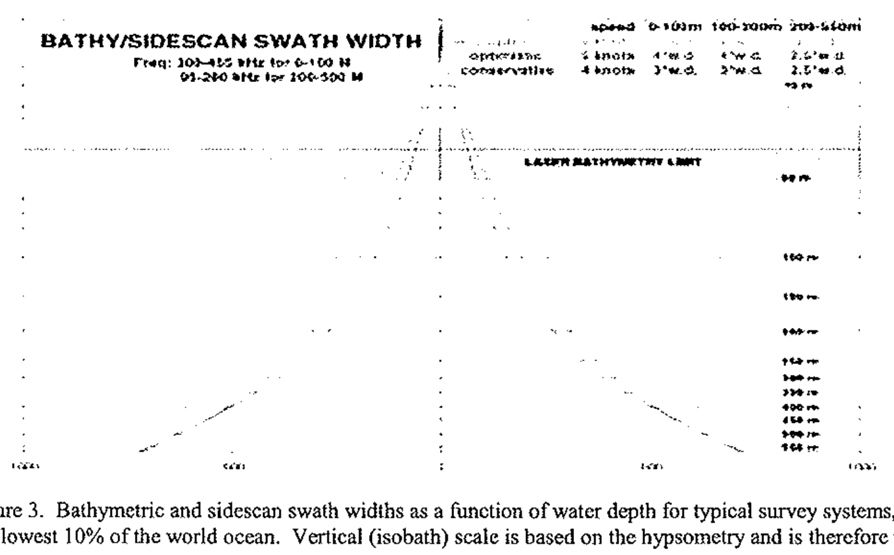

Figure 3. Bathymetric and sidescan swath widths as a function of water depth for typical survey systems, for the shallowest 10% of the world ocean. Vertical (isobath) scale is based on the hypsometry and is therefore non-linear.

estimate that over 600 ship years are required to map waters 25-500 m deep, compared to approximately 200-250 ship years for the deep ocean (500 m and greater). Figure 4 shows an estimate of survey kilometers for varying water depths needed for a global survey using a hull-mounted system and Figure 5 is for a typical towed system. Better pixel navigation accuracy suggests hull-mounted systems (9-16 kHz for deep water, and 30 kHz or higher for shelf waters) may be superior to towed systems but require dedicated ships, while towed systems may be operated from a variety of vessels. Seafloor mapping with air-deployed hyperspectral and laser bathymetric scanning may be required to replace or supplement shipborne and hydrographic survey launch mapping in clear waters less than 50 m deep.

Spatial resolutions for GOMaP multibeam sonar bathymetry and imagery would everywhere be 100 m or better in most locations except in the very deep sea, where it would approach 200 m. This is comparable to what has been achieved by the Shuttle Imaging Radar over the terrestrial earth, the MAGELLAN radar mapping of Venus, the MARS GLOBAL SURVEYOR and other probes on Mars, and the GALILEO mission to the moons of Jupiter. Presently co-registered multibeam (swath) bathymetric and sidescan data exist for only a relatively small portion of the ocean bottom (Figure 6).

Christian deMoustier of Scripps Institution of Oceanography (Personal Communication, 2000) proposed that bathymetry data and co-registered calibrated acoustic backscatter amplitude data should be collected at a horizontal spatial resolution sufficient to produce geographic grids with the following cell size vs. depth range:

	Grid Cell Size	
Depth Range	Bathymetry	Imagery
0-200 m	20 m	1 m
200-4000 m	100 m	2-5 m
4000-11,000 m	200 m	5-10 m

(Note: In most cases, 10-20 soundings per grid node will be needed to obtain reliable geostatistics during the bathymetry gridding process. Other data to be collected include those required for swath bathymetry (sound speed

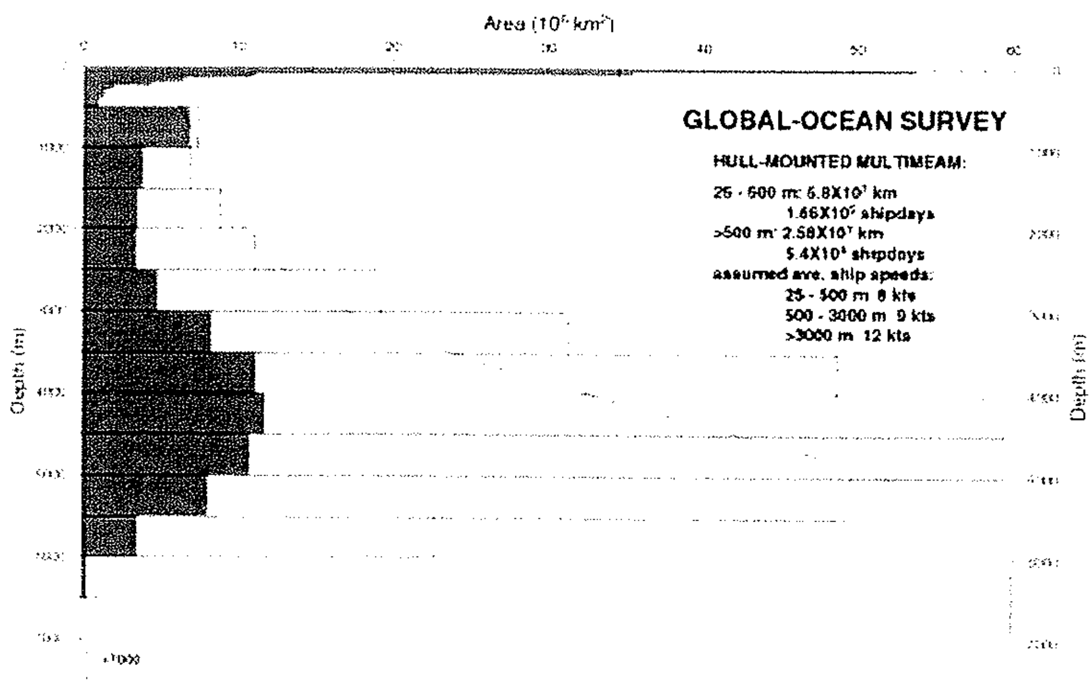

Figure 4. Histogram of track kilometers needed to produce a global ocean survey using typical hull-mounted multibeam survey systems and computations of ship days required for shallow (25-500 m) and deep (>500 m) surveys.

profile, sound speed at the acoustic arrays, attitude and navigation data) along with underway measurements of gravity, magnetics, acoustic subbottom profiling, sea surface temperature and salinity, and acoustic doppler current profiles. Occasionally, in very remote and uncharted areas, it may be desirable to stop the ship and take a sediment core or dredge the bottom for rocks. This would ensure that a few bottom samples are available in places that are unlikely to be revisited because of the logistics involved.)

Depth accuracy of individual soundings must be less than 0.2 percent of the sonar's altitude above the bottom. All depths must be reported as true depths (implies correction for tides, harmonic mean sound speed, and ship's dynamic draught or sonar dynamic depth).

In deep water, the 2D-RMS horizontal positioning accuracy must be at least 10 m. 3D measurements using GPS should have 1-m elevation accuracy. In

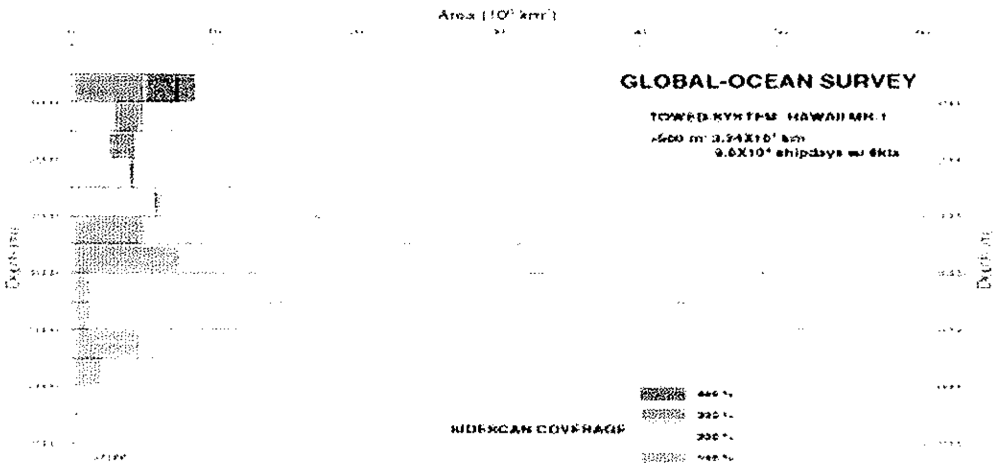

Figure 5. Histogram of track kilometers needed to produce a global ocean survey using typical towed multibeam or sidescan survey systems and computations of ship days required for shallow (25-500 m) and deep (>500 m) surveys.

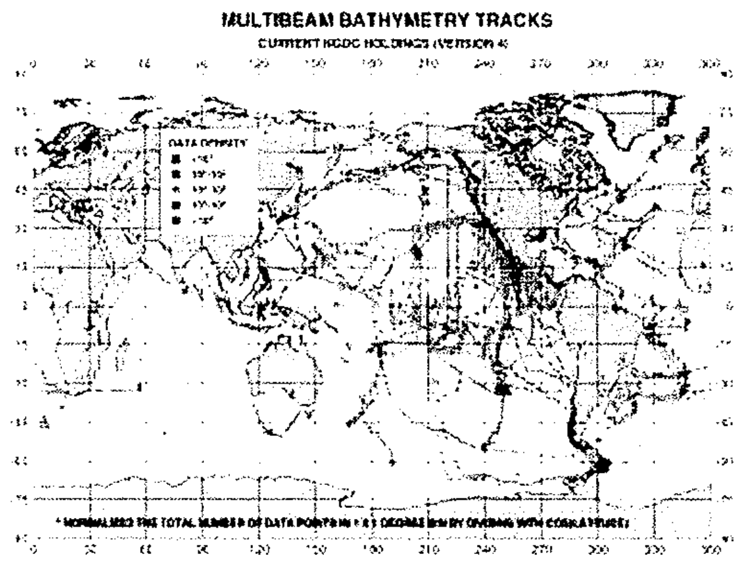

Figure 6. Current multibeam bathymetry tracks and data density from holdings at the National Geophysical Data Center. Data density is the number of soundings per 1 degree latitude x 1 degree longitude cell, corrected for the decrease of cell area with increasing latitude.

shallow water low-end Real Time Kinematic 3D position accuracy standards of 10 cm in x, y, and z should be met. (These would be similar to an International Hydrographic Organization Order 1 survey defined in IHO Special Publication 44.)

Data processing and cleaning standards have yet to be defined for the GOMaP, but ongoing discussions are being held. In particular, the minimum number of soundings per grid node and gridding techniques must be specified. All sonar systems must meet the accuracy standards described above and verify their compliance by running a patch test at the beginning and end of each survey.

The GOMaP "organization" should, working with appropriate international bodies (International Hydrographic Organization, for example), establish standard protocols for survey design in addition to specifications for instrument calibration, data processing, and quality control. For a typical (stylized) deep-ocean region (Figure 7) that spans the edge of the continental shelf, slope, rise, and ocean basin, one can imagine a schematic of existing seafloor mapping tracklines (Figure 8). One could opt to use a "Cartesian" survey pattern (Figure 9) or a hybrid "Cartesian/slope-parallel" pattern (Figure 10). The advantage of the pure Cartesian pattern is its ease in planning and execution. It's disadvantage is that it is not optimal in spatial coverage and requires constant sound velocity updates in the shallower areas. (Sound speed regime changes faster across shelf isobaths than along isobaths.) The hybrid survey pattern has the advantage in that it is easy to execute in deep-ocean areas, and executes optimally in shelf and shallow regions, and doesn't require sound velocity profile updates as often as cross-isobath surveys. Its disadvantage is that it is more difficult to execute while in the slope-parallel phase.

Is this worth doing if there is no light at the end of the tunnel?

GOMaP will take roughly 225 ship years to complete the portion of the world ocean deeper than 500 m (~90 percent) at a cost of between $8-16 billion, assuming US survey ship rates. There will be political hurdles concerning Economic Exclusion Zones and territorial seas (about one-third of the ocean area). Given the size of the seafloor mapping fleet and competing requirements for these resources, it may take between 20-30 years to just complete the deep- water portion, if fully funded. Mapping the shallowest 10 percent of the world ocean probably offers the greatest practical benefits to mankind, but presents special technical and political problems. We estimate that between 500-600 ship/survey launch years will be needed to complete this daunting task.

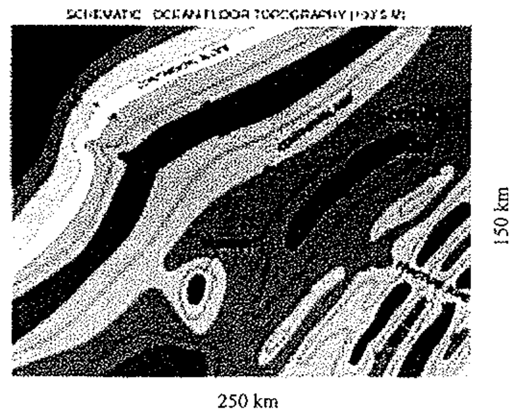

Figure 7. Schematic of typical ocean-floor topography (depths X 100 m)

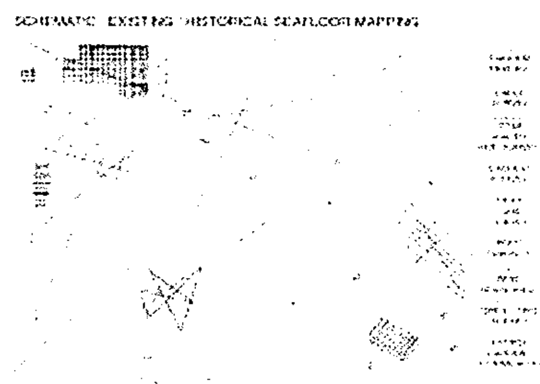

Figure 8. Schematic of typical existing seafloor mapping track lines. (depths X 100 m)

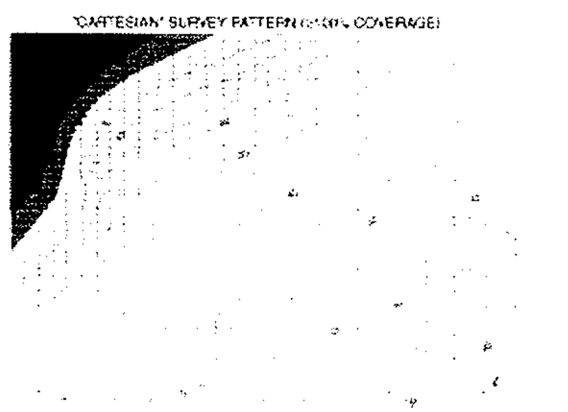

Figure 9. Schematic of typical "Cartesian" survey pattern with 100 percent or greater coverage. (depths X 100 m)

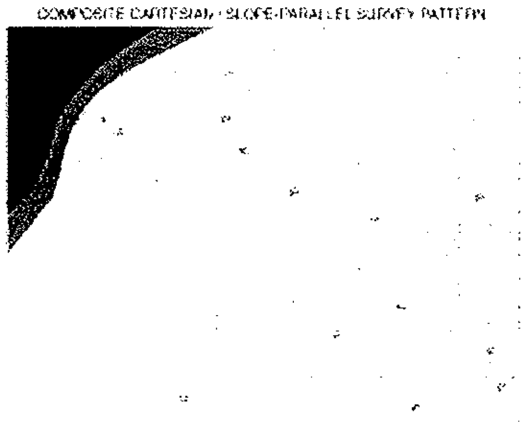

Figure 10. Schematic of typical hybrid "Cartesian/slope-parallel" survey pattern with 100 percent or greater coverage. (depths X 100 m)

We as a nation have spent tens and probably hundreds of billions of dollars on extraterrestrial exploration, while only spending an order of magnitude less on Earth exploration. While extraterrestrial exploration may be important for the long-term survival of mankind, recent events ranging from major earthquakes to threat of global climate change should make our understanding and ability to accurately model our planet our highest priority in Earth and planetary science. Most of us attending this forum will not be here to see the Earth mapped to the accuracy that we now have achieved for most of the other bodies in our solar system. Our generation needs to plan, influence policy and funding organizations, and implement a program to systematically map, understand, and model the major systems of the earth. GOMaP is our proposal to start the ocean-mapping phase.

How do we start?

The participants at the Bay St. Louis GOMaP Workshop are committed to begin work on this project. The Naval Research Laboratory is establishing a GOMaP web site to facilitate information exchange and discussion. The Naval Oceanographic Office has agreed to host an interim data server. The participants at the Workshop recommended that initially the GOMaP should focus on various pilot areas as a proof of concept: 1) The Gulf of Mexico [Good opportunities to utilize US Gulf Coast assets, and to demonstrate international cooperation]; 2) The Juan de Fuca plate [A nearly complete "ocean floor in miniature," a chance for US-Canadian cooperation, and supporting the NEPTUNE project]; 3) an area in the Southern Ocean with exceptional scientific interest but with very sparse data coverage; 4) the EEZ of a willing, small coastal state, as a demonstration; and 6) the Black Sea [A great opportunity for international cooperation and geological and archeological significance.].

We expect to see proposals submitted to various funding agencies during 2001.

Who should be players?

The next step in the political process is to engage the international organizations who have a vested interest in the long-term success of a project with GOMaP goals; the International Hydrographic Organization (IHO), the UNESCO Intergovernmental Oceanographic Commission (IOC), the Joint Commission on Oceanography and Marine Meteorology, and especially, the IHO/IOC General Bathymetry Chart of the Ocean (GEBCO) committee. These organizations can and must facilitate international coordination and funding.

This project will not succeed just because it needs to be done; it will only happen with the dedicated involvement of those individuals and institutions that have the "know how" and experience with oceanic surveys. We hope that members of the US Hydrographic Society, being just those types of individuals and institutions, will join the present active team in making GOMaP a reality.

Acknowledgements

We thank all the experts and stakeholders who attended the June 2000 GOMaP workshop in Bay St. Louis, especially the speakers. Christian deMoustier and Larry Mayer contributed ideas and information both before and after the workshop, as did R. Martino and C. Andreasen. We also thank GOMaP supporters who could not attend especially Jim Gardner, J. Delaney and A.N. (Sandy) Shor.

The workshop and EOS publications resulted in numerous inquiries from a number of nations. The two NRL authors were supported by ONR—and we particularly thank Vice Admiral Paul Gaffney (then Chief of Naval Research) for his endorsement of the GOMaP and for funding the Bay St. Louis workshop. We also think Rear Admiral Kenneth Barbor (Ret) (now Director, Hydrographic Science Research Center, University of Southern Mississippi) for his insightful welcoming discussion. H. Fleming of NRL management strongly supported the GOMaP planning and workshop. NRL marine geologist Joan Gardner assisted in every phase of the workshop.

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Conventional Bathymetry, Bathymetry from Space, and Geodetic Altimetry

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This article offers a general introduction to those aspects of bathymetric mapping and satellite altimetry that are relevant to bathymetry from space. We begin with a review of some of the strengths and weaknesses of conventional bathymetric measurement and mapping. This context highlights the case for and value of space-based mapping: it is the only way to achieve globally uniform resolution within reasonable time and cost. However, a space mission cannot "see" the ocean floor directly; instead, it observes gravity anomalies that can be correlated with ocean floor topography. Geological factors and physical laws limit the resolution of this technique to a particular range of spatial scales (~100 km to ~5 km). While this is not perfect, it yields an enormous improvement in the resolution of global bottom roughness over traditional methods (Figure 1).

A satellite altimeter mission designed for bathymetric mapping is simpler and cheaper than one designed to monitor ocean currents, tides, or climate. It also yields information about Earth's gravity field that is independently useful for resource exploration and for compensation of the errors in inertial navigation systems. A new mission with a state-of-the-art altimeter could optimize the mapping of gravity and bathymetry and resolve a key element of bottom roughness—abyssal hill orientation—for only $100M.

More complete and technical reviews of these topics may be found elsewhere. Smith (1993) reviewed the problems and errors in conventional bathymetric data. Details on the processing of altimeter data to yield gravity and bathymetry may be found in Smith and Sandwell (1994; 1997), Sandwell and Smith (1997; 2001), and Smith (1998). Chelton et al. (2001) present a thorough treatment of satellite altimetry, with a view toward measuring ocean currents and climatic signals.

Conventional Bathymetric Measurements

Direct measurement of ocean floor depth is done by echosounding from a ship. This technique has become highly refined since the 1980s and now systems can map a swath of area beneath a ship's track with a width as much as twice the water depth in deep water. However, the speed of the ship is limited, and thus also the rate at which ocean area may be mapped. A complete swath survey of the deep ocean would take about 200 years of survey time, at a cost of billions of dollars (Carron et al., 2001); shallow coastal areas would take even longer.

Estimates of how much ocean floor is already mapped by swath bathymetry vary because some data are classified military secrets or proprietarily held by their collectors. Publicly available data cover only a few percent of the ocean floor, and there is general agreement that even if all data became public, they would still cover only a small fraction of the deep ocean area. If a complete global survey could be made by swath mapping, it would have much higher resolution and accuracy than what can be done from space. Until such a survey is a reality, however, we must work with the available data, which are primarily older, "low-tech" analog echosoundings.

Historically, the mandate for soundings has come from the need to chart hazards to navigation, that is, bottom features that are so shallow that a ship could run aground on them at low tide. This naturally concentrates mapping efforts very close to shorelines. More recently, there has also been some interest in mapping exclusive economic zones (EEZs), which extend outward 200 nautical miles from shore. The distribution of soundings in the ocean is relatively dense in shallow coastal areas and EEZs, but very sparse in the open ocean. As Figure 2 shows, the distribution of survey lines covers the South Pacific as coarsely as the Interstate Highway System covers the United States.

Echosounding data also have an uneven geographical distribution of technology and quality. Most of the soundings in remote oceans are old analog measurements geo-located using only celestial navigation (Smith, 1993). Modern digital swath systems with

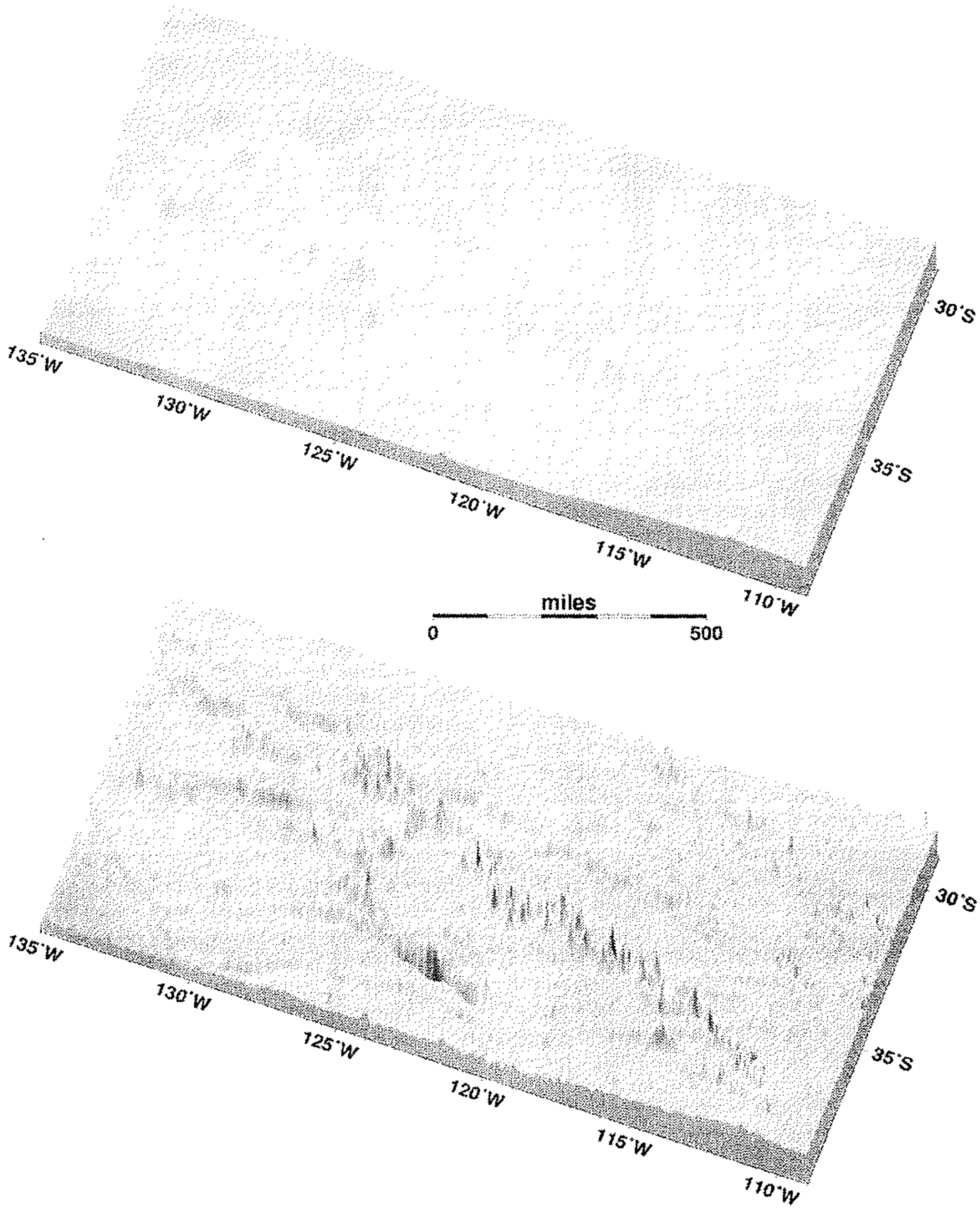

Figure 1. Traditional bathymetric mapping (top) misses many important features of seafloor topography. Bathymetry from Space (bottom) reveals all the major seamounts, fracture zones, and troughs that are important habitats, obstacles to currents, sites of enhanced mixing and tsunami scattering, and clues to the motions of Earth's plates. The uncharted seamount chains found by satellite mapping prompted ship surveys which verified their existence. Figure 7 shows a profile along a ship survey across the trough and seamounts of the lower left part of the image. The area shown here is in the South Pacific southwest of Easter Island; the southern East Pacific Rise is near the right hand edge of the images. Data in the top image are from the ETOPO5 grid produced from hand-contoured charts; data in the bottom image are from Smith and Sandwell (1997).

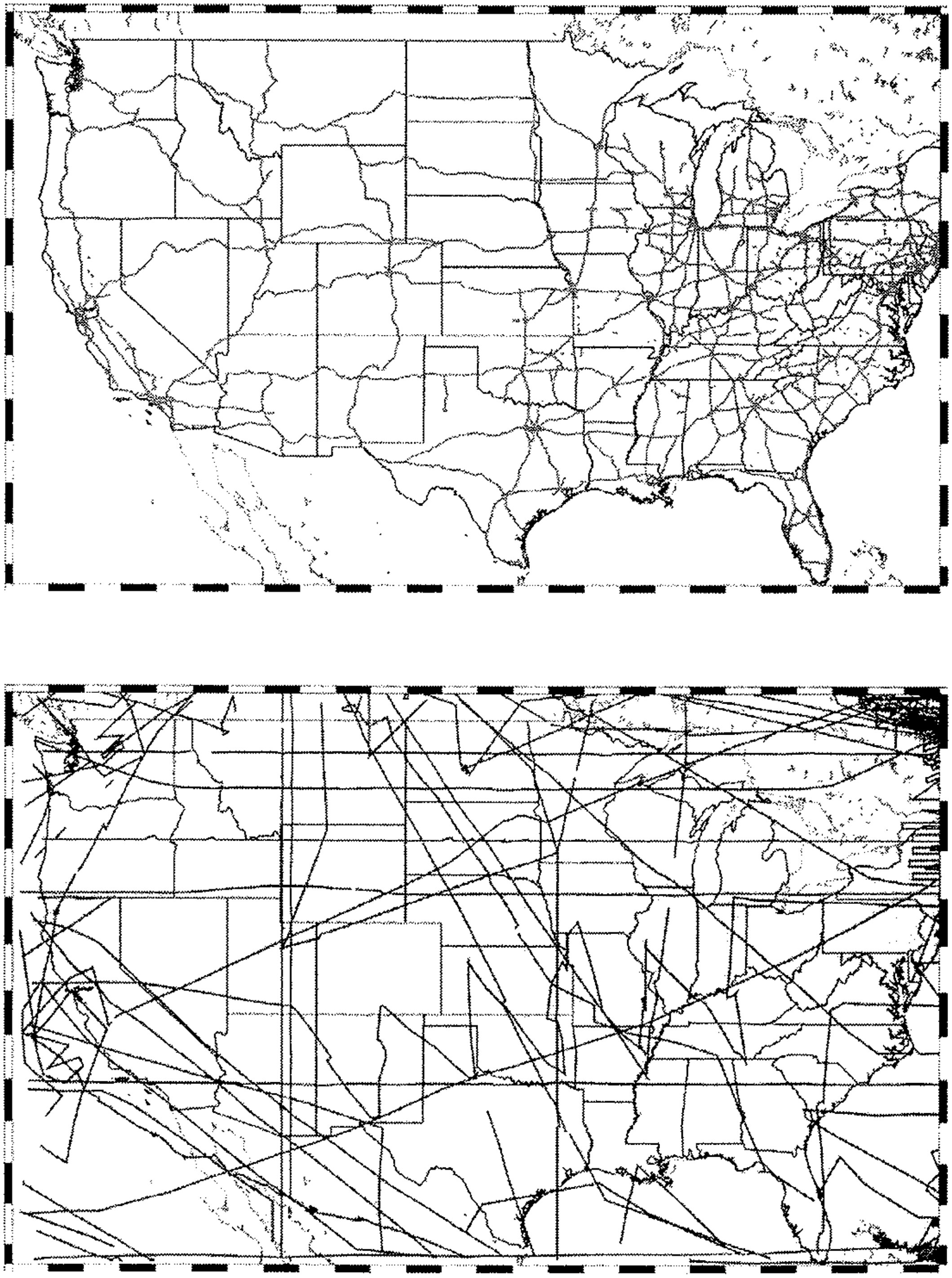

Figure 2. Imagine how poorly known the topography of the United States would be if survey data were confined to the U.S. Interstate Highway System (top). The remote ocean basins are just that poorly surveyed. The bathymetric survey lines in the South Pacific are shown (bottom) at the same scale as the Interstate highway map. The gaps between surveys are much larger than the bottom features of interest so conventional interpolation schemes fail to reveal the important features. Image courtesy of David Divins, NOAA.

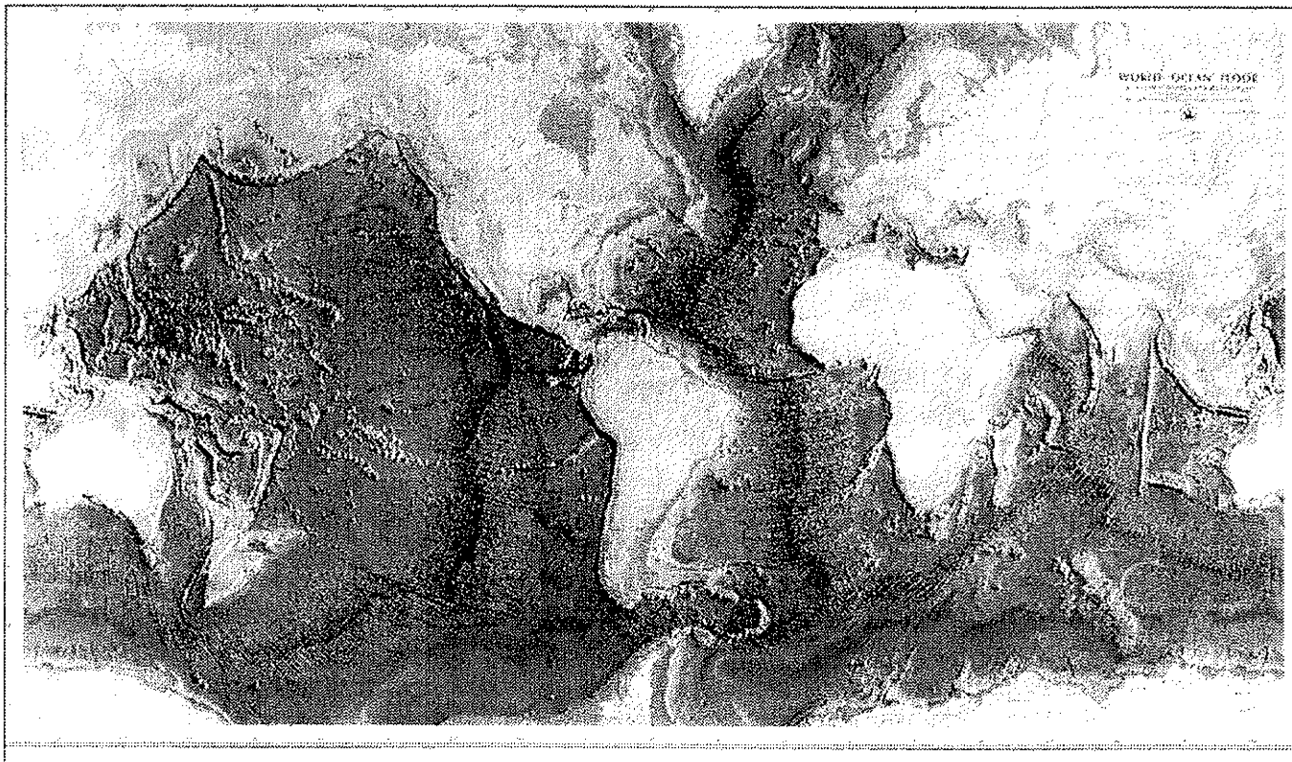

Figure 3. The strengths and weaknesses of human artistic license in interpretation are shown in this beautiful physiographic diagram of the world's ocean floors made by Bruce C. Heezen and Marie Tharp in 1977. Maps portraying similar features and texture were widely distributed by the National Geographic Society. These maps show the major features of plate tectonics in approximately the right locations and are also aesthetically pleasing as works of art. Perhaps for these reasons this view of the oceans has become fixed in the public mind, creating the illusion that the entire ocean floor has been mapped. In fact, however, only a few percent of the ocean has been surveyed. The position of plate boundaries is approximately correct in these diagrams because the cartographers were guided by teleseismically determined earthquake locations. However, the portrayal of bottom shape is misleading. The "back of the alligator" texture is an apt metaphor for the very rough parts of the Mid-Atlantic Ridge and Southwest Indian Ridge, but the East Pacific Rise and Southeast Indian Ridge are actually much smoother. Compare the texture shown here with that of the map on the cover of this special issue. (Photograph courtesy of John Diebold. Map copyright 1977 by Marie Tharp. Used with permission. The printed map acknowledges support to Heezen & Tharp from the U.S. Navy's Office of Naval Research. The phrase "back of the alligator" is due to Tibor Toth, artist for the National Geographic Society.)

satellite navigation are rarely deployed for exploratory mapping in unsurveyed areas.

Traditional Methods of Global Bathymetric Mapping

Since navigational charts exist to promote maritime safety, they often have a "shoal bias." They must portray any known bottom feature shallow enough to present a hazard to shipping, but they need not indicate any deeper aspects of bottom shape. (In fact, they need not exist at all in deep water areas.) Thus the depths indicated on these charts do not give a complete view of the seafloor.

In deep water areas of the open ocean, the gaps between survey lines are much larger than the size of features of interest. Prior to satellite altimetry, interpolation by machine algorithm proved unsatisfactory, and maps were drawn by hand, sometimes with a great deal of artistic license guided by plate tectonic theory and an understanding of seafloor fabric. This approach also allowed bathymetrists who had seen classified data to convey some of the essence of those data without revealing secret details. The most aesthetically pleasing maps also proved to have the greatest inspirational value and popular appeal. The justly celebrated "physiographic" diagrams of ocean basin shape produced by Bruce Heezen and Marie Tharp (Figure 3) seemed to satisfy an appetite for an illustration of plate tectonic features of the seafloor. This style of bottom portrayal was carried on and extended in a map series widely distributed by the (U.S.) National Geographic Society (NGS, a private organization). The NGS map series employed artists to paint the maps, ensuring their aesthetic appeal.

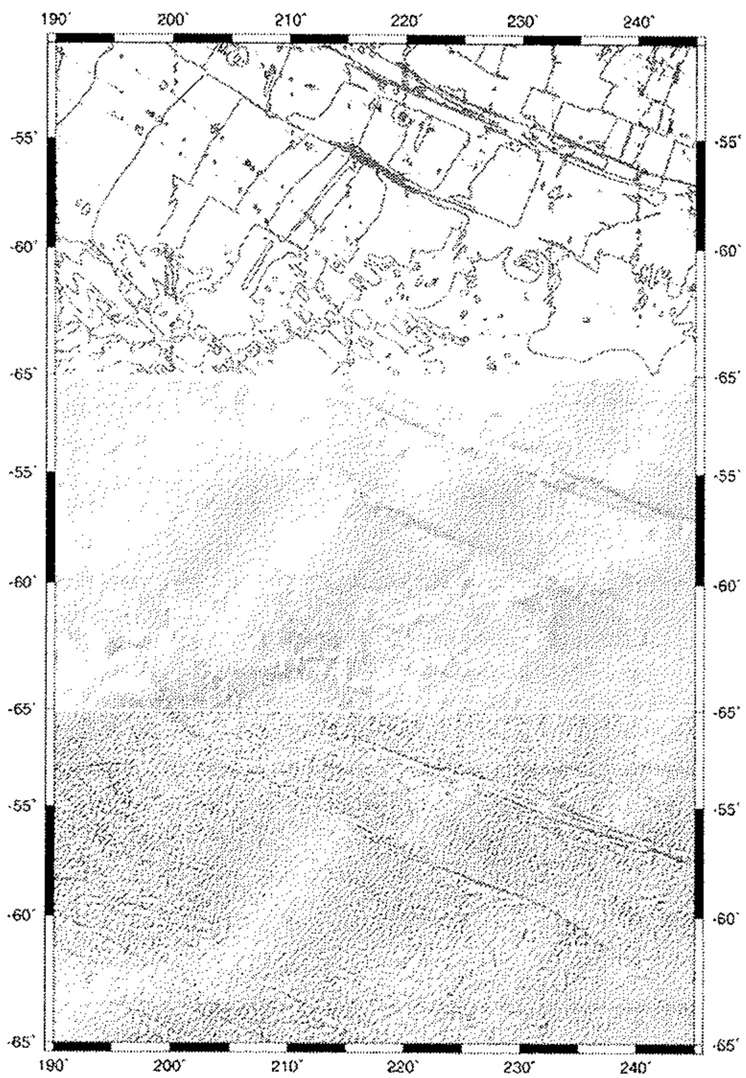

Figure 4. Human artistic license is evident in traditional bathymetric maps and gridded products. (Top): The General Bathymetric Charts of the Oceans (GEBCO) show a change in texture in the southwest Pacific Ocean, with roughness sharply increased south of 60°S. The solid lines are depth contours at 500 m intervals and the dashed lines indicate the locations of sounding surveys used by GEBCO bathymetrists to draw the contours. Close inspection shows that there are extra contours south of 60°S that are not required by the surveys and not included north of 60°S. Different people drew the contours in the two places, with different styles. Their influence extended to the ETOPO5 bathymetric grid (middle) that was produced from contours. Bathymetry from Space (bottom) uniformly and correctly portrays the ocean bottom texture. (Contours and tracklines in the top panel are from the GEBCO Digital Atlas, available from the British Oceanographic Data Centre.)

Hand-drawn maps also allowed intelligent synthesis of ancillary information in the era before easy computing. For example, knowing the plate tectonic theory, one could draw plate boundaries in unsurveyed areas by following teleseismically located earthquake epicenters. Assuming that depth should increase away from mid-ocean ridges approximately as the square root of distance from the ridge, and understanding the abrupt nature of fracture zones, one could guess where to place depth contours. These considerations led to a reorganization of the venerable Committee for the General Bathymetric Charts of the Oceans (GEBCO) to include marine geologists as well as hydrographers in the production of its 5th Edition chart series, begun in the 1970s.

All traditionally produced maps show the influence of human choices in the portrayal of seafloor texture. This is true throughout the ocean basins, not just at mid-ocean ridges. For example, the GEBCO charts show what appears to be a change in ocean floor roughness along some geographical boundaries (Figure 4, top panel). What changes at these boundaries is not the true ocean floor texture but the human beings who drew each chart.

The GEBCO and other contour charts, even with these artifacts in texture, ultimately had more impact on research than did the Heezen & Tharp and NGS maps because the contours could be digitized and fed into a machine algorithm to produce a grid yielding numerical values for depth estimates on a regular lattice of points. Such grids greatly facilitate a wide variety of research applications. The U. S. Naval Oceanographic Office produced a grid known as "DBDB-5" (digital bathymetric data base at five arc-minute spacing) in the 1970s and it was eventually widely distributed by the U.S. National Geophysical Data Center as part of "ETOPO-5" (Earth topography at 5 arc-min) in 1988. One can find in it the same artificial texture boundaries (Figure 4, middle panel) that appear in the original contours (Figure 4, top panel), as well as other artifacts (Smith and Wessel, 1990; Smith, 1993).

Regardless of the gridding scheme used, grids produced from contours are subject to a statistical bias known as "terracing": numbers in the grid are much more likely to be equal to or near to contour values than to other values in between

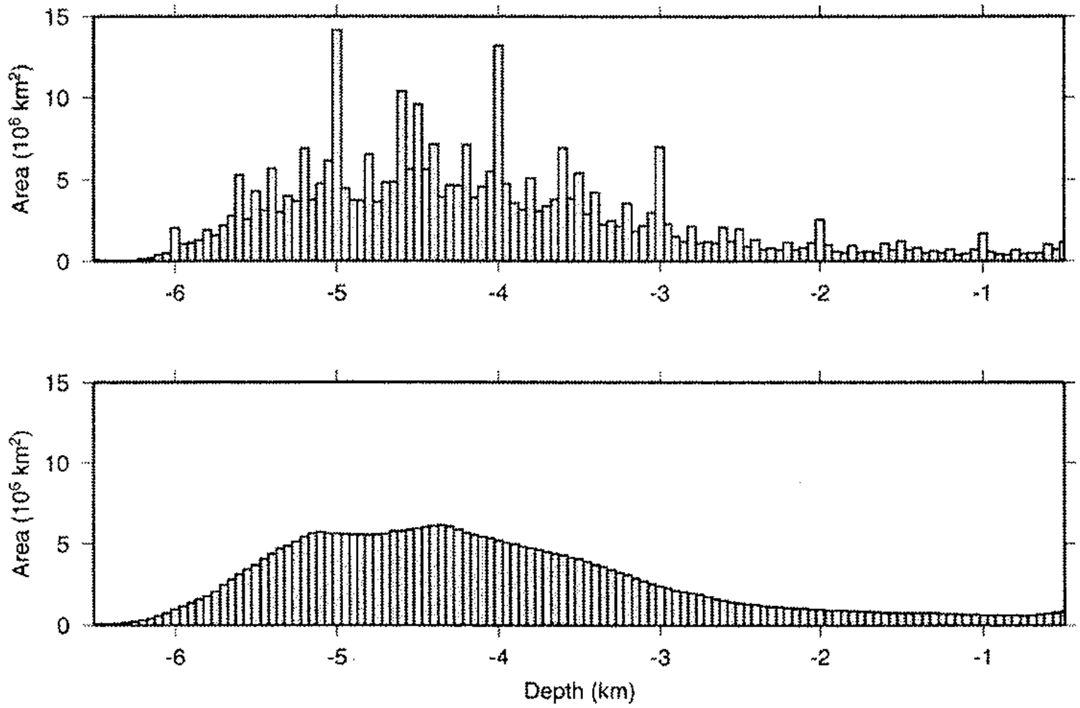

Figure 5. A "terracing" problem plagues traditional bathymetric grids produced from contours. Terracing causes a grid to have values equal to contoured values much more frequently than it has any other values. These hypsometric diagrams show histograms of the area of the ocean floor lying at depth intervals of 50 m. A grid produced from contours (top panel, ETOPO5 data) has spikes at multiples of 1000, 500, and 200 m, indicating that contoured depths occur more often than they should in that data set. This artifact leads to biases in physical models fitting the data by regression, and also prevents the grid from yielding useful calculations of bottom slope or roughness. Bathymetry from Space produces a smooth curve (bottom panel).

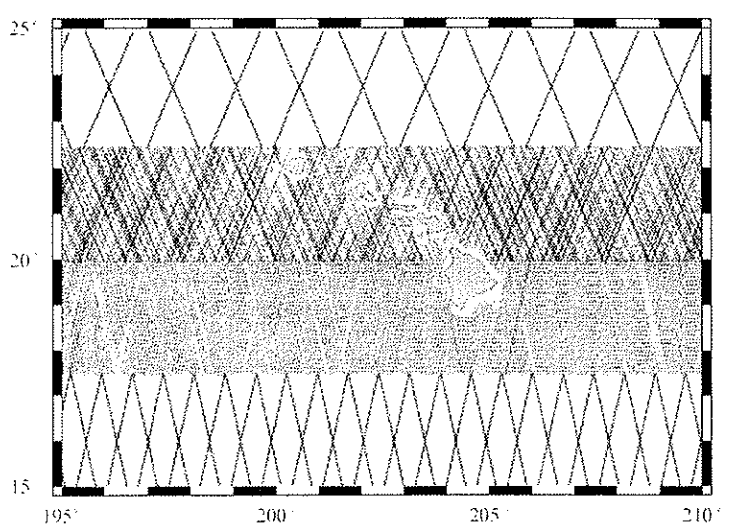

Figure 6. Satellite altimeter survey tracks cover the globe much more densely than the bathymetric survey tracks shown in Figure 2. This map shows the Hawaiian Islands for scale, and the track density of four orbital patterns. Each orbit produces continuous tracks, but only narrow strips of each track pattern are shown here for clarity. The middle two strips show the dense track patterns of "geodetic" orbits suitable for Bathymetry from Space; the top and bottom strips are "oceanographic" orbits used to monitor currents, tides, and climate. Top, the Geosat Exact Repeat Mission; 2nd from top, the Geosat Geodetic Mission; 2nd from bottom, the ERS-1 geodetic mission ("Phases E and F"); bottom, the ERS-1/ERS-2/Envisat 35-day repeat track. Not shown is the 10-day repeat track of the Topex/Poseidon and Jason "oceanographic" missions; those tracks are even more widely spaced than the tracks in the top strip shown here. Geosat was a U.S. Navy mission and ERS-1 a European Space Agency mission.

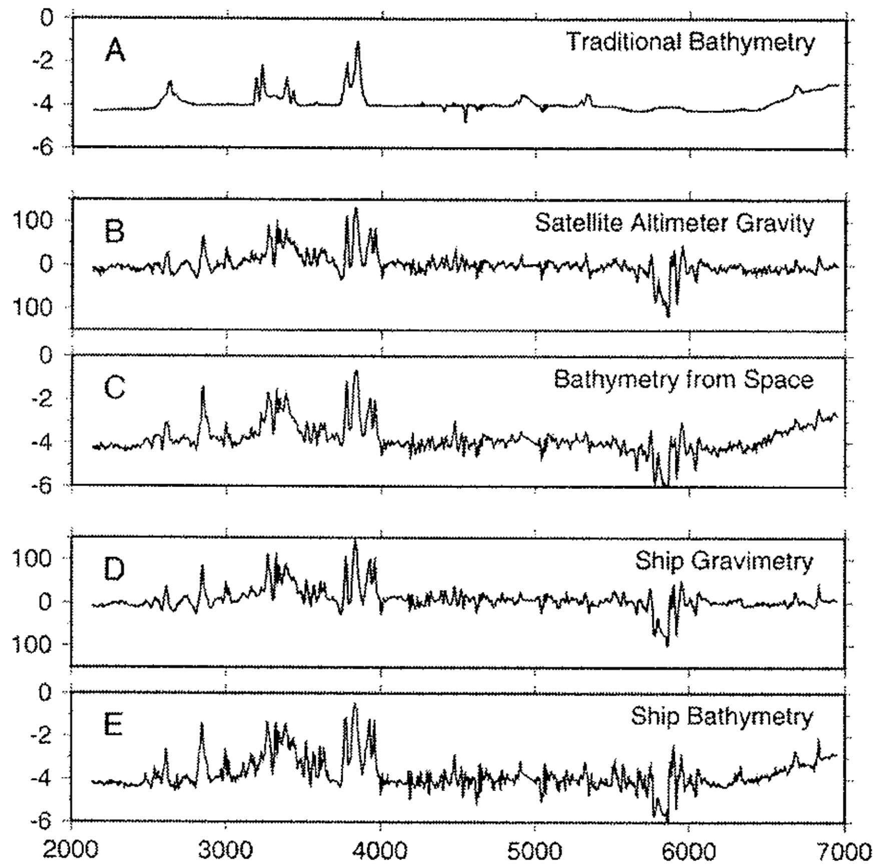

Figure 7. These profiles of gravity and bathymetry lie along a ship survey line in the southwest (lower left) part of Figure 1. Traditional bathymetry (A) shows a smooth seafloor with only a few seamounts of simple shape. Satellite altimeter data reveal gravity anomalies (B); these may be used to estimate bathymetry (C). The differences between (A) and (C) prompted a survey by a ship, yielding "ground truth" measurements of gravity (D) and bathymetry (E). Quantifying the cross-correlation between pairs of data types allows one to explore the signal-to-noise and limiting resolution of altimetric data. Correlations between space-based and ground-truth profiles are high at scales longer than 12 km in both gravity and depth; root-mean-square differences are about 5 mGal in gravity and 120 m in depth. At fine scales, the satellite gravity has a higher noise level than the ship gravity, while the space bathymetry is smoother than the true bathymetry. Ship gravity is correlated with ship bathymetry down to about 5 km scales, implying that a more-precise satellite mission with better signal-to-noise between 5 and 12 km half-wavelengths could yield higher-resolution bathymetry. Very-long-wavelength trends in bathymetry, such as the upward tilt in the profiles near the right hand edge, are not reflected in the gravity anomalies due to "isostasy." The horizontal scale is in km along the survey; vertical scales are in km of depth and mGal of gravity anomaly. Data sources: A, ETOPO-5 gridded from contour charts; B and C, Smith and Sandwell, 1994; D and E, 1997 cruise of the French research vessel Atalante.

(Figure 5). Terracing inhibits realistic calculation of bottom slopes from grids, and leads to biases when geophysical models are fit to gridded data by least-squares regression (Smith, 1993). Despite these problems, grids continue to be produced from hand-contoured charts. The Centenary Edition of the GEBCO Digital Atlas (British Oceanographic Data Centre, 2003) includes a grid made from hand-drawn contours, even though in some areas (such as the South Pacific) those contours have not been updated since the 1970s.

Satellites and Ships are Highly Complementary Mapping Tools

Satellites offer rapid global coverage at lower resolution while slower ships provide targeted high-resolution surveys. The speed at which the sub-satellite point moves over Earth's surface is more than 1000 times the speed of an oceanographic vessel, and a satellite can survey the ocean with a dense (order 5 km apart) network of ground tracks in a little over a year's time

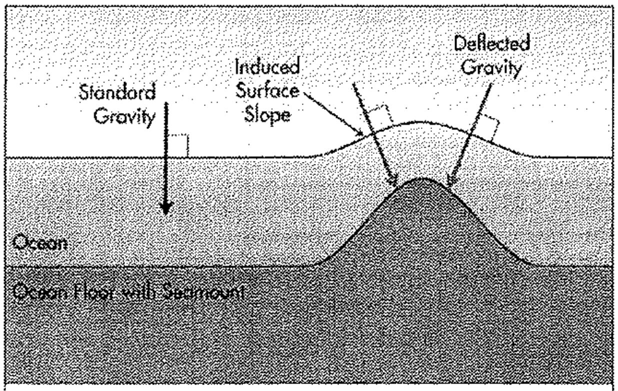

Figure 8. Topography on the ocean floor adds its own attraction to Earth's usual gravity. This additional gravity pulls extra water up around a seamount and tilts the direction of gravity. The slope of the sea surface is nearly perpendicular to the pull of gravity. A space-based radar cannot "see" the ocean bottom but it can measure the tilts of the ocean surface. These reveal gravity deflections and from these the ocean bottom topography may be inferred. Note that the overall sea level is irrelevant; only the local tilt over the length scales of bathymetric features such as seamounts is important. This means that the radar doesn't need absolute height accuracy, and tides, El Niño, and other large-scale sea-level events may come and go; the local tilt remains steadily detectable.

(Figure 6). The total cost of a satellite mission designed for bathymetry from space, including a suitable altimeter instrument, host spacecraft, launch, and operations, is slightly under $100M, according to a Johns Hopkins University Applied Physics Laboratory design study contracted by the National Oceanic and Atmospheric Administration (Raney et al., 2003).

It would seem that satellite surveys are about 2×10^4 times more efficient than vehicles in the water, with three orders of magnitude coming from speed and one from cost. However, the satellite method also has much lower resolution. State-of-the-art acoustic swath-mapping systems can image seafloor area "pixels" on the order of 100 m by 100 m in deep water, whereas the presently available satellite altimeter maps of the oceans do not easily resolve areas much smaller than about 10 km by 10 km (half-wavelength). A new space-based bathymetry mission would improve the resolution, but if cost-effectiveness is measured as resolution divided by cost, space bathymetry can beat acoustic bathymetry by perhaps only a factor of 8 or more.

While satellites may be more efficient and cost-effective mapping tools, their greatest virtue lies in their uniform and comprehensive global coverage. Satellites cannot be denied access to territorial waters. They also make no noise in the water column and so do not disturb marine life. By carrying the same sensor everywhere they yield a uniform level of detail across the globe. Thus if a satellite map shows a change in bottom texture, one can be sure it is real. Later, it can be investigated in greater detail with an accurately targeted ship survey, if desired (Figure 7). Many of the applications of bathymetric mapping, including all those in this special issue, require a globally uniform level of resolution and fidelity to spatial changes in texture or roughness.

Bathymetry via Altimetric Gravity

A space-based radar sensor cannot directly "see" the deep ocean floor. (In very shallow and very clear water the bottom may be visible to lasers or multi-spectral scanning systems.) Space-based ocean floor mapping is possible because topography on the seafloor creates gravity anomalies that tilt the ocean surface in ways that are measurable with a radar altimeter (Figure 8). These ocean surface tilts may be directly interpreted as an anomaly in the direction of gravity called a "deflection of the vertical." The vertical deflections of interest have amplitudes from 1 to a few hundred microradians, or 0.2 to 60 arc-seconds; a one microradian tilt of the sea surface is 1 mm of sea surface height change per km of horizontal distance.

Anomalies in the direction of the vertical are important information for compensating errors in inertial navigation systems (INS). Without such a correction, an INS mistakenly interprets a deflection anomaly as an acceleration of the vehicle. INS systems used on some submarines during the Cold War employed an error-compensating scheme requiring a map of vertical deflections at a fairly high level of precision. This limited the geographical range of operation of those subs to areas the U.S. Navy had covered with precise gravity surveys (satellite navigation signals cannot be received by a submerged antenna). Today, many military and civilian vehicles employ INS as a backup to GPS, and there is a need for worldwide operability. Current global altimeter data are about a factor of two too noisy to meet the one-arc-second precision goal set recently by the U.S. Air Force and the National Imagery and Mapping Agency. A new space bathymetry mission would be a factor of four better than current data and thus would meet the USAF-NIMA goal with a safety margin of a factor of two.

The gravity anomaly field at the sea surface obeys a mathematical equation (Laplace's differential equation) that allows one to recover anomalies in the magnitude of gravity (simply called "gravity anomalies") from the deflections of the vertical (Haxby et al., 1983; Sandwell, 1984). This is useful because the gravity anomalies are more easily interpreted and correlated with seafloor structure, and because they also can be checked against independent measurements made by ships carrying gravimeters (Figure 7). Roughly speaking, a one microradian vertical deflection can be related to a 1 milliGal anomaly in the acceleration of gravity. A milliGalileo is 10^{-5} m/s^2; since standard gravity is

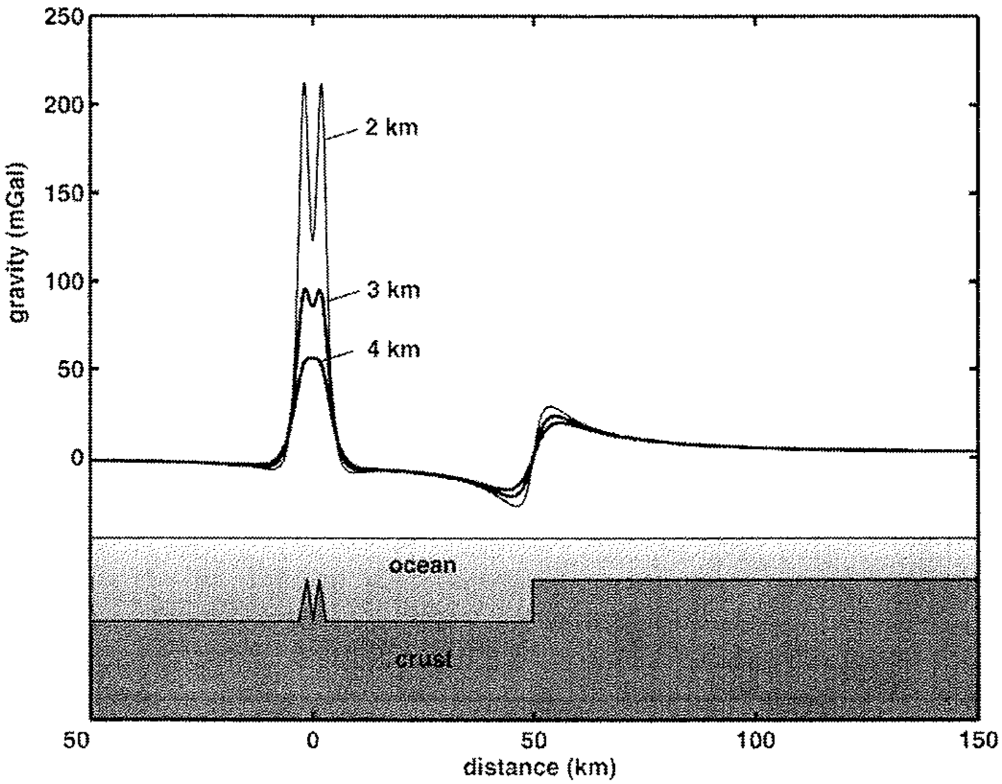

Figure 9. The gravity anomaly at the ocean surface does not exactly mimic the topography of the ocean floor below it at all length scales. Instead, it resembles a "band-pass-filtered" version of the topography. Very-broad-scale (longer than 100 km or so) changes in depth are in "isostatic balance" and so these contribute no gravity anomaly. However, if there is a sharp step from one regional level to another, such as at a plateau edge as suggested in this cartoon, then the gravity field may show an "edge anomaly," the zero-crossing of which locates the edge of the plateau. The shortest scales that gravity can see are limited by "upward continuation," which attenuates horizontal scales that are short compared to the average depth of the region. For example, two small seamounts that are 4 km apart and 1 km tall will create a gravity anomaly with two peaks if the water depth is less than 4 km but the anomaly will blur into one broad peak if the depth is 4 km. This "upward continuation" also makes the proportionality between gravity amplitude and topography amplitude a strong function of water depth for small-scale features. Therefore, the resolution of small-scale features in deep water requires precise gravity. Optimizing the signal-to-noise ratio at very short length scales is the key to detailed Bathymetry from Space.

about 9.8 m/s^2, both the microradian and the milliGal represent parts-per-million-sized anomalies.

Once the deflections have been converted to gravity, bathymetric mapping follows by exploiting the correlation of bathymetry with gravity, using the available sounding data to calibrate the correlation and maintain the accuracy of the map. In effect, this means that bathymetry from space is yet another interpolation scheme for filling in the gaps between surveys. However, this technique replaces human choices and artistry with an empirically determined cross-covariance between gravity and bathymetry, embodying real physical laws. The ocean floor texture so derived is in marked contrast to traditional maps (see Figure 1 and the cover of this special issue). Because satellites provide uniform and unbiased coverage, the only limitations on the technique come from the nature of the gravity-topography correlation, and the errors in the altimeter measurements.

Factors Limiting the Gravity-Topography Correlation

The gravity anomalies caused by topography have been discussed in the scientific literature since the 18th century, and a 19th century paper (Siemens, 1876) suggested using gravity to estimate depth, although this was a fanciful notion given the difficulty of measuring gravity at sea in that day. The last three decades have seen a vast literature on gravity-topography correlations, exploiting linear filter theory and a spectral approach. In fact, the expected relationship is not quite

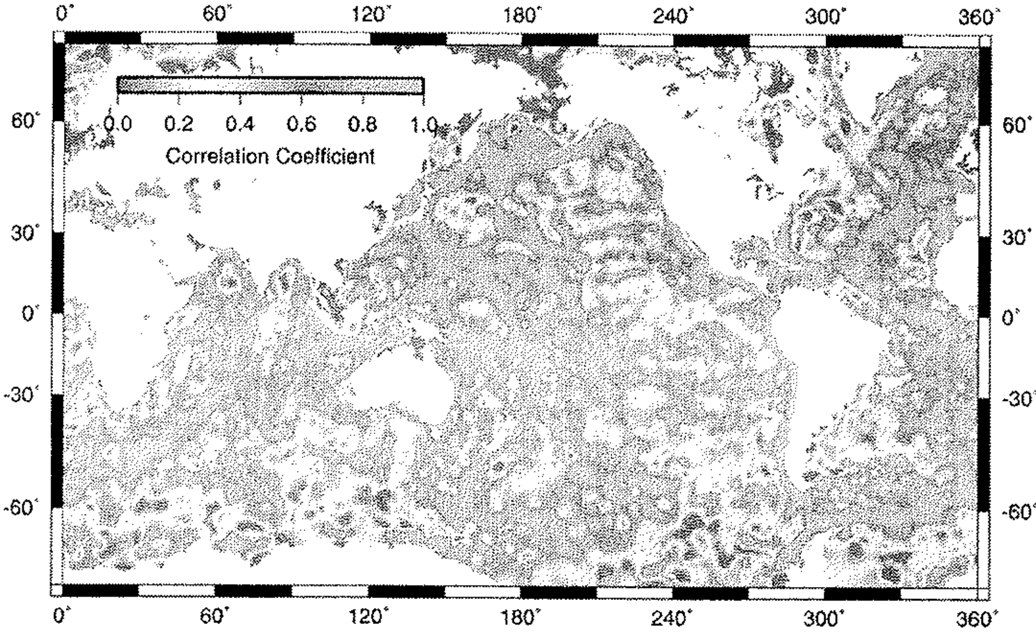

Figure 10. The Bathymetry from Space technique takes into account varying sub-bottom geology. Altimetric gravity and depth soundings are filtered to isolate the length scales over which they may be correlated. The correlation must then be determined empirically because it depends on seafloor geology. The correlation is high over large-amplitude seafloor topography, such as at the major seamount chains and the Mid-Atlantic and Southwest Indian Ridges. It is low over continental margins and abyssal plains where the seafloor is flat and there is essentially no topographic signal at scales shorter than ~100 km. Note that this doesn't mean bathymetry from space won't work in these areas; the method has correctly detected that the seafloor is flat. Correlations are intermediate over relatively smooth seafloor, such as in the central Pacific Ocean. Here altimetry is of some value in mapping topography but the signal strengths are small and so noise in the measurements has reduced the correlation. With a new mission having a better signal-to-noise ratio, these areas would show higher correlations. (Adapted from Smith, 1998.)

linear (Parker, 1973). Non-linearities are a significant fraction of the total effect only where the amplitude of the topography approaches the mean depth of the water and the slopes grow steep, as may occur at some very tall seamounts.

Gravity-topography correlation research was stimulated by a phenomenon called "isostasy," which reveals the mechanics of Earth's tectonic plates. The subject is thoroughly reviewed by Watts (2001). Earth's outer layers have finite strength and can only hold up topographic masses of limited size; larger objects are "isostatically compensated" and in effect contain less mass than their surface topography would suggest. The result is that long-wavelength (greater than a few hundred kilometers) topography is supported by buoyancy and generates essentially zero gravity anomaly (Figure 7). There are long-wavelength gravity anomalies, but these come from deeper inside Earth, not from the surface topography. Thus the long wavelengths in a bathymetric map must come from interpolation of soundings; they cannot be estimated from gravity. Features as large as oceanic plateaus cannot be fully mapped with gravity, although gravity may accurately locate their edges (Figure 9); however, medium-sized seamounts and smaller features are too small to be isostatically compensated and may be mapped with gravity (Smith and Sandwell, 1994; 1997; Smith, 1998).

While the long-wavelength resolution of bathymetry from space is limited by isostasy, the short-wavelength (about 10 km) resolution is limited by a phenomenon known as "upward continuation." This results from Newton's law that the strength of gravity falls off with the square of the distance between the source and the perceiver. Upward continuation of the gravity field to the sea surface from its source at the seafloor imposes a scale-dependent attenuation of the anomalies. Anomalies with wavelengths that are long compared to the mean water depth will suffer little attenuation, while those that are much shorter than about π times the water depth will be strongly attenuated.

Some readers may have heard of "space gravity" missions such as GRACE (Gravity Recovery and Climate Experiment) and GOCE (Gravity and Ocean Circulation Explorer) that measure Earth's gravitational field in space at ~400 km altitude. Upward continuation affects them too; they cannot resolve gravity anomalies much shorter than ~400 km scales. Because Earth topography is isostatically compensated at these wavelengths, these missions cannot do bathymetry from space. The virtue of satellite altimetry is that, by measuring ocean surface tilts, it measures gravity at the sea surface, not at orbital altitude. With altimetric gravity anomalies, there is 4 km of upward continuation, not 400 km, making bathymetry from space possible.

The limitations on long- and short-wavelengths are summarized in Figure 9. In effect, the sea surface gravity field is missing some information about the topography at both short and long wavelengths; the gravity effect of topography appears as a band-pass-filtered version of the topography. To predict topography from gravity one must stay within the band of wavelengths where gravity and topography may be correlated. The smallest feature that can be resolved depends on the integrated effect of the band-pass-filter, the signal-to-noise ratio in the altimetry, and the signal strength spectrum of the seafloor topography feature to be imaged. The paper by Goff et al. in this issue offers a more thorough investigation of the limiting resolution, for both currently available altimeter data, and data that could be obtained by a new mission. An important result of that paper is that a new mission would be able to resolve the fine-scale seafloor fabric known as abyssal hills, even in the smoothest seafloor areas.

In addition to the limitations on length scale, the gravity-bathymetry correlation is also influenced by sub-seafloor geology, primarily because of variations in sediment thickness. Areas of high and low correlation are easily detected by simply filtering the gravity field with a band-pass filter and then checking the resulting data for correlations with similarly filtered soundings (Smith and Sandwell, 1994; Smith, 1998). The results are shown in Figure 10. Interested readers may wish to compare Figure 10 to a map of sediment thickness currently under compilation at the U.S. National Geophysical Data Center (http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html). One should bear in mind that sediment thickness is known even more poorly than bathymetry. Monahan (this issue) speculates that the strength of the topography-gravity correlation may be useful as a proxy for sediment thickness.

Seafloor spreading creates oceanic crustal rocks with fairly uniform density and simple layering. Faulting and volcanism associated with the spreading process create abyssal hills, the "original" topography of the ocean floor. Later, sedimentation may alter the bottom shape by partly or completely burying this original topography.

Far from land the sedimentation rate in the ocean is very low, and the total accumulation of sediment is usually small. A thin layer of sediment is draped over the original topography but follows it closely. Under these conditions, the gravity-topography correlation is high. Since these conditions prevail in most of the deep ocean, the space bathymetry technique works well over most areas.

The sub-seafloor geology of continental margins can be quite complicated, with a heterogeneous mix of rock densities in complex shapes. Continental margins and nearby abyssal plains usually have thick sediments supplied to them by continental erosion. Significant gravity anomalies come from sub-seafloor geology in these areas, and consequently there is little correlation between gravity and seafloor topography.

This is actually not a problem, however, because bathymetric soundings are more common near land, and so there are enough sounding data to detect the lack of correlation. Then the bathymetry from space algorithm will correctly predict no seafloor topography over the length scales on which it operates, and this produces the correct result: the seafloor is essentially flat on continental margins and abyssal plains. Perhaps surprisingly, altimetric bathymetry also seems to correctly locate the 2500 m isobath midway up the continental slope (Monahan, this issue). Furthermore, the gravity anomalies in these uncorrelated areas are independently useful for exploring the sub-seafloor geology and its resource potential.

Geodetic Versus Oceanographic Altimetry

Applications of satellite altimeter data, and space missions or mission phases designed to furnish data for these applications, can be described as either "oceanographic" or "geodetic." Though both can employ the same space hardware, the two applications examine different signals, have different space and time sampling requirements, and different sensitivities to errors of various types. Bathymetry from space is a geodetic application.

If the wind ceased to blow and the currents ceased to flow, and the sun and moon vanished so there were no tides, then the ocean would come to rest in hydrostatic equilibrium on the solid Earth. In this situation, the ocean surface would lie on a gravitational equipotential surface called the "geoid." (In geodesy, "gravity" and its potential include both the Newtonian attraction and the centrifugal effect of a uniformly rotating Earth.) Mass redistribution associated with post-glacial rebound and climate change alters the geoid only at very long wavelengths and only at rates much less than 1 mm/yr. The geoid is essentially time-invariant on the length scales of concern in this paper. When the term was coined in the 19th century, geodesists imagined that the geoid was synonymous with "mean sea level." In fact the time-averaged "mean sea surface" is not quite on the geoid; the difference is due to the time-average of tidal deformations and dynamical displacements associated with the mean ocean circulation.

The gravity vector is perpendicular to the geoid; therefore deflections of the vertical at sea level are angles equal to geoid slopes (Figure 8). Because gravity

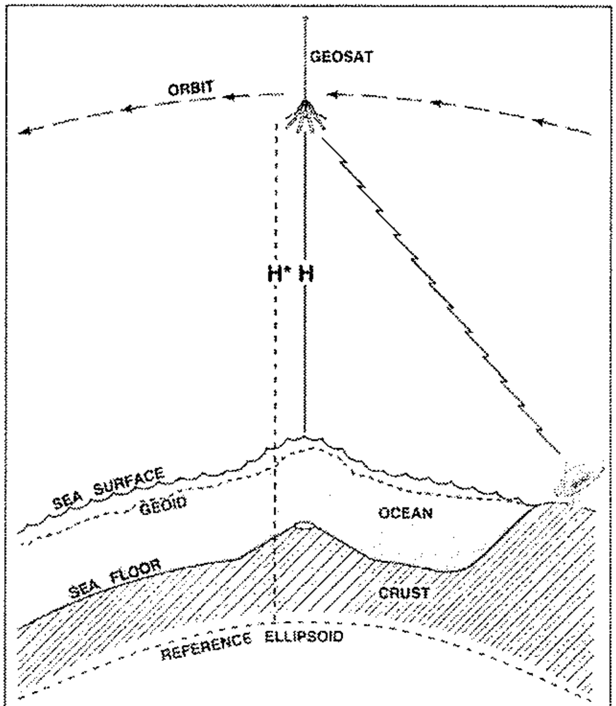

Figure 11. In satellite radar altimetry of the ocean surface, an Earth-orbiting spacecraft measures the distance between its antenna and the ocean surface, H, by precise timing of the round-trip of a radar pulse. The radar pulse samples enough ocean area to average out most of the effects of waves. The spacecraft's latitude, longitude, and height above a reference ellipsoid, H are determined by combining tracking data with a model of the forces on the satellite. The height difference H* minus H yields the height of the ocean surface above the ellipsoid. This surface is not quite on the "geoid," the equipotential surface of Earth's gravity field, due to various dynamical displacements. There are also errors in H and H* so that the altimeter data do not exactly yield the true sea surface height. However, all these effects are correlated over long enough distances that the local tilt of the surface as measured by the satellite is usually within 1 microradian of the slope of the geoid on bathymetric length scales, and hence the bathymetric gravity anomaly signal can be easily recovered in the presence of these error sources and oceanographic signals. Errors that might present a problem in other applications, like monitoring global sea level rise, are inconsequential to a geodetic altimeter mission like Bathymetry from Space.*

anomalies may induce deflections of the vertical from 1 to a few hundred microradians, the geoid may change by as much as a few meters vertically over 10 km horizontally.

The actual ocean surface departs from the geoid due to the dynamics of geostrophic flow and the ocean's response to tidal and meteorological forcing. In the open ocean in deep water, these departures are on the order of a few decimeters. Oceanographers want to observe a time series of these departures, and require an "exact repeat orbit" (Figure 6) that periodically revisits the same network of ground tracks and hence the same mean sea surface. The time series is only useful if all measurement errors and calibrations that might vary in time at the few centimeter level can be accounted for. Observing global sea-level rise requires stability in all the calibrations and error compensations at the mm/yr level; current research is investigating this possibility.

The altimetric measurement scheme is shown in Figure 11. Errors in the measurement are of three kinds. First, there is a random error due to ocean surface waves. Second, there is "orbit error" (error in H*) due to mis-modeling the spacecraft's trajectory. Third, there are errors in the range measurement, H. Some of these are accounted for by engineering calibrations, but there remain important "environmental corrections" for delay of the radar propagation by the ionosphere and troposphere. (Altimeters primarily use Ku-band radar that can "see" through clouds; the environmental problem is one of propagation speed, not attenuation.) The most accurate altimeters carry auxiliary instruments to measure these propagation delays *in situ*, with consequent increased complexity and expense of the mission. For geodetic and bathymetric purposes, these are not needed.

The altimetrically measured sea surface height is thus not the geoid height but rather the ocean surface height plus the measurement errors. Yet it happens that the slope of the measured height is almost exactly the slope of the geoid, and hence gives the vertical deflection and, in turn, the gravity anomaly and seafloor topography. This is because almost all the non-geoidal components of the height are of small amplitude (order of decimeters) and are correlated over long length scales (hundreds of km) and so have negligible slopes, well under one microradian.

There are some exceptions. The most energetic western boundary currents and their eddies produce dynamic signals of several decimeters with correlation scales of ~100 km (Jacobs et al., 2001) and so introduce an error of a few microradians. The tides can have significant slopes in shallow seas such as the North Sea, Yellow Sea, and Patagonian Shelf; however, tide models are usually good enough to remove most of this signal. In extreme cases in the Inter-Tropical Convergence Zone one may find water vapor delay gradients around 1 microradian.

To demonstrate that the slope of the altimetrically measured height profile is essentially the geoid slope, we use Exact Repeat Mission data from the U.S. Navy's Geosat. Geosat did an excellent job of mapping the marine gravity field despite the fact that it had no *in situ* measurement of ionosphere or troposphere delays. We did not apply any models for these delays to the data; however, we did subtract a modeled tide. We

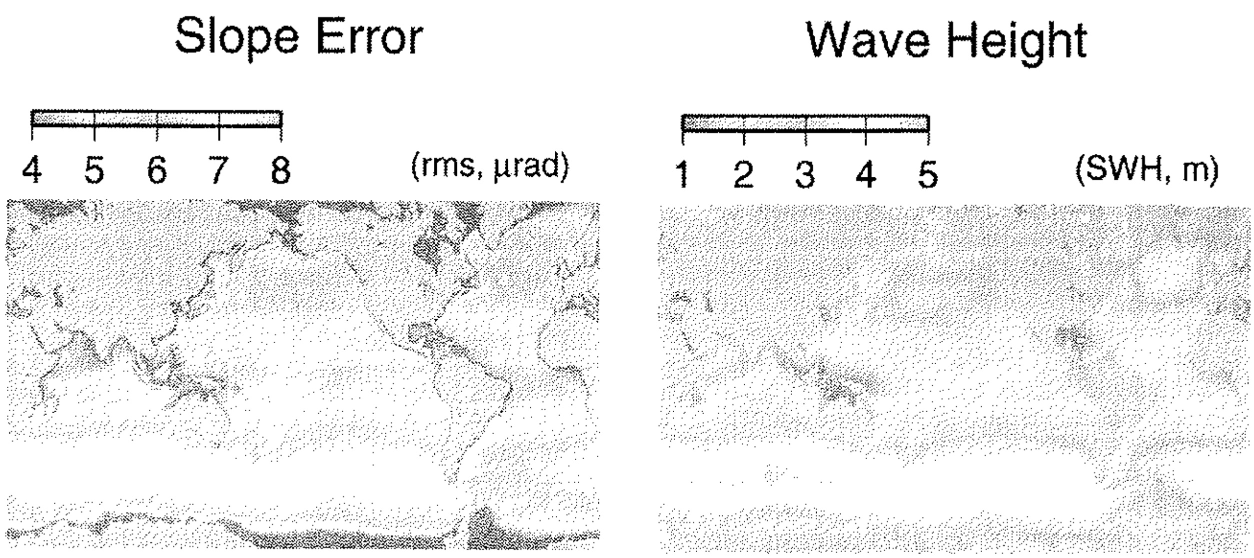

Figure 12. A map of the magnitude of the error in deflections of the vertical determined altimetrically (left) resembles a map of the average wave height (right). Just as significant, the error map pattern does not look like the map pattern expected for errors due to tides, ocean currents, or radar path delays in the ionosphere or troposphere. This confirms that the only important error source in geodetic altimetry is the random error induced by surface waves. A geodetic altimeter mission does not need expensive and complicated systems for measuring ionosphere or troposphere effects. Wave height data courtesy of P. D. Cotton (pers. comm.)

time-averaged all the repeat profiles along each repeated track, and then subtracted the average from each individual profile. The residual after subtraction is the height signal that cannot be repeated from one measurement to the next; this is the error plus the time-varying dynamical ocean signal.

The root-mean-square (rms) amplitude of the slope of this residual is shown in Figure 12. The geographical distribution of these errors does not resemble the expected pattern for errors due to water vapor, ionosphere delays, or the ocean circulation or tides. However, it does resemble the spatial pattern of the long-term average of wave height. This demonstrates that random errors in the altimeter measurement induced by waves are the dominant error source in geodetic altimetry. The slope error seen in Figure 12 in low wave height regimes is about 4 microradians. This level is to be expected, given that conventional altimeters orbit at about 7 km/s and have a random error of around 2 cm in a one-second averaged height in calm seas.

Prospects for Higher Resolution

Can bathymetry from space yield higher resolution in the future? The simple answer is yes! However, one must consider what limits the present resolution, what signal, if any, remains to be measured, and whether there is a technology to make the measurement.

The topography of the ocean floor at yet-to-be-resolved scales is made up of abyssal hills (see article by Goff et al. in this issue). These are self-affine (quasi-fractal) so that their amplitudes decrease with decreasing horizontal scale length. The sea-surface gravity signal of these hills diminishes even more rapidly due to upward continuation. It is probably impractical to attempt bathymetric estimation from sea surface gravity at scale lengths shorter than the mean depth of the ocean, or 4 km.

The self-affine nature of abyssal hills means that bottom slope and roughness statistics may be extrapolated to extremely small scales if the characteristic hill parameters can be resolved. Detailed modeling by Goff et al. (this issue) shows that the rms noise level in current altimetric gravity is about 4 mGal, and that these data allow extraction of hill parameters in only those areas where the bottom topography is particularly rough. They find that extraction of hill parameters typical of very smooth bottom would require a noise level around 1 mGal.

Other independent lines of evidence support the noise level estimates of Goff et al. (this issue). Slope error noise levels (Figure 12) and rms differences between altimetric gravity and ship gravity (Figure 7) confirm the 4 mGal estimate of the current noise floor. The expected noise level for state-of-the-art ship gravimetry is about 1 mGal and such data are correlated with ship bathymetry down to about 5-km scales.

This confirms that a lower noise level would allow altimetric gravity data to resolve smaller features.

These lines of evidence suggest that a new mission to optimize bathymetric resolution should achieve about a factor of four lower noise than at present, that is, 1 mGal of gravity noise, or on the order of 1 microradian of slope noise. In doing so, it would measure gravity as well as a ship can, and it would resolve bathymetry down to ~5 km scales (half-wavelength). Greater precision would not effect further resolution gain, as the signal rapidly becomes vanishingly small around this point, due to upward continuation. The spatial sampling characteristics of the mission would also have to support recovery of data at ~5 km scales.

Since the ERS-1 geodetic data have a higher noise level, wider track spacing, and a shorter mission duration than the Geosat geodetic data, the present 4 mGal noise level is determined mostly by Geosat. A new mission with a Geosat-quality altimeter could reduce the noise by a factor of four through averaging, but only with a 16-fold redundancy in data coverage. Because the new mission would need to have ground tracks spaced 5 km apart or closer, its orbit should not repeat for at least 18 months; to achieve 16-fold redundancy would mean a prohibitive 24-year-long mission. Thus improved resolution will have to employ a new technology. We consider here only radar technologies, as laser altimeters have a footprint much smaller than ocean waves and removing the wave height signal is a problem.

One new ocean altimeter technology in development is the Wide Swath Ocean Altimeter ("WSOA;" Rodriguez and Pollard, 2001; Fu, 2003). It is planned as an experimental payload on the successor satellite to the *Topex/Poseidon* and *Jason* series, expected to launch in late 2007 or 2008. That satellite will follow the same orbit as its predecessors, a 10-day exact repeat with 315 km between ground tracks at the equator. The WSOA will employ two antennae, each extending 3.5 m to either side of the spacecraft, and will operate the pair interferometrically as a real-aperture radar, to image a swath of area as much as 100 km on either side of the ground track. This instrument was designed to monitor temporal variability in ocean surface heights associated with the dynamics of mesoscale ocean currents. The designed data product will have a resolution of 15 to 25 km and will be given on a 15 km by 15 km grid of points within the swath. The error budget for these heights is ~5 cm, slightly worse than a conventional altimeter.

These specifications suggest that the WSOA cannot improve on existing geodetic altimetry, since the current resolution is already ~10 km. However, by designing a special processing of the WSOA interferometric signal, it may be possible to reduce the sample spacing in the "look direction," that is, along the line connecting the two outrigger antennae. Given a long-enough mission duration, one might achieve a higher resolution in the look direction of the time-averaged sea surface height.

Additional factors will also limit the WSOA's ability to measure geodetic signals. Even if the resolution in the look direction can be customized, there remains a limit of ~10 km resolution in the direction of flight due to averaging required in the space hardware. The swath will cover only 60% of the ocean at low latitudes, where most ocean area lies. Finally, there is the complication of "yaw steering." The spacecraft that carries the WSOA will be steered around its yaw axis to maintain good illumination of its solar panels, and consequently the WSOA's look direction will be steered as well. The look direction will be in the favorable direction, perpendicular to flight, only part of the time. (This problem applies only to the WSOA planned for the follow-on to the Jason mission. Some other satellite farther in the future could be designed to avoid a yaw steering problem.)

The other new ocean altimeter technology is the delay-Doppler altimeter ("DDA;" Raney, 1999). This instrument adapts some innovations of synthetic aperture radar and employs them in a nadir-looking instrument. Whereas conventional ocean radar altimeters pulse only fast enough to support incoherent processing, the DDA sends many more radar pulses and processes these coherently. It exploits Doppler shifts in the coherent reflections to slice the footprint into strips that are very narrow in the direction of flight (~250 m) and independent of any yaw of the spacecraft. This narrowing and slicing, when combined with the faster pulsing, yields several improvements over a conventional instrument that are ideal for a new bathymetry from space mission.

The European Space Agency's CryoSat mission, intended to launch late this year or in 2005, will carry a hybrid altimeter into polar orbit to measure the topography of Earth's polar ice caps and sea ice. It will use a high pulse rate near the poles for later DDA processing on the ground; it will not carry enough on-board computing power to do DDA processing in "real time." Over ice-free ocean water it will operate primarily as a conventional altimeter with a conventional pulse rate. Its data storage and telemetry capabilities will not permit it to operate in high-pulse-rate mode over the entire ocean, unfortunately. However, it may collect high-rate data during portions of a few selected orbits to support demonstration of the DDA technique over ocean water.

For geodetic purposes, the most important virtue of the DDA is that it is much less sensitive to random errors induced by ocean surface waves (Figure 12). On a flat, wave-free ocean, the random noise level in the DDA is about a factor of two less than that of a conventional altimeter. In both DDA and conventional instruments, the random noise level increases as the wave heights on the ocean surface increase, as in Figure 12, but with the DDA the rate of growth of this error is much slower than that of a conventional instrument. Thus the DDA would reduce the noise level most where the reduction is most needed.

Another virtue is better surface-following than a conventional instrument. If the DDA processing is done in real time by an on-board computer, then the surface-following algorithm (the "tracker") can exploit the narrow footprint slices to maintain "lock" on the ocean surface quite close to shore. Conventional instruments often suffer data losses near shore, particularly as the direction of flight leaves land and heads out to sea, when it can take the tracker a relatively long time to "find" the ocean surface and begin to follow it.

A DDA needs to transmit less power, so its electronics can be smaller and, for a given design life, cheaper than conventional hardware. Because the DDA is small and has low power requirements, and because a geodetic mission doesn't need auxiliary instruments to measure water vapor and ionosphere delays, a new space bathymetry mission could be small enough and light enough to use a Pegasus launch vehicle, among the least expensive of alternatives.

A design study for a mission of this kind ("ABYSS-Lite;" Raney et al., 2003) has been underwritten by NOAA. The mission employs on-board computing of Doppler processing to achieve all the benefits of a fully functional real-time DDA. The design considers the effects of wave height error and so conservatively assumes that the DDA performance will be only a factor of two better than Geosat. It uses a non-repeat orbit so that after 18 months, the ground track spacing is ~5 km. The noise level in the slopes so derived is so good that it should meet the NIMA-Air Force goal of 1 arc-second after only the first 18-month data collection cycle. However, the mission has a design life of six years, to furnish a four-fold redundancy. This will guard against losses and may permit the improvement of tide models in coastal areas; it also will allow averaging to remove some of the oceanographic error associated with western boundary currents. Averaging over the four-fold redundancy will cut the noise by a factor of two. This plus the two-times-better altimeter allows this low cost ($100M) mission to realize all the achievable resolution for bathymetry from space.

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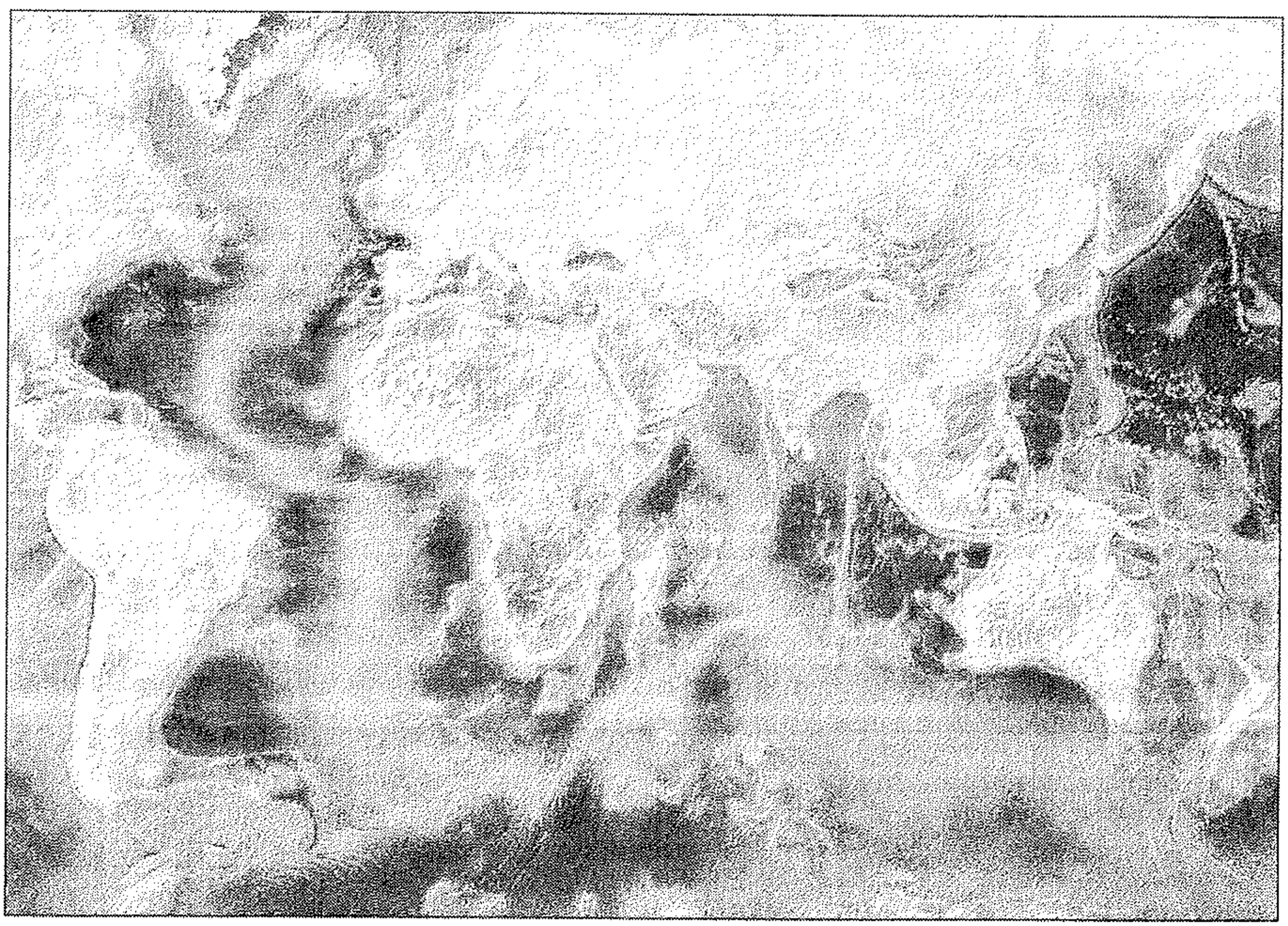

Endorsement of Global Ocean Mapping Project

Now that the surfaces of the Moon, Mars, Venus, the moons of the outer solar system, and the subaerial Earth have been mapped systematically at high spatial resolution, why not our own Earth's ocean floors?

Some 370 million km² of our planet, almost equal in area to two moons and two Mars-sized planets, are water-covered, and seafloor mapping efforts (for practical reasons, acoustic, sonar images, and topographic contours) have yielded only an irregular patchwork of disparate data, with large areas of remote seafloor remaining almost entirely unmapped.

An international, long-term Global Ocean Mapping Project (GOMaP) was considered and endorsed as important and technologically feasible at a recent meeting sponsored by the U.S. Naval Research Laboratory (NRL) with assistance from the Office of Naval Research (ONR).

Forty researchers and other ocean floor mapping experts from academia, government agencies, and private industry agreed that the technology was mature and the time was right—given the end of the Cold War, the good economy, and the pressing societal and research needs for greater knowledge of the oceans—for the world's nations to cooperate in launching GOMaP.

The workshop participants agreed that GOMaP was feasible with current marine technology and data handling capabilities and required only the necessary political will to undertake a project that would cost U.S. $10–20 billion and take several decades to complete.

Workshop speakers enumerated GOMAP's societal benefits, in addition to greatly increased basic geological knowledge, including the likelihood of many new discoveries. The assembled experts agreed that societal benefits would be important in "selling" the GOMaP concept.

Such benefits include improved assessments of seafloor and sub-bottom geologic resources, including methane hydrates; commercial and recreational fin and shellfish habitat mapping; geologic risk assessments (for example, submarine landslides, earthquake fault activity, tsunamis, and submarine volcanism); navigation hazards; and others. The workshop attendees agreed that GOMaP should have a strong educational and outreach component, providing opportunities for academic researchers, students, and science teachers to ride the research ships and share in the research process.

GOMaP could learn from NASA how to quickly disseminate information; for example, by putting new images on the Web and beaming real-time results into the world's classrooms.

The GOMaP meeting considered the Gulf of Mexico and the small Juan de Fuca tectonic plate—which lies off Oregon, Washington, and British Columbia—as the two leading candidates for "pilot" U.S. GOMaP areas. The Gulf of Mexico, rich in methane seeps, mass-wasting, and salt tectonics, would be a great locale for U.S. cooperation with Mexico and perhaps Cuba; while the Juan de Fuca plate, a good "microcosm" of the world's ocean-floor geologic settings, would be mapped by Canada and the United States.

Mapping this plate in detail as a part of GOMaP would optimize subsequent placement of seafloor sensors and observatories, and data interpretation and modeling, under the proposed "NEPTUNE" Project. Some workshop attendees also supported the idea of starting GOMaP in a very remote ocean area to maximize the harvest of new knowledge.

Mapping the deep ocean floor from surface ships is done with either hull-mounted or towed sonar arrays, which nowadays return both swaths of topographic seafloor contours and also swaths of acoustic backscatter imagery. Such ocean-floor data are analogues to what has been measured from spacecraft circling above dry planets and moons with scanning altimeters, imaging radars (the subaerial Earth and Venus), or digital "cameras" imaging in backscattered sunlight (Moon, Mars, etc.). However, GOMaP ships would simultaneously collect many other kinds of data as well; for example, the strength of the gravity and magnetic fields, seismic subbottom profiles, and meteorological, oceanographic, and biological observations. Any and all instruments or sensors could be "piggy-backed," providing their deployment does not compromise the basic seafloor mapping mission.

Time, Cost Estimates

GOMaP would take roughly 225 ship years for the 90% of the world ocean deeper than 500 m. If the U.S. University National Oceanographic Laboratory System (UNOLS) vessels or commercial vessels with similar costs are employed, it would cost about $25–$50 per square kilometer, or about $8–$16 billion to map our planet's whole deep-water ocean. Contributions of ship time by nations with lower labor costs, as well as economy of scale factors, would reduce this cost.

Workshop representatives of companies that survey fiber optic cable routes pointed out that GOMaP might utilize—on an opportunity basis, at favorable rates—otherwise idle ship time between commercially contracted surveys. Given the size of the seafloor mapping fleet and competing requirements for such large, deep-sea vessels, it might reasonably take 20–30 years to map the ocean floors beyond the 500-m depth contour. The relative advantages of towed and hull-mounted swath-mapping systems were debated at the workshop, with the majority agreeing with the experts that hull-mounted is the best way to go at present, primarily due to smaller positioning errors of data on the seafloor. However, towed systems were not written off, in view of possible future advances.

The GOMaP workshop participants also considered using deep-diving unmanned underwater vehicles (UUVs) to map the deep-ocean seafloor at much higher resolution than is possible from surface ship or surface-towed sonar systems. Most attendees agreed that the best use for such technology, which is still in the development stage, is for detailed follow-up investigations of interesting features discovered by the GOMaP project. However, if GOMaP looks like it will become a reality, UUV technology development would be accelerated, and it may be possible to field mother ships with small fleets of UUVs that return for data download and battery recharge at staggered intervals.

Mapping the shallowest 10% of the world ocean probably offers the greatest practical benefits to mankind but presents special technological and political problems. Over 500 ship years would be necessary to map the shallowest 10% of the oceans due to the progressive narrowing of data swath widths with decreasing water depth. However, smaller vessels with lower day-rates would be used to map the shallower seafloor, which mostly lies nearer to the coasts and supporting port facilities.

Moreover, GOMaP workshop attendees heard presentations of how the shallowest 50 m—at least those covered by relatively clear water—could also be mapped by aircraft using laser scanning bathymetry and hyperspectral imaging. About one-third of the ocean area is covered by Exclusive Economic Zones (EEZs), which extend seaward from the shores of coastal nations out to the edges of the continental shelves and beyond. Some of these coastal states may initially reject offers to help map their EEZs, although data and expertise would be shared at no charge and the mapping effort would not compromise national claims. Certain other areas may at least initially be kept off-limits to systematic surveying for reasons of military or political security.

The workshop attendees agreed that the coverage must be systematic and complete—that is, adjacent swaths of sidescan sonar and swath bathymetry must abut or overlap without any data gaps between the swaths. There was further agreement on the need for data quality control and quality assurance; at a minimum, a GOMaP cruise would need to collect data across a test area before heading out to its "survey box."

The GOMaP workshop ended before the issue of data standards had been worked out; however, attendees agreed to continue this discussion after the meeting adjourned. Data and survey standards, once adopted, will determine which, if any, ocean areas have already been mapped to the required standards.

GOMaP workshop attendees represented a number of universities and two cable-route surveying companies. Included were representatives from the Naval Research Laboratory, U.S. Geological Survey, National Oceanic and Atmospheric Administration, National Imagery and Mapping Agency, NASA's Jet Propulsion Laboratory, Naval Oceanographic Office, Office of Naval Research, Naval Meteorology and Oceanography Command, and the Oceanographer of the Navy.

The National Science Foundation representative could not attend but did submit a statement.

In addition to the U.S. attendees, two scientists from Canada and one from the United Kingdom participated. All workshop attendees endorsed the GOMaP concept and promised to "spread the gospel." Speakers agreed to contribute to a white paper in the months following the workshop and to help plan for an international, open-to-all symposium to further develop the GOMaP concept into a plan of action to be submitted to government leaders.

The Global Ocean Mapping Project workshop was held in Bay St. Louis, Mississippi, June 12–14, 2000.

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Conclusions: Benefits, lessons learned, and future challenges of marine spatial planning

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ABSTRACT

This article summarizes briefly the principal conclusions from papers presented in this special issue on marine spatial planning. It identifies potential economic, ecological, and administrative benefits (and costs) that might be realized from the implementation of MSP. Finally, the article summarize lessons learned and identifies future challenges and directions for MSP, including the development of international guidelines for its implementation.

"An invasion of armies can be resisted, but not an idea whose time has come."

Histoire d'un crime, 1852[1]
Victor Hugo (1802–1885)

"Let our advance worrying become advance thinking and planning"

Winston Churchill (1874–1965)

0. Introduction

Marine spatial planning (MSP) is an evolving idea, and one whose time has come. The place-based character of ecosystems, the spatial and temporal development of human activities and resource use conflicts (both current and potential) within them, together with the need to develop human uses in places that minimize their impacts on important natural places of the marine environment, all draw attention to the need to manage marine areas from a spatial and temporal perspective.

Spatial planning is an essential tool for managing the development and use of the terrestrial environment in many parts of the world. In North America and Europe, for example, it is commonly used as a central component of economic development and environmental planning. The principal purpose of spatial planning on land is to regulate development and land use in the public interest. Over the past century, the traditional approach of making individual permit decisions on a project-by-project, case-by-case basis—and the unplanned outcome of this approach—has been replaced by a more strategic planning process that lays out a vision—or comprehensive plan—that can guide individual sectoral planning and permitting. This approach has become the standard for terrestrial land-use planning and management.

We are now at a stage where ecosystem-based management, its place-based character, and the important role of marine spatial management to help implement it, has become generally accepted in many places. What is missing, however, is a clear demonstration of how it can be implemented. The time has come for clear, concrete, and comprehensive guidelines that outline—in a practical manner—the steps that need to be taken to implement ecosystem-based, sea use management in marine areas. This special issue is a step in that direction.

Only a few clearly articulated spatial visions for the human use of marine areas exist (see the article of Douvere in this issue). This situation does not mean that human activities taking place in marine areas are unregulated. On the contrary, they have been regulated in a number of different ways, but most importantly, they have been regulated incrementally and predominantly within sectors, such as shipping and ports, fisheries, or dredging. Little effort has made to anticipate conflicts; even less has been done to evaluate cumulative effects. Currently, there are few frameworks that facilitate integrated strategic planning across all activities within specific marine areas.

1. Conclusions

Some of the principal conclusions of this special issue on MSP are as follows:

(a) Sea use management is a continuous, iterative, adaptive, and participatory process, comprising a set of functions including research, analysis and planning (including MSP), financing, implementation, monitoring, and evaluation—all of these individual functions must be carried out for the management to be successful, i.e., to achieve specified objectives (see the

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[1] Special thanks to Elliott Norse for this inspirational quotation from Victor Hugo.

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articles of Douvere, Gilliland, and Laffoley, and Day in this issue).

(b) MSP is an important function of ecosystem-based sea use management. MSP can be used to identify biologically and ecologically sensitive areas of marine places in time and space, to identify existing and potential human uses of marine places, and to evaluate the cumulative effects of human activities on marine ecosystems. It can be used to influence the location in space and time of human activities and therefore encourage compatible uses, reduce conflicts among uses, and reduce conflicts between human uses and the environment (see the article of Gilliland and Laffoley in this issue).

(c) However, MSP is only one part of the tool box for ecosystem-based, sea use management—plans for sea use management should include a mix of many management measures including input, process, and output measures that can be used to influence the *performance* of human activities (see the article of Douvere in this issue).

(d) The management boundaries of the marine area often may not coincide with the boundaries of a single ecosystem, because typically a number of ecosystems of varying sizes exist within, and may extend beyond, the designated management area. The management boundaries may or may not coincide with the boundaries of regional, national, or local governments that have jurisdiction and powers of implementation. Finally, the boundaries are not likely to delimit the external influences of natural processes on the designated area, such as upwelling, sediment transport, and atmospheric deposition of contaminants. Thus, the boundaries for MSP often will not (and do not have to) coincide with the boundaries for management (see the article of Gilliland and Laffoley in this issue).

(e) Different marine places have differing values—and sensitivities—in both biophysical and human dimensions. Some ecosystems are more resistant or resilient to disturbance than others. As long as the productive capacity and resilience of marine ecosystems are left intact, marine areas can be managed for human uses that do not harm ecosystem functions (see the article of Crowder and Norse).

(f) Early and continuing engagement of stakeholders in a clear management process is critical to the long-term success and engenders trust and ownership of the process. People are at the heart of MSP and both the setting of objectives and the selection of management measures are ultimately a matter of societal choice. Stakeholder participation is not enough; stakeholders must be empowered to participate effectively throughout the MSP process (see the article of Pomeroy and Douvere in this issue).

(g) Integrating the human dimension into MSP requires the same diversity of disciplines/perspectives as does the ecosystem approach relative to the biophysical environment. Coastal communities increasingly recognize that they need to make themselves visible, i.e., to put themselves on the map, if they are to play an active and effective role in MSP (see the article of St. Martin & Hall-Arber in this issue).

(h) Monitoring, reporting, and evaluation are critical functions that allow MSP to adapt to changing conditions. The real value of evaluation is the extent to which its findings and recommendations feed back and improve management plans and decisions (see the article of Day in this issue).

2. What are the benefits of MSP?

Hard evidence of the benefits of MSP is relatively limited, given its early stage of evolution and the lack of rigorous evaluation of practical experience. However, quantitative evidence of the benefits of MSP is likely to appear in the next few years as new MSP plans are developed and implemented (see Gilliland and Laffoley, Table 1, in this issue for further discussion of benefits). While some of the benefits may be seen quickly, e.g., avoidance of use conflicts such as between new and existing uses through planning, many of the benefits may not be achieved for a decade or more (see the article of Plasman in this issue). Some of the anticipated benefits of MSP include the following:

(a) Economic benefits
- Identification of compatible uses and areas for development; integration of information on the current uses of the marine environment and key marine features across different sectors so that developers can be aware of potentially conflicting uses in selecting their proposed sites.
- Reduction of conflicts among uses and between uses and the environment.
- Consideration of the requirements of developers across a range of sectors for marine space to be considered at the same time so that potential conflicts can be identified and addressed at an early stage before significant capital has been invested.
- Provision of greater certainty for long-term investment decisions.

(b) Ecological benefits
- Management focuses on the whole marine ecosystem rather than individual sites for development or protection.
- Support for an ecosystem approach by seeking to ensure that economic and social objectives respect environmental limits.
- Identification and establishment of areas of biological or ecological importance or sensitivity, and reduction of risk of conflict with human activities.
- Opportunity for biodiversity commitments to be at heart of MSP and management.
- Allocation of space for biodiversity and nature conservation.
- Provision of a context for a representative network of marine protected areas.

(c) Administrative benefits
- Improvement in the speed, quality, accountability, and transparency of decision-making and better regulation.
- Improvement and reduction of the cost of information collection, storage, and retrieval.
- Opportunity to assess a combination of multiple objectives and balance benefits and costs of management measures in a particular marine area.
- Evolution of the management approach for marine areas from regulation and control to planning and implementation.
- Provision of a focus for stakeholder involvement.
- Potential improvement in the quality and availability of information for scoping and environmental assessments, including information with which to evaluate cumulative effects.

Costs will also be incurred in the development, implementation, monitoring, and enforcement of marine spatial plans. Certain human activities could be denied access to some areas of sea, but international agreements such as the United Nations Convention on the Law of the Sea (UNCLOS) provide common access rights and must be respected (see the article of Maes in this issue). If international co-operation is needed to develop an MSP strategy, it could take a long time to implement any plans. If the plans are too complex, both the business and the government will not support their implementation over time.

3. What have we learned from MSP practice so far?

MSP can only be successful if most, if not all of, the following factors are present:

(a) Legal authority and political support for MSP are important factors for success. Ideally, MSP should be implemented as a statutory, enforceable process, rather than a non-binding one. Experience with integrated coastal management, especially in Western Europe where it has been developed on a voluntary, non-binding basis, has shown the limitations of this approach. While a statutory basis may not be possible when MSP is initiated, it should be a goal toward which planning should work (see the article of Plasman in this issue).
(b) A sound information base, comprising both natural and social science information, is critical (see the articles of Crowder and Norse and St. Martin and Hall-Arber in this issue).
(c) MSP objectives should be clear and measurable (see the articles of Gilliland and Laffoley and Day).
(d) Stakeholder involvement should be early and often in the MSP process. It needs to be conducted in a manner that is sustainable over time (see the articles of Pomeroy and Douvere in this issue).
(e) MSP should consider explicitly plans and objectives of other sectors of the economy, e.g., energy and transportation, in terms of the time pattern of proposed, and in progress, capital investments and operations and maintenance expenditures. Activities in other sectors may have major implications for the marine sector, and vice versa.
(f) MSP should be integrated with plans for adjoining coastal areas, with terrestrial land-use plans, and with coastal watershed (catchment) plans (see the article of Gilliland and Laffoley).

4. Where do we want to go?

> "Knowing is not enough; We must apply. Willing is not enough; We must do."
>
> Johann Wolfgang von Goethe (1749–1832)

Some of the basic problems that must be addressed if ecosystem-based, marine spatial management is to continue to evolve from concept to implementation include the following:

(a) Define the purpose of MSP more clearly

> "Would you tell me, please, which way I ought to go from here?" "That depends a good deal on where you want to get to," said the Cat. "I don't much care where." said Alice. "Then it doesn't matter which way you go," said the Cat
>
> Alice's Adventures in Wonderland, 1865
> Lewis Carroll (1832–1898)

The concepts of MSP now included in many policy documents and plans are open to very diverse interpretations about meaning and direction. Concepts and terminology should be more commonly understood and consistent. Despite academic discussions and the fact that some countries already have started implementation, the scope of MSP has not been clearly defined. Terms such as integrated management, marine spatial management, and ocean zoning are often used inconsistently. This situation is one of the reasons why its importance is not more seriously reflected at the levels of policy and decision-making in most countries.

(b) Make the MSP knowledge base more certain: The ability to predict ecosystem behavior is limited. The knowledge about states, processes, and outcomes regarding ecosystem impacts is, and will continue to be very uncertain. Existing knowledge about the interdependence of marine ecosystems is insufficient or cannot be generalized. Limited resources for applied research should be directed toward reducing the uncertainty of management decisions related to the effects on both natural and social systems (see the articles of Crowder and Norse and St. Martin and Hall-Arber in this issue).

(c) Ensure that MSP practice is adaptive: Because of the uncertainty inherent in MSP, as well as the dynamic nature of marine and human ecosystems, management must be adaptive over time. Adaptive management is learning by doing. MSP and management should be seen as an experiment within which we can learn something about how human activities affect ecosystem structure and processes. In this way, we can learn how we can plan and manage human activities within marine places better over time.

(d) Build on the good work of MSP "pioneers"

> "The perfect is the enemy of the good." (*Le mieux est l'ennemi du bien).*
>
> La Bégueule, 1772
>
> Voltaire (François-Marie Arouet, 1694–1778)

When the US Congress established Yellowstone National Park in 1872, hunting and fishing were still allowed within the park boundaries. Hunting was banned in 1883; recreational fishing was banned in 1917—35 years after the park was established. The Great Barrier Reef Marine Park Authority took 13 years to develop and implement its first zoning plan. Often we criticize these early efforts because they are not as comprehensive or integrated as we would like them to be. Early "pioneers" in MSP may not get it quite right either on the first try, but they are establishing precedents and processes that can and should be built upon in the future.

(e) Develop methods to make existing knowledge relevant to marine spatial management: Ecosystems have real thresholds and limits which, when exceeded, can effect major system restructuring. Once thresholds and limits have been exceeded, changes can be irreversible. Specifically, management objectives and associated criteria and reference points need to be developed further. Similarly, methods for incorporating the diverse, dynamic, and multi-scalar social landscape into MSP will require new methods and data collection efforts that document "at-sea" locations, interests, and dependencies of specific communities and groups of stakeholders.

(f) Apply MSP principles and practice to the High Seas: The existing fragmented and piecemeal nature of existing management measures, combined with increasing pressures of human activities in the High Seas, suggests a growing need for international institutional arrangements to better coordinate MSP in the High Seas (see the article of Ardron et al. in this issue).

(g) Develop guidelines for ecosystem-based marine spatial management: The time has come to move beyond the conceptual level and develop a comprehensive, operational manual of principles and guidelines that outlines the steps to implement marine spatial management. As a result of the first International Marine Spatial Planning Workshop held at UNESCO in November 2006, the Gordon and Betty Moore Foundation and the David and Lucille Packard Foundations have provided funds to UNESCO to develop such international guidelines. To achieve this objective, a manual of principles and guidelines for marine managers will be developed that lays out a step-by-step procedure for the implementation of ecosystem-based, marine spatial management. The following activities are included in the project:

- Surveying, analyzing, and documenting the lessons learned from international case studies of good practice on ecosystem-based, marine spatial management.
- Creation of an international expert group of contributors and advisors (i.e., experts in the functions of ecosystem-based, marine spatial management) to help develop the principles and guidelines.
- Evaluation, clarification, and adaptation of the general principles and guidelines to two region-specific contexts.
- Revision and distribution of the final manual of principles and guidelines.
- Development of an international reference website for communications and outreach for ecosystem-based, marine spatial management.

The guidelines will be available by the summer of 2009.

Integrated Marine Spatial Planning in U.S. Waters: The Path Forward

by Morgan Gopnik

for the Marine Conservation Initiative
of the Gordon and Betty Moore Foundation

October 2008

Contents

SUMMARY

This paper, prepared for the Gordon and Betty Moore Foundation's Marine Conservation Initiative, explores the concept of integrated marine spatial planning (i-MSP) as a technique for managing diverse ocean uses in a comprehensive and sustainable way. The paper is based on a review of relevant, recent literature (on i-MSP and similar concepts and on land use planning and public lands management), discussions with a wide range of ocean stakeholders and thirty confidential hour-long interviews conducted with ocean managers, ocean user representatives, and conservation experts.

The strengths and weaknesses of i-MSP are examined, both in theory and as practiced in a handful of places around the world. The paper then looks at a century of U.S. experience with urban land-use planning and public lands management to see what has been learned about reconciling economic development, social well-being, and ecosystem conservation on land and draw lessons that might be applicable to ocean management. Several options for implementing i-MSP in U.S. waters are analyzed, with comments about their merits and drawbacks.

The author concludes that marine spatial planning is a promising approach for achieving improved economic and environmental results when compared to existing ocean management. Suggestions are made for advancing i-MSP in the U.S. through legislative, regulatory, and executive channels at state and federal levels. Experience on land indicates that managers will need to create open and inclusive planning processes to ensure acceptance of the resulting plans.

To bring a broad range of perspectives to the table and forge consensus, advocates of i-MSP will need to educate ocean stakeholders about the concept of marine planning, inform them about experiences in U.S. state waters and countries around the world, and show them how i-MSP can help them achieve their ocean objectives while minimizing conflicts with other ocean users.

I. Background

A. Introduction to Integrated Marine Spatial Planning (i-MSP)

For centuries, people thought of the ocean as a vast and somewhat mysterious expanse. As governments began to focus on its riches in the last century, they looked to the ocean as an exciting new frontier for harvesting food, extracting mineral and energy resources, and promoting other forms of economic development. Ocean resource managers were tasked with encouraging and guiding this development. Then, over roughly the last two decades, hundreds of academic studies, a barrage of media accounts, and two high-level Commission reports documented disturbing declines in ocean health and in the ability of oceans to provide critical "ecosystem services," such as storm protection, freshwater regulation, waste processing, and more (Field et al, 2002; Pauly, 1998; Worm et al, 2006; Millennium Ecosystem Assessment, 2005; Pew Oceans Commission, 2003; U.S. Commission on Ocean Policy, 2004). These reports also diagnosed many of the causes for these declines: the direct impacts of economic activities on land and at sea (such as intense coastal development, unsustainable resource extraction, crowded and conflicting ocean uses, pollution, changes in ocean temperature and chemistry, etc.) as well as failures of the ocean management system itself (including uncoordinated and sector-based management, limited understanding of ecosystem functioning, too many disconnected laws and agencies, etc.). The phenomenon of global climate change has added a whole new level of concern about potential human impacts on ocean ecosystems.

The solution commonly proposed by those who have studied these problems is to adopt a more integrated, systems approach, as embodied in the concepts of Integrated Coastal Zone Management (ICZM), a term coined in 1992 during the Earth Summit in Rio de Janeiro, and later Ecosystem-Based Management (EBM). Unfortunately there is continued confusion about what constitutes "true" EBM and how to translate it into management actions in ocean waters. One recent study (Arkema et al, 2006) distilled 18 different scientific definitions of EBM into a common set of distinguishing features. The authors then analyzed recent management plans at a number of ocean and coastal sites and found that the objectives being pursued were only loosely tied to the important features of EBM. Clearly there is much work to be done in translating integrative concepts into practice.

While this discussion continues, population growth and engineering advances are leading to increased demands on ocean space. Rising energy prices and concerns about climate change have led to a recent surge in proposals to develop renewable energy sources offshore; declining populations of fish and seafood species have spurred the development of large-scale ocean aquaculture; storm impacts, exacerbated by rising sea-level, create a demand for new sources of sand to replenish beaches. We are on the brink of a more crowded ocean and actions over the next few years will determine how well that growth is managed. A small but expanding community of academics and practitioners has been developing the concept of comprehensive, spatially-explicit ocean and coastal management as a practical way to implement integrated management, or EBM, and to plan proactively for the 21st century ocean.

Conveying complex concepts in accessible, consistent terminology has been a challenge in coalescing this growing movement. Box 1 describes some of the different terms that have been adopted over time, with an attempt to parse the nuances in their meaning and use. Preliminary market research sponsored by SeaWeb has attempted to determine which terms resonate most effectively with the public, but the results have so far been inconclusive. In this paper, the term integrated marine spatial planning (i-MSP) is used because it stresses three critical attributes: *integration* of all potential ocean uses, including conservation; *spatial* allocation for activities within a defined area; and the need to engage managers and interested stakeholders in a forward-looking *planning* exercise to guide subsequent actions. But i-MSP does not end with a plan--the subsequent phases of implementation, management, and monitoring must also be part of any i-MSP effort.

B. Purpose of this report

The Gordon & Betty Moore Foundation's (GBMF) Marine Conservation Initiative aims to "establish resilient and productive coastal marine ecosystems, managed sustainably for current and future generations, using comprehensive area-based management and improved fisheries management ..." Over the last few years, GBMF staff have explored the issue of area-based management through the academic literature and by speaking with its practitioners, resulting in multi-year investments to advance this topic. These grants have supported implementation efforts at state and regional levels in North America as well as research and policy development. The purpose of this report is to assist GBMF staff in better understanding the theory, practice, and future of i-MSP and to suggest ways that GBMF might be able to further advance this ocean management strategy throughout U.S. waters.

The Moore Foundation specifically asked that this study: "…examin[e] the potential benefits and drawbacks of using area-based management (ABM), and specifically ocean zoning, as a tool to protect and restore resilient and productive marine ecosystems while increasing user certainty and reducing conflicts. The [paper] will identify key opportunities and obstacles in implementing ABM in the United States, drawing on case studies and lessons learned in the U.S., Canada, and other countries. The […] paper will not only articulate the concept of ABM, but move to the next level by providing concrete evidence that demonstrates whether, and if so in what ways, this management structure is preferable and how it might be implemented in the United States."

Box 1 **What to Call It?**

There is a growing consensus that we must find a way to overcome the historically uncoordinated, sector-based system of ocean and coastal management, an approach that has allowed continued degradation of the oceans and disruption of ecosystem services. Deciding how to accomplish that, and what exactly to call the new approach, has been a challenge. Below are a number of concepts and terms that have been introduced, with some hints at the nuances in their meanings and use.

Integrated Coastal Zone Management (ICZM)
Coined during the 1992 Earth Summit in Rio de Janeiro, ICZM describes an adaptive, integrated approach for achieving sustainable resource management in coastal areas (UNCED, 1993). The European Commission (EC) describes ICZM as a dynamic, multi-disciplinary and iterative process to promote sustainable management of coastal zones that seeks to balance economic development and use of the coastal region, protection and preservation of coastal areas, minimization of loss of human life and property, and public access to the coastal zone (Recommendation 413/2002/EC of the European Parliament and Council). The EC encourages all its member states to practice ICZM.

Ecosystem-Based Management (EBM)
EBM aims to protect ecosystem structure, functioning, and processes; recognize the inter-connectedness within and among systems; integrate ecological, social, economic, and institutional perspectives; and be place-based or area-based (from McLeod et al, 2005). Some authors refer more generically to ecosystem *approaches* to management or more narrowly to specific applications such as ecosystem-based *fisheries* management, but neither of these captures the full value of EBM. The term is widely embraced in the scientific community and many people believe EBM is practical and sufficiently well-defined to be implemented now (Murawski, 2007). Others complain that it is too vague to help managers carry out their day-to-day responsibilities and not readily understood by the public.

Regional Ocean Governance
The concept of Regional Ocean Governance was embraced by both recent ocean commissions. As described on the Joint Ocean Commission Initiative website, “regional ocean governance refers to a governance mechanism established by a coalition of state governments, with participation by the federal government, to address ocean and coastal issues that cross political boundaries. While state and federal governments need to play a strong leadership role, regional ocean governance initiatives must engage participation by the full spectrum of governmental and nongovernmental stakeholders in the region.” (www.jointoceancommission.org) Regional governance embraces the principles of EBM, but focuses on the importance of cooperation between adjacent states and corresponding federal authorities to bring it about.

Marine Spatial Planning (MSP)
MSP is a process for analyzing and allocating ocean space for multiple uses in order to achieve specified ecological, economic, and social objectives (IOC, 2007). A stakeholder-driven MSP process results in a comprehensive plan for a marine region. Advocates of MSP, a term widely adopted in Europe, see it as a real-world solution that embodies the principles of EBM. Some scientists think MSP fails to capture the full complexity of true EBM, while some U.S. coastal managers have expressed concern that the term implies some form of centralized control. Unfortunately, this concept’s significance has been diluted by those who use the term to describe any form of spatial management, even when it is focused on a single sector. (For example, papers about siting MPA networks and creating closed areas for fishing were included in a recent conference session on marine spatial planning.)

Integrated Maritime Spatial Planning
A term officially adopted by the European Union in its Blue Book on Maritime Policy (Commission of the European Communities, 2007), it combines Marine Spatial Planning with the older concept of Integrated Coastal Zone Management to deliver a spatial planning approach that includes onshore, nearshore, and offshore areas.

Ocean Zoning
Similar to the distinction on land between comprehensive planning and zoning, ocean zoning takes a marine spatial plan to the next step by creating a zoning map for a marine region, with areas allocated for different uses and corresponding regulations for each use or area. For many years, advocates in the U.S. have been warned to avoid “the Z word,” on the premise that some people would associate it with top-down, bureaucratic, centralized planning. Although some managers repeated this fear in interviews for this report, others thought the public held generally positive views about the value of planning and zoning based on their local, land-based experiences.

Area-Based Management (ABM), Integrated Management (IM), Integrated Multiple Use Ocean Management (IMUOM), Integrated Marine Spatial Planning (i-MSP)
This is just a sampling of alternate coinages, in use in different regions or by different writers. These terms generally incorporate some combination of MSP and OZ, with the goal of achieving EBM. The proliferation of terms is evidence of the ongoing effort to find more descriptive and accessible language for a powerful new concept.

C. Methodology

This paper is based on two types of research: an extensive review of relevant, recent literature (on i-MSP and similar concepts, and on land use planning and public lands management; see Bibliography) and a series of confidential, one-on-one interviews, conducted in-person or by telephone, with a selection of ocean stakeholders including academics, NGOs, state and federal managers, and representatives of the major ocean industry sectors. Each interview lasted approximately one hour and drew from a common set of questions. Because the interviewees were so varied, with very different backgrounds and levels of familiarity with ocean policy, a strict script was not used. Rather, the conversation was allowed to flow naturally while covering as many core questions as possible.

II. The Strengths and Weaknesses of i-MSP

A. What is i-MSP all about?

Historically, people viewed the ocean as a vast expanse that could supply human needs, absorb human wastes, and accommodate human uses without limits. It was treated as a classic commons, with little, if any, centralized control. Gradually, coastal nations exerted increased sovereignty over ocean areas, mainly to assert ownership of resources and to oversee the primary activities of fishing, navigation, and military use. Over the last century, the kinds of activities taking place in ocean waters, and resultant claims on ocean space, have exploded (see Boxes 2 and 3).

In a series of interviews conducted by the Marine Conservation Biology Institute (MCBI) in 2006, federal agency staff reported significant conflicts between ocean users and foresaw more conflicts arising due to continued migration toward the coasts and new technologies. In my interviews, as in MCBI's, spatial conflicts were perceived as being particularly keen among ocean energy, aquaculture, and fishing, and between all of these and the designation of marine protected areas (MPAs). More subtly, marine scientists are beginning to realize that uncontrolled ocean uses also conflict with the ocean's ability to supply certain irreplaceable "ecosystem services" such as storm protection, freshwater regulation, waste processing, flood control, nutrient cycling, erosion control, climate regulation, and disease control.

Box 2 **Common Uses of Ocean Space**

Commercial fishing
Aquaculture
Shipping
Oil & gas production
Renewable energy production (e.g., wind, waves, thermal)
Sand and gravel mining
Dredging and dredged material disposal
Artificial islands for offshore use
Pipelines, cables, transmission lines
Bio-prospecting (for pharmaceuticals and other applications)
Water supply through desalinization
Military training and deployment
Recreational fishing
Shore based recreation
Recreational boating and cruise ships
Scientific research
Ocean observations (for research and applications)
Ecosystem conservation (through MPAs and reserves)
Cultural and historic preservation (e.g., shipwrecks and other submerged artifacts)

(adapted from Visions for a Sea Change, 2007)

As each new activity developed, some system of oversight was put in place, although the tenor of that oversight—from fairly strict controls to explicit cheerleading—has varied between uses and over time. The last fifty years have seen a shift from U.S. policies that actively promoted resource use (see the report of the Commission on Marine Science, Engineering and Resources, 1969) toward a focus on environmental protection and long-term sustainability (U.S. Commission on Ocean Policy, 2004). The end result of this evolution in ocean management is a tangle of uncoordinated, inconsistent laws overseen by dozens of different government agencies with conflicting mandates. The fundamental recommendation from both recent ocean commissions was for more efficient, integrated, ecosystem-based management of the nation's ocean space.

A number of proposals have been made for achieving this integration. The Joint Ocean Commission Initiative (JOCI), which includes members of the recent Pew Oceans Commission and U.S. Commission on Ocean Policy, is advancing the creation of broadly constituted, multi-stakeholder, multi-issue Regional Ocean Councils. A number of environmental NGOs are promoting new federal legislation (introduced to Congress in 2007 and 2008 as HR21) which would enshrine the concept of ecosystem-based management as national policy. But an eclectic mix of academics, managers, and politicians around the world have been exploring the possibilities of pursuing i-MSP, including explicit ocean zoning, as a concrete, practical way to coordinate expanding ocean activities.

Specifically, the purposes of i-MSP are:

- to provide a strategic, integrated and forward-looking framework for all uses of the ocean to help achieve sustainable development, taking into account environmental, social, and economic objectives;
- to apply an ecosystem approach to the regulation and management of activities in the marine environment that safeguards ecological processes and overall resilience to ensure the environment has the capacity to provide and support social and economic benefits;
- to allocate space in a rational manner which achieves stated objectives, avoids or minimizes conflicts and, where possible, maximizes synergy between sectors;
- to identify, safeguard, recover or restore important components of coastal and marine ecosystems including natural heritage and nature conservation resources. (adapted from English Nature, 2006)

The practice of i-MSP involves analyzing the physical and ecological attributes and the human uses within a defined marine region and then allocating space to different uses in a way that achieves agreed upon ecological, economic, and social objectives. Similar to the practice of land use planning, i-MSP typically results in a comprehensive plan for an ocean region that can then be implemented by creating a zoning map, issuing regulations for each zone and activity, and ensuring a system of monitoring and enforcement (IOC, 2007).

Box 3 Two Rapidly Expanding Ocean Industries: Renewable Energy and Aquaculture

Interest in i-MSP has accelerated over the last few years, due in part to the arrival of new members of the ocean family vying for space. Two of the most visible, and potentially valuable, new participants are discussed below.

(a) Ocean-based Renewable Energy

Background The ever-moving oceans, and the winds above them, represent huge reservoirs of energy. In recent years, engineers have discovered innovative ways to extract this energy via increasingly efficient and robust technologies. One industry enthusiast estimated that the power that could be extracted from the Gulf Stream off Florida's coast alone would be sufficient to supply all of that state's energy needs. At the same time, global climate change and rising oil prices have increased the urgency of finding new, carbon-free energy sources. The result is a surge of interest in ocean energy projects.

So far, three federal agencies have some role in the development of this new energy source: (1) Congress granted the Minerals Management Service (MMS) authority to regulate renewables on the Outer Continental Shelf (outside state waters, typically beyond 3 miles from shore), building on that agency's historic oversight of offshore oil and gas; (2) the Federal Energy Regulatory Commission (FERC) has asserted authority over wave and tidal energy in the Territorial Sea (i.e., within 12 miles from the shore) as an extension of their responsibility to regulate hydrokinetic energy projects (hydropower dams) on land; and (3) the Department of Energy (DOE), after a long hiatus, is investing new money in technology development and assessment for ocean-based renewables. (Note that there is a troublesome overlap in the MMS and FERC programs, namely authority over wave power in the area from 3 – 12 miles from shore.) Within state waters, many additional agencies may have roles to play.

Issues Virtually everyone seems to agree that safe, ecologically sensitive expansion of offshore renewable energy would be a good thing for the economy, the global environment, and perhaps even national security. But there are a number of challenges to overcome. The technical challenges involved in constructing and maintaining large, moving structures in the harsh, salty ocean environment are well-defined and probably surmountable—the industry, with support from DOE, is making excellent progress. Local environmental and aesthetic concerns will obviously need to be addressed. But administrative and management uncertainties may prove to be some of the trickiest problems to resolve.

In different ways, both MMS and FERC are having a hard time breaking out of their historical roles and perspectives. MMS is basing its program to a large extent on the one it created for offshore oil and gas. But the renewables industry is not nearly as experienced, well-financed, well-understood, or mature as oil and gas. They may need different approaches, with more built-in adaptability, to get started. Meanwhile FERC is treating ocean wave devices as analogs to hydropower dams since both harness the power of moving water. But the technologies involved, and the settings in which they operate, actually have little in common. (The interviews revealed widespread complaints about FERC's approach being "premature," "confusing," not transparent or inclusive, "inflexible," and was told that "FERC doesn't seem to understand the concept of coastal planning and management" or to accept the preeminent role of states in coastal waters. Fewer complaints were leveled at MMS, but their draft regulations had not yet been issued so people may have been reserving judgment.)

Furthermore, although both agencies understand the need to assess the potential negative impacts of proposed renewable energy facilities (such as collisions, ecosystem disruption, noise, direct injury to animals, etc.), neither is looking beyond specific permit applications to consider how renewable energy fits in with all the other potential uses in an area, or to assess the "opportunity cost" of allowing a semi-permanent structure to be built without considering other possible uses of that site that may have higher economic or social value.

From the perspective of industry proponents and investors, there is still a high level of uncertainty along the path toward commercialization. Before investing large amounts of money in advanced technology development and environmental assessments, they want to feel confident that ocean space will be available to them, at a known cost, under a stable regulatory regime. Based on my interviews, this industry includes a mix of "true believers," who feel that ocean renewables are akin to a public service, and more hard-nosed investors who are intrigued by a potentially lucrative business opportunity. In both cases they are looking to Congress and the states for direct subsidies, favorable tax treatment, and help in streamlining the regulatory process, all of which have been tried in European countries over the last decade.

What's next? There will undoubtedly be continued action on ocean renewables in Congress, through federal and state agencies, and within the private sector. But can the leaders in each of these venues be persuaded to think about offshore energy in the broader context of i-MSP? As mentioned above, Congress will need to clarify the overlap of FERC and MMS authorities in the 3-12 mile zone. That provides an opportunity to direct the agencies to look at how their programs relate to offshore management of other uses. The industry representatives I spoke with believed there could be value in multi-user, multi-agency dialogues about offshore use, as long as they are clearly focused on "finding compromises and solving problems, not intellectual debate!" Revision of the draft regulations at MMS and ongoing permit reviews at FERC provide additional venues to get a broader variety of ocean users involved.

One suggestion put forward by several observers is to establish a few "test sites," linked by transmission lines to land, where a variety of renewable energy companies could conduct operational-scale technological and environmental assessments at lower cost and with less administrative hassle than needed to obtain an actual permit. This would give everyone time to learn more before committing to expensive structures in specific places.

Box 3 (b) **Offshore Aquaculture**

Background With growing international demand for fish and seafood products, accompanied by declines in many wild fish stocks, ocean aquaculture (sometimes referred to as mariculture) has been a growth industry for some time, primarily in Europe and Asia. Initially, facilities were located in coastal and nearshore waters, at sites with protection from waves and storms. This has led to a number of problems including conflicts with other coastal users, water pollution, competition with native species, and destruction of sensitive coastal ecosystems. New technologies are allowing fish pens to be constructed in deeper waters further from shore. This may reduce some of the ecosystem impacts, although it does not eliminate conflicts over space. Even if all the engineering and environmental concerns were addressed, the U.S. regulatory regime remains unclear, with MMS possibly having authority through the Energy Act, the Regional Fisheries Management Councils asserting their interest, and NOAA's relatively new Office of Aquaculture acting more as a cheerleader than a regulator. (A recent report from that office is entitled "Why the U.S. Should Embrace Aquaculture" and calls for regulations that "encourage … investment in aquaculture.")

Individuals who have struggled to establish viable aquaculture operations were eager to share stories about their years of struggle and setbacks, from experimenting with different species, to reassuring anxious investors, winning over local communities and officials, navigating multiple permit agencies, struggling with engineering failures, and finding the right markets for their products.

Issues Many of the broad concerns raised about offshore aquaculture are similar to those discussed above in the context of offshore renewables: technical challenges, environmental impacts, and management confusion. Environmental advocates are pushing for strict controls and monitoring of any outflow from the fish pens, including excess feeds, waste products, chemicals, or escaped fish. They have also called for strict liability provisions in case problems arise down the road—a deal-breaker for most investors.

Potential investors are generally feeling skittish about the level of regulatory uncertainty in this country. As one venture capitalist said, "international proposals are more feasible." The permitting process in the U.S. is "unclear, with multiple authorities and unpredictable timelines." "It's hard to get permits for the kind of large scale operations necessary to reach profitability." A good argument can be made that the Regional Council system established to manage wild fisheries is not appropriate for the aquaculture industry: the nature of the participants involved and the activities themselves have little in common. Some aquaculture proponents believe they would be better off within the USDA, since aquaculture more closely resembles the raising and harvesting of livestock than the pursuit of wild stocks. However, introducing a new agency with entirely different traditions and practices into the ocean scene might make it even more difficult to achieve cross-sector coordination. Ironically, one aquaculturist commented that NOAA's new Aquaculture Office may have been too explicitly pro-aquaculture, leading to mistrust among NGOs and a very polarized debate.

None of the people I spoke with, no matter their perspective on the merits of offshore aquaculture, seemed to have thought about the broader multiple-use issues involved in allocating ocean space. As one enthusiastic promoter said, "Oh, there's lots of space out there!"

What's next? Offshore aquaculture will almost certainly continue to grow in response to demand. In fact, the potential for seaweed and other marine vegetation to serve as feedstocks for biofuels may provide a whole new angle for the industry. Some progress has been made in bringing ENGOs and responsible industry representatives together to share perspectives and begin to discuss mutually acceptable standards. The Ocean Stewards Institute was created as a trade group for growers, suppliers, equipment manufacturers, and others who want to promote a robust, sustainable, offshore aquaculture industry. One of their goals is to create widely accepted MSC-style certification standards for farmed fish.

The aquaculture legislation introduced repeatedly by the Bush administration was not widely embraced, so a new Congress and White House will have the ability to start fresh. Now is an excellent time to get all parties educated and thinking about how aquaculture will fit into the wider community of ocean users and how i-MSP can help.

Although different stages of the process may gain greater emphasis in different locations, at its best i-MSP includes everything from setting high-level policy goals, issuing guidance documents for planners, conducting spatial assessments of the ecosystem and human uses, engaging stakeholders, creating plans based on scenario analyses and negotiation, drawing detailed maps with assignments of zones (whether single or multiple use, optional or mandatory), issuing regulations, and then following up with appropriate monitoring and enforcement. Each step in the process is valuable in its own right, as well as contributing to a desirable end result, as discussed in the next section. Virtually every advocate for i-MSP also includes evaluation and adaptation as critical elements to ensure that plans perform as desired and make appropriate modifications when they do not. (However, see Box 6 for a discussion of the challenges associated with making i-MSP adaptive).

Because ocean activities vary widely in their spatial characteristics, several types of zones can be created. Some ocean uses, such as the preservation of a historic shipwreck or protection of a unique habitat, are confined to very specific areas. For other activities, such as wind energy, oil and gas extraction, and certain fisheries, the resource is more widespread and offers some flexibility in spatial allocations. Finally there are activities, such as navigation, recreational boating, and certain open ocean fisheries, that are not inextricably tied to specific locations, although participants in these sectors may still express strong spatial preferences. It is also important to remember that global climate change is likely to have profound impacts on the spatial distribution of all ocean features in decades to come.

While many people view i-MSP with some apprehension, seeing it as a significant departure from previous practice, it is important to note that many "zones" have already been created over time in the ocean (see Box 4). However, because each one was created with a single problem or sector in mind, they fail to add up to a coherent plan or advance higher level objectives.

Box 4 **Examples of Existing Ocean Zones**

Vessel traffic routes, separation zones, and precautionary zones
Anchoring and no-anchoring areas
Security zones in ports and waterways
Oil & gas lease or concession areas
Wind or wave energy lease or concession areas
Military operation or training zones
Sand and gravel extraction areas
Dredging sites
Dredged material dumping zones
Pipeline rights-of-way
Submerged communications cable and transmission line rights-of-way
Fishery closure or no-trawl areas (permanent or seasonal)
Critical habitat designations
Marine protected areas and reserves
Protected historic or archeological sites
Scientific reference sites

(adapted from Visions for a Sea Change, 2007)

There are a handful of countries where i-MSP is already being actively pursued, notably Belgium, the Netherlands, Canada, Germany, Australia, and China. A report on priorities within New Zealand's 200-mile EEZ (New Zealand Ministry for the Environment, 2001) laid the foundation for comprehensive zoning of that nation's waters, although development of an Oceans Policy was recently put on hold by their government. The United Kingdom is exploring marine planning legislation but efforts there have also been slowed by national political changes. The European Union is attempting to merge and build on the experiences of its member nations, realizing that national borders rarely match up with ecosystem boundaries. For example, marine management plans are being created separately in Belgium, the Netherlands, and Germany, although the ecosystems that constitute these nations' waters recognize no national authorities. In theory, an MPA designated in one EU member country's waters could directly adjoin another country's industrial zone. A range of international i-MSP programs is being documented and analyzed through UNESCO's marine spatial planning effort (see www.unesco-ioc-marinesp.be).

Australia has often been thought of as a leader in marine planning because of its creation and management of the Great Barrier Reef Marine Park (GBRMP). Although the GBRMP is a huge accomplishment, the underlying process was actually quite different from the i-MSP model since its stated purpose was to establish a large protected area, with multiple use zones as practical compromises rather than goals in themselves. A separate process is underway now in several regions of Australia to do genuine i-MSP, building on the experience gained and stakeholder relationships built during development of the GBRMP.

To convey a sense of the practical realities behind i-MSP, and the real world challenges that can arise, Box 5 describes a recent exercise in marine planning on Canada's Eastern Scotian Shelf in greater detail.

B. Advantages of i-MSP

Because i-MSP is a concept still in the earliest stages of implementation in relatively few places, there is not yet any quantitative documentation of its value, as measured by specific, pre-determined performance benchmarks. Nevertheless, a number of experienced scientists, managers, and policy experts have analyzed the process and goals of i-MSP, compared it to existing management approaches, and identified a number of i-MSP's best features (e.g., English Nature, 2006; GHK Consulting, 2004; IOC, 2007; Norse, 2005).

Of course, the perceived value of any policy proposal depends on the *values* of the individual doing the assessment. The literature reviewed and stakeholder interviews conducted as background for this paper illustrate this very clearly. When i-MSP is perceived as a mechanism for siting new ocean uses, business people get excited and environmental NGOs get nervous. But when i-MSP is seen as tilting toward the creation of MPAs and closure of large areas of the ocean, many users balk while environmental groups smile. To realize the potential benefits of i-MSP and create workable plans, these perspectives must be balanced and solutions must be proposed that meet the needs of all parties, even if they do not satisfy everyone's deepest wishes. The multiple objectives of i-MSP (as discussed in the previous section) must be acknowledged and all stakeholders must be taken seriously during the planning process.

The benefits associated with i-MSP can be grouped into three categories: (i) benefits of the planning process itself, (ii) tangible economic and social gains, and (iii) environmental improvements. In addition, Box 6 discusses the issue of adaptive management and explains how it can be seen as either an advantage or disadvantage for i-MSP.

Box 5 ESSIM: Rich Process, Uncertain Results

The Strategic Plan for Canada's Eastern Scotian Shelf Integrated Ocean Management (ESSIM) project (Fisheries and Oceans Canada, 2007) provides an excellent illustration of the principles of i-MSP and should be studied by anyone contemplating a similar exercise. Although implementation of the plan has been hindered recently by a number of factors (discussed below), there is much to be learned from the ESSIM process itself.

Although the level and variety of offshore uses was low to moderate at the time the 1996 Canada Oceans Act was passed, policymakers recognized that traditional uses would continue to grow and that new uses would be coming online. This prediction has been borne out in the decade since: a variety of ocean-based renewable energy facilities have been proposed, liquefied natural gas (LNG) terminals are being sited, offshore aquaculture tests continue, new fisheries are being pursued, and container ships are increasingly stopping in Canada's eastern provinces rather than traveling up the St. Lawrence River Seaway. As in the U.S., each of these activities is subject to different permitting regimes at different agencies, and space is being allocated without any broader vision of the future.

The Oceans Act, as implemented through the 2002 Oceans Strategy and the 2005 Oceans Action Plan, calls for regional planning for Canada's coastal and ocean waters. Without changing any existing authorities, the Act directs government agencies to cooperate in several regional pilot planning efforts and then pursue their regulatory activities in keeping with these plans.

The ESSIM project, which was formally announced in 1998 and picked up speed through the early 2000s, is built on a highly collaborative, consensus-based planning process, involving several levels of advisory and decision-making bodies. Enormous attention was paid to creating an atmosphere of openness and cooperation, which allowed the project to overcome difficulties as they arose along the way. ESSIM's operating principles for collaborative planning included:

1) *Jurisdiction:* Management authorities and jurisdiction of government departments and agencies is acknowledged and affirmed.
2) *Inclusion:* All stakeholders are included.
3) *Consensus:* Decisions and recommendations are made by consensus and the process includes mechanisms for dispute resolution.
4) *Accountability:* Accountability is expected of and demonstrated by all parties.
5) *Evolution:* The process is designed to permit and support evolution and will be monitored and evaluated to support shared learning and adaptation.
6) *Networking:* The process will continue to work through a network of stakeholders.
7) *Transparency:* Decisions and recommendations are made openly, with information and results shared with all stakeholders.
8) *Efficiency:* Issues are addressed in a timely manner.
9) *Knowledge-based:* Decisions and recommendations are based on best available information.

The next step was to articulate the project's purposes, which were boiled down to three high-level goals:
(1) Collaborative Governance and Integrated Management (which addresses the problems of sector specific, uncoordinated ocean management);
(2) Sustainable Human Use (which acknowledges the long term economic value of the ocean); and
(3) Healthy Ecosystems (which ensures conservation and restoration of ocean ecosystems).

Over the course of the planning exercise, each of the three high-level goals was broken down into sub-goals (or elements), to be achieved through Strategic Objectives and implemented through Management Strategies and Actions. Table 1 shows how one of the three goals, Sustainable Human Use, was broken down into elements, objectives, and strategies. The more specific Management Actions needed to implement each strategy are being developed now.

TABLE 1: Breakdown of ESSIM's Goal 2 for Sustainable Human Use

Element	Objective	Strategy
Social and cultural well-being	Communities are sustainable.	• Identify and characterize communities. • Identify community assets related to the ESSIM Initiative. • Promote and maintain access to sustainable livelihoods from ocean-related activities. • Enhance ocean-related education, training and awareness. • Support ocean-related services and infrastructure. • Improve government capacity (including fiscal) to implement social programs. • Involve Aboriginal peoples in planning and development decisions.

<table>
<tr><td rowspan="2"></td><td>Sustainable ocean/community relationships are promoted and facilitated.</td><td>• Recognize and celebrate coastal communities and their connection to the ocean.
• Recognize the social and cultural importance of traditional livelihoods.
• Recognize and preserve the social and cultural importance of heritage sites (e.g., archaeological sites).
• Promote social impact assessment to inform decision-making.
• Recognize and affirm intrinsic values that link people, communities, and the environment.
• Ensure community inclusion in ocean planning and decision-making.</td></tr>
<tr><td>Ocean area is safe, healthy and secure.</td><td>• Assess current status and risks and develop plans to address them.
• Support ocean-related services, training and infrastructure for health, safety and security.
• Monitor and manage chemical or biological contamination that could affect humans.
• Maintain and enhance integrated surveillance, monitoring and response system.</td></tr>
<tr><td rowspan="4">Economic well-being</td><td>Wealth is generated sustainably from renewable ocean resources.</td><td rowspan="4">• Assess current and potential wealth generating activities and opportunities.
• Identify, assess and link to existing policies, plans and initiatives for sustainable wealth generation/economic development.
• Support existing activities and opportunities, and future economic diversification and employment.
• Support positive investment environment for ocean-related activities.
• Assess constraints and enabling factors for investment (e.g., regulatory environment) and identify changes required.
• Identify and implement measures to improve retention of wealth and benefits within coastal and Aboriginal communities in Nova Scotia and Canada.
• Support initiatives to maintain or improve economic competitiveness for Nova Scotia.
• Balance industrial capacity with resource sustainability.
• Support the conservation of natural capital by recognizing, linking to and working with related ecosystem objectives and strategies.
• Recognize, link to and work with key related social and cultural well-being objectives and strategies (e.g., traditional livelihoods).
• Support innovation and research that may contribute to economic well-being.</td></tr>
<tr><td>Wealth is generated sustainably from non-renewable ocean resources.</td></tr>
<tr><td>Wealth is generated sustainably from ocean infrastructure.</td></tr>
<tr><td>Wealth is generated sustainably from ocean-related activities.</td></tr>
</table>

Another necessary precursor to zoning was a regional assessment to document ecosystem status and trends and human uses and impacts. This baseline assessment was also needed to facilitate adaptive management and ensure accountability over time. Each Management Action will be evaluated according to specific, publicly-reported Outcome Indicators (which have yet to be finalized), followed by revision or adaptation of the plan as needed.

Although this proliferation of process may seem daunting and complicated, it serves a vital purpose. By moving forward one step at a time, in an extremely deliberate way, a diverse group of participants could gain trust in each other and feel confident their views would be heard, before even beginning to talk about allocating specific uses to zones on a map.

Behind the Curtain

As might be expected, the reality behind the scenes proved far more complicated than the description above might imply. To start, the call for planning in the 1996 Oceans Act was not accompanied by new funding, forcing the Department of Fisheries and Oceans to borrow money and staff from other programs to initiate pilot projects. Although some core funding came in 2002 with the Oceans Strategy, ESSIM has been chronically underfunded compared to its task. Then, in 2006, the national government changed hands, having been led by the Liberal Party for twelve years. The new Conservative Party leadership had little investment in integrated ocean planning concepts. As in the U.S., the general public tended to be focused on economic problems and had little understanding of ocean issues, making it even harder for ESSIM planners to gain broad political support.

Additional problems arose when some of the participating agencies, despite having been fully involved in the planning process and having signed off on the result, pursued actions that were not consistent with the plan. The fishing industry, in particular, tended to go directly to the relevant Minister (the equivalent of a U.S. Cabinet Member) to get support for their desired actions. (Recent pressure to gain MSC certification for Maritime fisheries has brought some fishing interests back to the table as they seek help to demonstrate sustainability.) One of the surrounding provinces objected to the boundaries of the planning area. Even managers charged with implementation of a national MPA network complained that the integrated planning process might be a hindrance to their more specific ecosystem protection goals. *(CPAWS, 2008)*.

Those familiar with the ESSIM process cite several "lessons learned." First, politicians must accept that good planning takes time, professional expertise, and money, including funds dedicated to public education and capacity building among agencies, users, and the public. Second, no matter how thorough the process or how much good will is developed, some kind of high-level referee is needed to ensure compliance by disparate agencies. The suggestion was made that an inter-ministerial board (similar to the U.S. Committee on Ocean Policy) might fill that role, although this approach has not been adopted.

Despite these frustrations and shortcomings, the ESSIM process has advanced ocean management in significant ways. Regional leaders believed in the process and were determined to make it happen. They were backed by a law (the Oceans Act), not just an executive action. The staff who led the effort were deeply committed and had expertise and prior experience in planning. Despite some setbacks, the Eastern Scotian Shelf planning process is far ahead of the other Canadian regions (British Columbia, the Beaufort Sea, and the Gulf of St. Lawrence) that were supposed to undertake similar multiple-use ocean planning. Most important, agencies, users, and NGOs came together to an extent previously unheard of to forge a common vision for the future of their ocean.

(i) Benefits of the integrated planning process

Identifying a vision and objectives for human use of the ocean

Rather than the traditional piecemeal, first-come, first-served approach to ocean space, i-MSP involves local and regional interests in reviewing a variety of scenarios for the future, based on available economic and environmental forecasts. Participants can then articulate a shared vision embodied in a set of environmental, economic and social objectives for their ocean space. As stated in one interview, *"[i-MSP] has the potential to truly include and balance human needs, where traditional EBM seems to focus primarily on ecosystem protection."*

An illuminating example of the value of scenario development can be found in planning documents for the GAUFRE project in Belgium's North Sea waters (GAUFRE, 2005). Building on painstaking analyses of the area's oceanography, ecology, and uses, project managers illustrate how different objectives will result in different futures for the ocean, from the "Natural Sea" (where ecosystem protection is the overriding goal) to the "Rich Sea" (where economic development dominates), with a number of options in between. This process forces participants to acknowledge the consequences of hitherto unquestioned assumptions and choices.

Bringing all stakeholders to the table

By providing a transparent and structured mechanism in which different interests can be heard and reconciled, i-MSP helps minimize conflicts and search for synergies. It also increases awareness and ownership of marine conservation issues, particularly among users and regulators. The dialogue is made easier by ensuring that all stakeholders have a common base of understandable information. In the words of several interviewees:

"Fishermen will come to the table if there are dependable, honest partners, engaged in respectful, open dialogue, and they stand to gain something, not just give more up."
"The oil and gas sector has certainly had conflicts with MPAs and fishermen, but things sometimes go well, and even achieve synergies, when there's good dialogue and planning."
"[i-MSP] may prove to be the kind of paradigm shifting tool that marine conservationists have dreamed of."

Focusing on interactions between all sectors

An integrated planning process helps articulate links between different objectives, evaluate interactions among sectors (including "the environment" as one sector), clarify cumulative impacts, make choices and tradeoffs, and present outcomes within a spatial framework. The planning process also integrates socio-economic and bio-physical issues in a way that is rarely attempted under existing management regimes.

Here again, the Belgian GAUFRE (2005) project presents an excellent case study. For each existing or planned ocean use, planners systematically documented its projected spatial needs, regulatory requirements, compatibility with other contemplated uses, and impacts on (or benefits to) the environment. For example, the analysis of wind energy highlights its compatibility with recreational fishing, diving, and certain kinds of aquaculture, incompatibility with shipping lanes and aggregate extraction, and potential impacts on birds and marine mammals. Other cases of possible inter-sector synergies include shipping lanes with sand extraction, fishing near protected areas, ecotourism in MPAs, and coastal protection with recreation. The tables of cross-sector interactions that resulted from the GAUFRE

Box 6 **Adaptive Management: Boon or Burden for i-MSP?**

Monitoring, evaluation, and adaptive management are widely recognized as valuable additions to any management scheme. Wherever managers must cope with limited information and significant levels of uncertainty, monitoring and adaptive management can help determine whether objectives are being met, identify shortfalls, promote accountability, and enable ongoing modification of management actions, priorities, and resource requirements. In the ocean environment, change is a constant, with shifting shorelines and currents, ecological regime shifts, and the still unknown effects of climate change. Perhaps because i-MSP is relatively new and its proponents are familiar with past lessons of environmental management, adaptive management is always included as a key element of i-MSP.

Ocean planners wishing to pursue i-MSP are advised by proponents to identify clear management objectives/desired outcomes; choose relevant, measurable indicators for each objective; monitor for changes in the indicators; assess results; and adjust management actions as necessary. Because of the complex nature of i-MSP, the objectives and corresponding indicators will include environmental, social, economic, and governance elements.

However in interviews, ocean users repeatedly raised concerns about the adaptive aspects of i-MSP:
"Both agencies and users hate change. Everyone wants to move on after a decision is made."
"When monitoring reveals a failure to reach objectives, managers are open to criticism and funding cuts."
"How can we do adaptive management once there are structures in the water? The level of investment involved [in building offshore energy facilities] precludes frequent review, adaptation, or changes in location."
"Monitoring is expensive and lacks political support."
"Because [i-MSP] is new and untested, managers would be very conservative (precautionary) upfront. They would need to set very stringent requirements and then ease up over time."

Problems arise when one attempts to compare the costs and benefits of i-MSP, *assuming it includes monitoring and adaptive management,* with the status quo. Despite the recognition of its importance, very few existing ocean management schemes are actually required to set objectives, monitor performance, and adapt accordingly. Even where such evaluations are included, they tend to look at biological and physical endpoints, rather than the complex and less familiar social and economic elements.

This puts i-MSP in an awkward situation. To overcome fear of a new approach, maintain flexibility as we learn, cope with a changing ocean, and leave room for new uses to emerge, i-MSP advocates stress the importance of adaptive management. But adaptive management also raises fears of uncertainty and ever-changing regulations, a deal breaker for many participants in the process, particularly those who must make significant capital investments.

analyses were key to the subsequent process of creating an assortment of zoning maps.

Unifying and streamlining government actions
One coastal manager referred to interactions between federal agencies as “internecine warfare.” Users frequently complain that a lack of agency coordination leads to confusion, delays, and unexpected project changes, all of which cost money. By bringing all ocean interests—and the agencies that oversee, promote, or regulate them—to the table, such roadblocks can be avoided and efficiency improved.

Oil industry representatives pointed out that they must deal with MMS for leases, the Department Of Transportation (DOT) for pipelines, the Environmental Protection Agency (EPA) for air and water discharges, the Coast Guard for safety, nearby states to resolve coastal zone management and consistency concerns, NOAA for marine mammal interactions, and Immigration and Customs Enforcement (ICE) when anything is moved to or from an offshore platform. They supported the need for broader planning for ocean waters and submerged lands, including the designation of appropriate protected areas, but preferred that such planning be modeled after the MMS system of baseline resource assessments followed by 5-year plans with development targets, the approach most familiar to them.

A unified planning process would strengthen integration across economic sectors and agencies, and between national policy and regional implementation. Better communication can help streamline long, consecutive federal approval processes. Most important, i-MSP results in greater predictability for all parties, including the critical financial sector.

(ii) Economic and social gains

As remarked by one coastal manager:
“As the saying goes, ‘It’s the economy, stupid.’ Many coastal communities have suffered economic losses in traditional sectors such as timber, fishing, and manufacturing. The public wants to know whether new ocean activities, or ocean management schemes, will help or hurt their pocketbooks. Once that question is answered, environmental protection is a bonus.”

By maximizing efficient use of space and resources, minimizing conflicts, and searching for synergy, i-MSP promotes the sustainable development of a variety of economic activities in the ocean, enhancing income and employment over the long term. Most companies rely on some form of long-range planning to guide their investment decisions and there is reason to believe that ocean businesses such as fishing, renewable energy, and aquaculture would also benefit from improved long-term planning based on increased regulatory certainty. By integrating the full range of ocean activities, while leaving space for new and emerging uses, i-MSP also promotes local economic stability through diversity of income streams.

The i-MSP focus on conservation of marine ecosystems supports economic sectors that depend directly on environmental quality, such as tourism, recreation, and fishing. Equally important, by stressing ecosystem health and sustainability, i-MSP helps maintain the very real value of ecosystem services such as shoreline protection, human health, clean water, and global climate control. These benefits should not be underestimated, but greater efforts will be needed to quantify them and communicate their value to the public.

As documented in a number of reports (e.g., National Research Council, 2004), there are significant efficiencies to be realized through more coordinated environmental assessments and data collection. i-MSP facilitates cross-sector and cross-agency comparisons of data holdings, needs, and plans, thereby improving information collection, reducing duplication of effort, and allowing for cost savings. Some of the more lucrative ocean sectors, such as oil and gas, appear quite willing to help pay for assessments if they are allowed to be part of the broader planning conversation.

Finally, total regulatory and compliance costs should be lower under i-MSP due to better information exchange between agencies and a more predictable setting in which to make business and regulatory decisions.

(iii) Environmental improvement

Although facilitating additional uses of the ocean may seem antithetical to conservation goals, many analysts believe that i-MSP could actually advance the long-term protection of ocean health. In addition to existing environmental laws, regulations, and best practices governing specific activities, i-MSP places environmental commitments at the heart of planning and management and ensures that some portion of ocean space is allocated for ecosystem preservation. In a sector-by-sector approach, every proposed MPA becomes a battle in which conservation interests appear to be pitted against other users. But i-MSP puts conservation interests at the table with others as equal (or sometimes dominant) players. It also requires consideration of cumulative impacts from all sources in a region, a critical step which has been frequently neglected in traditional management.

In the Belgian, North Sea, and Eastern Scotian Shelf marine plans, which are among the most fully developed to date, conservation concerns were at center stage during deliberations. Planners documented the impacts of each proposed use and participants debated where and how many MPAs should be sited, not whether they were legitimate. Similarly, in the Rhode Island Special Area Management Plan process, the first step will be to locate sensitive ecosystems to be protected, with other uses sharing the remaining space under suitable regulatory regimes. As discussed above, the establishment and management of the Great Barrier Reef Marine Park in Australia did not follow a true i-MSP process, but a similar stakeholder-driven procedure demonstrated that environmental protection can co-exist, and even flourish, along with ocean uses.

It is too soon—and too few marine spatial plans have been fully implemented and assessed—to know how well long-term conservation goals will be realized in the water under i-MSP. Several remaining concerns on this score are laid out in the next section.

C. Concerns about i-MSP

Most of the available literature on i-MSP sets out to demonstrate its value and discusses how it should be implemented. However some writers have raised red flags about this approach, and many worries were expressed in the course of the personal interviews. The following section presents the main themes behind these concerns and some of the counter-arguments against them.

(i) "It's not practical."

Interviews confirmed that many people, primarily managers, remain worried about the trouble involved in taking on i-MSP and skeptical that the significant effort required will bring commensurate benefits. These concerns were often vague, but some typical quotes include:

"[i-MSP] is too complex, too abstruse; there aren't enough conflicts or perceived problems to justify the time and money."
"Ocean zoning would never get public or political support." (Note that this same commenter saw great value in, and support for, zoning on land)
"People say there'll be synergies, but that's not really practical because each user will be too concerned about protecting their turf and capital investments."
"[i-MSP] would require fundamental changes in the way people and organizations behave; even new legislation can't accomplish that in a hurry."
"It was incredibly hard navigating the [Marine Life Protection Act] process in California, where we were just negotiating with the fishing community. Trying to include all the other users would make it impossible!"
"Some states remain uncomfortable with 'zoning.' It sounds too top-down, deterministic, and simplistic."
"It's too expensive and will become an unfunded mandate."
"Users must perceive conflicts to come to the table, so this will only work in crowded areas." And, by contrast, "This might be easier where there are few activities [but not in my crowded area]."

(ii) "It's really hard and we don't know enough yet."

A bit more accepting than those who ruled i-MSP out as impractical were those who saw the value of the concept, but felt that the current state of knowledge (about ecosystems, human behavior, economics, etc.) and the availability of data were too limited to move forward. In their words:

"It's too soon for [i-MSP] because new uses are too untested. For example, it will be years until offshore renewable energy is ready to come online. We don't want to be 'locked in' to certain areas when technologies are still so new."
"We don't know how to draw and enforce meaningful lines in the water."
"It's not enough to do ocean planning unless it can be linked with watersheds, which adds a whole new set of players and layer of complexity."
"How can we reconcile the scale of ecosystems (e.g., LMEs) with the smaller scale needed for planning and stakeholder involvement?"
"Planning in nearshore areas will be especially challenging because of socio-economic issues that we don't fully understand."
"It's better to proceed incrementally: 'evolution not revolution.' Try doing sector-specific EBM before going for big changes."
"There just isn't enough information. In our state, seafloor mapping covers only 5% of state waters and we would need at least $6 million to complete it."
"[The oil and gas industry] would be unwilling to see zones designated since they've been prevented from doing basic exploration for years and don't know what's out there."

(iii) "*They* [the agencies, or users, or NGOs] will never cooperate."

At this moment in the history of U.S. ocean management, with few exceptions, the level of trust between stakeholders appears to be quite low. Since i-MSP depends on the willing participation of many players representing all sectors and all agencies, its success will require a major effort to bring people together, build relationships, and instill confidence. California's Marine Life Protection Act (MLPA) stakeholder process may provide one useful model. Many of the papers reviewed and people interviewed saw problems in getting "those other folks" to play fairly:

"We've seen it before: fishermen will never share their data. It's all self-reported anyway, so it's totally unreliable. And fishermen will never place their activities on a map."
"Agencies will run to Congress, OMB, or the White House to get what they want. It would take someone with a baseball bat to make everyone work together. Only top-down orders and pressure can change that."
"The environmental community is always looking for ways to tie everything in knots, using MMPA, ESA, MSFCA, NEPA, etc."
"Allowing wind farms in the ocean will lead to massive area closures, ostensibly for security reasons, then structures and cables will be abandoned and get in the way forever. It's just a quick tax break for industry."
"Environmental groups blame everything on fishing, which leads to bad feelings. [They] went too far in pushing MPAs as an excuse to stop fishing, just like the spotted owl was an excuse to stop the timber industry."
"Without a legal requirement, people just won't take [i-MSP] seriously."
"People are hiding behind doubts about the science and process to mask their self-interest in the status quo."
"Fishermen are afraid that [i-MSP] is just a Trojan horse for more MPAs."

"[Environmentalists] have a hard time appreciating the societal value of ocean-based businesses; mostly they just see them as annoying but unavoidable threats to the environment."
"[i-MSP] could add work through the planning exercise, but then not remove any existing steps. [We] need to eliminate, replace, or consolidate existing NEPA or other permitting requirements to make [the i-MSP process] attractive."
"Current users, especially fishermen, or at least their official representatives, have come to view use of the entire ocean as their right. That makes it difficult to compromise."

(iv) "The environment will lose if it has to compete with users."

Environmental advocates are worried that they may give up more than they gain by coming to the table with powerful economic interests. Based in part on experiences with public lands (discussed in greater detail in Section III), they fear that the prospect of fees and royalties coming to state budgets from growing ocean uses will outweigh public concerns about environmental protection. Having experienced some success with traditional environmental laws, economic tools, and MPA designations in recent years—despite intense opposition and major investments of funds and staff time—some environmental NGOs would rather stick with "the devil they know" than take a chance with one they don't. (These arguments carry less weight in light of the abject and continued failure to protect ecosystems under existing management regimes.) As they see it:

"[i-MSP] doesn't guarantee ecosystem protection; unless there are specific, legal requirements for protected areas, resource users will keep chipping away at ocean space."
"It's easy to put lines on maps [designating protected areas], but political will can always thwart implementation."
"The MMS offshore leasing program was supposed to include environmental protection, and their Environmental Studies Program spent lots of money to appease the research community, but it never led to real ecosystem protection."
"Generally, tradeoff processes undervalue conservation. Look at the Sanctuaries program, Forest Service, BLM."
"Ocean zoning is just a backdoor way to put the ocean under private control."
"[i-MSP] could be a tool to help get to EBM, but it doesn't have to be and we shouldn't confuse the two."
"Complete multi-use optimization is obviously too complicated; we should start by optimizing ecosystem protection, and then fit other uses around that."
"The top priority should be to get more refugia in place (using climate change as the excuse…I mean justification). This will raise public awareness of oceans in general and then we can do more sophisticated planning."

Although the concerns outlined above raise legitimate questions and are deeply felt, none is irresolvable. Most of the same concerns were initially raised, and then assuaged, in the few places that have engaged in some form of ocean planning. Such concerns can be answered in several ways: highlight the problems that are occurring in the absence of planning; demonstrate the likely benefits of planning for different sectors (as explained in the previous section); show that i-MSP is already being pursued in many places and get planners and managers from those places to share their experiences; and sponsor engaging simulation exercises that make i-MSP concepts more familiar and accessible and help build trust among different stakeholders.

The fact that one hears similar arguments in many quarters does confirm the need for continued strategizing, dialogue, education, and negotiation before we are likely to see widespread adoption of i-MSP in the U.S.

III. Lessons from the Land

A. Land use planning and zoning

(i) Background

In explaining i-MSP to unfamiliar or skeptical audiences, proponents frequently use the analogy of urban land use planning (LUP) and zoning (e.g., Sivas and Caldwell, 2008; Tyldesley and Hunt, 2003). This can provide an “Aha!” moment, since most people are already comfortable with the idea that government and citizens should think about their vision for the future of a city and then create plans that allow for economic development while maintaining attractive areas to live and play. But does the analogy have value beyond a simple narrative device? A quick review of the history of urban planning reveals many differences compared to the ocean context (Box 7) while yielding several useful lessons.

States hold the power to regulate the use of land, but this responsibility has generally been delegated to local (and sometimes county) governments in acknowledgment of the intimate connection between land use and residents’ sense of community. Some states set broad policies, goals, and standards and reserve the authority to regulate certain land uses. Some specify elements to be included in local plans, processes to be followed, the extent to which a plan must be implemented and adhered to, the frequency of required updates, etc. Other states, notably Texas, defer almost completely to local control. In all cases, the authority to plan and zone is limited to jurisdictional limits, in other words, townships can only zone within their own township, cities within their city, etc. In this way, decision makers remain accountable to residents—and voters—within their districts.

The first U.S. zoning ordinance was passed in New York City in 1916 to move noxious industrial uses away from increasingly crowded neighborhoods. Then, in the 1920s, a Commerce Department team led by Herbert Hoover drafted a model land use planning law (the 1924 Standard Zoning Enabling Act) which was widely adopted by the states and has formed the backbone of LUP ever since. The legitimacy of zoning was solidified further by the U.S. Supreme Court in *Village of Euclid, Ohio v. Ambler Realty (1926).* In that decision, the justices said Euclid could promote “the health and safety of the community" by protecting residential areas from the "danger of fire, contagion and disorder, which attach … to the location of stores, shops or factories."

Box 7 **Some Important Differences between Terrestrial and Marine Planning**

Ownership - The seabed and ocean space are held in trust by the government for the benefit of the public, whereas land can be either publicly or privately owned. The problem of parcel-by-parcel fragmentation of ownership, and thus the recurrent need to purchase private lands to protect intact ecosystems, does not arise in the ocean (although fragmentation of authorities remains a problem, as we have seen). Note: The Public Trust Doctrine is the basis for state control over waters within the 3-mile coastal zone. It remains unclear how this applies to federal authorities in the EEZ.
Mobility of Activities and Ecosystems – Activities, species, and processes in the ocean are typically highly mobile, moving from area to area according to prevailing conditions and circumstances. Pollution can spread more quickly than on land, and notable seabed features (such as sand-banks, sea grass beds, and other undersea elements) and harvested species are highly dynamic. Land-based uses tend to be more static, with seasonal variations in intensity rather than type of use. The more stable distribution of habitats on land also makes it easier to identify places where vulnerable species might be found and protected.
Three-dimensionality - The marine environment is highly variable across latitude and longitude coordinates and through depth. Land use planning generally sticks to a two-dimensional grid, although implementing regulations sometimes address sub-surface uses or building heights. In the ocean, different uses can be carried out on the surface, in the water column, and on or beneath the seabed.
Maps, Information, and Understanding - There is much less known about the marine environment and its functioning than about the terrestrial environment. Virtually every square meter of the land surface has been surveyed (by land, air, or satellite) and mapped, but less than five percent of the ocean bottom has been similarly charted (National Research Council, 2003). Even in coastal areas, complete GIS-based mapping of bottom topography and ecosystem features is the exception rather than the rule. The sea has been drastically under-sampled and understudied until quite recently.
Population and communities - On land, local communities have a major influence in planning their surroundings. Areas in the ocean do not have equivalent resident communities, although their primary users can often be traced back to specific coastal communities that should be involved in spatial planning efforts.
Buildings and Infrastructure - Land use is frequently determined by the nature of existing fixed assets, such as buildings and related infrastructure, which do not change significantly from year to year. For now at least, these factors are less influential at sea.
Transportation - On land, linear routes tend to be set aside exclusively for transportation. By contrast, vessels can generally travel widely across the surface of the sea for many different purposes.
Monitoring and Enforcement - Enforcement is more difficult at sea due to the geographic area involved and the environmental conditions under which monitoring and enforcement must operate. The uncoordinated, sectoral approach to ocean management can compound this problem. In addition, unlike on land, there are no permanent, nearby residents looking out for illegal or nuisance activities.
International Dimensions - Many activities at sea are subject to international regulation, law, or convention. This is less true (although not entirely absent) for land-based activities.

(adapted from Tyldesley and Hunt, 2003)

LUP establishes a framework and guidelines for public and private development, starting with the drafting of a Comprehensive, or Master, Plan. Consistent with the Plan, zoning scheme then delineates areas for agricultural, residential, commercial, industrial, and mixed uses on a map, in keeping, indicating areas of different intensities and issuing regulations that guide the review of subdivision and building permits within each zone. This last step in the process is sometimes underemphasized: the process is not done when zones are created. To be effective, LUP (and i-MSP) must be able to regulate the form, scale, intensity and conditions of development, not merely its location.

The LUP process typically provides opportunities for stakeholder input through open meeting requirements, public comment periods, and similar venues. But the result does not attempt to reflect community consensus. The process relies on career professionals to devise the plan and zoning maps, with guidance and approval from elected officials who can then be held accountable at the ballot box. Local input tends to have a greater influence on specific permit reviews.*

(ii) Combining land use planning with conservation

When city managers first started regulating land use, their interest was in the *uses*, not the *land*. The goal of achieving sustainable development was not discussed and an emphasis on protecting natural areas seemed unnecessary. This has changed over time, although provisions for conservation are still often treated as add-ons to the traditional planning process.

Just as states differ in their level of delegation to local planners, they also differ widely in their requirements to provide for "open space," "wildlife habitat," or "critical (or sensitive) areas" in LUPs. By now, virtually all local LUPs include some conservation elements (although there is disagreement about whether to count general green space, such as parks, toward conservation goals). Permits are routinely denied or significantly altered to protect natural areas, often in response to local pressure. Nevertheless, limited resources typically push more proactive environmental policies, such as land acquisition, to the bottom of the list. A few states, notably Vermont, Maryland, and Oregon, have made more profound changes to their LUP laws to emphasize growth management and conservation over development.

For many people, nature-sensitive urban planning is associated with the Smart Growth movement. (In fact, the concept dates back to the 1960s, while the term "Smart Growth" has only been in common use for the last ten years and includes a broader set of community development principles.) Smart Growth ideas grew out of EPA's efforts to improve urban air and water quality and clean up contaminated urban "brownfields" for re-use. It became clear that better planning could alleviate, and may have helped prevent, these problems. In the late 1990s, three important events took place: the American Planning Association released a draft of its "Growing Smart Legislative Guidebook;" the Natural Resources Defense Council and Surface Transportation Policy Project published "The Tool Kit for Smart Growth"; and Maryland passed its Smart Growth and Neighborhood Conservation Act. This three-pronged endorsement propelled the concept into the public realm.

* This is a very rough sketch of a complex and variable process. It should be adequate for the purposes intended here, with apologies to land use planning professionals who may chafe at its oversimplification.

As Box 8 shows, the Smart Growth movement is oriented toward promoting "livable communities" which will also have lower environmental impacts and be sustainable over time. Because there are no comparable human communities at sea, it may be hard to see the applicability of some of these principles to ocean planning. However, the EPA defines Smart Growth as "development that serves the economy, the community, and the environment. It changes the terms of the development debate away from the traditional growth/no growth question to how and where new development should be accommodated." This sounds very much like a credo for i-MSP.

Box 8. Principles of Smart Growth

- Create a Range of Housing Opportunities and Choices for All Income levels
- Create Walkable Neighborhoods
- Encourage Community and Stakeholder Collaboration
- Foster Distinctive, Attractive Communities with a Strong Sense of Place
- Make Development Decisions Predictable, Fair and Cost Effective
- Mix and Integrate Land Uses Where Possible
- Preserve Open Space, Farmland, Natural Beauty and Critical Environmental Areas
- Provide a Variety of Transportation Choices
- Strengthen and Direct Development Towards Existing Communities
- Take Advantage of Compact Building and Neighborhood Design

(from www.SmartGrowth.org)

(iii) Lessons from land use planning

After almost a century of experience, practitioners and observers of LUP have accumulated many lessons about what works. Many of these are not directly relevant to the marine context because they involve the purchase and control of privately-owned land. But a few lessons, particularly those pertaining to the decision-making process itself and the balancing of conservation and development, may be helpful in avoiding pitfalls as i-MSP moves forward.

Lessons about process

Everyone who has ever practiced or observed LUP seems to agree that *process matters*. A successful planning process collects information about what's there and projections of what's coming; sets high-level goals before looking at maps; encourages broad public participation; explains the process and ground rules up front; is open, transparent, and fair to all participants; results in reasonably predictable decisions; and includes provisions for review and revision.

These principles have become almost cliché, but that doesn't mean they are easy to achieve. No two participants are likely to agree about what level of openness is enough or how many rounds of public input are appropriate. Some unavoidable tradeoffs include: local control vs. national, regional, or state guidelines; timely results vs. thorough consultation; voluntary compliance vs. centralized enforcement; innovation and adaptation vs. certainty and consistency. A well-managed planning process should even the playing field between disparate interests and decrease conflicts, while increasing efficiency and certainty (Eagle, 2008).

Nevertheless, no matter how well-conceived the process, it still requires leadership—and is never immune from politics. As one planner said, “The rules and process do matter, but the people making decisions matter more.” In the world of land use planning, local legislative bodies always retain final responsibility for approving master plans (whether actively or through default provisions) and can be held accountable by their constituents. Many observers believe this is essential and should be emulated by budding marine planners (Eagle, 2008). They argue that government agencies are inherently ill-suited to make tough choices, as they tend to shy away from controversy and prefer to keep all options open for the future. Elected officials have the legitimacy and accountability to stand behind decisions that will inevitably not please everyone.

Since zoning regulations do not cover pre-existing uses on private land, planners often struggle to incorporate grandfathered uses into the goals and framework of a Master Plan. Typical strategies involve concentrating similar uses around existing sites, constructing real or virtual barriers around problematic uses, purchasing land outright, or just waiting it out. For i-MSP, this may be less of a *legal* problem than a *political* one. Longstanding users, like fishermen, have no property-based right to ocean space, but they have tradition and strong political support behind them.

Experiences with enforcement of zoning laws may also be instructive. On land, there are never enough inspectors to keep up with all new building activity. As a result, the enforcement of zoning and building regulations is often initiated after the fact by unhappy neighbors or competitors. The problem of enforcement is likely to be even more severe at sea.

Lessons about balancing conservation and development

On land as at sea, there are clear economic benefits, both direct (e.g., tourism) and indirect (e.g., ecosystem services, land values), to be gained from preservation of natural ecosystems. But communities must *document* these benefits and then *communicate* them clearly to the public to balance the inevitable pro-development arguments.

A number of Smart Growth principles address conservation goals: preserve open space, farmland, natural beauty and critical environmental areas; direct development toward existing communities; take advantage of compact building and neighborhood design. These principles are aimed at limiting sprawl, which is inefficient and consumes natural lands. At first glance they may not seem as relevant to the less crowded ocean context. But then, they may not have seemed relevant on land fifty years ago, when they could have been implemented with less pain and may have prevented some of the negative impacts we are now trying to undo. These are precisely the kinds of lessons we should be heeding as we move forward with marine planning.

A detailed examination of communities across the country that have successfully incorporated conservation into LUP (Duerksen and Snyder, 2003) identified a number of common elements in their approaches, many of which overlap with the more general principles already discussed:

- leadership (both political and agency level);
- good program structure (adequate staff and funding, solid partnerships);
- solid planning (good inventories, maps, tools);
- innovation (recognize and embrace new ideas);
- social justice (avoid disparate impacts);
- land acquisition;
- strong regulations (EIAs, economic analyses, use regulations);
- restoration of habitats where needed;
- measurable results (metrics, performance assessments); and
- education (to build citizen involvement and support).

Equally important, the study found that the best results were achieved where a variety of approaches were combined, echoing the growing belief among ecologists, economists, and many other social scientists that diversity—whether of species, investments, or tactics—is almost always a good thing. (Note: Although land acquisition is not directly applicable in the ocean, government programs that use direct economic intervention to achieve an environmental goal, such as boat buybacks and publicly-funded removal of outdated structures, serve similar functions.)

One complicated topic that has generated a wide range of opinions concerns the optimum level of separation of land uses. Some argue that effective zoning requires single use areas that are relatively hard to rezone, with variances as the exception (Eagle, 2006). They see this as the surest way to minimize conflict and guarantee a place for everything, including no-use conservation areas. Others (e.g., Elliott, 2008) have concluded that areas should be integrated as much as possible, with more mixed use districts, more flexible definitions of permitted land uses, and regular review and revision of zoning rules. This approach can promote greater cohesiveness by forcing different constituencies to interact and negotiate with each other and creates efficiencies through shared infrastructure and services. The translation of such LUP ideas to the ocean context may require new ways of thinking about "ocean communities" that include both marine ecosystems and the people who use, visit, capture, benefit from, or work among them (see Shackeroff et al, 2008 and recent work by Kevin St. Martin).

One final lesson from land use planning: not everyone likes it! A large majority of the people I spoke with embraced the i-MSP/LUP analogy, particularly the emphasis on creating a shared vision and goals. But one federal manager said, "Zoning doesn't even work well on land so I'm not convinced it will help in the ocean," and several people pointed out that planning is neither required, nor widely practiced in Texas: "Texans don't trust government interference and don't like hindrances to development." To gain support in the face of this attitude, it will be important to stress that, unlike on land, ocean space belongs to all citizens and the government has a duty to manage it for the benefit of all.

B. Public lands management

Although comparisons with urban land use planning have the advantage of being familiar to a broad audience, the conservation and use of ocean space actually has more in common with the management of publicly-owned lands. The following sections review the broad history of federal lands management and identify a few more "lessons learned" that may inform the development of i-MSP.

(i) Background

Historically, public lands were managed to facilitate resource use and early laws, as far back as the 1872 Mining Law, assumed users would have the primary say in setting the rules. Broadly speaking, the Forest Service (USFS) promoted timber harvesting, the Fish and Wildlife Service (FWS) looked out for hunters and fishermen, the Bureau of Land Management (BLM) took care of grazing and mining, the Minerals Management Service (MMS) supported energy development, and even the Park Service (NPS) saw its role as encouraging recreation and tourism. Not surprisingly with such different "clients," over time the agencies developed different styles and cultures which became self-reinforcing.

In each realm, a relatively small group of legislators, agency managers, and user groups worked together to set policy regarding distribution of a public resource, with relatively little national attention. As one writer noted, "The history of public land law created a number of private privileges, which morphed into expectations, and became a sense of entitlement among commodity users." (Nie, 2008) Typically, local communities were also accommodated in some way, with extra opportunities for review of proposed uses and, perhaps more important, with a share of the fees or royalties raised on nearby federal lands. (This picture is somewhat analogous to the current ocean situation, where NMFS advances fisheries, MMS works closely with the oil and gas industry and more recently with the offshore renewable energy sector, NOAA's Aquaculture and Sea Grant offices promote aquaculture, etc.)

Through the 1960s and '70s, environmental groups advocated increasingly loudly for the public's interest in environmental values on public land. During the same period, OMB started realizing that the government was not getting a very good return on the use of public resources by private businesses. Revised authorizing laws for public lands agencies (e.g., the 1960 Multiple Use and Sustained Yield Act for USFS, the Wilderness Act, and many others), accompanied by a new suite of environmental laws (the Clean Air Act, Clean Water Act, RCRA, etc.), substantially changed the goals and process for land management, raised fees (although usually nowhere near fair market value), and asserted the value of wild, unexploited lands. These changes greatly increased the number of interested parties, including many new Congressional committees and the national media. For better and for worse, the cozy cliques could no longer operate behind closed doors and management decisions were fought out in very public and often acrimonious ways. The fight over management of old-growth forests in the Pacific Northwest (which degenerated into divisive slogans such as "owls vs. jobs") is a classic example.

At the same time these transformations were taking place, local and regional economies in the West were also migrating from a focus on resource extraction and traditional industrial development to a desire for sustainable, recreation- and amenity-based economies. In the '90s, President Clinton's Secretary of the Interior, Bruce Babbitt, introduced the relatively new concept of "ecosystem management" as a guiding principle for the use of public land, over the vociferous objections of users and many politicians from Western states, and quieter grumbling from agency staff who were simply not sure how to do it. (One agency staff person told me that under the current administration "ecosystem management" has become a forbidden term within DOI.)

After decades of tension and controversy, proposals are being advanced for balancing multiple objectives on public lands in a less adversarial way, some of which have been implemented at a small scale or as pilot projects. The following section attempts to summarize some lessons that can be incorporated into the marine context.

(ii) Lessons from public lands management

The level of conflict and antagonism that has built up around federal land management does not yet exist in the ocean context. By learning from experience, perhaps it can be avoided. Many analysts have examined how conflicts over public lands become so intractable and considered how we could do better. Not surprisingly, no silver bullet has been uncovered, but a number of ideas are worth taking to heart.

The Platonic ideal of impartial natural resource professionals administering a range of land uses, based on objective analyses of good data and science, with helpful input from stakeholders, remains a mirage. The root problems have been traced to many sources, many of which will also be present in ocean space:

- limited supplies of space, resources, and money;
- scientific uncertainty;
- imprecise, complex, and conflicting laws;
- elevation of emotional symbols ("owls" or "salmon") above real, complex problems (the goals of forest and watershed management);
- differing views about the scale and meaning of "community";
- posturing and polarization associated with electoral politics;
- fragmentation of responsibility and authority;
- the news media's focus on controversies over problem-solving;
- the adversarial nature of legal proceedings;
- and, at the root of it all, common human foibles such as short-term thinking, competition, self-interest, incomplete understanding, reliance on oversimplified narratives or frames, and the tendency to advance extreme positions in the hope of skewing later compromise.

In light of this daunting list of challenges, what seems to help?

Distinguish between political leadership, agency expertise, and stakeholder desires
Each of these elements has value, but they play different roles in the process. Elected politicians should write laws that reflect clear policy choices. As discussed above in the context of urban land use planning, only elected officials have the legitimacy to make value choices, the power to enshrine those choices into law, and the ability to be held accountable if those choices fail to reflect popular will. Vague laws with too much delegation actually politicize the entire process by forcing agency staff to make policy decisions, either explicitly or implicitly. For example, laws that called for "multiple-use" land management never specified what weight, if any, should be given to the impacts of decisions on local community stability, an omission that led to huge trouble for the agencies. "Broad discretion makes a politician out of a bureaucrat" (Nie, 2008).

Career agency staffs are in a better position to do the heavy lifting involved in sifting through technical analyses and assessing alternative scenarios. They also have the time and access to hear from a broad variety of stakeholders—democracy with a small "d." In addition, if new findings emerge, it is much easier to revise and adapt regulations than to amend legislation.

Members of the public also have important roles to fulfill. First and foremost, they have the responsibility to elect thoughtful, competent public officials and hold them accountable. Second, they should engage in rulemaking processes by staying informed, offering testimony, and responding to draft documents, whether individually or through appropriate associations or NGOs. Last, constituencies have an obligation to listen to each other and engage in constructive dialogue. "The tragedy of the commons can be avoided if users can communicate and develop trust" (National Research Council, 2002).

It would be hard to find an individual who opposes good jobs, a healthy environment, and vibrant communities. But that common ground gets quickly buried under a barrage of slogans and accusations. Collaborative, stakeholder-driven processes can be perfect venues to iron out issue- or site-specific disagreements, but they are not the appropriate venue for making broad policy choices. In fact, a number of experts believe that any agreement reached through negotiation should subsequently be enshrined in law to have staying power and legitimacy. (Nie, 2008)

Separate funding from decision-making
Money is always in short supply for federal, state and local agencies. This can become particularly insidious when government-supplied budgets are supplemented by income from regulated industries. Historically, agencies and local communities have received a portion of the revenues generated from the private use of public lands, putting them in a bind as they grow dependent on the funding and jobs created by industry. Consciously or not, environmental goals can be shortchanged under these circumstances. This is not to say that government should forego the collection of fair returns on the use of public space and resources. Rather, those revenues should be pooled in a larger fund, along with general tax revenues, and distributed to agencies and affected communities according to budget requirements, to decouple funding from decision making. (Brick and Cawley, 1996)

Avoid excessive fragmentation
One of the mistakes made on federally-controlled lands, and one that is just beginning to be remedied, is fragmentation of space. More than 100 years ago, a checkerboard pattern of lots interspersed with federal lands was given to private landholders and states based on the belief that this intermingling would be beneficial to all. Instead, it has exacerbated conflicts between users with different goals and made it difficult to preserve intact ecosystems at a meaningful scale. Over the last few decades, government agencies and private organizations like The Nature Conservancy have been trying to buy back some of these lands to consolidate protected areas. There is still time to avoid this kind of harmful fragmentation in the ocean by planning ahead.

Take chances with new ideas
When the old ways aren't working, try something different. This has historically been very difficult for government, but there are ways to make it more palatable. Pilot programs and small-scale tests, linked to measurable goals, pre-determined indicators, regular monitoring, and review can decrease the risk involved in adopting new approaches. (On a cautionary note, one expert notes that so-called "pilot programs" often develop a life of their own. They develop a cadre of beneficiaries and evade the kind of rigorous review that should lead to either wider adoption or cancellation.) One new idea in public land management involves shifting some functions from government regulation and enforcement to market-based mechanisms. For example, proposals have been made to require all forestry on public lands to meet third party certification standards. This approach could be helpful in the ocean as well, where independent organizations could develop standards for sustainable practices.

Wrestle with the tradeoffs between centralization and diversification of authority
For many of the issues discussed above, there appears to be fairly widespread agreement about better ways to move forward. But on one question, opinions are both divergent and strongly held: Is it better to have one agency administer a range of uses in a unified way or to assign an oversight agency for each use, with some mechanism for coordination?

The Joint Ocean Commission Initiative is advancing the unified, multiple-use model, advocating a stronger role for NOAA, plus Regional Ocean Councils that would oversee the full range of ocean uses. This is consistent with the holistic vision put forward by EBM and would help counteract historic fragmentation.

However, Josh Eagle (2006) makes a case for the opposing model of agency diversity. Based on an analysis of public lands management, he concludes that having a variety of agencies, each with a narrow mandate, (such as USFS, FWS, NPS) actually achieves better ecosystem results than a comprehensive, multi-use agency (such as BLM). Eagle finds that multiple-use agencies become overly influenced by organized economic interests, at the expense of less wealthy users and especially conservation advocates. The dispute about unified vs. dispersed management approaches is related to the earlier discussion about whether i-MSP should create single or multiple use zones. Eagle argues that the creation of single use zones, each with a corresponding regulatory agency, is the best way to level the playing field between all users and ensure that someone is looking out for conservation. "Agency diversity divides interests, clarifying and legitimizing perspectives and concerns, to help those interests conquer their differences."

He suggests that either (1) the mandates of existing land agencies should be broadened into ocean space or (2) an agency should be assigned for each ocean use, to be carried out in a specific, segregated ocean zone, as designated through a public process, and ratified by Congress. (Note: A third alternative put forth by Eagle is to create exclusive conservation zones, i.e., marine reserves, managed by one agency, and then let all other users find their places within the remaining multi-use zone, but he admits this is unlikely to gain broad support.)

Eagle's cautions should be heeded even if a multiple-use, unified management approach is pursued, by including provisions to prevent undue influence by specific industries and ensure sufficient provisions for protected areas.

IV. Bringing i-MSP to U.S. Waters

If we conclude from the preceding analyses that i-MSP may bring significant benefits in U.S. waters, how might it be achieved? The most foolproof approach would be to pass a federal statute that sets out goals (presumably some combination of conservation and economic development) and guiding principles (such as sustainability, transparency, stakeholder input, and adaptability), creates national guidelines for the process, and designates a responsible agency (or agencies). Based on that directive interagency bodies, probably at the regional level, would define the precise scope of the planning exercise (what areas and activities are included), and the procedures and timeline to be followed. Stakeholder and scientific advisory bodies would provide input along the way. Master Plans, zoning maps, and implementing regulations would be issued for each zone or activity, and all relevant authorities at the local state and federal levels would conform their actions to that plan. Unfortunately, "[in] public policy, there is often an inverse relationship between potential effectiveness and political feasibility" (Nie, 2008).

Given the huge political hurdles in achieving a comprehensive, national mandate for i-MSP, we will most likely need to pursue a variety of strategies—top-down, bottom-up, and sideways—to reach a similar endpoint. All the avenues that have been used to influence public policy on the land also exist for the ocean. At the federal level, the President and Executive Branch can exert control through appointments, Executive Orders, agency reorganization, regulations, studies, and planning. Congress's muscle comes from its ability to pass laws, confirm political nominees, oversee agency conduct, authorize budgets, and appropriate funds (including earmarks for pet projects and backdoor policy provisions). The Courts get to interpret the law through resolution of specific disputes. Each state has a parallel executive, legislative, and judicial system. Thus there are many ways for interested parties and the general public to influence policy at every stage of the process.

Outlined below are several options for advancing i-MSP in U.S. waters over the next five years, with comments on their strengths and limitations.

A. National legislation

Strong national legislation, including clear assignments of authority and an allocation of resources, would certainly be the most direct way to put i-MSP in place. As one agency manager said, “Without a legal requirement, agencies won’t take [i-MSP] seriously.” The governments of Australia, Canada, and Germany have required some form of marine planning, and Great Britain has similar legislation pending. But this approach is likely to be extremely difficult in a U.S. Congress where budgets are tight, a war is ongoing, climate change is the environmental issue of the day, and the level of interest in ocean issues is slim. One impetus for action could be the pressure to develop new sources of renewable energy offshore. Unfortunately, the intense controversy about the Cape Wind project off Nantucket forced quick, targeted action on that issue (as an amendment to the 2005 Energy Policy Act) without any debate about the broader problem of planning for all offshore uses. However, because of the continued need for Congress to resolve jurisdictional disputes between FERC and MMS concerning offshore renewables (see Box 3), another opportunity may arise to require integrated planning and inter-agency coordination.

For now, the main legislative vehicle for ocean governance reform is OCEANS21 (HR21) which is being actively promoted by the Pew Environment Program in coalition with NRDC, Oceana, WWF, Ocean Conservancy, and Ocean Champions. The bill was voted out of subcommittee in the summer of 2008, but stands little chance of moving farther this year. Although spatial planning is not mentioned explicitly in HR21, its proponents believe it will help advance that issue by establishing the principles of EBM in law. They argue that the practical implementation of EBM will then, inevitably, lead to calls for i-MSP.

Unfortunately, my interviews found little support for, and substantial antagonism toward, HR21 among users and managers:

“HR21 is a non-starter.”
“HR21 is too command & control oriented. It has too much baggage and a bad history with users and states.”
“They need to start fresh, with broader participation from the start.”
“HR21 will just be used to stop things. It gives NOAA too much control and new responsibilities that it’s not up to.”
“The idea of regional dialogue is good, but creating a new “box” with another layer of sign-off won’t help. Folks will get together where there’s a “community of practice” [i.e., common needs] and then small successes can catch fire. You can’t try to force that.”

Many of these perceptions reflect misimpressions about the current bill language as amended this session, but it appears to be too late to change these biases.

Other national legislative options were suggested by various interviewees, although none of them has been translated into specific bill language. Ocean industries like the idea of creating a clearinghouse to streamline all federal permitting for offshore activities. Representatives of state governments would like to get more federal support for their ocean and coastal activities, both in the form of dollars and help with data collection, but are reluctant to accept intervention or national standards in return: "The feds must accept that each state program will look different because of different approaches and authorities."

Several people noted that it would be helpful to find ways to piggyback on Congress's interest in climate change legislation. One such approach, being pursued by several environmental NGOs, is to get ocean and coastal ecosystems included in language about adaptation to climate change and eligible for use of possible "cap and trade" revenues.

In Great Britain (English Nature, 2006) planners have suggested that Parliament issue unified national ocean policy objectives (e.g., specific renewable energy targets, fishing and/or aquaculture quotas, etc.) which could then be implemented regionally. Although this would facilitate i-MSP by clarifying goals and prioritizing uses upfront, such centralized, top-down decision-making would be less useful in the U.S. and probably unacceptable politically. Unlike the small countries of Europe, U.S. waters vary widely from one coastal state to the next in their bathymetry, their coastal population density, and their political landscapes. As discussed previously, stakeholder involvement will be key in setting regional goals for i-MSP in the U.S. and ensuring support from all participants.

One ocean-related bill under active discussion is reauthorization of the Coastal Zone Management Act (CZMA). Suggestions have been made that EBM concepts could be incorporated into that Act, with language that would encourage state and regional ecosystem assessments, goal setting, planning, and performance standards. One state manager felt that some of their most positive interactions with federal agencies have centered on CZMA implementation and these relationships could be the springboard for broader cooperation. Others, including some environmental NGOs, are strongly opposed to this approach, believing that CZMA is not a suitable vehicle for fundamental reform of ocean governance and fearing that it would distract lawmakers from the central debate about HR21. Any broadening of CZMA's scope also runs the risk of getting bogged down in additional Congressional committees. All things considered, it would be a mistake to ignore *any* ocean-related legislative opportunity. CZMA reauthorization will move ahead in the next Congress: those who support i-MSP should make sure the concept of long-term, multiple-use spatial planning is included in any discussion about coastal management. The Coastal States Organization would be a logical partner in this effort since CZMA is a high priority for them and they have also expressed interest in marine planning.

Another possible target for Congressional action is agency reorganization. (Although elements of reorganization can be achieved through Executive Orders, it is seen as more credible and longer lasting when it comes from Congress.) Merging, streamlining and clarifying various agency authorities could make implementation of i-MSP much easier, even without specific legislation requiring such planning. Suggestions for agency improvements include clarifying NOAA's mandate and getting rid of its current line office structure. One user thought that NOAA would be better off in the Department of the Interior "where they understand resource management," and a DOI staff person echoed that by suggesting that "all fisheries, wildlife, and other resource management should be together under one roof." However, an oft-repeated (if perhaps overly cynical) reaction to such suggestions is that the creation of the Department of Homeland Security—and its rocky performance—depleted Congress's interest in any further agency reorganization so this approach would probably not be fruitful right now.

As one experienced observer noted, "To get anywhere with Congress, politicians need to know precisely what problem is being fixed, what it will cost, who benefits or loses, and when results will be seen." Equally important, they must hear these facts from constituents they care about and trust. Based on my research, and the work of many others, I believe we can begin to make a solid case for i-MSP. But credible spokespeople are in short supply. Now is the time to start building broad support for a new ocean governance bill that includes i-MSP, to be introduced in a new Congress, preferably representing consensus language from a "coalition of the unlike" (see section above on Lessons Learned from Public Lands Management). The need for coalition building is discussed further below.

B. Reinterpretation of existing authorities

A number of experts believe that substantial progress can be made toward i-MSP based on existing laws, management mechanisms, and programs. Options include issuance of Executive Orders or other administrative actions (the Dutch approach), enhanced cooperation between existing agencies (as done in Belgium), and more expansive interpretation of current laws, forced through litigation if necessary.

Creative state and local efforts that involve elements of spatial planning but fall short of true i-MSP—such as the MLPA process in California, fish and wildlife plans for marine areas in Florida, essential fish habitat planning processes under the MSA, or the eco-regional assessments and planning being spearheaded by The Nature Conservancy—provide a wealth of experience on which we can build.

A recent thorough review of existing laws and their adaptability to EBM and ocean zoning identified many promising opportunities (Parenteau et al, 2008). The authors conclude that EBM can be implemented now in the U.S. through determined and better coordinated application of existing agency authorities (including the Marine Mammal Protection Act, Endangered Species Act, Magnuson-Stevens Fisheries Conservation and Management Act, Outer Continental Shelf Lands Act, Coastal Zone Management Act, Clean Water Act, Clean Air Act, National Marine Sanctuaries Act, and National Environmental Protection Act). The main missing element has been Executive branch commitment and leadership. The authors suggest that an Executive Order could make a huge difference, simply by directing all federal agencies to use the full extent of their authorities and resources to advance EBM and to prohibit actions that impede it. An inter-agency body under the Council on Environmental Quality (similar in structure to the current Committee on Ocean Policy) could oversee development of spatial plans for each LME, working with stakeholders through regional councils. Then each agency would exert its existing authorities in keeping with the plan. A number of the agency managers I spoke with agreed that much more could be done under current law if they received support from their political leaders. A cautionary note was raised by one interviewee noting that if individual agencies continue to regulate different activities, even within designated zones, overall impacts will need to be monitored and controlled. Similar to the TMDL concept, broader area-based environmental standards will be needed, and a mechanism created for agencies to work together to achieve them.

The existing White House ocean coordinating mechanisms (the alphabet soup of COP, ICOSRMI, SIMOR, and JSOST[†]) are not viewed as being terribly effective. One insider noted that “high-level people don’t show up and there’s no clear agenda.” The subcommittees can be useful when several agencies share a specific common need, but they have not been drivers for change since they possess neither carrots nor sticks to offer reluctant agencies. More than one person commented that it would take a White House appointed “Ocean Czar” to reinvigorate the interagency structure. One agency manager familiar with the process thought that COP’s location in CEQ could at least give it a built-in mandate to improve NEPA implementation, including a greater emphasis on cumulative environmental impact assessments. It remains to be seen whether the new administration will maintain or strengthen this coordinating structure.

The National Marine Sanctuaries Program was mentioned by a number of respondents as a possible test bed for i-MSP, with statements such as “[The Sanctuaries Program] is the best, maybe the only, existing framework for doing EBM across state-federal boundaries,” and “sanctuaries could be a starting place for federal marine planning.” The related NOAA effort to create a national network of MPAs was also identified as a possible avenue for broader planning, “if it ever gets more funding or energy.” Although specific Sanctuaries could serve as interesting test sites for i-MSP, it is very unlikely that this small NOAA program, whose mission is to create and oversee protected areas, would be the best home for truly integrated i-MSP in the long run.

One provision of the Energy Act of 2005 created pilot projects within which agencies work together as a team under one lead agency to issue certain offshore oil and gas permits. So far, industry is pleased with this streamlined one-stop system, and suggests that the model could be extended for other uses, each with an appropriate lead agency. Such an approach does not constitute true i-MSP since it remains sector-based, but its acceptance may open the door for similar multi-agency test projects.

[†] The Committee on Ocean Policy (COP), the Interagency Committee on Ocean Science and Resource Management Integration (ICOSRMI), the Subcommittee on Integrated Management of Ocean Resources (SIMOR), and the Joint Subcommittee on Ocean Science and Technology (JSOST).

In the waning days of the current administration, we are unlikely to see progress on any of these administrative options. But a new White House (including a raft of new agency heads) will take over soon, and both major party candidates have expressed a commitment to environmental issues. To get ahead of the game, proponents of i-MSP should use the next 6-12 months to become unified behind a few well-developed proposals that could be presented to the new leadership, including appointment of a high-level White House point person on oceans, a renewed commitment to the CEQ/OSTP interagency coordination process (including funds and a list of action items with deadlines), and specific direction to the agencies to work together on an i-MSP pilot, most likely off New England or the West Coast.

C. State and regional level strategies

In a country as large as the U.S., with 3.4 million square nautical miles of ocean space in its Exclusive Economic Zone, it would be almost impossible to implement i-MSP in all regions at once. Proceeding at smaller scales has the advantage of greater feasibility, lower cost, and an ability to test concepts that can inform subsequent national action or legislation. Fortunately, this experimentation is already taking place in a number of states and regions. If certain models prove successful, the states involved will be in a good position to pressure federal authorities to harmonize planning in the EEZ adjacent to state waters.

One existing authority which might be put to greater use at the state level is the Public Trust Doctrine, a legal principle derived from English Common Law and further interpreted by the U.S. courts. The essence of the doctrine holds that the tidal and navigable waters of each state are a public resource owned by and available to all citizens for the purposes of navigation, commerce, recreation, and fishing. In many places the doctrine has been expanded by the courts to include a broader state interest in protecting the environment. A report of the U.S National Project on the Public Trust Doctrine (cited in Bray, 1998) pointed out that, "area-wide management programs may be structured, using the public trust doctrine … to encourage comprehensive management over lands, waters and resources within the area, and thus avoid the limitations inherent in ad hoc permitting decisions."

Below is a brief roundup of some of the more interesting developments taking place at state and regional levels. (This is by no means a comprehensive review of all relevant state coastal and ocean management efforts.) There are many ways that GBMF and others can nurture these budding efforts, but one of the most important may be to help like-minded state managers and coalitions to learn from each other’s efforts. I was repeatedly surprised in my interviews at how little each state’s leaders and activists seemed to know about developments elsewhere. A success in one place can be hugely instructive and encouraging in less receptive political environments.

Massachusetts
Efforts to advance i-MSP in Massachusetts have been developing over several years. Finally, in May 2008, Massachusetts passed the Oceans Act, which calls for creation of an ocean management plan to guide development, including renewable energy, in state ocean waters. Advocates worked hard for passage of the bill and hope to stay closely involved in the planning process. Although fishing activities are exempt from both the planning effort and associated user fees, and several already-permitted LNG terminals will go ahead in advance of any planning, this bill still constitutes an important step forward for i-MSP in the U.S. As one state manager said, “For too long we’ve been reactive to proposals. Now we’re thinking ahead.”

As in many states, the need for legislation was made more urgent by active requests to site offshore renewable energy facilities, but the plan being created now (and due in draft form by late 2009) will address all existing and foreseen uses. Although there will be opportunities for stakeholder input, leaders in the Office of Coastal Zone Management make it clear that this will not be a consensus process—ultimately they are responsible for making decisions and designating zones. Ecosystem protection is an overarching theme in the legislation, so the agency intends to start by identifying areas in need of protection, and then locating other functions around them.

The Massachusetts Ocean Partnership is a multi-sector coalition that has been working for three years to build bridges among the state’s ocean constituencies, in anticipation of the legal mandate for comprehensive ocean planning. Their role in the next phase of activities is not yet clear. One interviewee complained that “MOP outcomes do not match up with management needs” and hoped that it would become more directly supportive of the state-led process.

Rhode Island
Although overshadowed by ocean activities in larger nearby states, RI is in the vanguard of ocean planning. The state’s Special Area Management Plans (SAMPs), which have been around for 30 years, are now being used to create a complete system of ocean zones. As part of RI’s CZMA planning in the 1980s, the state’s Coastal Resources Management Council (CRMC) first zoned all coastal ocean areas, ranging from Type 1 areas that received the highest level of protection to Type 6 areas designated for industry and transportation. As part of that original process, areas deeper than 500 feet were assigned as Type 4, for multi-purpose use. It is those areas that are now being re-assigned to more specific use designations.

Requests to site offshore wind energy farms were the primary impetus behind the new process—and that industry is paying for a large portion of the environmental assessments—but the zoning exercise will cover all existing and predicted uses and leave room for the future. The head of the CRMC, who is very supportive of the planning effort, told me that when political leaders push him to site wind energy facilities right away he responds: “That would be like trying to choose the best place for a shopping center in a vast undeveloped land parcel.” One advantage for marine planning in RI is that the CRMC serves as both the regulatory agency and the submerged lands agency, with authority over coastal and ocean areas and the ability to regulate upstream activities that affect the coast. This consolidation eliminates the inter-agency conflicts present in some other states.

Another noteworthy aspect of RI's effort is the explicit incorporation of climate change and its impacts: planners are assuming a sea level rise of 3-5 feet by 2100, probable ecosystem changes due to temperature increases, and the likelihood of more and stronger storms. The RI legislature has been generally supportive of long term, thoughtful planning, but budgets are tight and funding levels will determine the pace of progress.

New York
As evidence that competition and state pride can work as positive motivators, coastal managers in New York insist that they (not Massachusetts, Rhode Island, or Oregon) have "the only statutory charge in the nation to do multiple-use ocean management." (One insider pointed out there is no specific legal requirement for comprehensive ocean planning, but was pleased to hear that the implementing agency is interpreting their mandate broadly.)

The Ocean and Great Lakes Ecosystem Conservation Act, passed in 2006, established a multi-agency Ocean Council, chaired by the Department of Environmental Conservation and staffed by the Department of State. For now, the Council is overseeing two pilot EBM projects (building on existing EBM projects initiated by The Nature Conservancy), creating a research and monitoring plan, assembling a coastal atlas, establishing statewide EBM guidelines, setting up internet-based "communities of practice," and requiring every state agency with coastal or ocean responsibilities to review all its programs and provide lists of additional actions that the Executive branch could take to advance EBM over the next two years. Above all, the aim of the Council is to create a new culture of collaboration and change the decision making process. Here again, political pressure to advance alternative energy, particularly offshore wind power, provided the initial incentive for action.

Over the next two years a working group of the Council has been directed to draft a spatial plan, "from the watershed to the edge of the EEZ," including specific goals and metrics. (Although the drafters realized that state authority is limited outside the state's territorial waters, they were concerned about future growth in the EEZ and want to make their vision clear in advance of any action at the federal level.) The working group will also make recommendations about legislative or jurisdictional changes needed to implement the spatial plan.

New Jersey
Spurred on by permit applications for offshore wind farms and the actions of its neighbors, NJ is just beginning to look at offshore planning. The legislature established an ocean council to make recommendations about marine EBM, but participants and observers expect slow, cautious progress.

California

California's state waters are already busy places and activities are increasing, with recent proposals for LNG terminals, desalinization facilities, and wave energy turbines. However, integrated spatial planning is not being pursued, in part because the ongoing effort to site MPAs pursuant to the MLPA has been so time consuming. Several active participants in that process are adamantly opposed to looking at a broader spectrum of ocean uses until the network of protected areas is completed. Although the MLPA has been effective in protecting a number of sensitive marine ecosystems, an argument could be made that this limited approach is no different from FERC and MMS efforts to site offshore energy facilities without considering other priorities for ocean space (such as MPAs!). In the long run, a multiple use planning process could prove more economically and environmentally effective, as well as less adversarial.

A recent detailed legal analysis (Sivas and Caldwell, 2008) explores options for moving toward ecosystem-based ocean zoning in California waters. The authors are thorough, thoughtful, and creative, and their recommendations should be valuable to anyone thinking about i-MSP. However, it is worth noting that the article, particularly in its lists of desirable legislative attributes and good governance principles, conveys an unequivocal conservation perspective, with much less emphasis on the value of economic development. In general, similar ocean policy papers emerging from Europe strike a more balanced tone. California has traditionally been a test bed for innovative policy ideas and a move toward i-MSP there would be very influential nationally.

Oregon

Since 1973, Oregon has maintained an ambitious statewide program of land use planning. At the heart of that program are nineteen Statewide Planning Goals that express the state's policies on land use and related topics, such as citizen involvement, housing, and natural resources. Most of the goals relate to land-based activities, but Goals 16-18 address estuaries, beaches, and shores, and Goal 19 calls for "[conservation of] marine resources and ecological functions for the purpose of providing long-term ecological, economic, and social value and benefits to future generations."

The state's Territorial Sea Plan (TSP) was originally issued in 1976 to implement Goal 19, and has been updated several times since under the auspices of an interagency Ocean Policy Council. Now the TSP is being significantly revised to address the coordination of growing offshore uses. The plan does not alter existing agency authorities, but all regulatory actions must be consistent with the plan. (Unlike RI, Oregon divides ocean responsibilities between the Department of State Lands, which controls the ocean bottom and regulates many offshore activities, and the Department of Land Conservation and Development, the planning agency. Fishing and boating are regulated separately, as in many states.)

Agency managers describe an interesting evolution in their approach to ocean management over the last few years. In the late '90s, then Governor Kitzhaber called for establishment of a network of MPAs off Oregon's coast. The agencies were attempting to implement that mandate, in the face of heavy resistance from the fishing industry which was reluctant to share spatial information about their activities. (One environmental NGO described the original MPA siting process as "unworkable.") Several years later, with new Governor Kulongoski in office, FERC received a number of permit applications for wave energy facilities in state waters and proceeded to consider them, with little input from the state (see Box 3). That threat to their space prompted fishermen, and many other interested parties, to come back to the table in a more cooperative state of mind, asking the state to produce a coordinated ocean management plan (a revised TSP) in which renewable energy would be just one player. The state has now signed an MOU with FERC to allow time for the new TSP to be completed before any facilities are permitted.

The manager of the current process says that he "fully expects to produce actual maps, at least for MPAs, fisheries, and renewable energy, with room left for future uses." But another state agency staffer expressed concern that "this process will take leadership and courage" fearing that, once uses are tentatively assigned to certain areas, conflicts will be perceived and opposition will solidify. The revised draft TSP is due to be issued in early 2009.

New England/Gulf of Maine

The states and provinces bordering the Gulf of Maine have a long history of cooperation. The Gulf of Maine Council on the Marine Environment was established in 1989 by the Governments of Nova Scotia, New Brunswick, Maine, New Hampshire, and Massachusetts to foster cooperative actions within the Gulf watershed. Its mission is to "maintain and enhance environmental quality in the Gulf of Maine to allow for sustainable resource use by existing and future generations." One of the Council's projects is the Gulf of Maine Mapping Initiative, a partnership of government and non-governmental organizations conducting comprehensive seafloor imaging, mapping, and biological and geological surveys. The Initiative aims to produce maps of bottom type and topography throughout the Gulf basin.

The more recently formed Northeast Regional Ocean Council (NROC) is a partnership of six New England states (Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, and Vermont) with a similar aim, "to provide regional long term protection of ocean resources, balanced use of those resources for economic and ecological benefits, and a coordinated approach to finding and implementing solutions to our most pressing problems." The Nature Conservancy's ongoing marine regional assessment process should be helpful in bringing together data in an integrated manner across federal and state levels. NOAA and DOI serve as federal co-leads for NROC's supporting Northeast federal interagency team, which includes ten SIMOR member agencies and receives praise from state-level managers. To date, NROC has focused primarily on cementing relationships and connections among the different players, but they hope to develop more concrete plans over time. With two NROC members, Massachusetts and Rhode Island, in the forefront of spatial planning in their state waters, this region should have a head start toward comprehensive i-MSP.

Mid-Atlantic Region
Monmouth University's Urban Coast Institute has convened state managers and non-profit groups in the Mid-Atlantic region to promote EBM-oriented, multi-issue "regional governance" (adopting the Ocean Commission terminology). The organizers have not fully embraced the notion of i-MSP, but they believe that a lot can be accomplished simply through more proactive application of existing laws and improved coordination.

Gulf of Mexico
The Gulf of Mexico Alliance was established by the Governors of Alabama, Florida, Louisiana, Mississippi, and Texas in 2004, responding at least in part to recommendations from the U.S. Commission on Ocean Policy. In 2005, thirteen federal agencies coordinated by EPA and NOAA convened a corresponding Federal Workgroup to support and work with the Alliance. They have held several large meetings and issued an Action Plan that calls for coordinated science, improved Gulf water quality, and wetlands restoration but environmental NGOs in the region have generally been disappointed by the narrow agenda and limited progress.

The Harte Research Institute in Texas has played a significant role in encouraging and facilitating the Alliance. One professor there felt that the political climate in the Gulf States, which is generally pro-development and anti-government, would make it more difficult to advance i-MSP. In Texas, for example, the entire territorial sea (out to 10.3 miles) is now open for bids from offshore wind companies. This area overlaps with oil and gas leasing areas and the construction of wind farms could also have major effects on shrimp fisheries, but there has been no attempt so far to address these potential conflicts. Emphasizing the need for fairness among commercial users in the Gulf region is likely to be more effective than stressing the broader value of planning and regulation.

West Coast
The West Coast Governors' Agreement on Ocean Health, signed in September 2006, establishes a regional mechanism to collectively advance the goals of: clean coastal waters and beaches; healthy ocean and coastal habitats; effective ecosystem-based management; reduced impacts of offshore development; increased ocean awareness and literacy among the region's citizens; expanded ocean and coastal scientific information, research, and monitoring; and sustainable economic development of coastal communities.

A draft Action Plan, released in October 2007, set out specific actions needed to implement the goals. Although the Plan does not mention spatial planning or zoning, proponents of i-MSP could make a good case that a number of the items in the Action Plan would be well-served by such an approach, in particular:

- "Examine ongoing community-based efforts using ecosystem management principles in all three states and share lessons learned from these initiatives in order to encourage effective ecosystem-based management efforts across the West Coast;
- Explore the feasibility for offshore alternative ocean energy development and evaluate the potential environmental impacts of these technologies;

- Complete a seafloor map of the bathymetry and habitat of all state tidelands and submerged lands out to three miles; and
- Establish baselines for coastal economies and promote sustainable coastal community development."

MMS is hosting a series of workshop on alternative ocean energy which was tagged as a critical element of the Governors' Agreement. These will be excellent opportunities to raise questions about how offshore renewables will fit in with other proposed uses.

D. Stakeholder dialogues and public education

In the U.S., the concept of i-MSP is still virtually unknown outside a limited circle of ocean policy aficionados who talk to each other and read each other's papers. As a necessary complement to any legislative, administrative, or state-level efforts, i-MSP proponents need to explain the value of i-MSP to a broader audience of managers, ocean users, and coastal communities. Even in countries that have legislative mandates in place, like Canada and Australia, planning is falling significantly behind schedule due to the absence of political or public pressure. In one state that is trying to implement ocean planning, the project manager said, "there are plenty of supporters for MPAs, funded by foundations, but we need credible folks to support the bigger idea of marine planning."

i-MSP is probably not an appropriate topic for a major media campaign aimed at the general public, and no one would expect marine planning to become a daily subject on talk radio. Rather, a targeted, strategic communications plan should be designed that would speak to coastal and ocean managers, federal, state, and local politicians with an interest in ocean issues, coastal residents who are active in local and state politics, conservation groups, and the ocean industry and user community.

This campaign should be accompanied by focused stakeholder dialogues, conducted in small groups, with clear ground rules (including confidentiality) and professional facilitation. The purpose would be to air participants' perspectives and concerns, identify trouble spots, and find areas of common ground. One potential participant in such a process suggested that dialogues would be most useful if they involved realistic planning exercises for some portion of ocean space: "Don't let them devolve into a clash of 'I wants' among different sectors." Another individual suggested that the relatively new regional ocean coordinating bodies (in New England, on the West Coast, and in the Gulf of Mexico) could be suitable hosts for these conversations.

Although a few non-profits and academic policy centers (e.g., NRDC, TNC, and the Nicholas Institute at Duke University) have shown an interest in i-MSP, and some are advancing spatial planning projects at international or state levels, no one has yet made it a signature national issue or devoted sustained resources to advancing it throughout U.S. waters. In fact, the very nature of i-MSP, with its emphasis on multi-stakeholder, mixed-use, economically and environmental sustainable planning makes it hard to see where its natural home would lie. The Joint Ocean Commission Initiative could be a suitable host because of its multi-sector composition, but to date it has focused primarily on regional ocean governance, rather than i-MSP. The Coastal States Organization has expressed some issue in the issue but again, they represent just one of the many constituencies that need to be involved.

Another potentially intriguing new player is the World Ocean Council (WOC), which has been simmering for 12 years on the international scene and is poised to become more visible. According to its founder, WOC is a consortium of "ocean businesses who want to do the right thing," including representatives from the shipping, oil and gas, fishing, aquaculture, and tourism industries who are committed to stewardship and sustainability. Its goals are to 1) determine shared ocean industry issues, 2) pursue dialogues to address conflicts within the private sector, 3) improve practices, standards, and certification programs for ocean industries, 4) foster better interactions with other ocean stakeholders. A partnership between the WOC and an environmental NGO could potentially break new ground.

E. Funding

In an era of tight government budgets, new programs struggle to find support. Every manager I spoke to who is attempting to implement some type of marine spatial planning complained of utterly inadequate funding. Most said they were "borrowing" funds and staff from other programs, applying for federal and private sources of support, getting pro bono help from universities, and pursuing whatever other tactics they could think of to move forward with their goals. Funding shortages are particularly acute for data collection, mapping, and ecological assessments. This situation leads to two questions: how much will it actually cost to support i-MSP, and where might those funds be found?

(i) The cost of i-MSP

Getting accurate estimates of the costs involved in a thorough marine planning and zoning process would be a major undertaking and was not included in the scope of this research effort. To get started, one would need to determine which elements to include in the cost estimate. Should i-MSP bear the costs of all coastal and seafloor mapping, environmental assessments, and stakeholder dialogues? And should the analysis assume that these elements will be carried out by agency staff, private contractors, non-profits, or universities? The answers to these questions will have huge impacts on the ultimate cost estimates. Moreover, each state or region is likely to be so different in its oceanography, user community, agency capacity, data holdings, and other factors, that the notion of estimating a "price per square mile zoned" is probably unrealistic.

In any case, it is safe to assume that a complete, well-run i-MSP process will cost more in the short term than the current piecemeal approach to ocean management. The tougher task, then, is to estimate the likely long-term *benefits* of i-MSP that justify the expense. Many of those benefits are outlined in an earlier section of this report, although it will be difficult to assign dollar values to items such as "reduced conflict." Here again, it may be helpful to look to the history of public lands management which has struggled with similar issues of cost-benefit analysis.

(ii) Sources of funding

A major outstanding question that has not yet been thoroughly explored is whether, or how, i-MSP could be supported by revenues from the use of ocean space. The existing offshore oil and gas industry pays substantial royalties to the federal government, a portion of which is shared with nearby states. On the other hand, the commercial fishing industry does not pay any rent for its use of publicly-owned ocean space and resources. The U.S. Commission on Ocean Policy recommended that Congress establish "a policy that requires a reasonable portion of the resource rents derived from [offshore] activities to be returned to the public" and called for the creation of an Ocean Trust Fund that would receive such revenues (U.S. Commission on Ocean Policy, 2004). (A similar approach was attempted in 1965 with creation of the federal Land & Water Conservation Fund. That Fund was intended to use a portion of OCS revenues to support federal and state public land acquisition and conservation. Unfortunately, Congress has frequently diverted these funds for other purposes. Any legislation intended to fund i-MSP efforts would have to address this problem.)

Many mechanisms could be devised to compensate the public for private use of the commons, but no one seems to be suggesting a pure free-market approach where ocean space would be auctioned to the highest bidder, since that would almost certainly not meet broader policy objectives, especially the desire to conserve ocean ecosystems. MMS is looking at possible fee schedules for offshore renewable energy facilities under its new program, but said "royalties will probably not be keyed to fair market value, as they are for oil and gas." Some states are considering similar fees for activities in state waters, although managers seemed very unsure about how they would determine a reasonable cost structure and how users would react. In Oregon, the owners of undersea fiber optic cables pay for 20-year leases, while royalties of 3-6% of net revenues are being considered for new wave energy installations. The new Massachusetts legislation creates an Ocean Trust Fund that receives the mitigation fees from ports and LNG terminals, but these will not be large amounts. No decision has been made about a broader structure of fees/royalties/or rents for offshore users in Massachusetts.

Looking back to lessons from land use planning, practitioners there found that the best way to attract increased public funding for conservation was to present a clear case for the *value* of healthy ecosystems to local economies. The same is likely to hold true in the ocean context. By collecting and disseminating information about the value of ocean resources and ecosystem services (including food, recreation, flood control, water quality, storm protection, etc.) and then showing how better planning can ensure the continued availability of these benefits, advocates can increase public support for i-MSP and create political pressure at budget time.

F. Tools and data

Ideally i-MSP should be accompanied by a thorough analysis of the relevant ocean region, including studies of its physical, chemical, and biological characteristics, an inventory of all the uses projected to take place in that region, an examination of how all the uses and ecosystems interact with each other, and an iterative process of testing out the results of different spatial allocations. Very little of that information is readily available to managers in most places, nor do they have the tools they need to process the information into useful scenarios and maps.

On the other hand, a number of managers made the point that agencies *always* operate with insufficient data and it would be a mistake to wait for complete information before attempting i-MSP. In fact, several supporters of i-MSP wondered whether it is being held to a higher standard (requiring extensive data collection, adaptive management, and broad stakeholder buy-in) than the status quo alternatives to which it is being compared.

(i) Data and Mapping

Ocean and coastal managers always wish for more complete three-dimensional, GIS-based data on ocean bathymetry, habitat type, species composition, and human factors, including ocean uses, relevant laws, economic impacts, and links to communities.

The most basic need, and one which could long ago have been met, is for accurate sea-floor data. Available ship-based multi-beam sonar technology can produce detailed and accurate seafloor maps that include both bathymetric data and information about the composition of the seafloor. However, a 2004 report from the National Research Council found extremely uneven coverage of the country's coastal areas and EEZ. At least 15 federal agencies are involved in coastal and ocean mapping activities, often with responsibilities shared among several divisions within the same agency. Many state and local agencies, academic institutions, and private companies also undertake mapping and other data collection efforts. As explained in Congressional testimony explaining the NRC report, "the result has been an inefficient and often chaotic collection of potentially overlapping, and often uncoordinated offshore mapping datasets and products that have been wasteful of resources and frustrating to users." The U.S. Commission on Ocean Policy (2004) also recommended that federal agencies should "coordinate resource assessment, mapping, and charting activities with the goal of creating standardized, easily accessible national maps that incorporate living and nonliving marine resource data along with bathymetry, topography, and other natural features."

In response to the NRC and Commission reports, the Federal Geographic Data Committee's Marine and Coastal Subcommittee, along with the Office of Science and Technology Policy's Interagency Working Group on Coastal and Ocean Mapping, are working to integrate and coordinate all federal marine data collection and mapping efforts. Unfortunately, a staff member at one of the agencies involved said that "coordinated assessments and mapping are very difficult and are not really happening. Each agency [USGS, MMS, and USACE] has different program needs, and there are conflicts about who pays and who gets the credit." One development that may help was a requirement in the 2005 Energy Act for the Departments of the Interior and Commerce and the Coast Guard to create a "multi-purpose marine cadastre" to support the MMS offshore renewable energy siting process. The agencies are using this mandate—and the money that accompanied it—to collect a range of data in both state and federal waters.

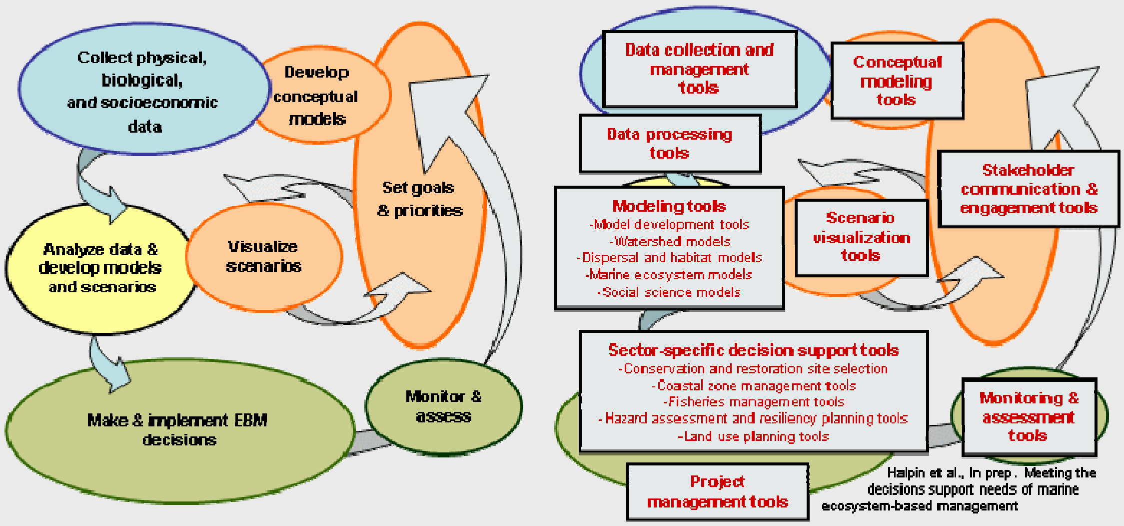
The methods of collecting ocean-related data (satellites, coastal radar, airplanes, ships, written and phone surveys, personal interviews, tax and business records) are as varied as the kinds of data needed. The two most pressing needs expressed by managers are for ecological information (species composition and habitat location) and spatially-linked socio-economic data. Certainly more funding is needed to fill in the blanks in our ecosystem maps, but the collection of socio-economic data is even trickier. Some of the most innovative work being done in the field of ocean mapping involves efforts to link activities in the ocean to related land-based communities and decision-making bodies (St. Martin, 2008).

Some suggestions for improved ocean data collection that emerged from the interviews include: making the Ocean Observing System (an expensive project being designed mainly for research purposes) include more management-oriented measurements; pushing NOAA's regional science centers to undertake regular *ecosystem* assessments, not just commercial fish stock assessments; and encouraging more state/federal/private partnerships for ocean data collection. In a number of regions, The Nature Conservancy's eco-regional assessment program has been able to gather much of the available information into one database, working closely with government agencies and others. The "Holy Grail" for ocean managers would be to have one unified, GIS-based, web-accessible database of features, uses, resources, and human factors throughout U.S. waters that could be depicted as different layers on a universal base map. That goal is unlikely to be reached anytime soon without significant investment by the federal government and/or ocean industries.

An artificial distinction is sometimes made between "data" and "maps." A map is simply the visual representation of spatially-linked data. GIS-based mapping capabilities are well-developed and readily available (if not always entirely user-friendly). Technical mapping expertise is widely available (for example, at Lamont-Doherty Earth Observatory, the Center for Coastal and Ocean Mapping at the University of New Hampshire, the U.S. Geological Survey, Duke's Marine Geospatial Ecology Lab, and NOAA's Coastal Services Center) but maps are only as useful as the data that underpin them, which remain all too sparse as discussed above.

(ii) Analytic tools

A number of software tools have been developed to help managers and stakeholders analyze available data and compare different scenarios for the future. Up until now, this sort of spatially-explicit, multi-criteria analysis has been used primarily to site MPAs in a way that maximizes ecosystem protection while minimizing disruption to fishing and navigation. Of course, the task becomes much more complex when a multitude of ocean uses is being accommodated and a larger set of objectives must be optimized. Figure 1 illustrates the main steps for managers wishing to undertake ecosystem based management or i-MSP and the tools needed at each stage.



a. EBM steps **b. Tools needed at each step**

<u>Figure 1.</u> Opportunities for EBM Tools
Fig. 1a. shows the different steps needed to accomplish ecosystem based management and 1b. lists the kinds of tools needed at each stage. (from Halpin, et al in prep., downloaded at http://www.ebmtools.org/about_ebm_tools.html)

Analytic tools can serve two purposes: improving decision makers' understanding of the ocean area, uses, and impacts under discussion and helping to inform and engage stakeholders. As observed in the context of land use planning, when all affected parties are given good information and can readily see the implications of proposed management actions, the chances of acceptance and eventual compliance are greatly enhanced.

Managers interviewed expressed different views about the need for additional tools. Several felt there were plenty of analytic methods, but not enough underlying data to feed into them. Others seemed quite vague about how analytic tools could even help them. A survey conducted by the EBM Tools Network (www.ebmtools.org) identified four major problems for managers: insufficient funding and staff to acquire and effectively use tools, lack of consensus about which methods to use, insufficient cooperation between agencies supplying the underlying data, and lack of basic knowledge about the ecosystems being affected. The Network concluded that additional training is needed to help managers deploy decision-support and scenario visualization tools, analyze the socio-economic impacts of management, and better engage stakeholders.

One coastal manager, tasked with overseeing an ocean planning process, reacted with particular vehemence when asked about the availability of analytic tools. This person felt they do *not* have what they need for trade-off modeling and scenario visualization. Instead, they are being forced to make do "with tools that were not designed for managers [such as The Nature Conservancy's ecosystem assessment models] or to work with university-based researchers who don't appreciate real-world deadlines." This manager was clearly frustrated, and longed for increased funding that would allow managers to set their own specifications for tools and insist on timelines for their delivery.

The EBM Tools Network is a tremendous resource, including a database of hundreds of potentially useful software packages and a program of outreach and training for managers. But to make i-MSP less daunting, we will need to select a handful of proven modeling, scenario analysis, and visualization products (under guidance from real-world managers in the U.S. and abroad) that can be standardized, documented, and disseminated with clear training protocols. If i-MSP is to be widely implemented, we will need to graduate from the fascinating chaos of the academic world to the accessibility and universality associated with standardized business software packages.

V. Observations and Conclusions

The research and analysis outlined in this paper lead to a number of conclusions and raise some interesting questions. First and foremost, there is a growing body of evidence, from scholarly studies and a limited set of international examples showing that i-MSP can be an effective tool for managing burgeoning demands for ocean space. This section focuses on specific action items that might be pursued by the Moore Foundation and its grantees to refine i-MSP and advance its practice throughout U.S. waters.

Perhaps the most important observation, echoing lessons learned from management on land, is that there is no silver bullet. By pursuing multiple lines of attack, we can hedge against uncertainties and take advantage of the varied skills and personalities of i-MSP's advocates to advance this approach in U.S. waters. Academics can refine concepts, GIS professionals can improve maps and other tools, NGOs can engage the public and advocate for change, and states can experiment with different approaches and share successes and challenges. The history of the environmental movement and other efforts at social change tells us that the best laid plans can encounter obstacles, while champions can emerge from unexpected places.

Many advocates for i-MSP have come to it as an extension of their interest in marine conservation and specifically EBM (e.g., Sivas and Caldwell, 2008). In some cases, i-MSP has been explicitly equated with the movement to control fishing and site more MPAs (Norse, 2005; Agardy, 2007). But the value of i-MSP is that it moves beyond a traditional "us vs. them" approach. It embodies the premise that marine protection is one "use" of ocean space, albeit a fundamental and extremely important one, but that economic development is also legitimate and valuable. If it's wrong for fisheries, renewable energy, LNG terminals and other specific users to make end runs around a broader, integrated planning process, then it's also problematic to advocate the creation of MPAs without placing them within a long-term vision that considers all users.

To date, EBM/ABM/i-MSP meetings in the U.S. have included primarily academic, government, and environmental group representatives. Even this project heard from only a limited set of ocean users (primarily fishing, oil & gas, renewable energy, and aquaculture). A broader range of perspectives must be brought in quickly to avoid allowing i-MSP to be branded as an academic concept or environmentalists' strategy. One of the clearest lessons learned from land use planning and from the few i-MSP efforts already underway is that a clear, open, inclusive process has lasting value. One obvious next step then, is to begin to convene inter-sector and inter-agency dialogues, preferably assisted by user-friendly spatial planning and visualization tools, drawing from the full range of ocean stakeholders listed in Box 2. If a diverse group can articulate a shared, balanced vision for the future of their ocean region, the first step toward i-MSP will have been taken.

To draw new voices into the conversation, we will need to reach out actively to ocean industries, agency staff, and elected representatives at all levels with clear, accessible, consistent information about the goals and potential benefits of i-MSP. A small but diverse group of speakers carrying a consistent message would be extremely valuable in introducing new audiences to i-MSP and making them comfortable with the concept.

With a few exceptions, I found that analogies to the more familiar concept of land use planning can be very useful in raising people's comfort levels and breaking down possible mistrust of i-MSP. In many coastal regions, the public and its elected leaders believe that land use planning has helped them create a shared vision of community and prevent unwanted sprawl. Making i-MSP an extension of this experience should ease the way. (Although we have seen that i-MSP bears a greater resemblance, legally and technically, to the management of public lands, that history does not evoke the same positive associations as city planning.)

One potentially controversial question will be whether to include the offshore oil and gas industry in stakeholder dialogues on i-MSP. Conservation groups and many states hold to the existing offshore drilling moratoria as hard-won and sacred victories. But realism and recent politics suggest that it would be better to invite this industry inside the i-MSP tent rather than let it focus only on its own goals. They bring money and clout to the table, and have the experience and resources to help conduct desperately needed offshore mapping and environmental assessments. With rising oil prices and growing calls for energy independence, it would be more prudent to acknowledge the likelihood of future offshore oil and gas development *during* the marine planning process than to have those activities trump everything else, quite possibly in an atmosphere of urgency and short-term need.

One surprising finding from the interviews I conducted was the lack of communication between states engaged in very similar ocean planning and management efforts. As described in Section IV. C. above, there is a lot going on at the state level, at different scales and under different names. With better sharing of practices, information, and tools, and improved synthesis of results, these individual state efforts could gain momentum and put pressure on federal agencies to follow suit. The learning process can be enhanced by disseminating information about experiences in other countries and sponsoring exchanges between U.S. and foreign i-MSP practitioners.

In terms of specific legislative or regulatory strategies, HR21 is probably not the most straightforward way to advance i-MSP at this time, due to its indirect connection to marine planning and considerable political baggage. (HR21 may achieve other important marine conservation goals not specifically examined in this paper.) One useful task for a multi-sector working group would be to draft the kind of legislative language that could advance i-MSP, whether such language were introduced as a stand alone bill or as an amendment to other legislation. In any case, every ocean-related bill that comes up for debate in the next Congress (such as action on CZMA, climate change, aquaculture, renewable energy, or offshore oil drilling) should be scrutinized to see how it connects with broader ocean management needs. When a new administration is in place in 2009, its top appointees and advisers should be encouraged to reinvigorate the federal interagency ocean policy process, including giving specific instructions to the agencies to begin spatial planning in one or more regions, backed up by a mix of carrots and sticks to make it happen.

Obtaining integrated assessments of all U.S. coastal and ocean regions, including information about economic activities and their links back to coastal communities, will be a critical task. However, it will also be expensive, time consuming, and difficult. This task will undoubtedly require creative partnerships between government, industry, foundations, NGOs, and academia, an approach being pursued already in some areas (for example, see the discussion above about activities in New England). Data that document the economic benefits provided by healthy ocean ecosystems will be particularly helpful. Such information can help guide spatial planning and, equally important, help build broader public and political support. Although the initial steps of marine planning can get started without complete information (as has been done for all other management approaches), the results will be greatly improved over time with better information about the ecosystem and its users.

Although it seems like a small point, achieving consistent nomenclature remains a challenge (as seen in Box 1). I have used the term integrated marine spatial planning (i-MSP) in this paper because it incorporates what I consider to be key attributes. It could be criticized for referring to *planning* without the subsequent phases of zoning, regulation, and management, although I intend it to encompass those aspects. It will be hard to build a broader base of support for i-MSP when even its proponents aren't quite sure what it includes or what to call it.

All of my research and interviews lead me to believe that some form of spatial planning will be necessary for the future of ocean management. Fortunately, this is an opportune moment to advance new approaches: offshore energy production, both from oil and renewable sources, is being actively promoted for the first time in years; the need to make wild fisheries sustainable seems to have finally sunk in; and discussions about the impacts of climate change have communities thinking about the future. The i-MSP elements of consensus building, goal setting, and planning can be done carefully and thoughtfully now, while space is relatively plentiful and new uses are just being developed, or it will need to be done later as conflicts grow between entrenched interests.

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SUSTAINABILITY

Resolving Mismatches in U.S. Ocean Governance

Problems in ocean resource management derive from governance, not science. Ocean zoning would replace mismatched and fragmented approaches with integrated regulatory domains.

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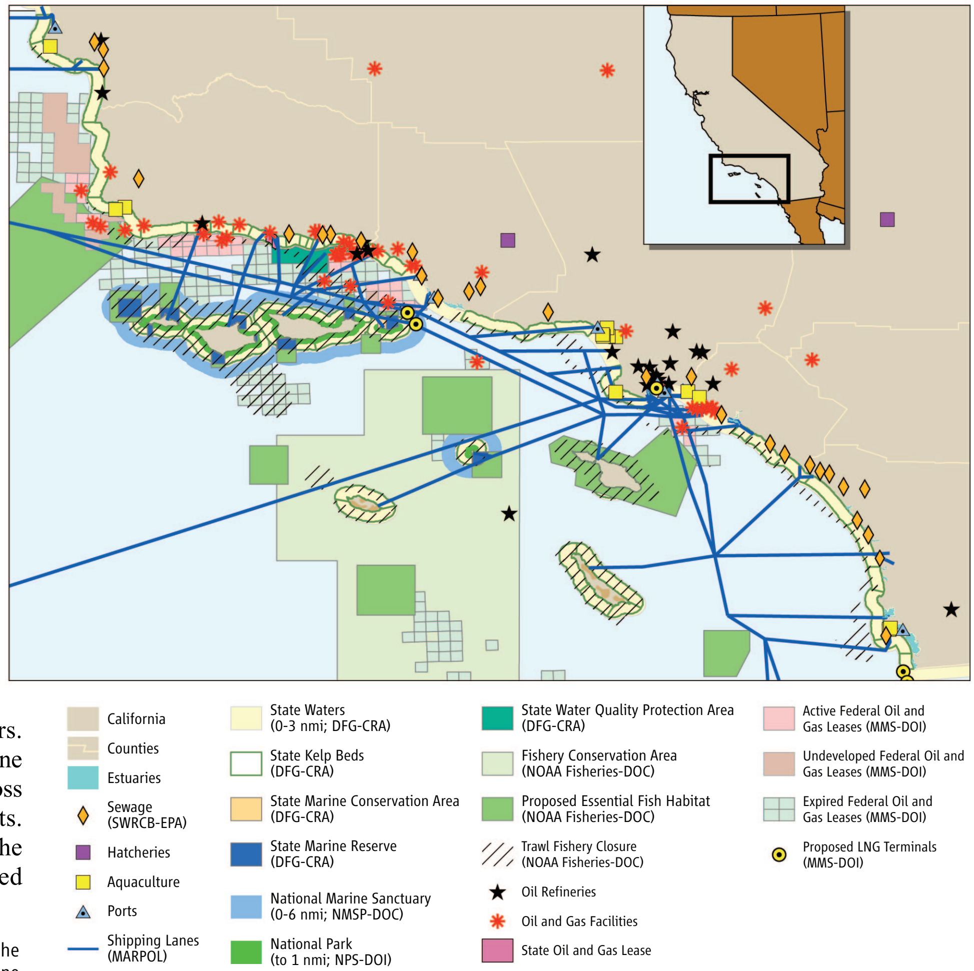
That the oceans are in serious trouble is no longer news. Fisheries are declining, formerly abundant species are now rare, food webs are altered, and coastal ecosystems are polluted and degraded. Invasive species and diseases are proliferating and the oceans are warming (*1*). Because these changes are largely due to failures of governance, reversing them will require new, more effective governance systems.

Historically, ocean management has focused on individual sectors. In the United States, at least 20 federal agencies implement over 140 federal ocean-related statutes. This is like a scenario in which a number of specialist physicians, who are not communicating well, treat a patient with multiple medical problems. The combined treatment can exacerbate rather than solve problems. Separate regimes for fisheries, aquaculture, marine mammal conservation, shipping, oil and gas, and mining are designed to resolve conflicts within sectors, but not across sectors. Decision-making is often ad hoc, and no one has clear authority to resolve conflicts across sectors or to deal with cumulative effects. Many scientists are now convinced that the solution can be found in ecosystem-based management (*2*). Ecosystem-based management focuses on managing the suite of human activities that affect particular places. This is a marked departure from the current approach. The time has come to consider a more holistic approach to place-based management of marine ecosystems, comprehensive ocean zoning (*3*).



Fragmentation of management for human uses of marine areas in southern California.

Management regimes for individual sectors operate under different legal mandates and reflect the interests of different stakeholders, so governance is riddled with gaps and overlaps (*4*). Fishing has a larger impact on biological diversity than any other human activity (*5*), but the Magnuson-Stevens Act, which governs fisheries, contains no mandate to maintain biodiversity. Ecosystem-based fisheries management (*6*) is only a partial solution—it does not account for impacts on nontarget species or manage other activities that degrade fisheries, such as pollution or wetlands loss (*7*). The problem of fragmented governance is growing, as new place-based activities in the sea [e.g., aquaculture, wind farms, liquefied natural gas (LNG) terminals] are increasing the potential range and severity of conflicts across sectors.

California's Channel Islands illustrate the potential for conflict and fragmentation of management authority (see figure, above).

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In 2003, California established a network of fully protected marine reserves and conservation areas that allow limited take in the state waters (0 to 3 nautical miles) of the Channel Islands National Marine Sanctuary. This followed a 5-year multiagency, multistakeholder process. Yet federal agencies still have not implemented the proposed reserves in federal sanctuary waters (3 to 6 nautical miles) because the roles of the two National Oceanic and Atmospheric Administration agencies (Fisheries and National Marine Sanctuaries) are unclear.

Spatial mismatches between scales of governance and ecosystems are common. Current subdivisions of state, federal, and international waters are understandable in historical and political terms. But it makes little ecological sense for managing highly migratory fishes or for LNG terminals, which can be built in state or federal waters.

Spatial mismatches typically arise from jurisdictional boundaries too small for effective management. Leatherback and loggerhead sea turtles forage over much of the Pacific, but bycatch reduction efforts required in U.S. fisheries are not used in foreign fisheries, which potentially contributes to ongoing declines (*8*). Western and Eastern substocks of Atlantic bluefin tuna migrate, so the high catches in the East may cancel the potential benefits of restricted catches in the West (*9*).

Sometimes, the causes of the problems are too far removed from the effects. Farming in the Mississippi River watershed contributes to nutrient loading and hypoxia in the Gulf of Mexico, displacing fishes and other marine organisms (*10*). Jurisdictions can also be too large. Cod management in the northwest Atlantic focused on the whole region as local stocks experienced serial depletion (*11*).

Temporal mismatches between biological systems and human institutions can also degrade marine ecosystems. Annual appropriations and 2- or 4-year voting cycles drive many policy processes. But problems affecting marine systems can occur on time scales that are too fast for these policy rhythms (e.g., sudden collapses of fish populations, outbreaks of invasive species or harmful algal blooms) or too slow (e.g., increases in ocean temperatures, acidification, or the cumulative loss of wetlands). The white abalone fishery in California expanded and crashed rapidly in the early 1970s, 20 years before the management agency restricted fishing (*12*). Longline tuna fisheries in the Gulf of Mexico reduced oceanic whitetip sharks by 99.7% over five decades, but the change was so gradual that managers failed to notice or prevent it (*13*).

Problems generated by fragmentation and mismatches become particularly severe in systems that include multiple, interactive, and cumulative stressors. Just as stressed humans are more susceptible to opportunistic infections, stressed ecosystems lack robustness and resilience. On the U.S. West coast, the combination of degraded spawning habitat, shifting ocean temperatures, and overfishing led to population declines and endangered species listings for salmon. This did not occur in Alaska, because of better river conditions, protection of spawning habitat, and a spatial fisheries permit system (*14*).

These governance problems are difficult to alleviate even after they become well understood (*15*). Incremental improvements in sectoral governance can reduce some problems (e.g., overfishing of target species), but they generally cannot address fragmentation and mismatches.

Marine spatial planning with comprehensive ocean zoning can help address these problems. Although property rights and management arrangements in the sea differ from those on land, spatial planning could be initiated with cooperation among federal, state, tribal, and local authorities. Zoning would not replace existing fishing regulations or requirements for oil and gas permits, but would add an important spatial dimension by defining areas within which compatible activities could occur.

Key elements of successful zoning include locating and designating zones based on the underlying topography, oceanography, and distribution of biotic communities; designing systems of permits, licenses, and use rules within each zone; establishing compliance mechanisms, and creating programs to monitor, to review, and to adapt the zoning system. Not only does comprehensive ocean zoning directly address fragmentation and spatial mismatches, zoning also facilitates efforts to adjust governance to the rhythms of human institutions and the dynamics of spatially bounded ecosystems.

Of course, establishing an effective system of ocean zoning in the United States will present a formidable challenge. But other countries, including Belgium, China, Germany, the Netherlands, and the United Kingdom, have already begun implementing or experimenting with marine spatial planning (*16–18*). Massachusetts is considering legislation to develop and implement an ocean management plan (*19*). A striking example of comprehensive, multiple-use zoning of marine resources is Australia's Great Barrier Reef Marine Park. It provides specific areas with high levels of protection, while allowing other uses, including fishing, to continue elsewhere (*20*).

The transition to comprehensive ocean zoning in the United States will not be easy. Critics point to the contentiousness of efforts to introduce zoning, the difficulties of developing legislation acceptable to all stakeholders, and failures to achieve desired results even after zoning is established. But our current approach simply cannot address the critical issues in the oceans. Recovering ocean ecosystems will require a better understanding of the consequences of interconnections among ecosystem components, as well as a systemic change in the way we consider issues and make choices regarding ocean use.

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OCEANS

Legal Bedrock for Rebuilding America's Ocean Ecosystems

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Recent discussions about ocean policy reform have focused on ecosystem-based management, which fully incorporates humans and considers the cumulative impacts of their activities on ecosystems and the services they provide (*1*). This approach is logical given the highly interconnected social-ecological systems of the ocean (*2*) and may be best realized through comprehensive marine spatial planning and ocean zoning (*3*). But U.S. ocean governance as currently configured cannot easily accommodate ecosystem-based management (*4*).

Federal waters, which include the territorial sea and the Exclusive Economic Zone (EEZ), reach from the 3 or 9-nm borders of state waters out to the 200-nm outer boundary of the EEZ, an ocean area in which the United States has rights to exploring, exploiting, and managing living and nonliving resources (*5-7*). Because of the United States' extensive coastlines and territorial holdings, the U.S. EEZ covers 3.6 million nautical square miles and is larger than the combined land area of the fifty states. Over 20 federal agencies operating under dozens of laws regulate activities in the EEZ, support ocean-based commerce, and protect marine species and habitats (*8*). These agencies separately manage parts of marine ecosystems, without any systematic effort to coordinate their actions for the public good (*9*).

With new leadership in place in Washington, U.S. ocean policy is poised for a long-overdue transformation. Since two national ocean commissions highlighted the need for dramatic reform 5 years ago (*8*, *10*), progress has been made towards understanding how to rebuild ocean ecosystems (*e.g.*, *11*, *12*). But implementing a new, ecosystem-based policy regime for federal ocean waters will require a solid legal foundation that provides the authority for, and imposes responsibility upon, disparate federal agencies to collaborate in their management of ocean resources.

The Public Trust Doctrine would provide this critical foundation. The Doctrine is a simple but powerful legal concept that obliges state governments to manage certain natural resources in the best interest of their citizens (*13*). More generally, a "trust" is a legal relationship in which a person or entity (the "trustee") manages a property or resource for the benefit of another person or group. The trustee is legally bound to preserve the assets of the trust, allowing only judicious use of the assets and repairing the trust should it be harmed. The trustee must also manage the trust in the exclusive interest of the beneficiaries (*14*). The beneficiaries of states' public trusts include living and future citizens (*14*). Thus, inherent to the Doctrine is the idea of intergenerational equity; trustees must manage trust assets so that needs of current beneficiaries are met without sacrificing needs of future beneficiaries. A federal Public Trust Doctrine, if formally extended from state waters to the edges of the EEZ, would identify federal agencies as having responsibility for marine resources as trustees of the U.S. ocean public trust and U.S. citizens as the sole beneficiaries.

Many analysts, including the presidentially appointed U.S. Commission on Ocean Policy, have assumed that the Doctrine already extends to the vast space of the territorial sea and EEZ (*8, supporting online text*). But our recent review (*15*) reveals that the legal authority and responsibility of the federal government to manage marine resources in the best interest of U.S. citizens have not been formally articulated by the courts or established in federal law. Instead, the Doctrine is well established in the U.S. only at the state level (*16*), where courts have consistently held that the Public Trust Doctrine requires state agencies and attorneys general to seek legal action against private parties infringing on the public trust. Also, a widely upheld tenet of the Doctrine is that state trustees cannot abdicate their responsibility to manage the trust; if they do, the Doctrine enables citizens to seek judicial review of their actions (or inaction; *supporting online text*). In some states, courts have used the Public Trust Doctrine to protect coastal ecosystem services (*17*, *18*), and Massachusetts recently passed the first state law mandating a comprehensive ocean management plan "to ensure its effective stewardship of the ocean waters held in trust for the benefit of the public" (*19*). Though states do work cooperatively with federal agencies on issues such as coastal zone and fisheries management, they alone cannot protect U.S. ocean resources and the services they provide: ocean ecosystems are interconnected across state and federal political lines, and states have limited authority in federal waters (*supporting online text*).

In addition to providing a consistent framework for federal ocean agencies implementing ecosystem-based management, a Public Trust Doctrine for U.S. federal waters would be a policy backstop for these agencies to enforce the public trust against infringing parties. Importantly, the Doctrine would also extend greater standing to U.S. citizens to protect their interest in the management of ocean trust resources in the instance of abuse or neglect of the trust (*supporting online text*). And, with the current scientific understanding of the necessity of coordinated, comprehensive action to stem the widespread declines of U.S. marine ecosystems (*9*), it would be difficult for a federal agency operating under a public trust mandate to avoid working cooperatively with agencies that manage other components of

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the ocean ecosystem. Therefore, explicitly mandating the common responsibility of these agencies to protect the ocean public trust could catalyze cross-sectoral ecosystem-based management in U.S. oceans.

A federal Public Trust Doctrine for U.S. ocean waters could be established in a number of ways:

Executive Order: The President could make expanding the Doctrine a signature of his administration through an Executive Order that directs all federal ocean agencies to apply their resources towards cooperatively and sustainably managing the ocean public trust (*supporting online text*).

Judicial Interpretation: Federal judges could extend the Doctrine into the territorial sea and EEZ by invoking the same instruments relied upon by state courts to enlarge the reach of the Doctrine – judicial precedents, language in existing statutes, and the common law (*supporting online text*).

Congressional Mandate: The Congress could unambiguously write the Doctrine into federal oceans law. As one example, the National Oceanic and Atmospheric Administration (NOAA) could be given the following directive: "NOAA's mission is to manage and protect public trust resources within the waters and atmosphere of the U.S. with the cooperation of other federal and state agencies." Once mandated, the Doctrine could be put into practice via agency memoranda – a top-down approach to implementing broad changes in agency practice for which there is ample precedent (*e.g.*, *20*) – directing all workers to carry out the legislated work of their agencies under their newly articulated duties as trustees of the ocean public trust.

Just as assets in our economy are inextricably linked, assets in our ocean trust portfolio are linked with one another. To move past the failing status quo in U.S. ocean management and build a vigorous mandate that provides both the authority and the responsibility for federal agencies to jointly work to manage U.S. oceans as whole ecosystems will require that we answer, as soon as possible, two critical questions: for whom should our country's oceans be managed, and for what purpose? The Public Trust Doctrine answers both of these questions. By insisting that federal agencies manage the U.S. ocean public trust for the long-term benefit of all American citizens, citizens and the governments they elect can begin to harmonize the concepts of representative democracy and sustainable resource use and stewardship.

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"Addressing the Effects of Human-Generated Sound on Marine Life:
An Integrated Research Plan for U.S. Federal Agencies"

A Report of the Joint Subcommittee on Ocean Science & Technology (JSOST)

~ INTERAGENCY TASK FORCE ON ANTHROPOGENIC SOUND AND THE MARINE ENVIRONMENT ~

Contributing Federal Agencies (in alphabetical order):

Marine Mammal Commission (MMC)
Minerals Management Service (MMS)
National Oceanic and Atmospheric Administration (NOAA)
National Science Foundation (NSF)
U.S. Army Corps of Engineers (ACE)
U.S. Coast Guard (USCG)
U.S. Department of Defense, U.S. Navy (USN)
U.S. Department of Energy (DOE)
U.S. Department of State (DOS)
U.S. Fish and Wildlife Service (FWS)

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Cover page photo credits (from left to right)
(1) Sperm whale beginning a dive in Mississippi Canyon Block 127 in the Gulf on the 2002 S-tag cruise (photo credit: Christoph Richter, Texas A&M University-Galveston).

(2) Acoustic and behavioral monitoring tag being applied to a pilot whale in Hawai'i by Duke University researcher Doug Nowacek; NOAA's research vessel Oscar Elton Sette is visible in the background (photo credit: NOAA/NMFS Pacific Islands Fisheries Science Center).

(3) Harbor seal participating in behavioral hearing experiments in a specialized anechoic testing chamber at Long Marine Laboratory, University of California, Santa Cruz, CA (photo credit: Brandon Southall, NOAA).

(4) Harbor porpoise (photo credit: Ari Friedlaender, Duke University)

Council on Environmental Quality
Office of Science and Technology Policy
Executive Office of the President
January 13, 2009

Dear partners and friends in the ocean and coastal community:

We are pleased to present this report, ***Addressing the Effects of Human-Generated Sound on Marine Life: An Integrated Research Plan for U.S. Federal Agencies***. This report was developed in response to an Interagency Committee on Ocean Science and Resource Management Integration request for a focused, coordinated Federal science and technology plan from the National Science and Technology Council's Joint Subcommittee on Ocean Science and Technology (JSOST). The JSOST's Interagency Task Force on Anthropogenic Sound and the Marine Environment prepared this report.

Whether and how human-generated sounds in the ocean affect marine life has become an issue of increasing awareness, within scientific and regulatory circles as well as among the general public. Many activities vital to our society, including the actions of many Federal agencies, introduce sound into the marine environment. Consequently, there is much interest and effort involved in understanding associated environmental impacts and, where appropriate and practical, developing ways of minimizing them. A number of Federal agencies are actively engaged in advancing the science and technologies needed to address these challenging issues.

This report provides an explicit interagency roadmap for the next decade to focus and prioritize research efforts addressing this issue. It summarizes collective research efforts by Federal agencies in several key areas and includes a number of specific and prioritized research recommendations regarding future efforts, with particular emphasis on interagency collaboration. Finally, it summarizes some general coordinating actions and means of increasing the transparency and public recognition of ongoing interagency efforts in this field. The findings indicate that many of the challenging scientific, regulatory, and legal issues regarding underwater sound can be addressed with focused, prioritized, and sustained effort coordinated among the Federal agencies. We hope it will be useful to a broad range of interested parties.

Sincerely,

James L. Connaughton
Chair, Committee on Ocean Policy
Chair, Council on Environmental Quality

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Report Overview and Summary

The issue of anthropogenic sound[1] and its possible impacts on the marine environment has created unique challenges for virtually all federal agencies conducting, supporting, or assessing operations in the marine environment. These agencies are charged with regulating, supporting, and/or performing activities in the marine environment vital to our nation's health, economy, and security across a wide scope of sectors. Sound (both intentionally produced as a tool or as a by-product of other activities) is an integral part of the activities of these agencies and of many critical human activities, including vessel operation and navigation, offshore minerals exploration, national defense, and scientific research. Federal agencies are challenged with achieving their mission goals in conducting and/or regulating these critical activities while meeting their mandated responsibilities as environmental stewards for the nation. Continuing to develop a scientific basis for determining potential impacts and the appropriate response is an urgent requirement for federal agencies, if they are to continue to achieve their primary missions for our nation in an environmentally safe manner.

There is considerable scientific uncertainty regarding the nature and magnitude of the actual impacts of anthropogenic sound on the marine environment, as well as the most appropriate and effective mitigation measures where effects have been demonstrated or are likely. Societal benefits from the full spectrum of sound-producing activities should be considered along with, and not overshadowed by, any potential negative impacts of those activities. The goal of federally-supported research in this area

1 Within this report, the term "sound" is used to refer to the acoustic energy radiated from a vibrating object, with no particular reference for its function or potential effect. "Sounds" include both meaningful signals and "noise" which may have either no particular impact or may have a range of adverse effects. The term "noise" is only used where adverse effects are specifically described, or when referring to specific technical distinctions such as "masking noise" and "ambient noise."

is to obtain mission-critical data that are used in a timely and effective manner to inform policy guidance, develop targeted mitigation measures, and develop and improve regulatory criteria.

How anthropogenic sound may affect marine life is a new field of study. What began as a simple concern that commercial shipping might affect the long-distance calls of whales (Payne and Webb, 1972) has now evolved into a more complex recognition that various anthropogenic acoustic sources have the potential to adversely affect marine life. Additionally, concerns regarding potential impacts are compromising human applications of sound for important scientific, commercial, and military purposes, particularly where scientific data are lacking or ambiguous. These concerns stem from both an increased understanding of the biological importance of sound to most marine vertebrates (particularly marine mammals and many fish) and a growing appreciation of the value of acoustics as a tool for ocean research, energy development, monitoring ocean health, resource management, military activities, and ship operations. How do we as a society reconcile our growing dependence on sound as a tool for studying, using, and conserving the marine environment with a similarly growing understanding of the potential for unintended adverse environmental consequences? How do we balance the potential negative environmental impacts from the incidental introduction of sound with the benefits of ocean-based commerce, national security, research, or transportation? And most important, how do we regulate these

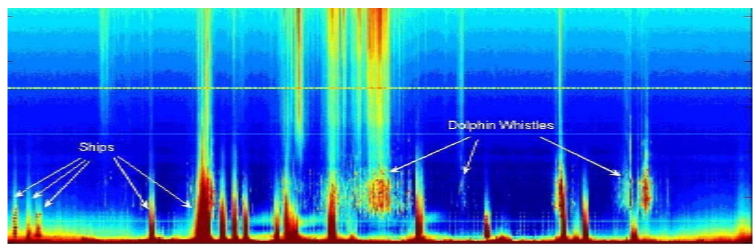


Image courtesy of Dr. John Hildebrand, Scripps Institute of Oceanography essential human activities in the face of significant scientific uncertainty about adverse effects? Many of these fundamental questions remain to be answered and they clearly require additional scientific data to be adequately addressed.

The most immediate response by U.S. federal agencies has focused on understanding and minimizing the potential adverse effects of their activities, or activities they support or regulate. The current status of science (in terms of exactly what level and types of sound will result in a specific effect) often results in estimates of potential adverse impacts that contain a high degree of uncertainty.

Public perception of threats and scientific analyses of risks may lead to different priorities for acoustic research. There is growing concern by scientific experts in relevant disciplines, that the public and legal focus on a very narrow range of active sources and the predictable agency responses are distorting an appropriate scientific approach to assessing the broader impacts of anthropogenic noise as a global issue (see NRC, 2000; 2003; 2005; Nowacek *et al.*, 2007; Southall *et al.*, 2007). This creates a growing need for both transparency and public and stakeholder outreach as agencies respond to the increasing awareness of sound as an environmental issue.

The laudable aim of minimizing acoustic effects has produced controversy, social tension, and litigation. It has also led to precautionary restrictions, considerable additional costs and delays, not the least of which has been the paradoxical effect of hindering ocean acoustic science essential to understanding not only this issue but also other important environmental issues such as the marine aspects of climate change. These anticipatory restrictions and other precautions imposed through litigative challenges have taken place against a background of considerable uncertainty as to the nature and extent of impacts from noise exposure. It is this gap, between what should and can be done with scientific confidence and what is currently being done with abundant precaution but demonstrable societal cost, which we seek to reduce through the coordinated federal research strategy depicted here. A summary of key overarching summary points is given below (Box 1).

Box 1 – OVERVIEW OF KEY POINTS

Sound is of vital importance for most marine vertebrates.

Natural and human sounds can have benign (or no) to significant effects on marine life.

Public, media and regulatory attention has focused on known and/or potential adverse impacts of active sonar and seismic systems, but agencies must consider a wider array of sound sources.

Existing data needed to assess and mitigate effects are limited, leading to uncertainty in determining the necessary responses (if any).

Federal research has been largely focused on immediate needs specific to individual agencies.

However, agencies often have common science and technology needs on this issue that could be most quickly and economically met through a coordinated program of effort.

Purpose of Report

As the scope and nature of the issue has expanded, so has the need for increased communication and collaboration across federal agencies[2]. At present, federal agencies have already begun working to develop tools, technologies, and knowledge to provide empirical data on these difficult questions, but these have largely occurred at an agency-specific level. In response, the Interagency Committee on Ocean Science and Resource Management Integration (ICOSRMI) formed an "Interagency Task Force on Anthropogenic Sound and the Marine Environment" within the Joint Subcommittee on Ocean Science & Technology (JSOST). This Task Force was comprised of federal

2 Brief descriptions of the mandates of involved U.S. federal agencies relative to the issue of marine sound, as well as agency representatives contributing to this report are listed in Appendix 1.

agencies most directly involved in this issue with each individual agency providing a representative to participate and speak for their agency perspective. The Task Force was charged with developing a focused, coordinated science and technology plan of action among federal agencies and reporting on this plan through JSOST to ICOSMRI. Therefore, this report represents an overall, interagency (not individual agency) perspective, as determined through the interactions and deliberations of Task Force members.

The recommendations offered within this report provide a strategic vision for integrating, prioritizing and optimizing the science and technology efforts of U.S. federal agencies on marine anthropogenic sound over the next decade. It is based on lessons learned from inter-agency coordination on ocean science issues generally, as well as coordination on pressing research needs regarding this issue specifically. The intent is to promote and develop better scientific understanding, thereby leading to better documentation of effects, less controversy regarding risks, increased scientific certainty underlying policies and regulatory decisions, and effective mitigation efforts where impacts are known or likely. The report is also intended to improve the combined federal effort by increasing inter-agency coordination, planning, and leveraging resources, while reducing redundancy and disproportionate focus in a few areas.

The report is organized into a general overview (this section) that summarizes the key issues and recommendations of the task force, followed by a list of acronyms, five primary chapters, and three detailed appendices. Throughout the report, completed research and specific recommended research actions are given within five general subject categories: (1) Sound Sources and Acoustic Environment; (2) Baseline Biological

Information (Physiology, Distribution, and Abundance); (3) Effects of Sound (Criteria and Thresholds); (4) Monitoring and Mitigation; and (5) Outreach, Education, and Scientific Peer Review. Chapter 1 states the general issue in greater detail than this general overview and provides a sense of the limits to currently available information. Chapter 2 provides an overview of effort to date by federal agencies. Chapter 3 offers specific recommendations for future effort and sets priorities within specific action areas. Chapter 4 considers the opportunities and obstacles for inter-agency coordination. Chapter 5 draws together both general and specific recommendations for a coordinated federal science and technology response to this issue, acknowledging the pragmatic challenges that are known or expected. Appendix I provides a summary of the roles and responsibilities of the participating federal agencies on the marine sound issue; it also includes a list of the agency representatives that contributed to the preparation of this report. Subsequent appendices are more detailed versions of Chapters 2 and 3, providing additional specific information on the current federal effort (Appendix II) and prioritized recommended future federal research and development (Appendix III).

Task Force Conclusions and Recommendations

The Task Force considered both positive and negative outcomes of anthropogenic sound in the marine environment, both through direct use of acoustics for sensing and communication, and through the noise generated as an unwanted, but often unavoidable, aspect of essential human ocean-related activities (*e.g.*, shipping, marine construction, energy exploration and production). Additionally, we note that the scientific understanding and technologies that are needed to enable the federal government to respond appropriately will, in some cases, be the same tools and technologies required to better execute federal national security and resource management missions. The full extent of research required to address the environmental consequences of anthropogenic marine sound can seem overwhelming. However, some clear, high-priority actions exist that should be undertaken collaboratively among federal agencies for effective action on this issue, including better understanding of the actual impacts of noise, both acute and cumulative.

Of these, the Task Force has identified both specific research action areas and general coordination recommendations which are of the greatest importance to the federal government. Table 1(below) provides an ordinal ranking of these *highest* priority research action areas, their associated suggested timelines (*i.e.*, short-term vs. long-term), and those agencies most likely to have leading/direct interest and/or secondary level of involvement. Each recommended research action area in Table 1 is subjectively categorized by the overall importance and social relevance of the work ("importance") and the relative level of effort required for significant progress ("effort"): (1) High importance/moderate effort; (2) High importance/high effort; (3) Moderate importance/moderate effort; (4) Moderate importance/high effort. [note: additional details regarding the research action areas specified here are given in Chapter 3 and Appendix III].

Table 1 – Overview of Highest Priority Research Recommendations

Prioritized Recommended Federal Research Action Areas	Short or Long-term?	Relative Importance and Level of Effort *	Agencies Involved (see notes below)	General Subject Area(s) (described in Chapter 2)
(1) Improve ability to identify and understand biologically-significant effects of sound exposure in order to improve effectiveness and efficiency of efforts to mitigate risk.	Ongoing and long-term	**High Importance/ High Effort**	NOAA[1]MMC[2] NSF, USN, MMS	Effects of Sound
(2) Hearing, physiological, behavioral, and effects data (*e.g.*, controlled exposure studies) for key species of concern (baleen whales, beaked whales, Arctic & endangered species).	Ongoing and long-term	**High Importance/ High Effort**	USN[1], NOAA[2], NSF, MMS, MMC	Baseline Biological Information; Effects of Sound
(3) Develop new technologies (*e.g.*, acoustic monitoring) to detect, identify, locate, and track marine mammals, in order to increase the effectiveness of detection and mitigation.	Ongoing and short-term	**High Importance/ Moderate Effort**	USN[1], NOAA[1], MMS, NSF, USCG, ACE, DOT, FWS	Sound Sources and Acoustic Environment; Mitigation and Monitoring
(4) Develop and validate mitigation measures to minimize demonstrated adverse effects from anthropogenic noise.	Short-term and long-term	**High Importance/ High Effort**	NOAA[1], MMC[2], USN, MMS, NSF, FWS, USCG, ACE	Mitigation & Monitoring; Effects of Sound
(5) Support the development, standardization, and integration of online data archives of marine mammal distribution, abundance, and movement for use in assessing potential risk to marine mammals from sound-producing activities.	Ongoing, short, and long-term	**High Importance/ Moderate Effort**	NOAA[1], USN, FWS, MMS, MMC	Baseline Biological Information
(6) Long term biological and ambient noise measurements in high-priority areas (*e.g.*, Arctic, protected areas, commerce hubs).	Ongoing and long-term	**High Importance/ High Effort**	NOAA[1] USN, MMS	Sound Sources and Acoustic Environment
(7) Test/validate mitigating technologies to minimize sound output and/or explore alternatives to sound sources with adverse effects (*e.g.*, alternative sonar waveforms).	Long-term	**High Importance/ High Effort**	USN[1], NSF[1], MMS[1], NOAA, MMC, DOE	Mitigation & Monitoring
(8) Explore need for and effectiveness of time/area closures versus operational mitigation measures.	Ongoing and long-term	**Moderate Importance/ Moderate Effort**	MMS[1], NOAA[2], MMC[2], USN, NSF	Mitigation and Monitoring
(9) Develop and improve noise exposure criteria and policy guidelines based on periodic reviews of best available science to better predict and regulate potential impacts.	Ongoing and long-term	**Moderate Importance/ Moderate Effort**	NOAA[1], FWS[1], MMC[2], USN, MMS, NSF	Effects of Sound
(10) Standardize data-collection, reporting, and archive requirements of marine mammal observer programs.	Long-term	**Moderate Importance/ Moderate Effort**	NOAA[1], FWS[1], MMS, NSF, USN, USCG, MMC	Mitigation and Monitoring
(11) Expand/improve distribution, abundance and habitat data for marine species particularly susceptible to anthropogenic sound.	Ongoing and long-term	**Moderate Importance/ High Effort**	NOAA[1], FWS[1], USN, MMC, MMS	Baseline Biological Information

Notes:
* note shading corresponds to four relative importance/effort categories; see text for more detailed explanation
[1] denotes agencies with a leading and/or direct interest on each recommended action
[2] denotes agencies with a secondary level of involvement in each recommended action

Many of the research action areas included in these recommendations are to some extent already being investigated or acted upon by some of the participating agencies in this task force. However, our intention is to focus on those action items and research recommendations that are most likely to remain important for the U.S. federal government, now and over the coming decade. Some of these will require prioritization and action by individual agencies; others will need more concerted inter-agency collaboration.

Perhaps the most important outcome of this report, and of the Task Force generally, is the increased coordination, communication, and planning across federal agencies on this important environmental issue. In order to sustain existing collaborations and enhance further coordination, the Task Force felt it was also imperative to identify the *highest* priority coordination action items. The Task Force feels these actions are critical for the successful implementation of this strategic plan and will ultimately maximize the diverse capabilities and perspectives of the federal agencies. These highest priority coordination action items include:

- **Sustained interagency collaboration and coordination, including:**
    - High-level, inter-agency coordination among individuals with sufficient authority to make timely planning and budget recommendations within their respective agencies; and
    - Program-level, inter-agency coordination among agency subject matter experts and program managers to implement directives and provide technical advice to leadership.

- **Enhanced communication and coordination on the marine sound issue with private sector interests and with the governments of other nations to reduce duplication of effort and advance a consistent scientific response.**
- **Continued efforts to streamline research permitting involving acoustic sources.**
- **Development of a biennial forum for information transfer to report on the results of inter-agency research to various stakeholders (*e.g.*, federal and state government agencies, industry, academia, public, educators, media, and environmental groups).**

ACRONYMS USED IN THIS REPORT:

Behavioral Response Study (**BRS**)
Controlled Exposure Experiment (**CEE**)
Discovery of Sound in the Sea (**DOSITS**) [website: www.dosits.org]
Endangered Species Act: (**ESA**)
Environmental Consequences of Underwater Sound (**ECOUS**)
Interagency Committee on Ocean Science and Resource Management Integration: (**ICOSRMI**)
Inter-agency Coordinating Group (**ICG**)
Interagency Task Force on Anthropogenic Sound and the Marine Environment: (**IATF**)
Joint Subcommittee on Ocean Science & Technology: (**JSOST**)
Marine Mammal Commission: (**MMC**)
Marine Mammal Protection Act: (**MMPA**)
Minerals Management Service: (**MMS**)
National Environmental Policy Act: (**NEPA**)
National Oceanic and Atmospheric Administration: (**NOAA**)
National Oceanographic Partnership Program (**NOPP**)
National Research Council: (**NRC**)
National Science Foundation: (**NSF**)
Office of Naval Research (**ONR**)
Passive Acoustic Monitoring (**PAM**)
Permanent Threshold Shift (**PTS**)
Temporary Threshold Shift (**TTS**)
U.S. Army Corps of Engineers: (**ACE**)
U.S. Coast Guard: (**USCG**)
U.S. Department of Defense, U.S. Navy: (**USN**)
U.S. Department of Energy: (**DOE**)
U.S. Department of State: (**DOS**)
U.S. Fish and Wildlife Service: (**FWS**)
U.S. Government: (**USG**)

Chapter 1. Anthropogenic Sound and the Marine Environment: Framing the Issue

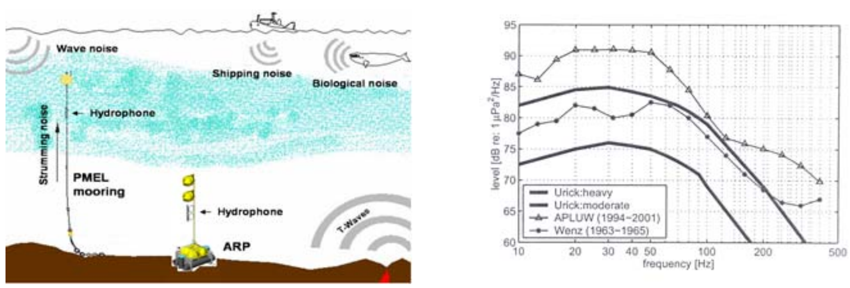
Chapter 1 – Key Points
• **Sound is of vital importance for most marine vertebrates.** • **Natural and human sounds can have various effects on marine life, along a continuum from benign (or no) to severe, depending on conditions.** • **Much attention has been on the impacts of active military sonar systems, but federal agencies must also consider the characteristics and purposes of other sound sources.** • **U.S. federal agencies have varied mandates, and thus varied research objectives, but do share overlapping needs in many areas** • **This report represents a synthesis of those shared needs and a strategic vision of collective federal research and development objectives for the coming decade.** • **The coordinated federal research strategy depicted here seeks to reduce the gap between what should and can be done with scientific confidence and what is currently being done in certain cases with abundant precaution but demonstrable societal cost.**

Introduction

Sound is integral in the lives of most marine vertebrates, as many species have converged on sound as a particularly effective mode of communication and orientation. Fish, marine mammals, sea turtles, and even some invertebrates have evolved functional and, in some cases, quite elaborate sound production and reception mechanisms (see Tavolga, 1964; Richardson *et al.*, 1995; Popper and Edds-Watson, 1997; Wartzok and Ketten, 1999; Popper *et al.*, 2004). For many marine animals, acoustic communication is

(photos courtesy: A. Friedlaender, P. Tyack, B. Southall, D. Nowacek) central to social interactions such as mating and tending to offspring. Some species, such as dolphins and porpoises, actively use sound to feed and sense their environment (*e.g.*, Au, 1993). Others listen for predators and prey sounds, or to navigate in a vast, visually-opaque sea (*e.g.* Tyack, 1998, Schusterman *et al.*, 2000).

The ocean is far from a quiet place. Sounds from waves, animals, precipitation, earthquakes, wind, and other natural sources contribute to the background (or "ambient") acoustic environment, although humans have increasingly added sound into the sea throughout the Industrial Age. Many anthropogenic sound sources produce sound as a by-product of their operation (*e.g.*, commercial shipping). Others generate signals for the express purpose of locating objects or characterizing environmental features (*e.g.*, seismic surveys for oil exploration). Anthropogenic sound sources, either purposeful or incidental, can be intense, but those sources are typically rare or intermittent (*e.g.*, explosions, active sonars, pile-driving). Others may be relatively quieter but more continuous (*e.g.*, boats, dredging, drilling, and off-shore energy production and/or distribution terminals). Anthropogenic sound sources can affect marine ambient noise and, in some specific areas, appear to be resulting in increases over time of ambient noise at low frequencies (*e.g.*, Andrew *et al.*, 2002; McDonald *et al.*, 2006). However, such



Schematic diagram of various underwater sound sources and monitoring hydrophones (left; courtesy S. Moore) and low-frequency ambient noise measurements (right) at a site off California measured over a period of several decades (see Andrew *et al.*, 2002) measurements have been relatively rare, and actual changes are expected to vary as a function of time, location, and other factors. The environmental implications of this human contribution to low frequency ambient ocean background noise are as yet poorly understood.

Over the past several decades, there has been increasing recognition, concern, and debate over the environmental effects of various anthropogenic sound sources. While certain sounds may be inaudible or entirely benign to marine animals, various adverse effects of noise have been documented, ranging from minor orienting responses to injury and even mortality (for detailed discussions see NRC 1994, 2000, 2003, 2005; Richardson *et al.*, 1995; Wartzok and Ketten, 1999; McCauley *et al.*, 2000; Popper *et al.*, 2004; Samuel *et al*., 2005; Cox *et al*., 2006; Nowacek *et al.*, 2007; Southall *et al*., 2007).

While there has been much recent progress, including work supported by U.S. federal agencies, scientific knowledge remains limited. The biological significance of the varied effects of anthropogenic sound on marine life remains hard to objectively identify, or predict in realistic conditions, and as a consequence the potential overall magnitude of the issue remains unclear. In fact, a recent NRC (2005) report concluded that: “On the one hand, sound may represent only a second-order effect on the conservation of marine mammal populations; on the other hand, what we may have observed so far may be only the first warning signs or ‘tip of the iceberg’ with respect to sound and marine mammals.”

Our inability to fully assess environmental impact is having significant implications for both federal agency activities, as well as private-sector interests. This scientific uncertainty complicates management actions directed to minimize adverse impacts, including some impacts that are subject to speculation and hypothesis but that have not been scientifically documented. Additionally, the elements of the environment perceived most at risk are the marine mammals which are the subjects of protective legislation (*e.g.*, Marine Mammal Protection Act of 1972), and which enjoy a correspondingly high public interest.

These factors contribute to the frequent occurrence of acoustic-related litigation, longer review time for environmental risk assessments and other analyses and, in some cases, serious delays or other difficulties in obtaining regulatory approvals for activities important to our nation (*e.g.*, national defense, energy development, scientific research). Additionally, some of the mitigation and monitoring measures imposed during the regulatory process have costly, restrictive consequences. However, few of those measures have actually been tested to determine their actual effectiveness. The wide scope of potential impacts in very different conditions, coupled with limited available data on actual impacts, allows for widely divergent ‘conclusions’ on the relative magnitude of the issue relative to other human stressors (*e.g.*, climate change, overfishing, contaminants) and a broad diversity of opinion about the proper course of remediating action.

These disparate viewpoints were evident in a lengthy stakeholder panel recently convened by the U.S. Marine Mammal Commission under the Federal Advisory Committee Act (see MMC, 2006), which failed to produce the initially sought consensus regarding an appropriate course of scientific and management actions. Amidst this background of heightened awareness and differing opinions among conservationists, scientists, managers, and sound-producing industries, the federal agencies must assess the best course of action in fulfilling their respective mandates.

The federal agencies are striving to improve requirements that address the matter of which sound-producing activities do or do not have actual impacts and how to mitigate anticipated adverse effects when a given activity is reasonably expected to pose a risk of impact. A particular challenge is achieving mitigation of noise impacts to protect the marine environment while not unnecessarily compromising important actions that produce sound (*e.g.*, mitigation of military sonar that might reduce national defense effectiveness). Agencies must comply with numerous environmental statutes before they are allowed to authorize or permit activities, including but not limited to: the National Environmental Policy Act (NEPA), Marine Mammal Protection Act (MMPA), Endangered Species Act (ESA), and Magnuson-Stevens Fishery Conservation and Management Act (MSA). These statutes all apply different requirements and thresholds for effects and individually impose mandatory mitigation and monitoring measures. Federal agencies are then faced with the difficult and at times conflicting tasks of fulfilling their public obligations in a data-poor environment and meeting statutory and regulatory requirements that are varied and, at times, conflicting. Ultimately, affected agencies benefit from coordinating their efforts to better define scientifically the environmental impacts of proposed major actions involving sound as well as the effectiveness and efficacy of mitigation and monitoring measures. Achieving this goal will move federal agencies away from addressing this issue according to their specific statutory mandates and instead entering into greater scientific collaborations that will better allow agencies to meet their mandates, define and reduce adverse impacts on the marine environment and minimize adverse impacts to important U.S. government, scientific, and commercial activities.

Task Force Report: Scope and Structure

In response to these current and emerging challenges, there is an urgent need for a focused, coordinated science and technology plan of action among federal agencies. This report therefore represents a strategic vision for integrating and optimizing the research efforts of U.S. federal agencies over the next decade. This strategic vision is based on lessons learned from inter-agency coordination on ocean science issues generally, and emerging science on this issue specifically. Better scientific understanding of the issue leads to greater clarity, and therefore less basis for controversy.

The existing data on known and reasonably foreseeable adverse consequences of anthropogenic sound on marine life are limited (see: Southall *et al.*, 2007). Consequently, *the guiding principle of this strategic plan is to recommend actions that build the capacity to better document and respond to the actual environmental effects from anthropogenic sound.* Uncertainty about the scope of potential problems increases the risk that regulatory oversight of federal and private sector activities and the associated requirements for mitigating and monitoring sound emissions may be either insufficient or excessive, or even unnecessary, in some cases. Since many of the necessary technical capabilities and scientific understanding needed to better diagnose the problem are also integral to mitigating it when it is understood, we should not treat understanding and mitigation as two purely dichotomous activities. Many efforts required to improve understanding, such as improving marine animal detection and monitoring capabilities, will also be needed for more effective mitigation action if and when a problem is identified. However, improving our understanding of the problem itself is the best and most immediately effective action that agencies can take toward resolving uncertainty and determining the most effective immediate course of action.

This report identifies and prioritizes research in specific areas that is required to better understand and address the demonstrated, hypothesized, and as-yet unconsidered adverse effects of anthropogenic sound on the marine environment. Implementing this coordinated scientific strategy, should provide sound-producers and decision-makers with the data and technical capabilities needed to ensure a safe and healthy marine environment while avoiding unnecessary constraints on U.S. federal agencies and private enterprise.

Chapter 2. Current U.S. Federal Research and Development Effort

Chapter 2 – Key Points
• **Some federal agencies already support or conduct research and development in this field.** • **USN, MMS, and NSF have traditionally been most active in supporting science and technology on this issue, with NOAA, MMC, FWS, and several other agencies playing lesser overall roles.** • **Specific research efforts are divided into five general subject areas (see *Appendix II*).** • **Despite this effort, available information is still insufficient to support non-controversial assessments of environmental risk or to effectively mitigate the potential adverse effects of anthropogenic sound.**

Regulatory requirements and increasing public awareness of and interest in possible environmental impacts from anthropogenic underwater sound have generally driven federal research and development. Efforts to date have been strongly affected by the specific requirements of a few agencies and the targeting of certain actions (*e.g.*, the use of military sonar and seismic airguns) by environmental groups. This focus has often limited the extent to which data or capability developments have been effectively applied to a broader set of relevant conditions, user needs, or basic scientific questions. For instance, active sound sources (such as seismic airguns and down-looking research sonars) are vital to the geophysical and oceanographic research objectives of numerous academic research groups, as well as all federal agencies operating or supporting marine activities using oceanographic research vessels. The results of such studies are proving to be essential in safety of marine navigation, understanding historical climate patterns needed to interpret climate change, geological variables relevant to understanding the risk of tsunami, possible extension of the U.S. continental shelf to include resource-rich areas, and other timely and important issues. Given the significance of active sound sources in basic marine research, NSF has directed some research effort toward understanding characteristics and potential environmental impacts of some of these sources, seismic airguns in particular. Similarly, MMS has focused on understanding the effects of specific sources involved in locating and extracting offshore hydrocarbon deposits and removing offshore oil and gas platforms (which include seismic airguns as well as explosions).

The impacts of active sonar systems used in military applications are another area of particular interest. A wide array of military sound sources used in training and readiness (*e.g.,* sonars and explosions) are of critical importance to the mission of the U.S. Navy to ensure national security. Navy-funded research and public interest in the potential environmental effects of military sources has intensified following a series of high-profile marine mammal stranding events associated with specific kinds of tactical mid-frequency military sonars (see Cox *et al.*, 2006).

In contrast to these highly-focused, mission-relevant areas of emphasis, other agencies have mandates for understanding, managing, and mitigating the adverse effects of a wider range of human sounds on marine mammals (MMC) and marine life (NOAA, FWS). These agencies are broadening their focus and expertise, based on the increasing realization that sound sources such as large vessels, pile driving, offshore energy development, navigational and/or imaging sonars, and oceanographic research sources may be of concern in addition to the naval and geophysical sound sources currently receiving the greatest attention. While some of these sources may lack the instantaneous output power of some of the powerful active sonars and seismic airgun sources, many of them occur in far greater numbers and cover much greater geographical ranges and deployment times than more intense, acute sounds. The potential for impact from certain lower-power but more ubiquitous sources is increasingly being considered and scientific measurements are required to inform these considerations. Some of this broadening of focus and expertise is occurring within the federal agencies. However, competing priorities have hindered the regulatory and oversight agencies (NOAA, FWS, and MMC) from directing resources they would need to support or conduct research consistent with their statutory obligations for regulation and oversight.

Public perception of threats and scientific analyses of risks may lead to different priorities for acoustic research. There is increasing concern by scientific experts in relevant disciplines that the public and legal focus on a very narrow range of active sources and the predictable agency responses are distorting an appropriate scientific approach to assessing the broader impacts of anthropogenic noise as a global issue (see NRC, 2000; 2003; 2005; Nowacek *et al.*, 2007; Southall *et al.*, 2007). This creates a growing need for both transparency and public and stakeholder outreach as agencies respond to the increasing awareness of sound as an environmental issue.

Historically, USN, MMS, and NSF have been the most active in investigating marine sound impacts and use of sound in the oceans. Resulting research has been focused primarily but not exclusively on marine mammals and a subset of anthropogenic sound sources. Other federal agencies (notably NOAA, MMC, and FWS) are playing a limited but slowly growing role in also conducting or supporting non-government entities in science and technology development. Specific research activities conducted or supported by these agencies is described below and in much greater detail in Appendix II.

A condensed summary of current federal effort is given here in each of the following five general subject areas identified by the Task Force: *(1) Sound Sources and Acoustic Environment; (2) Baseline Biological Information (Physiology, Distribution, and Abundance); (3) Effects of Sound (Criteria and Thresholds); (4) Monitoring and Mitigation; and (5) Outreach, Education, and Scientific Peer Review.* [Note: see *Appendix II* for a more detailed description of specific science and technology efforts by the individual federal agencies in each area.]

(1) Sound Sources and Acoustic Environment

Research in this area has included measurements and modeling of various anthropogenic and natural sound sources, how the sounds they produce then travel (or propagate), and the interaction of anthropogenic sound with natural sound to affect overall marine ambient noise. USN has supported extensive work on propagation models, measurements of military and biological sound sources, and signal processing technologies, both for environmental compliance and military tactical applications. This work has resulted in many of the existing state-of-the-art technologies for predicting radiated sound fields from specific sources used in the context of assessing potential impacts, among other accomplishments. Subsequent effort in certain aspects of this general area (*e.g.*, propagation modeling) is thus a much lower priority than other key topics for which less effort has been expended.

Similarly, NSF and MMS have investigated the acoustic properties of active sound sources used for seismic surveys – activities of particular interest to those agencies. These have included field measurements and source characterization of seismic airguns and other technologies used in geophysical research and industrial sources used in visualizing mineral deposits. While there are important differences among these sources that require multiple lines of investigation, this is perhaps an example of where collaboration of effort across agencies to meet common research needs might have improved the overall efficiency and power of the results. Nevertheless, these substantial measurements similarly decrease the urgency of obtaining similar such measurements, at least relative to the other pressing needs facing federal agencies.

NOAA and MMS have increasingly begun applying passive acoustic technologies in surveys of the marine animals. For instance, NOAA has, in conjunction with academic researchers and others, deployed acoustic listening sensors to determine the seasonal presence and activity of endangered right whales in Stellwagen Bank National Marine Sanctuary, various large whales in Arctic areas, and the responses of marine mammals to shipping activity near the busy port of Long Beach. Some of these (and other) deployments are research to better understand basic biology and ecology of protected species, whereas others have a more applied conservation management purpose (such as the use of listening sensors to localize right whales and report that information to vessels in an effort to minimize ship strikes). Finally, NOAA has begun to take a somewhat unique, broader interest than other federal agencies in how collective human activities may affect animals through increases in overall marine ambient noise. While research in this area has been limited, NOAA has begun working with USN to recover and analyze historical measurements of ambient noise from decades ago. NOAA is also supporting subsequent measurements of marine ambient noise, in

"Pop-up" passive acoustic recorders (courtesy: C. Clark) order to expand the scientific understanding of potentially increasing low frequency noise.

(2) Baseline Biological Information (Physiology, Distribution, and Abundance)

There have been substantial efforts to generate baseline biological information, but the complexities in natural systems render this an inherently challenging research area. In many cases, a limiting factor in assessing potential impacts has been uncertainty regarding species presence and abundance in the area of concern, requiring additional costly survey effort to produce the needed information. Surveys of animal distribution, as well as baseline measures of anatomy and physiology, have been conducted by management agencies (NOAA and USFWS) in some areas. Other agencies (USN, MMS, and MMC) have supported similar efforts in specific geographical locations of interest to those particular agencies. These surveys form the basis of current knowledge used, among other places, in environmental assessment and compliance documentation. Certain species (*e.g.*, bottlenose dolphins, grey whales, California sea lions) appear to be fairly well understood in terms of their general distribution, population trends, and basic anatomy as a result of these efforts. However, many key species (*e.g.*, beaked and other deep-diving whales, Arctic ice-breeding seals, most marine fish) remain quite poorly understood in many key aspects of natural history.


Acoustic tag attached to a northern fur seal (courtesy: S. Insley)

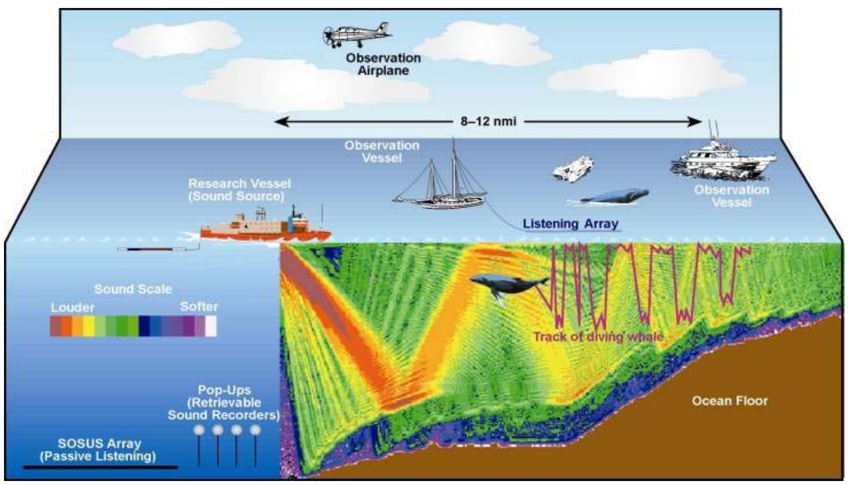
Various animal tagging technologies (developed largely through support from USN are becoming critical in supporting and validating distribution models, as well as conducting research on the behavioral responses of marine animals to anthropogenic sound. A large body of information has also been generated through mandatory environmental compliance monitoring by both federal agencies and private sector activities, but these valuable data have not been systematically archived, analyzed, or made readily available for use in subsequent risk assessment and mitigation actions, often due to limited resources and/or technologies for systematically archiving the data in a manner useful for subsequent analyses. This represents an important area for progress with relatively lower additional effort than in other areas, with potentially large impact to not just the marine noise issue but in terms of value added to other environmental compliance and conservation management efforts.

(3) Effects of Sound (Criteria and Thresholds)

U.S. federal agencies have also supported and/or conducted direct measurements of the effects of sounds on marine life to support science-based acoustic exposure criteria, with substantive advances in specific areas. Research on the effects of noise on hearing has proven more definitive and broadly-applicable than quantifying the biological significance of behavioral responses to sound (see NRC, 2003; 2005; Southall *et al*., 2007). Uncertainty regarding which exposures are consistent with demonstrated adverse impacts (particularly behavioral responses) and the overall potential magnitude of environmental impacts from noise are perhaps the greatest obstacles to determining the appropriate federal response. For this reason, we have prioritized this particular area of investigation highly in the recommendations made throughout this strategic plan.

USN (and to a lesser extent NOAA) has funded research on how noise can affect the hearing, behavior, and physiology of certain marine mammal species. These measurements form the current basis for marine mammal noise exposure criteria

(Southall *et al.*, 2007). However, they are limited in many ways, including the fact that a very small percentage of the total number of species have been tested, almost always with small sample sizes, and most of the work has been conducted in laboratories on captive animals that may not fully represent free-ranging individuals for certain types of effects (*e.g.*, natural behavioral patterns). A significant current collaboration of USN and NOAA is facing the daunting task of understanding the nature and scope of behavioral responses to specific anthropogenic sounds (including active military sonars) using controlled exposure experiments to obtain empirical measures of behavior in the wild.



Simple schematic of nominal behavioral response study elements (source: R. Gisiner).

MMS has also provided considerable support for distribution patterns of marine mammals during and after oil/gas exploration and production, including key studies on noise impacts. These included observational and controlled studies on marine mammals over the last two decades monitoring responses to seismic surveys and other aspects of oil and gas exploration and production. The resulting data are significant and represent much of the current understanding of whether and how certain large whale species typically respond to such sounds. However, certain key questions remain about such impacts even in those species studies, and many key species (especially in Arctic areas) have not been systematically tested. FWS has similarly assessed manatee behavior relative to boat operations. Finally, NSF provided use of its former seismic research vessel (*R/V Maurice Ewing*) for use in controlled exposure experiments in research lead by MMS, with support from ONR, NMFS, and private industry (see Jochens *et al.*, 2008).

(4) Monitoring and Mitigation

Once specific impacts are demonstrated or reasonably likely to occur under specific conditions, choosing effective monitoring and mitigation measures is important for minimizing both environmental risk from anthropogenic sound and the impact of these requirements on human activities that generate sound. At present, a number of monitoring and mitigation measures are required of federal and federally-funded researchers, and private enterprise to mitigate environmental risk from sound-producing activities. However, most, if not all, are undocumented in their efficacy and carry financial or logistic costs that impose serious (and possibly unnecessary) burdens on agency mission effectiveness.

USN has supported considerable technology development to enhance detection methods for marine life using a variety of modalities. For instance, the use of passive acoustic monitoring (PAM) on military ranges to locate and track some marine mammals is proving to be an increasingly useful tool in determining reactions to sounds involved in military operations. Additionally, active acoustics, radar, infrared imaging, and other methods are expanding the methodological toolkit available for use in sensing and characterizing marine mammals around operations. MMS, NSF, NOAA, and FWS have supported related efforts, mainly in the realm of using PAM for marine mammal monitoring. Specific examples include the use of listening sensors to localize endangered right whales in Stellwagen Bank National Marine Sanctuary (NOAA) and NSF work using PAM aboard the *R/V Marcus G. Langseth* for marine mammal monitoring.

(5) Outreach, Education, and Scientific Peer Review

All of the involved federal agencies concur on the need for public awareness and understanding of this complex and evolving issue. This is particularly in the face of often-inaccurate or sensationalized depictions in the media and various public fora. For example, a recent cover of the Honolulu Weekly (Vol. 18, no. 12; March 19-25, 2008) depicts active sonar as an "all purpose killer" and "anti-marine life military power" that "kills whales on contact". Such emotionalized hyperbole confuses the public and some decision-makers into believing conclusions that are wildly inconsistent with reality, amplifying the divisiveness and acrimony that has unfortunately become synonymous with this issue.

Most of the federal agencies participating in this task force have contributed to public outreach and scientific peer-review to some extent, the most notable examples being the series of National Research Council reports (1994; 2000; 2003; 2005) and the peer-reviewed, award-winning Discovery of Sound in the Sea (DOSITS) educational website (www.dosits.org) operated through the University of Rhode Island.

Dr. William Ellison delivering an educational lecture at the National Aquarium in Washington D.C. as a part of NOAA's educational lecture series on marine acoustics (photo credit: NOAA)

Chapter 3. Science and Technology Directions for U.S. Federal Agencies

Chapter 3 – Key Points
• **Targeted research in key areas, coordinated across agencies, is in the vital interest of the U.S. government, the public, and the biological resources we seek to protect.** • **Specific, prioritized science and technology objectives are discussed (briefly here and in greater detail in *Appendix III*).**

A full understanding of the complex suite of relevant questions for tens of thousands of marine species is simply impossible, regardless of the amount of effort by federal (or other) sources. However, through targeted, proactive, and integrated research and development, federal agencies can provide greater confidence in decisions about mandated conservation requirements. In an effort to develop a strategic roadmap toward this objective, the Task Force determined research priorities in a sequential manner:

- First, the Task Force gathered information regarding the roles and responsibilities of the involved agencies (see Appendix I) and agency efforts to date in addressing this issue from a scientific perspective (see Appendix II).
- Next, the Task Force underwent a series of discussions centered on reviewing Appendices I and II and individual agency scientific priorities on this issue and identifying specific research action areas. These actions items were considered within the five general subject categories (Sound Sources and Acoustic Environment; Baseline Biological Information; Effects of Sound; Monitoring and Mitigation; and Outreach, Education and Scientific Peer Review).

- The Task Force then prioritized research action areas within each category according to three levels of importance (*highest*, *high*, and *moderate*; below and see Appendix III).
- Finally, the resulting highest priority subject areas for federal research were coalesced into a recommended strategic plan of prioritized research recommendations that includes an ordinal ranking of priorities as well as a simplifying approach that considers not only the relative importance of the work, but also the respective level of effort required (see Chapter 5; Table 1).

Summary of Prioritized Research Needs by Subject

(1) Sound Sources and Acoustic Environment

- <u>Highest priority</u>:
  - ➢ Passive and/or active acoustic deployments to detect and characterize biological and anthropogenic sound sources and ambient noise (including trends) [needed to enhance animal detection for improved mitigation measures, and improve overall understanding of specific sources and the full scope of anthropogenic contribution to marine noise]; and
  - ➢ Characterize/verify measurements for specific sources of highest immediate concern (*e.g.*, ice-breaking, certain military sonars, seismic airguns, new classes of large vessels) [needed to accurately predict noise fields around specific real-world sources in order to estimate potential impacts].
- <u>High priority</u>:
  - ➢ Sound source verification for new wide-azimuth seismic surveys, pile driving, as well as oil drilling and production [need is same as above, just slightly lower priority].
- <u>Moderate priority</u>:

- Characterize/verify measurements of additional sources (emerging or less prevalent technologies than in the above category – *e.g.*, offshore alternative energy technologies, underwater data communications, oceanographic research or mapping sonars, acoustic harassment and deterrent devices) [need is same as above, just slightly lower priority]; and
- Develop online data archives of sound source data [needed to provide existing data on sources of interest for use in impact assessment and to reduce probability of duplication of effort].

(2) Baseline Biological Information (Physiology, Distribution, and Abundance).

Determining baseline biological and life history data for marine life generally is beyond the scope of this report, as it is not strictly specific to acoustic issues. There is ongoing work in those areas, as well as additional efforts needed, much of which is relevant to a complete assessment of the impacts, both direct and cumulative, of specific sounds on marine life. What is intended in this section is basic biological information relating specifically to the marine noise issue (perhaps considered baseline acoustical information) as well as direct information on the effects of noise on hearing, behavior and physiology.

- <u>Highest priority</u>:
  - Develop, standardize, integrate, and maintain online databases of marine mammal distribution, abundance, and movement (it is worth noting the considerable value-added aspect of this action relative to other marine resource management issues such as fisheries, monitoring of marine protected areas) [needed to provide a common source of data access and management of information used in both managing and studying these species];
  - Improve distribution and abundance measurements for key species (*i.e.*, very common, endangered, or particularly important to specific types of sound sources) [needed to increase the biological precision of impact assessment and targeted mitigation efforts]; and

- Obtain baseline biological data on "particularly sensitive" (*e.g.*, beaked whales, harbor porpoise, migrating bowhead whales) and Arctic marine species (because of the apparently rapid climatic and habitat changes they are experiencing and the increasing human activities in Arctic areas) [needed to better understand and manage species of particular concern for various reasons]

- <u>High priority</u>:
  - Obtain targeted physiological, behavioral, distribution, and longitudinal life history data for "representative" marine species (those thought to adequately represent related species on which such data are not available – see NRC, 1994, 2000, 2003) as surrogates for less-common or more-difficult-to-test species [needed to provide a more complete understanding of a few relatively accessible species that may be appropriate surrogates for estimating some impacts in other species].
- <u>Moderate priority</u>:
  - Develop specific assays for stress and immune functions [needed methodology to assess the potential impacts of noise exposure on certain non-auditory tissues and processes].

(3) Effects of Sound (Criteria and Thresholds)

- <u>Highest priority</u>: develop, improve, and/or validate noise exposure criteria by:
  - Obtaining advanced measurements of hearing (*e.g.*, evoked potential audiometry and sophisticated behavioral methods) [needed to more rapidly obtain basic hearing data, including on certain species that may be unavailable for more conventional hearing methods];
  - Testing hypotheses on the non-auditory, physiological effects of noise [needed assessments to assess recent observations of specific types of non-auditory tissue damage in animals exposed to certain sound source as well as expected phenomena based on non-marine animals];
  - Obtaining measurements of the behavioral effects of high priority sound sources in key sensitive (*e.g.*, beaked whales) and representative (*e.g.*,

common dolphins, minke whales, salmon) species [needed to provide direct measurements of how key species respond when hearing specific sounds; for use in impact assessment, monitoring and mitigation efforts, and/or development of alternative source technologies (where appropriate and possible)]; and

    - Quantify the actual biological consequences of signal masking [needed to understand the real biological costs of simultaneous noise interference with communication in marine animals].

- High priority:
    - Measure acoustic perception/localization for realistic signals over realistic noise exposures [needed to advance the state of current hearing data to include some measurement of how actual biological and other sounds are actually perceived and located in space – current data are generally limited to artificial stimuli]; and
    - Advance anatomical modeling capabilities to predict various effects, especially where *in vivo* testing is difficult [needed to provide science-based estimates of potential impacts in situations where direct measurements may not be possible].
- Moderate priority:
    - Measure (following development of specific assays – see above) effects of noise on stress and immune functions, including synergistic effects [needed measurements to assess potential impact of noise exposure on non-auditory tissues that may be expected to occur in certain circumstances based on non-marine animals].

(4) Monitoring and Mitigation

- Highest priority:
    - Improve/advance remote sensing technologies for marine mammals [needed to enhance detection of marine mammals in the contexts of both scientific research and mitigation of potential impacts from certain sound sources];

  - Validate new and existing mitigation measures [needed to provide scientific assessment of and possible improvements to procedures currently in place];
  - Investigate source modifications to reduce acoustic footprints [needed to consider whether reductions of the acoustic output of certain sources may be possible based on function(s) and other practical considerations; and
  - Explore need for and effectiveness of time/area closures versus operational mitigation measures [needed to consider which approach, or some combination thereof, may be more appropriate and best suited to a particular operational scenario].
- <u>High priority</u>:
  - Improve/advance remote sensing technologies for other marine species (*e.g.*, sea turtles, fish, squid) [needed to enhance detection of species other than marine mammals in the contexts of both scientific research and mitigation of potential impacts from certain sound sources]; and
  - Standardize observer program data collection and reporting [needed to ensure that observed data being obtained is accessible to others conducting impact assessments in a useful and common format].
- <u>Moderate priority</u>:
  - Develop and validate simple decision-making criteria for source shutdown, modification or movement [needed to provide a common set of protocols for modifying sound-producing activities, where appropriate].

(5) Outreach, Education, and Scientific Peer Review

- <u>Highest priority</u>:
  - Develop a biennial forum for information transfer to report on the results of inter-agency research progress to various stakeholders (*e.g.*, federal and state government, industry, academia, public, educators, media, and environmental groups) [needed to provide a regular and transparent exchange of information regarding progress and research directions within and among federal agencies and various stakeholders];

- Encourage timely peer-reviewed publication of scientific data supported with federal funding [needed to ensure that federally-funded research is made available in a scientifically-acceptable format]; and
- Conduct periodic expert panel reviews of existing scientific data in the relevant fields [needed to assess current status of science and how it may be applied, as well as to assess additional needed research].

- High priority:
  - Enhance the availability of educational/outreach material, including effort directed to K-12 education, oceanaria, marine reserves, and interest groups [needed to ensure that scientific information on this issue is fairly and transparently communicated to society through a variety of acceptable and known conduits].

Chapter 4. Inter-Agency Coordination Mechanisms: Opportunities and Obstacles

Chapter 4 – Key Points
• **There are existing coordination mechanisms within and between federal agencies on the issue of anthropogenic sound impacts.** • **Sustained and expanded dialogue among agencies is extremely important on both domestic and international issues related to anthropogenic sound.** • **Ample opportunities exist to further the diverse capabilities and perspectives represented in the combined federal agencies.** • **Significant challenges to progress also exist. These include differing and often complex budgeting and permitting processes, as well as increasing litigation of both ongoing activities and research designed to inform conservation management**

Key elements in implementing any coordinated federal strategic plan are (1) identifying existing and needed coordination mechanisms among the federal agencies and (2) an objective assessment of opportunities and challenges in successfully enacting the envisioned course of action(s). For a highly visible, contentious, and data-poor issue such as the effect of anthropogenic sound on marine life, these elements take on even greater significance. This chapter briefly addresses these key considerations.

Existing Coordination Mechanisms

Many of the federal agencies that have been dealing extensively with this issue either as sound-producers or in a regulatory function have developed internal coordination and communication mechanisms. These are *ad hoc* in some cases and more structured in others, but are generally intended to enhance communication and consistency across different branches within those agencies.

In terms of inter-agency communication, there are also existing mechanisms, ranging from informal (such as the Inter-agency Coordinating Group (ICG) on ocean sound) to much more structured mechanisms for coordination of funding efforts (principally the National Oceanographic Partnership Program (NOPP)).

While communication and coordination can and will continue to improve among federal agencies, there is also a need for increasing international discussion and collaboration. There is a growing international scope of this issue, a trend that will likely continue, involving many of the federal agencies and coordination by DOS. In addition, many industries (*e.g.*, commercial shipping, energy exploration and development) and federal agencies (*e.g.*, NSF, USN) affected by the regulation of sound-producing activities also operate internationally and, in many cases, face differing regulatory mechanisms and mitigation and monitoring requirements depending on the location. This further reinforces the need to also look globally for information sharing and solutions to this issue. For instance, the United States recently proposed to the International Maritime Organization's Marine Environmental Protection Committee (MEPC) that it add to its work agenda the issue of minimizing the introduction of incidental noise from commercial shipping to reduce the potential adverse impacts on marine life. In October 2008, the Committee agreed with the U.S. proposal. This work is a prime example of interagency cooperation addressing sound issues in the international arena. In addressing this issue, the correspondence group established to work on it will begin to assess and identify practical, effective solutions to this issue, and work on the development of non-mandatory technical guidelines for ship quieting technologies as well as potential navigation and operational practices.

Opportunities for Inter-agency Coordination

Currently the science and technology efforts of the federal agencies are primarily driven by individual agency needs. There are collaborative approaches to certain questions, for example through NOPP or interagency research agreements, but agency science programs generally identify and support research meaningful to specific agency mandates. This is logical and not necessarily something that requires change.

However, there is an opportunity within the inter-agency collaborations that have been initiated to maximize the diverse capabilities and perspectives of the federal agencies in moving the overall issue forward. Many of the research needs of federal agencies have some overlap or commonality. For instance, tools and technologies to improve the detection and characterization of marine life will benefit all participating agencies. Better understanding of animal distribution, abundance, and life history, particularly as it relates to acoustic communication and potential noise impacts, will improve the abilities of agencies that utilize sound-producing technologies to determine and mitigate their potential environmental impacts, as well as enhancing the abilities of regulatory agencies to fulfill their obligations. Further, some uniformity of effort, peer-review, and information transfer to the public and educational programs (*e.g.*, availability of on-line databases and other resources) are common goals of all involved federal agencies. Certain categories fall more logically within the mandates and expertise of certain agencies rather than others, and this issue is addressed in greater detail in Chapter 5. However, there is a pressing need at the federal level for a more unified and integrated strategic approach on a topic that is becoming increasingly broader and more complex.

The strategic federal response on marine sound must be coordinated, yet optimized to the individual strengths of the individual agencies and adaptive in responding to this rapidly-evolving field. Therefore, while the Task Force is keenly aware of the potential downside in adding additional layers of bureaucracy, we do see a clear need in formalizing coordination among the agencies at two different levels. This should include:

- Program-level coordination of managers and scientists intimately familiar with the status and future directions of science in relevant subject areas (as well as how they relate to federal agency missions) to formulate action plans for achieving specific goals and milestones, and facilitate program level interagency interaction on specific projects, data sharing, etc.; and
- Higher-level agency representatives with sufficient authority to make internal budgeting and planning recommendations and decisions that relate to future needs and obligations for partnerships with other federal agencies.

The overall aim of each of these inter-agency mechanisms should be to coordinate mutual research goals, projects, data management/sharing, and co-funding opportunities in the short term, but, more importantly, to also coordinate advanced planning across the federal agencies with sufficient lead time to constructively affect the federal budgeting process.

Potential Obstacles for a Federal Research Strategic Plan

Long-term collaboration will require coordinated efforts for informing budget planning processes within all relevant agencies. Currently, internal agency processes for setting goals occur in the absence of knowledge of whether another agency will be able to collaborate in future years on mutual needs. While it is difficult enough to plan within individual agencies several years out, much less on an issue across multiple agencies, there should be some coordinated thought and sustained discussion given to both short and long-term fiscal requirements for the involved agencies in a manner that is consistent with overall federal need. This will allow the Executive Branch to make a stronger case to Congress that it is properly addressing an issue of high public and Congressional interest, which spans the actions of multiple agencies.

Additionally, there are considerable challenges in terms of planning and conducting many of the kinds of research proposed here. Some of these challenges have to do with the regulatory/permitting procedures required under various federal laws, which can be difficult given the level of required analysis, current levels of scientific uncertainty, and the contentious political-legal climate of the overall issue. These processes can be time-consuming, expensive, and variable across jurisdictions (which can include federal, state, local, and institutional authorizations), sometimes resulting in the postponement or canceling of critical activities (*e.g.*, operation of mid-frequency military sonar off the west coast, oil exploration activities in Arctic Alaska waters), or re-prioritization of limited available research support. Further, complex and often protracted permitting processes are also making it increasingly difficult to synchronize the application for and acquisition of research funding. Resources and effort should be focused on streamlining and improving the necessary permitting and regulatory processes at the federal level, particularly for those research efforts that will feed data on acoustic effects back into the regulatory process.

Finally, there are certain societal realities that may impede scientific progress on the marine sound issue, notably lawsuits. In some instances, litigation has served as an effective mechanism for balancing the federal regulatory and decision-making process where needed. In other examples, lawsuits appear to be mainly driven to draw an agency into lengthy legal disputes with federal agencies spending valuable resources to defend actions the court ultimately upholds. The increasingly litigious response has affected the USN, NOAA, NSF, MMS, academic researchers, and others. The effective use of scientific information to formulate regulations and enhance decision-making rather than controversy and litigation formulating what science can be effectively accomplished is a complex process, perhaps requiring some adjustments for this issue. Procedures exist to help ensure reasonable and effective decision-making and regulatory responses. No explicit suggestions are provided in this report to reduce the negative consequences of increased litigation, but it is identified as a significant factor that may cause delays, increase costs, or otherwise limit various types of research and development and ultimately not lead to a better understanding of sound impacts on the marine environment. Further, we note that the improved understanding and ability to take effective action which will arise from the actions recommended in this report are likely the best means to resolve strong divergences of opinion that lead to litigation, as well as to provide federal agencies the ability to defend themselves in future court cases that do arise.

Chapter 5. Conclusions and Recommendations

Chapter 5 – Key Points

- **The general coordination and specific research recommendations made in this report represent a strategic vision to develop targeted, coordinated, inter-agency science and technology efforts, over the short and long-term on the effects of sound on marine life.**
- **General recommendations include: actions directed to increase and sustain coordination within and among agencies and with private-sector and international organizations; continued efforts to streamline the scientific research process; and developing a biennial forum for information transfer on the results of inter-agency research efforts and planning.**
- **Eleven (11) specific research recommendations are given in prioritized order and within subjective categories relating their relative importance and required level of effort.**
- **Additional high and moderate research priorities (see Chapter 3 and *Appendix III*) provide additional guidance.**

The information to follow outlines the Task Force's strategic vision for integrating, prioritizing and optimizing the science and technology efforts of federal agencies on marine anthropogenic sound over the next decade. From these deliberations, the Task Force has derived an overall prioritization of needed research action areas, with specific examples of research topics within these action areas. Further, the plan presented here also provides some information on the timeframe for these actions (short-term, long-term, or ongoing), relative effort required for implementation, and the federal agencies most likely to be involved in a specific action area. Collectively, this information presents the Task Force's strategic plan for addressing the pressing requirements of a coordinated federal response.

The recommendations of the Task Force are given in two areas: necessary actions to ensure a coordinated federal response and specific research action area priorities for the coming decade (below). Again, it should be realized that this report represents an overall, interagency perspective as determined through the Task Force members and the views given here do not necessarily reflect individual agency priorities. Highest priority coordination action items include:

Sustained interagency collaboration and coordination, including:

- "High-level" inter-agency coordination among individuals with sufficient authority to make timely planning and budget recommendations within their respective agencies; and
- "Program level" inter-agency coordination among agency subject matter experts and program managers to implement directives and provide technical advice to leadership.

- **Enhanced communication and coordination on the marine sound issue with private sector interests and with the governments of other nations to reduce duplication of effort and advance a consistent scientific response.**
- **Continued efforts to streamline research permitting involving acoustic sources.**
- **Development of a biennial forum for information transfer to report on the results of inter-agency research progress to various stakeholders (*e.g.*, federal and state government agencies, industry, academia, public, educators, media, and environmental groups).**

In addition to these recommended coordination items, Table 1 (below) identifies the top eleven specific research action areas presented in an ordinal ranking of overall importance. Suggested timelines (*i.e.*, short-term vs. long-term) for these action areas within the five general subject categories and those agencies most likely to have leading/direct interest and/or secondary level of involvement are also given. Additionally, each recommended research action area is assigned to one of four subjective categories according to the relative level of effort required to make significant progress and the overall importance and social relevance of the work: (1) High importance/moderate effort; (2) High importance/high effort; (3) Moderate importance/moderate effort; (4) Moderate importance/high effort.

Table 1 – Ocean Sound and Marine Life: Prioritized Research Recommendations

Prioritized Recommended Federal Research Action Areas	Short or Long-term?	Relative Importance and Level of Effort	Agencies Involved (see note below)	General Subject Area(s) (described in Chapter 2)
(1) Improve ability to identify and understand biologically-significant effects of sound exposure in order to improve effectiveness and efficiency of efforts to mitigate risk.	On-going and long-term	**High Importance/ High Effort**	NOAA[1]MMC[2] NSF, USN, MMS	Effects of Sound
(2) Hearing, physiological, behavioral, and effects data (*e.g.*, controlled exposure studies) for key species of concern (baleen whales, beaked whales, Arctic & endangered species).	Ongoing and long-term	**High Importance/ High Effort**	USN[1], NOAA[2], NSF, MMS, MMC	Baseline Biological Information; Effects of Sound
(3) Develop new technologies (*e.g.*, acoustic monitoring) to detect, identify, locate, and track marine mammals, in order to increase the effectiveness of detection and mitigation.	Ongoing and short-term	**High Importance/ Moderate Effort**	USN[1], NOAA[1], MMS, NSF, USCG, ACE, DOT, FWS	Sound Sources and Acoustic Environment; Mitigation and Monitoring
(4) Develop and validate mitigation measures to minimize demonstrated adverse effects from anthropogenic noise.	Short-term and long-term	**High Importance/ High Effort**	NOAA[1], MMC[2], USN, MMS, NSF, FWS, USCG, ACE	Mitigation & Monitoring; Effects of Sound
(5) Support the development, standardization, and integration of online data archives of marine mammal distribution, abundance, and movement for use in assessing potential risk to marine mammals from sound-producing activities.	Ongoing, short, and long-term	**High Importance/ Moderate Effort**	NOAA[1], USN, FWS, MMS, MMC	Baseline Biological Information
(6) Long term biological and ambient noise measurements in high-priority areas (*e.g.*, Arctic, protected areas, commerce hubs).	Ongoing and long-term	**High Importance/ High Effort**	NOAA[1] USN, MMS	Sound Sources and Acoustic Environment
(7) Test/validate mitigating technologies to minimize sound output and/or explore alternatives to sound sources with adverse effects (*e.g.*, alternative sonar waveforms).	Long-term	**High Importance/ High Effort**	USN[1], NSF[1], MMS[1], NOAA, MMC, DOE	Mitigation & Monitoring
(8) Explore need for and effectiveness of time/area closures versus operational mitigation measures.	On going and long-term	**Moderate Importance/ Moderate Effort**	MMS[1], NOAA[2], MMC[2], USN, NSF	Mitigation and Monitoring
(9) Develop and improve noise exposure criteria and policy guidelines based on periodic reviews of best available science to better predict and regulate potential impacts.	On going and long-term	**Moderate Importance/ Moderate Effort**	NOAA[1], FWS[1], MMC[2], USN, MMS, NSF	Effects of Sound
(10) Standardize data-collection, reporting, and archive requirements of marine mammal observer programs.	Long-term	**Moderate Importance/ Moderate Effort**	NOAA[1], FWS[1], MMS, NSF, USN, USCG, MMC	Mitigation and Monitoring
(11) Expand/improve distribution, abundance and habitat data for marine species particularly susceptible to anthropogenic sound.	Ongoing and long-term	**Moderate Importance/ High Effort**	NOAA[1], FWS[1], USN, MMC, MMS	Baseline Biological Information

Note:
[1] denotes agencies that are the logical "action" leads on each recommended action
[2] denotes agencies that are the logical "oversight/coordination" leads on each recommended action

Conclusion

This strategic plan is intended to both substantially increase scientific understanding of the most pressing issues and reduce the costs, limitations to agency mission capability, and litigative burden on the government which currently attends this unsettled matter. Scientific uncertainty drives, if not allows, much of the current debate and disagreement on this issue. The application of targeted science through a coordinated, multiple agency effort directed towards identifying the nature and scope of real and potential problems, will provide answers to reduce uncertainties and ultimately result in more effective federal decision-making on important marine conservation issues.

This is a tractable matter. There are many opportunities for collateral benefit in areas of basic biology, biomedical science, oceanography, marine geology, climate science, and marine resource management and conservation. Many federal agencies have achieved considerable progress already on this and other issues through the use of available informal and formal mechanisms for cost-sharing, information transfer, and division of labor according to individual agency capabilities and mandates. Effective resolution of the myriad challenges in the marine noise issue must enable the agencies to more fully carry out their missions while meeting environmental requirements. This will enable the government to better serve the public and private sectors through more informed, effective action for the protection of our shared ocean environment.

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Appendix I. Roles and responsibilities of U.S. federal agencies relative to anthropogenic sound and the marine environment [and agency representatives contributing to this report].

Marine Mammal Commission (MMC)

[Representatives to the Task Force: Drs. Robert Gisiner and Timothy Ragen]

MMC is mandated to ensure the protection and conservation of marine mammals and the ecosystems of which they are a part. Human activities pose a variety of threats to the marine ecosystem, such as fishery impacts, contaminants, sound, harmful algal blooms and dead zones, habitat loss, and climate change. Although other threats are undoubtedly more serious than sound, the magnitude of the risks posed by sound appears to be growing while the nation, and the world, remains uncertain about the appropriate course of action to mitigate those risks. Much remains to be learned, not only about sound sources but also about the biological significance of sound to marine mammals and marine mammal populations. Development of national capability in ocean acoustic sensing and monitoring is essential to promote safe ocean resource exploitation and management, while also protecting and conserving the marine environment.

Minerals Management Service (MMS)

[Ms. Jill Lewandowski and Ms. Judy Wilson]

MMS, a bureau in the U.S. Department of the Interior, is the Federal agency responsible for managing the nation's natural gas, oil, non-energy minerals and alternative energy resources on the outer continental shelf. MMS currently administers close to 7,500 active leases on 40 million acres and collects more than $8 billion per year in revenues from Federal leases. In implementing its programs, MMS is charged with ensuring that activities it regulates are conducted in a technically safe and environmentally sound manner. For activities which introduce sound into the environment (e.g., seismic surveying, drilling, production), MMS uses the best available information (rather than scientific certainty) to analyze impacts and design mitigation and monitoring requirements and regulations that reduce or eliminate the potential for effects. MMS also funds and conducts research necessary to help fill important information gaps. These collective efforts allow MMS to play an integral role in improving our understanding of acoustic impacts and advancing management systems while maintaining an energy program important to the nation.

National Oceanic and Atmospheric Administration (NOAA)

[Drs. Brandon Southall (Task Force Lead) and Amy Scholik-Schlomer]

NOAA has broad and numerous mandates under various federal laws (*e.g.*, Endangered Species Act, Marine Mammal Protection Act, Magnusson-Stevens Fishery Conservation and Management Act, National Marine Sanctuaries Act, and National Environmental Policy Act) include studying and managing protected marine species. NOAA thus has both regulatory responsibilities and science and technology leadership requirements with regard to the marine environment and offshore resource management, creating broader responsibilities for this issue than most, if not all, other federal agencies. NOAA applies the relevant statutory authorities, cited above, in managing the adverse effects of noise on marine life, and does so using the best-available scientific information.

NOAA also conducts research or supports external research efforts strategically directed toward increasing scientific understanding of this and similar marine resource issues. NOAA remains focused on understanding and mitigating the adverse effects of intense, acute noise sources on marine life, but NOAA is increasingly concerned with chronic, long-term sources of anthropogenic sound input to the ocean and their potential impact on overall marine ambient noise. While much of NOAA's focus on the marine sound issue has involved marine mammals, NOAA is increasingly aware of and dealing with impacts on fish, sea turtles, and even some marine invertebrates.

National Science Foundation (NSF)

[Dr. William Lang and Ms. Holly Smith]

NSF is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" NSF is the funding source for approximately 20 percent of all federally supported basic research conducted by America's colleges and universities. Another essential element in NSF's mission is support for science and engineering education, from pre-K through graduate school and beyond. NSF funds proposals on basic research and technology that advances basic research. There are few limitations on topics and intense competition on quality. Proposals directed to NSF can address the full range of marine acoustic subjects, including design of new acoustic instruments and research on marine sound, the use of sound by marine organisms, and the effects of sound on the marine environment. Proposals directed to NSF also include proposed use of active sound sources as a research tool. In contrast to directed research programs in other agencies, the extent and topics to which NSF funds research on acoustic issues is largely dependent on the response of the greater academic community. However, in support of vessel operations, NSF can 'direct' limited funds to assessing and mitigating impacts of operations.

U.S. Army Corps of Engineers (ACE)

[Dr. Joseph Wilson]

U.S. Coast Guard (USCG)

[Dr. Jon Berkson]

USCG is one of the five Armed Services of the United States and the Nations' primary maritime law enforcement agency. In addition, USCG provides a wide range of maritime safety, security, and environmental protection services. The Coast Guard protects vital interests of the United States from foreign and domestic threats, both natural and man-made, and serves in America's ports and inland waterways, along the coasts, on international waters, or in any other maritime region where the United States' interests are at risk. USCG is a military, multi-mission, maritime service that possesses a unique blend of humanitarian, law enforcement, regulatory, diplomatic, and military capabilities. These characteristics are underscored by the Coast Guard's five fundamental roles: maritime security, maritime safety, protection of natural resources, maritime mobility, and national defense.

U.S. Department of Energy (DOE)

[Ms. Susan Gregerson and Mr. John Prydol]

DOE conducts research and development to support the domestic petroleum industry in developing new technologies and operating practices that are more environmentally-sensitive and cost-effective for both offshore and onshore oil and natural gas development. This R&D is focused on high-risk, high-potential petroleum resources and technologies that are not being addressed by the domestic industry.

U.S. Department of State (DOS)

[Mr. John Field and Ms. Maggie Hayes]

DOS is charged broadly with developing and implementing U.S. foreign policy and advancing U.S. interests in the international community. Issues involving the marine environment and its resources are handled through the Department's Bureau of Oceans, Environment, and Science (OES). The bureau promotes transformational diplomacy through advancing environmental stewardship, encouraging economic growth, and promoting social development around the globe to foster a safer, more secure and hopeful world. The Department's specific interest in anthropogenic sound lies in effective communication of U.S. activities to the international scientific and maritime communities, and assisting U.S. technical agencies in securing bilateral or multilateral cooperation as appropriate on particular science and technology issues.

U.S. Fish and Wildlife Service (USFWS)

[Ms. Diane Bowen and Mr. Martin Kodis]

USFWS was given authority to implement the Marine Mammal Protection Act for the conservation and management of sea and marine otters, walrus, polar bear, 3 species of manatees, and the dugong. Several of these are also listed under the U.S. Endangered Species Act (ESA) and the Service has a responsibility to manage and protect these species in accordance with the ESA. All of these animals spend the majority of their life in the ocean environment and, therefore, all are potentially impacted by anthropogenic sound in that environment. Although we are gaining more information about potential acoustic impacts on each of these trust species, there are still many unanswered questions surrounding the effects of various acoustic-related activities and possible ways to minimize any adverse effects. In addition, each of these species has unique needs and behaviors that differ and must be studied and addressed accordingly.

U.S. Department of Defense, U.S. Navy (USN)

[Dr. James Eckman (Office of Naval Research), CAPT Robin Brake (Office of the Deputy Secretary of the Navy, Environment and Installations), Dr. Robert Winnokur (U.S. Department of Defense, Joint Chiefs of Staff), and Dr. Augustus Vogel (U.S. Department of Defense, Office of the Oceanographer of the Navy)]

The **Navy's** mission, established in Title 10 of the U.S. Code, is to be continually ready to support the U.S. national interest with prompt and sustained combat operations when directed. This includes ensuring the free use of the high seas, and maintaining continued maritime superiority. In order to achieve this mission, the Navy must engage in at-sea anti-submarine warfare training using active sonar technologies. Military sonar use has been implicated in marine mammal mass stranding events. The Navy is interested in determining the impacts of anthropogenic sound on marine mammal populations so that readiness and operational needs are properly balanced with the service's responsibility to protect the marine environment in which it operates. While active sonar is the primary concern, other sources such as ship and explosive noise are of concern as well.

Appendix II. Detailed summary of current federal science and technology effort in each of five subject areas regarding anthropogenic sound and marine life.

(1) Sound Sources & Acoustic Environment – U.S. Government (USG) Efforts to Date

Assessments of potential impacts rely heavily on measurements and modeling of the source characteristics of different anthropogenic sound sources and how sounds travel (propagates) through the marine environment. Sound frequency, directivity (radiation) pattern, duration, and environmental conditions (*e.g.*, bathymetry, depth, temperature, salinity, and bottom type) can be as or more important as the source level in determining exposures. Yet as complex as these subjects are, they are arguably the best-understood aspects of the overall issue of how anthropogenic sound affects marine life.

Sound propagation measurements and modeling capabilities to predict sound fields around specific sources are generally advanced. Validated standard models are available for most types of sound sources (natural and anthropogenic) and environmental/bathymetric conditions (for example see http://oalib.hlsresearch.com/).

Most anthropogenic sound sources are also reasonably well-known, especially those used in active sonar and communication systems for military, research, and commercial applications. Sources used in geophysical research and exploration (*e.g.*, seismic airguns) are characterized in great detail for the desired, downward-focused, low-frequency signals, but horizontal and higher-frequency output has generally been ignored. Other sounds produced as a by-product of their intended function, such as explosives, pile-driving, and large vessel sounds, are also less well-characterized, though ongoing or planned efforts by the relevant agency(s) or industry(s) appear likely to resolve most uncertainty about these sources in the near future. The one significant exception to this trend appears to be large vessel sounds and their contribution to marine ambient noise.

Sound production characteristics for most marine animals are relatively poorly known. Certain species, such as the bottlenose dolphin, have been intensely studied both in the field and in the laboratory and are fairly well-understood, but the sound production features of many marine species remain completely unknown. There has been a varying level of effort to measure sound output characteristics of marine animals, driven largely by interests in either emulating the animals’ biosonar capabilities or in listening for their sounds to detect and identify them.

(1) Sound Sources/Acoustic Environment – USG Efforts to Date

USN	MMS	NOAA	NSF	USFWS
- Highly calibrated measurements of sounds produced by many military sound sources in water; - Development, validation, and standardization of sophisticated sound propagation models; - Measurements of biosonar characteristics of various cetaceans (dolphins and porpoises) - Acoustic signal characteristics (other than biosonar) in various marine mammals and fish; - Spectrogram correlations and neural network detection.	- Source characterization of seismic airguns and ambient noise measurements during scientific research; - Measurements from field verification of geophysical survey technologies other than airguns.	- Passive acoustic sensor deployments in Stellwagen Bank and Channel Islands National Marine Sanctuaries; - Recovery and analysis of archived USN acoustic measurements for studying trends in ambient noise; - Comparative measurements of ambient noise in areas of variable industrial activity; - Source levels of humpback whale vocalizations; - Blue whale vocalization characteristics; -Development of sound field visualization software.	- Field measurements and modeling efforts on acoustic output from high-intensity, short-duration sound sources (airguns, boomers, and sparkers) used in geophysical research (most often through interagency support and enhanced NEPA analyses)	- Coordinate and review studies to assess sound sources within and the acoustic environment of West Indian manatees

(2) Baseline Biological Information (Physiology, Distribution, & Abundance) – USG Efforts to Date

Another key element in assessing potential impacts of sound on marine life is understanding the anatomy/physiology and presence/abundance of living marine resources. Specific information is needed on the temporal and spatial distribution for selected species, including nominal feeding, breeding/spawning, diving, migrating, habitat utilization patterns, and interactions within ecosystems. Certain species and areas are reasonably well known, and predictive animal distribution models based on environmental features are advancing rapidly. However, more often than not, an individual or organization planning a sound-producing activity may find that the available baseline data are insufficient to provide sufficient confidence in quantitative risk-assessment. This can lead to costly, time-consuming efforts to intensively survey the area of interest before the planned activity can proceed. The action proponent then must undergo the expense and delays associated with contracting survey experts to collect the necessary data.

These baseline biological data requirements generally fall within the scientific and management obligations of resource management agencies (*i.e.*, NOAA and USFWS) and are obtained by directed surveys of populations or management stocks (*e.g.*, marine mammal ship-based line-transect surveys, or fisheries stock assessments). However, an increasing source of baseline biological information is environmental compliance monitoring supported by other federal agencies involved in the marine sound issue (particularly MMS and USN). This has created a *de facto* set of data of potentially great value to all agencies with shared needs regarding risk assessment. However, this resource is currently not centrally archived in a standardized format for access by the resource mission agencies, other affected agencies, or the concerned public.

Recent advances in predictive modeling and the use of acoustics (passive and active) as a research tool are producing additional, high-quality baseline data to support environmental risk assessment. Biological information related to hearing and other physiological responses to sound are discussed in the subsequent section (3).

(2) Baseline Biological Information – USG Efforts to Date

NOAA	USFWS	MMS	USN	MMC	NSF
- Marine mammal, fisheries (including various fishes and invertebrates such as shrimp, crab, lobster), sea turtle, and other stock assessments; - Habitat and ecosystem modeling development and validation; - Baseline research on marine mammal anatomy/physiology; - Integration of passive acoustics in marine mammal stock assessments; - Blood nitrogen levels during diving in bottlenose dolphins.	- Polar bear, walrus, sea otter, and manatee abundance, distribution, habitat, and baseline anatomy & physiology; - Coordination and review of other studies that assess baseline biological information on these species.	- Directed and pilot studies to assess baseline behavior and impacts of acoustic (seismic) exposure on sperm whales; - Long-term study of bowhead presence and migration through the Alaskan Chukchi/Beaufort Sea; - Measurements of bowhead feeding ecology; - Technological improvements to marine mammal survey and tracking methodologies for large whales and belugas; -Behavioral ecology of bowhead, gray, sperm, and beluga whales; - Distribution of North Pacific right whales in North Aleutian Basin.	- Cetacean distributions and density at USN ranges; - Development of acoustic and satellite tagging technology; - Baseline data on cetacean immune systems; - Living marine resources information systems development; - Cetacean vocalization recording and identification.	- Western Pacific gray whale research; - Morphologica l identification of beaked whales; - Analysis of statistical power in predicting population trends.	- Secondary information generated from marine process studies and seismic cruise monitoring efforts.

(3) Effects of Sound (Criteria and Thresholds) – USG Efforts to Date

Understanding the type, magnitude, and consequences of effects from sound exposure is the crux of assessing the relative importance of anthropogenic sound as a potential stressor on marine life. Ideally, information would be available regarding normal patterns of hearing/behavior and how exposure to sound induces various effects with sufficient certainty to support science-based exposure criteria. There has been increasing effort to quantify direct effects of exposure in a few species, and a limited effort to address the challenging subjects of long-term and/or cumulative impacts of chronic noise exposure. However, this remains well beyond the scope of current understanding. With the current lack of data on acute effects as well as longer-term chronic impacts, it is difficult to objectively consider the overall magnitude of the potential problem and determine the appropriate level of federal response.

The past decade has seen some progress in our basic understanding of acoustic communication and hearing processes in a limited number of marine mammals, fish, invertebrates, and sea turtles, increasingly through the use of electrophysiological methods (which measure neural signals as a means of estimating hearing sensitivity). This has largely been through funding from USN, though NOAA has recently supported some work in these methods and novel behavioral techniques to measure hearing. However, the hearing of many thousands of marine species remains untested and sample sizes for all species are generally very small, limiting efforts to establish statistical hearing norms within a population. The direct measurements that have been made of the effects of sound on hearing functions in perhaps a dozen different marine mammal species (generally those typically held in captive settings such as bottlenose dolphins and California sea lions) have demonstrated simultaneous interference with ("masking") hearing, as well as residual effects of exposure, such as temporary threshold shifts (TTS) in hearing sensitivity. Additionally, extensive effort has been devoted to determining the risks from impulsive sounds (*e.g.*, explosions and airguns) and to determining the physiological effects of low frequency sound. These studies have measured direct effects on hearing systems as well as the likelihood of other non-hearing physiological effects (*e.g.*, tissue or airspace resonance, vestibular (balance) effects, and neurological effects).

The establishment of general quantitative metrics for behavioral effects is proving to be a more daunting task, due to the complex and variable nature of changes in behavior. Current "exceptions" to general hearing-based models for estimating behavioral effects all tend to revolve around reactions that are unique to a species or limited taxonomic group, such as the sensitivity of harbor porpoises to acoustic harassment devices and the apparent sensitivity of beaked whales to mid-frequency tactical sonar sounds in certain conditions. There is rapidly increasing realization among the academic research community and the federal agencies that well-controlled, quantitative measures of behavioral response may be most effective in identifying and mitigating adverse behavioral effects from anthropogenic sound. The cost and complexity of experimental methods to provide specific exposure-response data, such as controlled exposure experiments (CEEs), argue for some level of inter-agency collaboration, which is beginning to occur as well (*e.g.*, the ongoing joint NOAA-USN Behavioral Response Study (BRS) in the Bahamas).

Cox *et al*. (2006) consider the various hypotheses for mechanisms underlying the apparently strong and in some cases lethal reactions of beaked whales to mid-frequency active sonar in certain conditions. A number of the potential explanations involve damage to non-auditory tissues. USN (and to lesser extent NOAA) has directed efforts to measure how sound exposure may affect non-auditory tissues either directly or secondarily through changes in behavior, although current understanding of these phenomena is very limited.

Similarly, studies of the cumulative and/or long-term effects of multiple exposures to persistent or recurrent sources of manmade sound have been few, despite their importance. As difficult as it is to adequately understand the effects of a single exposure event, such an approach is insufficient to characterize the extent of real-world effects in which animals may have many exposures to a diversity of sound sources of the course of months or years. The cumulative impacts of exposure to chronic acoustic sources could have greater potential impacts on populations of marine organisms than intense, discrete exposures. Despite the recognized need for assessing cumulative and/or long-term effects, relatively few specific efforts have been directed toward these matters.

(3) Effects of Sound (Criteria and Thresholds) – USG Efforts to Date

USN	NOAA	MMS	MMC	USFWS
- Hearing sensitivity measurements and masked thresholds in marine mammals and sea turtles; - Evoked potential hearing technology development; - Behavior response/controlled exposure studies in marine mammals and fish; - Tagging technology development; - Marine mammal safety criteria (TTS); - Auditory effects of sonar on marine mammals; - Nitrogen bubble formation in odontocetes.	- Evoked potential hearing measurements in marine mammals; - Development of rapid behavioral hearing measurements in marine mammals; - TTS measurements cetaceans; - Effects of blast trauma on sea turtles; - Passive acoustic deployments to investigate marine mammal distribution and vocal trends as a function of anthropogenic activity; - Efforts to quantify overall increases in marine ambient noise.	- Numerous noise/disturbance studies since early 1980s (seismic, production, drilling, explosive removal) on marine mammals; - Assessments of effects from oil/gas industry noise on migratory patterns of bowhead whales; - Integrating recent and long-term studies with marine mammals, bearing on cumulative and/or long-term exposure.	- Contracted scientific review of agency-generated environmental impact statements and NEPA-related documents.	- Assessed manatee behavior in the absence/presence of boats in protection areas; - Coordinated and reviewed other studies that assess manatee behavior in response to vessels.

(4) Monitoring and Mitigation – USG Efforts to Date

Concern about the potential environmental effects of sound-producing activities has led to the implementation of various mitigation measures and verification monitoring intended to reduce environmental risk. These requirements have added considerable cost to NSF and ONR research efforts and agency mission-critical activities for USN, MMS, and others. Such costs could reasonably be considered part of a new cost structure for doing business, as for other environmental compliance actions, provided that the required monitoring and mitigation was empirically shown to be effective in reducing actual environmental risk. This is not the case.

To the best of our knowledge, none of the currently required monitoring and mitigation measures have been sufficiently verified and validated for effectiveness, nor have alternatives been adequately explored to assess potential increases in effectiveness or reductions in cost and loss of agency mission capability. For instance, sound source "ramp-up" (where the output level is gradually increased) is a widely imposed practice, founded on the principle that animals potentially at risk from a sound will be given sufficient time to move away. However, despite the cost of implementing this mitigation, there has never been a demonstration that it works as intended. Similarly, some level of visual survey effort is usually agreed upon, at considerable cost (both in time and resources) to the activity being monitored, even though visual monitoring under the best of conditions may detect less than 50 percent of most marine mammals and only 1-10 percent of some deep-diving mammals (see Barlow and Gisiner, 2005). In poor weather and at night those percentages are reduced to effectively zero. Promising new monitoring solutions such as passive acoustic detection, radar-based marine mammal detection, active acoustic detection of fish schools or marine mammals, and the use of underwater gliders or unmanned underwater and aerial vehicles as sensor platforms have received some minor levels of research funding but remain important areas of future research in developing and validating the effectiveness of a more multi-modal approach to the detection of marine life for risk mitigation and effects monitoring.

The area of mitigation and monitoring has seen perhaps the broadest overall effort of U.S. federal agencies. This is not surprising, given that various federal laws, and increasingly lawsuits directed at regulating agencies, require action agencies to apply mitigation measures. While regulatory agencies have attempted to apply the available scientific information to develop science-based mitigation requirements, legal actions directed at process tend to increase regulatory burdens independent of research efforts. Again, these efforts are generally poorly (if at all) supported by direct empirical measures of the justification and/or efficacy of the mitigation and monitoring measures being required or applied. Nevertheless, most of the principal federal agencies dealing with the marine sound issue have exerted considerable effort to identify marine life around sound-producing operations and develop mitigation measures to reduce potential impacts.

(4) Mitigation and Monitoring – USG Efforts to Date

USN	MMS	USFWS	NOAA	NSF
- Electronic tag development; - Radar monitoring capability development; - Passive acoustic technology development on gliders; - Marine mammal monitoring on ranges technology development; - A4I-SIPS (Scaled improvement performance sonar); - Active acoustic sensing of marine mammals or fishes; - Critical habitat predictive modeling capability development	- Passive acoustic monitoring for marine mammals, including hardware applications and improved signal processing; - Research and development of acoustic tagging technology; - Analysis of observer reports.	- Monitoring and mitigation measures developed in conjunction with incidental take for walrus and polar bears; - Assessing the effectiveness of manatee mitigation measures; - Coordinate and review other studies that assess effectiveness of mitigation measures.	- Right whale detection and reporting system using passive acoustics to detect and localize whales for mitigation of ship-strikes.	- Monitoring &mitigation conducted for all research cruises using airguns; - Support of instrument purchases and engineering proposals for monitoring and mitigation measurements.

(5) Outreach, Education, and Scientific Peer Review – USG Efforts to Date

The review and dissemination of scientific information to the scientific community, decision-makers, and the general public is a vital step that cannot be overlooked. The effects of anthropogenic sound on the marine environment is a complex issue, often mischaracterized in the popular press, that is confusing to a concerned public presented with widely varying viewpoints on the issue. A key role of federal agencies is to support high-quality subject matter expert peer-review and synthesis of pertinent information (*e.g.*, NRC, 1994, 2000, 2003, 2005). Another important function is making science-based information available in engaging formats to the interested public, teachers, reporters, docents, students, foreign governments, and intergovernmental organizations. Finally, future decisions and discoveries will only be possible with sufficient infrastructure and programs to support undergraduate, graduate, and post-doctoral students working in key areas.

The federal agencies have recognized these specific needs for ensuring that high-quality scientific information is obtained, published, made available, and interpreted appropriately and have supported various actions accordingly (described in detail below). Most of the federal agencies involved here have contributed significantly in supporting various technical symposia, panels, and workshops on a wide variety of important scientific topics. The agencies recognize the need and value of supporting the highest-quality levels of peer-review for research efforts followed by considerable public outreach and education via school programs, lecture series, and on-line information. Finally, many of the federal agencies here have contributed support, information, and/or expertise to the Discovery of Sound in the Sea (DOSITS) website (www.dosits.org), which provides a wealth of information at various levels of complexity.

(5) Education, Outreach, and Scientific Peer-Review – USG Efforts to Date

NOAA	MMS	USN	NSF	USFWS	MMC	DOS
- Support of international symposia on large vessel sound and marine life; - Technological and economic considerations of quieting large commercial vessels; - Support of scientific panels developing noise exposure criteria for marine mammals, fish and sea turtles; - Partial support of DOSITS educational website; - National lecture series on ocean acoustics; - Partial support of several National Research Counsel panels on marine noise; - Bioacoustic information integrated into NOAA online educational materials.	- Literature review contributio n for Marine Mammals and Noise (1994) NRC report; - Support of scientific peer reviews, conferences and symposia; - Partial support of fish bioacoustic s workshop.	- Web-based library development; - Field guide for stranded animals; - Graduate and post-doctoral education through the bioacoustic oceanography summer workshops; - Partial support of the DOSITS website; - Periodic open program reviews (ECOUS meetings); - Support for conferences on marine mammal biology and acoustics; - Auditory evoked potential workshops.	Partial support of DOSITS website; outreach and community meetings on specific projects; extensive peer review for proposals and peer-reviewed publications; support for technical meetings and workshops	- Various outreach and educational materials on polar bears, walruses, sea otters, and manatees.	- Congressionally -commissioned FACA panel on marine mammals and sound; - Beaked whale symposium and related journal issue.	Transmissio n of salient research findings and literature on marine acoustics in response to United Nations requests; ongoing assistance to USG agencies interested in multilateral and bilateral research efforts

Appendix III. Detailed summary of prioritized science and technology for U.S. federal agencies in each of five subject areas regarding anthropogenic sound and marine life.

The Task Force undertook the task of identifying specific research and development needs in each the five specific subject areas. It then segregated these needs into an inter-agency view of those of highest, high, and moderate priority. This process was undertaken for each subject category individually, and the resulting prioritized actions are given in detail in this appendix. Following this process, the task force synthesized and considered these priority recommendations across all subject categories and summarized categories of the most important near and long-term actions in order to identify effects of exposure, develop technical capabilities, advance monitoring and mitigation, and improve data archive and analysis capacity. This secondary process is described in Chapter 3, culminating in the task force recommendations in Chapter 5.

(1) Sound Sources and Acoustic Environment – Prioritized USG Needs

Acoustic characterization of specific sound sources is relatively advanced, though there are certain existing and emerging sources that require calibrated measurement. Specific agencies or industries deploying these sources should likely bear the burden of ensuring such measurements (*e.g.*, as NSF has recently done with airgun seismic sources). Where they are made, source characterizations should include full-azimuth measurements, careful reporting of all calibrations, and wide-frequency bandwidth measurements. There is a particular need for source characterization measurements for new and emerging sources, as well as those operated in areas such as the Arctic that are experiencing rapid changes in both climate and human activity using such sources.

Regarding the larger and more difficult matter of characterizing marine ambient noise, current knowledge is much poorer and the needs are consequently more daunting. The question of whether there is an historical and ongoing change in ambient noise arising from overall increases or changes to the diverse array of anthropogenic sound sources, and, if so, what effect it may have on marine life, is a broad, complex matter. The issue of non-directional ambient noise is sufficiently non-specific to a particular source or operation that it arguably falls outside any of the mandated requirements of any of the federal agencies other than NOAA. NOAA will require external expert assistance in dealing with this issue (which has in fact already occurred in the form of NOAA-ONR collaboration on recovery of archived USN data for ambient noise analysis).

(1) Sound Sources and Acoustic Environment – Prioritized USG Needs

Subject Category	Specific Science/Technology Need(s)	Relative Priority (within subject)
(1) Sound Source & Acoustic Environment	- Longitudinal measurements of ambient noise budgets in variable locations (particularly Arctic). - Continued development of passive acoustic monitoring technologies for detecting/characterizing biological sources. - Sound source characterization/verification for icebreakers (Alaskan Arctic) and new classes of large commercial vessels.	**Highest (A)**
(1) Sound Source & Acoustic Environment	- Sound source verification for new wide-azimuth seismic surveys. - Sound source characterization/verification of pile driving of variable types and in variable substrates. - Advancement of shallow-water propagation models for impulsive sound stimuli. - Sound source characterization/verification for oil drilling and production.	**High (B)**
(1) Sound Source & Acoustic Environment	- Development of online sound source library (both anthropogenic and biological sources). - Sound source characterization and (where appropriate) long-term monitoring of: (*a*) offshore LNG terminals; (*b*) wind farm arrays; and (*c*) emerging tidal & wave energy technologies. - Sound source characterization/verification for seismic sources other than airguns.	**Moderate (C)**

(2) Baseline Biological Information (Physiology, Distribution, & Abundance) – Prioritized USG Needs

Determining baseline biological and life history data for marine life generally is beyond the scope of this report, as it is not specific to acoustic issues. There is ongoing and needed work in those areas, of course, much of which is relevant to a complete assessment of the impacts of specific sounds on marine life. What is intended in this section is basic biological information relating specifically to the marine noise issue (perhaps considered "baseline acoustical information") as well as direct information on the effects of noise on hearing, behavior and physiology.

Knowing what marine life is or will be present at a given site of interest is often a limiting factor in terms of planning, assessing impacts, and devising mitigation strategies. Effort to sufficiently sample the marine environment requires agencies to develop common procedures for sensor calibration, standards for how data and metadata are recorded, and processes for shared access to data for other agencies, researchers, and the public. Historically, most or all of this information has been generated by a relatively small scientific community, or was generated by NOAA for resource management purposes. Perhaps for the first time, external sources of quality data may equal or even exceed the pace of data generation by NOAA itself. A similar situation already exists for standard oceanographic data, with USN and others contributing to ocean data archives maintained by NOAA. A key federal effort could be achieving national data standards, interagency data sharing agreements, and the resources to support a national data archive for ocean biological data comparable to our ocean physical data archives. This data archive should include both direct sampling as well as the validated performance of increasingly-sophisticated habitat modeling efforts. Such an archive would logically be NOAA-led, with considerable data input from agencies – or agency-supported researchers – including USN, NSF, MMS, USCG, and USFWS.

The federal agencies participating in the task force also identified related important data needs on specific baseline physiology, diving, migration, and other life history parameters in order to adequately predict and assess impacts. The task force additionally prioritized needs to investigate certain species, apparently more sensitive species and those in the rapidly-changing Arctic, as noted in the table below.

(2) Baseline Biological Information – Prioritized USG Needs

Subject Category	**Specific Science/Technology Need(s)**	**Relative Priority** (within subject)
(2) Baseline Biological Information	- Expansion/improvement of spatio-temporal measurements of distribution and abundance of marine species (direct measurements integrated with predictive modeling of habitat features). - Develop, standardize, integrate, and maintain online databases of marine mammal distribution, abundance, and movement (it is worth noting the considerable value-added aspect of this action relative to assessing other potential impacts on marine mammals) - Baseline physiological and life history data (including diving/migratory behavior) for "particularly sensitive" species (*e.g.*, beaked whales) and Arctic marine species.	**Highest (A)**
(2) Baseline Biological Information	- Baseline measurements of behavior and movement patterns of other "representative" marine species not listed as Priority A, both short-term (*e.g.*, diving behavior) and long-term (*e.g.*, migratory behavior) - Baseline physiological and life history data for other "representative" marine species. - Develop better baseline data on recruitment, reproduction, and mortality with which to assess long-term/cumulative impacts.	**High (B)**
(2) Baseline Biological Information	- Develop basic assays for stress and immune functions and invest in low level of advancement to diagnostics, as a means of quantifying non-obvious low-level, long term cumulative effects. - Improve tools and technologies (including active acoustics) to measure foraging ecology of "representative" marine species.	**Moderate (C)**

(3) Effects of Sound (Criteria and Thresholds) – Prioritized USG Needs

As discussed, the crux of this environmental issue is determining those specific exposure conditions that result in demonstrated adverse effects of noise exposure. Without such knowledge, it is unclear how much overall attention and/or effort is warranted and which monitoring and mitigation requirements will be effective in a particular sound-producing activity. Consequently, the task force considers a relatively large number of priority research requirements within this category (see below). These include basic measurements of hearing for untested or underrepresented species, including measures of "absolute" or unmasked hearing thresholds and sound localization capabilities, as well as more sophisticated measurements of auditory masking and noise-induced hearing loss. Of additional pressing importance is the need for objective means of distinguishing between relatively benign effects and the more biologically-significant changes in behavior arising from sound exposure that might lead to serious adverse consequences at the individual and population level. Finally, and while admittedly very challenging and poorly understood, we deemed it very important that science and technology efforts begin seriously addressing cumulative and/or long-term adverse impacts from repeated or sustained exposures, including the potential interactions of noise with other anthropogenic stressors (e.g. chemical contaminants or climate change effects) leading to cumulative adverse consequences for marine life.

(3) Effects of Sound – Prioritized USG Needs

Subject Category	**Specific Science/Technology Need(s)**	**Relative Priority** **(within subject)**
(3) Effects of Sound ***(Criteria & Thresholds)***	- Obtain hearing & effects of noise on hearing measurements for "particularly sensitive" (*e.g.*, beaked whales), Arctic, mysticete cetacean species (various sex/age classes). - Empirical measurements of effects of sound exposure on behavior of "representative" marine species (controlled exposure experiments), particularly for high-intensity sources. - Increase ability to identify biological effects from sound exposure. - Improve/validate exposure noise exposure criteria and policy guidelines. - Measure acoustic perception/localization of biological signals and interference from realistic masking noise.	**Highest (A)**
(3) Effects of Sound ***(Criteria & Thresholds)***	- Obtain/expand hearing & effects of noise on hearing measurements for other "representative" marine species (various sex/age classes). - Develop/expand anatomical modeling.	**High (B)**
(3) Effects of Sound ***(Criteria & Thresholds)***	- Quantify effects of auditory masking at both individual and population levels. - Determine effects of noise on foraging behavior, stress hormones, and immune function (cumulative effects). - Develop techniques to investigate/quantify interaction of noise exposure with other stressors (synergistic effects)	**Moderate (C)**

(4) Mitigation and Monitoring – Prioritized USG Needs

The need to detect and/or characterize the activities of marine life offers tremendous opportunity for rapid growth in tools and technologies valuable to national and international marine resource management. The recognition that current visual sampling methods from surface platforms are have serious limitations to sample highly mobile animals in opaque, three-dimensional environments has led several agencies to explore alternative or supplemental means of detecting and monitoring marine life.

Rapid advancements are occurring in this field, but additional investment and attention is needed to improve sensor technologies, including passive acoustic sensors on various stationary and mobile platforms and advances in various visual, electromagnetic, and other sensors. Many of these technologies have been and will continue to be developed by the USN; they are the logical lead agency on many topics, although some other agencies are interested in advancing and applying these capabilities as well. Depending on internal agency expertise and existing capabilities for basic research, applied research, and end-stage technology development, the path from novel concept to readily-usable technology may require the coordinated efforts of multiple agencies.

Additionally, there is a clear and immediate need for scientific verification of the performance of existing and new mitigation measures, often made more difficult by the lack of clear, observable effects. No current mitigation or monitoring measures offer metrics for detection and classification probabilities, including false alarm rates or performance limitations under conditions of poor weather, darkness, or other variable at-sea conditions. There is a need for some standardization in the process by which mitigation and monitoring requirements are determined for the purposes of reducing acoustic impacts.

Where specific impacts are known, or where sound output serves no particular function but is simply incidental to an activity, there should be particular attention and effort applied to reducing the overall acoustic footprint, weighted against the cost of noise reduction or impairment to the activity of concern (*e.g.*, vessel speed, maneuverability, safety, training efficacy). A further mitigation option (beyond modifying sources or their operation) that should be explored in some conditions (where effects are clearly known and the need to reduce them of known biological significance), is temporal or area restrictions to certain sound-producing activities. Recognizing the substantial challenges, there should also be some level of attention given to mitigation of cumulative and/or long-term impacts, above and beyond the reduction in immediate effects.

(4) Mitigation and Monitoring – Prioritized USG Needs

Subject Category	**Specific Science/Technology Need(s)**	**Relative Priority (within subject)**
(4) Mitigation & Monitoring	- New and improved technologies for identifying, locating, and tracking marine mammals (real-time where possible). - Develop validation and performance metrics for all mitigation measures (detection probability, false alarm rate, coverage per unit time or effort, etc). - Explore alternatives to existing sound sources and/or mitigating technologies to minimize unwanted and unnecessary sound output (*e.g.*, vessel-quieting technologies) or to reduce impacts of specific sources by alterations that do not adversely affect performance (*e.g.*, alternate waveforms). - Explore need for and effectiveness of time/area closures versus operational mitigation measures.	**Highest (A)**
(4) Mitigation & Monitoring	- Improved technologies for identifying, locating, and tracking fish and sea turtles (real-time where possible). - Standardize data-collection, reporting, and archive requirements of marine mammal observer programs; sufficiently analyze existing data and render available to inform future mitigation efforts.	**High (B)**

(4) Mitigation & Monitoring	- Develop performance metrics for monitoring, mitigation, and reporting. - Develop and validate simple decision-making criteria for source shutdown, modification or movement.	**Moderate (C)**

(5) Outreach, Education, and Scientific Peer Review – Prioritized USG Needs

While this category is discussed last, it should clearly not be interpreted as the least important. Rather, the review, dissemination, and general impact of scientific information regarding all areas of the marine sound issue are in many ways among the most important ongoing and future efforts of federal agencies. Federal agencies contributing to this report identified a number of specific needs in terms of peer-review, systematic reviews of available data, capability-development, and general outreach and education. Many of these are consistent with standard or existing practices, whereas others suggest more innovative, proactive approaches than has historically been the case. There is a general sense that all of these subjects will require serious and consistent effort by the federal agencies to ensure that the next generation of scientists and engineers enter and improve this field, and that the general public has open and full access to understandable and scientifically accurate information.

(5) Outreach, Education, and Scientific Peer Review – Prioritized USG Needs

Subject Category	**Specific Science/Technology & Other Need(s)**	**Relative Priority (within subject)**
(5) Outreach, Education, & Peer-Review	- Develop a biennial forum for information transfer to report on the results of inter-agency research progress to various stakeholders (*e.g.*, federal and state government, industry, academia, public, educators, media, and environmental groups); Timely peer-reviewed publication of all (unclassified) scientific results. - Periodic national expert panel review of existing scientific data relating to all subject categories.	**Highest (A)**
(5) Outreach, Education, & Peer-Review	- Enhance availability/visibility of educational/outreach materials to the general public through existing mechanisms (*e.g.*, DOSITS website). - Some level of investment in K-12 education (via some established program such as Lawrence Hall of Science) and public information resources at oceanaria, marine reserves, etc.	**High (B)**