UNOLS Fleet Improvement Plan: 2015

Report of the UNOLS Fleet Improvement Committee

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Executive Summary

The US academic research fleet includes research vessels, deep submergence vehicles, aircraft and pools of specialized equipment for technically advanced multidisciplinary research and educational activities in the ocean sciences. This infrastructure is critical to nearly every major US science undertaking at sea, making possible the collection and processing of data and samples from the marine atmosphere, the water column, and the seafloor. Planning with respect to the make-up and capabilities of the academic research fleet has been an on-going process through the University-National Oceanographic Laboratory System (UNOLS) for over four decades. As a result, extensive fleet modernization and "right-sizing" has occurred in recent years, and fleet infrastructure continues to evolve to stay well matched to research priorities and budgets of supporting US Federal agencies.

In the next decade the most important renewal events for the academic research fleet will be mid-life refits and enhancements to extend the service lives of three global class ships and the construction of two new regional class ships. Under this plan the academic fleet

in 2025 will provide 15 ships of diverse capabilities and may possibly be further expanded by additions in the coastal/local class. This rebuilt capability and capacity will diminish again in the following decade, however, unless current fleet renewal plans are extended.

Therefore, the major forward-looking recommendations of the 2015 Fleet Improvement Plan are for the UNOLS community to:

- **Determine a course for building future global vessels capable of supporting large (>30) interdisciplinary or discipline-focused science parties**.

An activities timeline is needed that will lead to the federal acquisition of new general-purpose global class research ships during the decades of the 2030s and 2040s. FIC will start the process with a redefinition of global class Science Mission Requirements (SMRs). An assessment of the demand for, operational costs of, and unique missions of present global vessels including the new ice-capable R/V Sikuliaq compared to the new ocean class R/Vs Neil Armstrong and Sally Ride will also be conducted to help develop the SMRs of a future global class.

- **Support developing plans to renew and utilize the capability of coastal/local class vessels as components of the UNOLS Fleet.**

Efforts to raise state and private funds are critical to support the construction of these vessels, but new federally-funded near-shore science programs and partnerships that provide stable utilization are also needed so these assets may enhance understanding of processes in areas vulnerable to sea-level rise and environmental change such as the Great Lakes, US estuaries and inner shelf regions. Furthermore, new coastal/local vessels are practical platforms for green-vessel designs such as the use of hybrid propulsion systems. The best avenue to test cutting-edge technologies for science missions at sea is through the coastal/local class of vessels.

- **Support the acquisition of new ice-breaking capabilities for science community access to the high latitudes.**

UNOLS should assist efforts led largely by the Coast Guard to replace aging icebreakers for operations and science programs in the Arctic and Antarctic. Research at high latitudes is critical to predicting ocean conditions globally, and shared technical resources and joint operations between the academic research fleet and US icebreakers are essential for adequate high-latitude sampling and supply missions.

TABLES

FIGURES

Report Release and Approval History

Submitted to UNOLS Council for review: 5-1-2015
Approved for distribution:

List of Acronyms

AGOR	Auxiliary General Purpose Oceanographic Research Vessel
AUV	Autonomous Underwater Vehicle
BIOS	Bermuda Institute of Ocean Sciences
BOEM	Bureau of Ocean Energy Management
CLIVAR	Climate Variability and Predictability
EPA	Environmental Protection Agency
FIC	Fleet Improvement Committee
FIP	Fleet Improvement Plan
FOY	Full Operating Year
GeoPRISMS	Geodynamic Processes at Rifting and Subducting Margins
IWG-FI	Interagency Working Group on Facilities and Infrastructure
LDEO	Lamont-Doherty Earth Observatory
LUMCON	Louisiana Universities Marine Consortium
MARSSAM	Marine Sediments Sampling Group (at OSU)
MREFC	Major Research Equipment and Facilities Construction
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSF	National Science Foundation
OCE	Division of Ocean Sciences (at NSF)
ONR	Office of Naval Research
OOI	Ocean Observatories Initiative
OSU	Oregon State University
PRV	Polar Research Vessel
R2R	Rolling Deck to Repository
RCRV	Regional Class Research Vessel
ROV	Remotely Operated Vehicle
R/V	Research Vessel
SIO	Scripps Institution of Oceanography
SkIO/UG	Skidaway Institute of Oceanography/University of Georgia
SMR	Science Mission Requirement
STEM	Science, Technology, Engineering and Mathematics

TEI	Trace Elements and Isotopes
UAF	University of Alaska, Fairbanks
UDel	University of Delaware
UH	University of Hawaii
UMiami	University of Miami
UNOLS	University-National Oceanographic Laboratory System
UMinn	University of Minnesota, Duluth
URI	University of Rhode Island
US	United States
USCGC	US Coast Guard Cutter
USGS	US Geological Survey
UW	University of Washington
WHOI	Woods Hole Oceanographic Institution

Photo Credits:

Cover: R/V *New Horizon* by James Wilkinson, during a 2014 CalCOFI cruise
Page 6: (Top) R/V *Roger Revelle* operated by Scripps Institution of Oceanography. Photo copyright John Soloman
Page 6: (Middle) R/V *Savannah* operated by Skidaway Institute of Oceanography, photo by Michael Sullivan, SIO.
Page 6: (Bottom Left) Fantail at sea of R/V *Endeavor* (photo credit Andrew Steen, University of Tennessee, 2013).
Page 6: (Bottom Right) CTD/rosette deployment directed by Lynne Butler, University of Rhode Island, from R/V *Endeavor* (photo credit Andrew Steen, University of Tennessee, 2013).
Page 8: Fig. 1. Photo of the R/V Sikuliaq by Mark Teckenbrock, University of Alaska Fairbanks
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ROGER REVELLE


R/V SAVANNAH

1. Introduction

US research vessels are designed to provide access to the ocean at any depth, anywhere on the globe, and they serve thousands of researchers each year. These researchers are engaged in studies related to nearly every major question in Earth systems science. They rely on technically advanced ships and icebreakers to enable the collection and processing of data and samples from the atmosphere, the water column, and the seafloor. This collective reach is extended by autonomous and remotely operated vehicles, and linked to satellites, aircraft and land- and ocean-based observatories, to inform a greater understanding of the Earth, its resources and climate.

A modern and effective oceanographic fleet can only be maintained through continuous evaluation of facility capabilities and future needs. This process requires visionary inputs from ship operators, scientists, engineers, technicians and educators on what systems and technologies will best serve basic and applied academic research. In the US the University-National Oceanographic Laboratory System (UNOLS) is the body of such experts who advise the Federal agencies that support science at sea, on academic fleet improvement and new acquisitions. The UNOLS Fleet Improvement Committee (FIC), a standing committee of UNOLS, has the specific mandate to continually assess the number and mix of ships in the UNOLS fleet and to develop plans for ship additions, replacements or retirements in the context of other national facilities serving ocean science. To this end the FIC has published a "**UNOLS Fleet Improvement Plan**" in 1990, 1995 and again in 2009 to make specific recommendations with respect to fleet size and composition. These printed plans, although comprehensive have each quickly become outdated.

To maintain a current, informative and forward-looking plan for updating UNOLS facilities, the FIC now is migrating to a web-based UNOLS Fleet Improvement Plan (FIP) with the first release in 2015. This plan is linked to supporting documents and past plans, and henceforth may be revised and readopted by the UNOLS community more easily. In this format it is expected to be most useful for maintaining a coordinated national oceanographic fleet in the service of ocean-related societal needs.

1A. Why Is Maintaining a Modern Academic Fleet Important?

The 2013 Federal Oceanographic Fleet Status Report lists a dozen over-arching activities oceanographic ships make possible. In fact many of these activities are only possible with modern vessels or vessels that are of a certain size, draft, hull strength, load capability and/or stability. This is why in an oceanographic fleet, one size does not fit all, and old ships may have low demand.

In this 2015 Fleet Improvement Plan the current and projected make-up of the UNOLS fleet is examined and compared to assessments of what the US scientific community will need and be able to afford in coming decades. Need and affordability are functions of

OCEANOGRAPHIC SHIPS ARE NECESSARY TO:

- Conduct basic research on the ocean, atmosphere and seafloor's physical, chemical, geological and biological processes and interactions.
- Provide tactical and strategic oceanographic information in support of national defense, homeland security, commerce and environmental health.

FIG. 1: THE IMPORTANCE OF OCEANOGRAPHIC VESSELS AND THE R/V *SIKULIAQ*.

societal priorities, which evolve with changing events, changing technology and expanded knowledge

Today the most comprehensive statement of US Ocean Policy is the Joint Ocean Commission's 2013 report Charting the Course: Securing the Future of America's Oceans. This report recognizes the oceans as a national lifeline that is being frayed by the impacts of many human activities including, but not limited to, fossil-fuel extraction and consumption, destruction of coastal wetlands, agricultural and municipal-waste dumping, and industrialized fishing. Another important and timely document that addresses the high relevance of the academic research fleet to decadal science priorities supported by the National Science Foundation is the National Research Council's Sea Change: 2015-2025 Decadal Survey of Ocean Sciences.

The societal benefits of a modern, well-equipped, fully utilized and response-ready oceanographic fleet are first and foremost objective information products backed by cutting-edge research methods and technology. These data, images, reports, and publications can be freely used by policy makers, educators, private-sector industries, non-profits and our national defense services. Oceanographic research extends from characterizations of the smallest free-living cell known, SAR11, discovered only two decades ago, but a bacterium that's now understood to dominate life in the oceans (Zhao et al. 2013), to a megavolcano, Tamu Massif, found below the Pacific Ocean and characterized by seismic reflection studies from the R/V *Marcus G. Langseth* in 2010 and 2012 (Sager et al. 2013).

Oceanographic data gathered from ships include assessments of ocean turbulent mixing, and transfers of momentum, heat, salt, nutrients and gases within the ocean and across the air-sea interface. Increasingly essential is research that shows changing baselines brought on by global warming, ocean acidification and ocean deoxygenation. Additionally, there is the need to understand and forecast the response of ocean ecosystems to climate change as well as extreme weather events, and natural or human-caused disasters. As an example of the latter, soon after the April 20, 2010 explosion of the Deepwater Horizon drilling platform in the Gulf of Mexico, US scientists and engineers on UNOLS vessels were applying advanced underwater tools (ROVs, AUVs and submersibles) and sensor technologies for tracking the oil plume, estimating how much material was spewing into the Gulf, and assessing contaminant dispersal patterns.

With similar tools in 2013 geophysicists led a nearly month-long research cruise on R/V *Atlantis* during which they located the section of the Cascadia subduction zone fault that is likely to rupture and produce a large tsunami. This knowledge is helping to develop regional warning systems and realistic plans for tsunami hazard mitigation.

1B. The 2015 UNOLS Fleet

In 2015 seventeen vessels of various sizes and capabilities make up the UNOLS fleet, with operations shared by 14 institutions or regional consortia. This composition is not stagnant and over the past decade many changes in the fleet have occurred to both improve capabilities and control costs. UNOLS vessels are owned by the National Science Foundation (NSF), the Navy, or they are institutionally owned (Table 1). UNOLS also provides oversight and advice to the Coast Guard for the purpose of enhancing facilities and science aboard their icebreaker fleet (currently 2 vessels).

In part because of its multi-agency oversight, size and diversity, the UNOLS fleet provides a number of significant advantages to the nation and academic researchers conducting seagoing research. These include:

- *a distributed fleet located throughout the United States, and in Bermuda*
- *ship availability to all federally funded investigators, requested using a common on-line Ship Time Request Form*
- *coordination of scheduling to promote efficient operations*

- *flexibility of scheduling by virtue of large number of member institutions, vessels and capabilities*
- *access to additional science facilities (including deep submergence vehicles and oceanographic aircraft) through numerous federal agencies*
- *common safety standards for ships and their crews, as well as for science activities at sea, ensuring a uniformly safe and known working environment for both science and crew*
- *broad and multi-purpose mission capabilities on a range of vessel size classes, as well as mission specific capabilities such as deep submergence and seismic capabilities*
- *continuity and broad base of highly trained ships' crews and technicians, providing an unparalleled resource for seagoing research, including opportunities for collaborating and sharing expertise and knowledge among UNOLS operator institutions.*

The ship class categories of the UNOLS fleet are generally prescribed by Science Mission Requirements (SMRs) and by basic design elements such as vessel payload and endurance. One responsibility of the FIC is to periodically review class definitions and revise SMRs to reflect current mission priorities.

Table 1. 2015 UNOLS Fleet Composition.

Ship/Class	Owner	Operator	Length-Over-All (m [ft])	Delivered (y)	Projected End of Service (y)
Global Class					
Thomas G. Thompson	Navy	UW	84 [274]	1991	2036*
Roger Revelle	Navy	SIO	84 [274]	1996	2026**
Atlantis	Navy	WHOI	84 [274]	1997	2027**
Sikuliaq	NSF	UAF	80 [261]	2014	2044
Marcus G. Langseth	NSF	LDEO	71 [235]	1991	2030
Ocean/Intermediate Class					
Kilo Moana	Navy	UH	57 [186]	2002	2032
Endeavor	NSF	URI	56 [184]	1976	2020
Oceanus	NSF	OSU	54 [177]	1976	2019
New Horizon	SIO	SIO	52 [170]	1978	2015
Atlantic Explorer	BIOS	BIOS	51 [168]	1982	2026
Regional Class					
Hugh R. Sharp	UDel	UDel	44 [146]	2005	2035
Coastal/Local Class					
Robert Gordon Sproul	SIO	SIO	38 [125]	1981	2018
Pelican	LUMCON	LUMCON	35 [116]	1985	2020
Walton Smith	UMiami	UMiami	30 [96]	2000	2030
Savannah	SkIO/UG	SkIO/UG	28 [92]	2001	2031
Blue Heron	UMinn	UMinn	26 [86]	1985	2025
Clifford Barnes	NSF	UW	20 [66]	1966	2016

***Thompson* service-life extension is anticipated after mid-life refit program to begin in 2016.
**Extension of the service end dates for *Revelle* and *Knorr* are dependent on funding to support mid-life refits.

1C. The Federal Agencies Supporting Science at Sea

Since it was established in 1971, UNOLS has had as its primary mission the safe, efficient and comprehensive support of US ***federally-supported*** research at sea. The composition of the UNOLS fleet has been designed with this key objective as the first priority. The US Federal agencies that support science at sea are the National Science Foundation (NSF), Office of Naval Research (ONR), the National Oceanographic and Atmospheric Administration (NOAA), Coast Guard and to a lesser degree the US Geological Survey (USGS), Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), Army Corps of Engineers, and Bureau of Ocean Energy Management (BOEM). Overarching mission statements of these agencies as they relate to vessel operations are provided in the 2013 Federal Oceanographic Fleet Status Report.

Since federal priorities range from near-shore research in US waters including the Great Lakes to blue-water oceanography around the world, and include a wide array of sampling and observational requirements, the ships necessarily vary significantly in size, scientific capability and geographic location of their home ports in order to meet these needs. As the focus of research changes, so do new ship designs and equipment, as reflected, for example, in the recent addition of R/V *Sikuliaq* for improved capability for research at high latitudes, to investigate key issues in these critical ice-covered regimes.
The common objective of most vessel use, however, is to support basic research on topics

FIG. 2: THE DIVERSITY OF FEDERAL AGENCIES THAT SUPPORT RESEARCH CONDUCTED FROM UNOLS VESSELS. UNOLS ITSELF DOES NOT FUND RESEARCH OR THE FLEET.

in physical, chemical, biological and geological oceanography, or in related disciplines in ocean, atmospheric and earth sciences that require observations from a floating platform. These topics largely reflect the programmatic makeup of the Ocean Science Division of the National Science Foundation, which is the largest source of funds for the fleet, supporting more than 65% of use in recent years. For this reason, NSF serves as the cognizant federal agency responsible for overall fleet management and coordination, and it is the agency with which each UNOLS operator negotiates a cooperative agreement to support its vessel operations.

1D. Private and Non-Federal Entities Supporting Science at Sea

US-based scientific expeditions aboard non-UNOLS vessels have become more common in recent years, at least in some oceanographic subdisciplines such as ocean engineering, and for research in certain environments such as ocean trenches. Part of what drives this trend is the reduction in federally supported science days at sea. Examples of private organizations that fund sea-going expeditions include the Schmidt Ocean Institute, Beta Maritime, and Ocean Exploration Trust. Examples of state institutions or consortiums with vessels and programs furthering marine research and education are the Florida Institute of Oceanography, the University of Connecticut, and New York's Great Lakes Research Consortium. Some UNOLS operators also operate non-UNOLS vessels of various sizes (including UH, LUMCON and WHOI). Any use of a non-UNOLS vessel by a federally-funded researcher requires that the vessel be inspected for compliance with the Research Vessel Safety Standards (per RVSS Section 18). Unfortunately, upholding this requirement has been difficult as not all researchers may understand the inspection standards.

Private donors can be generous supporters of oceanographic expeditions, although typically these situations involve a private organization, founded by the donor, through which financial resources are channeled. In some instances, foundations support particular shore-based research institutes (e.g., the David and Lucille Packard Foundation supports the Monterey Bay Aquarium Research Institute). Other organizations provide funds for graduate student research, scientific equipment and/or sensor development, but will not necessarily provide oceanographic ship access.

FIG. 3: R/V FALKOR OF THE SCHMIDT OCEAN INSTITUTE IN NORTHERN GULF OF MEXICO.

A general theme of non-UNOLS research vessel access is leveraging of existing funding. One of the most successful relationships to date in this regard is Schmidt Ocean

Institute, which provides ship time to researchers, and the Moore Foundation Marine Microbiology Initiative, which funds laboratory analyses.

These larger scale non-UNOLS ventures emphasize public outreach and immediate sharing of data. Because of this general tendency, many projects aboard non-UNOLS research vessels are technology-driven projects involving new instrumentation that produces visually appealing data or video opportunities. In some cases, the vessels (or funding entity) require dedicated personnel for outreach; some even demand live streaming over the web. Such efforts can demand considerable time, effort and resources.

From a different (non-funding) perspective, smaller vessels, including fishing boats, can be chartered directly by the researcher. In remote regions (e.g., the Bering Sea), this is sometimes the best avenue of ship access and local fishermen / vessel owners often welcome the extra opportunities. Of course, the size and configurations of fishing vessels mandate their functionality.

A survey of scientists with recent non-UNOLS expeditions indicates that in general the non-UNOLS vessels can be very accommodating and are generally safe. The user should be aware, however, that each vessel differs in terms of provision of basic necessities such as meals, linens, Internet, medical expertise and shore-support equipment. UNOLS vessels have excellent and consistent track records for all of these "housekeeping" issues.

Recently, there have been concerns about the use of UNOLS-designated assets on non-UNOLS vessels (e.g., UNOLS supported Remotely Operated Vehicles (ROVs) or Autonomous Underwater Vehicles (AUVs) aboard the Schmidt vessel *Falkor*). Issues can be financial, accessibility (scheduling), or fairness (priority).

Pre-cruise planning with non-UNOLS operators varies considerably. Some operators are quite organized and initiate the planning well in advance of the expedition. Others can be less prepared. Further, in multiple instances, the promised non-UNOLS platform became unavailable with short notice, even though extensive planning and costs had already been incurred by the science party. For example, a non-UNOLS vessel became unavailable shortly before a scheduled expedition; the project had

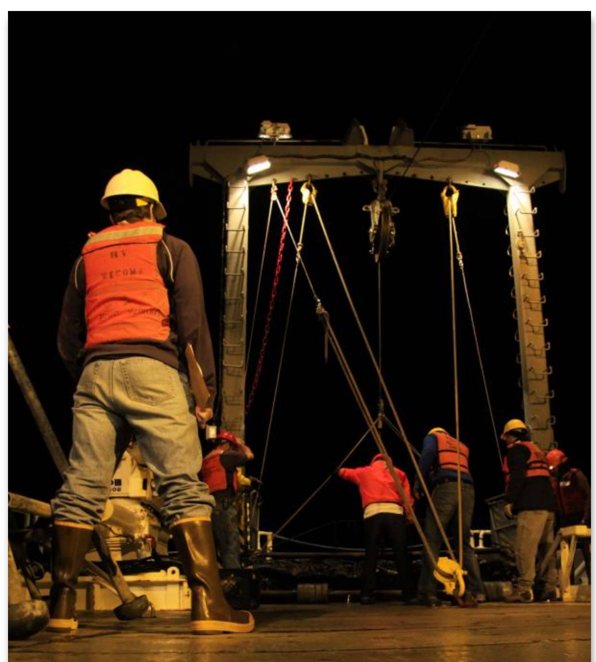

FIG. 4: NIGHT OPS – 24/7 WORK AT SEA.

already purchased multiple airline tickets for cruise participants and had shipped their scientific gear to the expected port of call.

Another possible negative aspect of working with non-UNOLS vessels may arise especially if there is a need for foreign clearance and permitting. In general, UNOLS operators are familiar with permitting procedures while private vessels often do not have experience especially with scientific permits.

Non-UNOLS vessels are often not designed specifically for scientific use, whether it is deep-sea sampling, ROV / AUV operations, and/or SCUBA operations. Crew and ship handlers often have little experience with oceanographic operations, which can jeopardize people and equipment. While over-the-side events might be unaffected, sometimes laboratory space is insufficient, causing a major negative impact on the science and sample processing. In terms of scientific equipment, many times vessels are not equipped with instrumentation and facilities generally expected by US oceanographic researchers. For example, winches may lack tension readouts, there may be no dedicated taglines or extension poles, and lab areas may lack purified water and cold storage space for samples. Some do not allow use of flammable gases; others put restrictions on particular scientific instruments (i.e., one scientist noted that a GC (gas chromatograph) was not allowed on one non-UNOLS vessel).

1E. Scientists at Sea-The Importance of Being There

Oceanographic ships worldwide support increasingly complex, multidisciplinary and multi-investigator research programs with 24-7 operations as well as sole-PI single discipline focused projects. This has led to increased demands for marine technicians with technical specialties and for telepresence capabilities and high bandwidth communications to link the scientist at sea with an arsenal of support personnel and collaborators onshore. The advantages of this connectivity are many (as discussed in section 1F below), but it is still the overwhelming view of oceanographers that they discover more, accomplish more, and excite more by being there, fully immersed in the scientific process and day-to-day life at sea. “We see with our mind’s eye” wrote Fryer et al. (2002) when making a case for rebuilding the submersible *Alvin.* Being present from preparation to execution in the company of other oceanographers, technicians and mariners is real-world oceanography. It is a privilege, and one that UNOLS is dedicated to preserving with the highest safety standards possible. There are also many types of oceanographic sampling and/or sample processing and analysis that cannot be done without a trained scientist(s) actively involved and making decisions in real-time. One of the main goals of fleet improvement is broadening the suites of information routinely collected at sea and making this information readily available to those at sea and colleagues on the shore.

1F. Broader Impacts Through Telepresence

The connectivity of 21st century technologies is changing how ocean science is conducted, disseminated, and portrayed to the public. Data and imagery collected at sea today can be visualized and integrated much more readily than in the past so that all modern research ships support some level of telepresence.

FIG. 5: RESEARCH SHIPS ARE SUPPORTING INCREASING LEVELS OF TELEPRESENCE ENABLED BY SHIPBOARD NETWORKS, NEW SENSORS AND SATELLITE COMMUNICATIONS. THE VAN IN THIS PHOTO CONTAINS A MOBILE TELEPRESENCE SYSTEM INSTALLED ON THE R/V *ATLANTIS*.

The ability to share near real-time web-based data, products, and observations with other experts on shore means much more immediate science return and impact from oceanographic facilities. Telepresence facilities on some ships like NOAA's *Okeanos Explorer* look like NASA mission control centers, but UNOLS is exploring other models such as a newly developed van-based mobile telepresence unit (Fig. 5) and systems that emphasize data integration and visualization in addition to video.

This connectivity also comes with a price for shore-based receiving stations or command centers, additional shipboard sensors and networking, technical support staff, and data quality control and management that must be factored into future facility support budgets. When real-time video feed to shore is advantageous, the shore location may seek to be connected to Internet2 and have encoders to compress high-definition video. What justifies these expenditures is that large audiences can be readily engaged through public viewing of high definition video during structured outreach events. Telepresence should also enable better data standardization and opportunities for synergies with mobile and fixed platform ocean observatory systems.

Broader impacts can be measured by the engagement of early career scientists and the reach and effectiveness of education and outreach programs developed for multiple audiences including K-12 classrooms, STEM lessons, undergraduate and graduate internships, and job training. Examples can be found in Bell et al. (2012) *New Frontiers in Ocean Exploration: The E/V Nautilus and NOAA Ship Okeanos Explorer 2011 Field Season*, a journal special issue highlighting NOAA's programs dedicated to telepresence-enabled ocean exploration, technology development and public engagement.

1G. The Process of Improvement and Renewal of a Fleet Designed for Academic Research

As introduced above, long-range planning for fleet renewal is the purview of the UNOLS Fleet Improvement Committee (FIC) and a reason for a "continuous" **Fleet Improvement Plan**. In the early years of academic fleet renewal, there was a drive to replace old inefficient and uneconomical conversion vessels with ships designed specifically for multi-disciplinary research. The Navy and NSF were successful in making requests for new ship acquisitions by stressing late cold-war-era anti-submarine warfare imperatives and a need for gaining fundamental knowledge and understanding of the ocean environment through observations and experiments. As a result, from the 1960s to the 1980s, federal funding accounted for more than 80 percent of the acquisition costs of new vessels (Committee on Evolution of the National Oceanographic Research Fleet (2009) **Science at Sea**). New ships were also designed and constructed by "best-effort" practices after funds were budgeted or politically earmarked. The management of design, construction and outfitting processes was considerably simpler and advanced faster than the present process of shipbuilding.

Current renewal activities are guided by the prescribed SMRs that represent a community consensus of what a given class of vessel should be capable of in the coming years. New designs are subject to an unprecedented level of scrutiny, review and oversight to ensure the incorporation of new technological solutions and to prepare realistic bottom-up cost estimates and risk assessments that give a firm basis for contingency funds during construction. For example, the recent evolution of the Alaska Regional Research Vessel into the *Sikuliaq* Project took over 15 years but did reach completion in 2014 through NSF's four phase Major Research Equipment and Facilities Construction (MREFC) process. MREFC projects must demonstrate science need and meet management requirements outlined in NSF's Large Facilities Manual. This document clearly states the policies, recommended procedures and deliverables pertinent from conception to construction/acquisition, operations, renewal and/or phase-out and termination of NSF-owned facilities. Requirements are based on best practices in construction engineering identified over many years so that NSF program officials can ensure accountability and prevent cost over-runs. The Navy is following a similar 4-phase acquisition process to control scope, timeline and budget during the Auxiliary General Purpose Oceanographic Research Vessel (AGOR) 27 and 28 acquisition process that will soon deliver the R/Vs *Neil Armstrong* and *Sally Ride*. For shipyards these new levels of managerial oversight and earned value management (EVM) reporting carry costs. Thus, multi-ship builds can be more attractive to bidders and are also cost effective for the nation overall.

2. THE UNOLS FLEET OF 2015-2025

2A. Decadal Core Research Questions and Major Science Programs (Overview)

Over the next several decades, ocean scientists will be challenged with increasing urgency to understand the ocean's role in regulating climate and shaping the biological and chemical systems of a human-stressed Earth. New ocean discoveries, observations and experiments will have major repercussions politically, economically and socially while remaining central to the missions of the federal agencies that support science.

Meeting the future challenges in the ocean sciences requires a versatile and mission-ready research fleet equipped with new technologies for ocean observation, sampling and data assimilation. This is a conclusion in **Sea Change: 2015-2025 Decadal Survey of Ocean Sciences**, the report for the National Research Council that also presents eight high-level questions, ordered from the ocean surface, through the water column, to the seafloor, to guide interdisciplinary research programs supported by NSF.

In the context of the eight *Sea Change* priorities, ships are critical for all (see Table 3.2 from the study). Approximately half of the funded projects in the core ocean research programs of the NSF require ship time, and many of the projects without ship time are based on datasets or samples acquired from ships. At present at least four major US research programs have extensive plans for the use of UNOLS vessels during the upcoming decade: the Ocean Observatories Initiative (OOI), US Climate Variability and Predictability (CLIVAR) program, Geodynamic Processes at Rifting and Subducting Margins (GeoPRISMS) and GEOTRACES.

OOI is a highly multidisciplinary project covering many aspects of biological, chemical, geological, and physical oceanography – it is organized around three scales of observations and interactions: coastal, regional and global. In 2015 OOI is moving into its primary phase of operating both deep water and coastal observatories in the Atlantic and Pacific Oceans (OOI Science Plan, 2005; OOI Final Network Design. 2010. http://www.oceanobservatories.org/wp-content/uploads/2012/04/110100000_FND_OOI_ver_2-06_Pub.pdf). The OOI Global Arrays involve deployments of large moorings that require vessels with requisite large trawl winches and A-frames, and sufficient deckspace for not only the moorings themselves, but the associated nodes and cabling; these requirements are expected to be met into the future with Ocean and Global UNOLS class vessels. Maintenance envisaged for these Arrays could be accomplished from smaller vessels, with the design lifetime of Arrays being 25 years (OOI Science Plan, 2005). The coastal arrays can require the deployment of much more equipment, but the sizes and weights are smaller than the Global Arrays so that Regional vessels should be able to handle both deployment and maintenance.

SEA CHANGE: 2015-2025 DECADAL SURVEY OF OCEAN SCIENCES

Priority Research Questions

1. What are the rates, mechanisms, impacts, and geographic variability of sea level change?
2. How are the coastal and estuarine ocean and their ecosystems influenced by the global hydrologic cycle, land use, and upwelling from the deep ocean?
3. How have ocean biogeochemical and physical processes contributed to today's climate and its variability, and how will this system change over the next century?
4. What is the role of biodiversity in the resilience of marine ecosystems and how will it be affected by natural and anthropogenic changes?
5. How different will marine food webs be at mid-century? In the next 100 years?
6. What are the processes that control the formation and evolution of ocean basins?
7. How can risk be better characterized and the ability to forecast geohazards like mega-earthquakes, tsunamis, undersea landslides, and volcanic eruptions be improved?
8. What is the geophysical, chemical, and biological character of the subseafloor environment and how does it affect global elemental cycles and understanding of the origin and evolution of life?

FIG. 6: PRIORITY RESEARCH QUESTIONS FOR THE NEXT DECADE TAKEN FROM THE SEA CHANGE REPORT.

The US CLIVAR program has been in operation since 1997 to examine the ocean's role in the Earth's climate variability. Its Repeat Hydrography cruises have made extensive use of UNOLS and NOAA vessels in the world's oceans over the last 18 years. Its science plan envisions at least another 10-15 years of hydrographic measurements (via ships and moored arrays), process studies, and modeling, with a significant move into examining the Arctic Ocean. Particular emphasis is placed on process studies that would examine the physical and biogeochemical linkages between the ocean and atmosphere; these would be conducted in many different locations and likely involve large collaborative groups of observationalists and modelers. Because climate is not just physically controlled, the next decade of US CLIVAR is expected to seek interdisciplinary collaborations with other observational programs like OOI and GEOTRACES. Overall, the newest US CLIVAR science plan recognizes the importance of observations to calibrate and validate climate models, and indeed cites the importance of having access to UNOLS and other research vessels to conduct its continuing survey and process study efforts.

The GeoPRISMS program is an ongoing special NSF-OCE funding opportunity designed for investigations between geodynamics, earth surface processes, and climate interactions that build and modify continental margins over a wide range of timescales. The program's overarching science topics include 1) Origin and evolution of continental crust; 2) Fluids, magmas and their interactions; 3) Climate-surface-tectonics feedbacks; 3) Geochemical cycles; and 5) Plate boundary deformation and geodynamics. Each of the initiatives has identified primary sites for focused investigations, as well as thematic studies that will complement primary site studies.

GEOTRACES is an international program whose mission is "To identify processes and quantify fluxes that control the distributions of key trace elements and isotopes (TEIs) in the ocean, and to establish the sensitivity of these distributions to changing environmental conditions" (GEOTRACES Planning Group. 2006. GEOTRACES Science Plan. Scientific Committee on Ocean Research, Newark, Delaware, 79pp.). Implicit in this mission is the aspect of global change, not only how the changing ocean affects TEIs, but also how these TEIs affect biological productivity in the ocean as micronutrients (e.g., iron) and toxicants (e.g., arsenic, copper) and therefore the oceanic uptake of carbon dioxide. A major activity in GEOTRACES is a global survey to determine the distributions and concentrations of these TEIs in the ocean – from surface to the bottom – and this requires Global class research vessels capable of deploying state-of-the-art sampling systems to acquire uncontaminated water and particle samples across ocean basins. The US has taken a leading role in the international GEOTRACES program and has led expeditions across the North Atlantic Ocean and throughout the equatorial eastern Pacific Ocean. The GEOTRACES program will take at least another 10 years to complete, and the US has a cruise to the Arctic in 2015 and a meridional transect in the Pacific from 60°N to 15°S planned for 2018; depending on funding, US GEOTRACES plans staging major ocean cruises every two years.

Another important consideration for future planning is that the polar regions are undergoing change at a much more rapid pace than the rest of the global ocean. Ice cover at both poles is shrinking (e.g., Ringot et al. 2008, Yamamoto-Kawai et al. 2009) creating brand new navigational areas and unknown coastal hazards. Ice shrinkage has consequences for global albedo, air-sea heat flux, ocean circulation and ice-adapted higher trophic level animals (e.g., seals, polar bears, walrus, penguins), and the endemic populations that depend on them. Additionally, with the loss of ice, sunlight is able to better penetrate the water for longer periods during the summer, which can result in ecosystem changes that propagate to all levels of the polar food web (e.g., Moline et al. 2008; Grebmeier et al. 2006). Due to the increased solubility of CO_2 at decreasing temperature, and due to generally lower alkalinity and correspondingly weaker buffer capacity caused by ice melt and river discharge (e.g., AMAP 2014), polar ocean acidification is expected to occur at accelerated rates relative to the rest of global oceans (Feely et al. 2009) (Fig. 7). The Arctic Ocean in particular is highly susceptible, and observations in the Bering Sea have revealed aragonite undersaturation through the water column and new areas of $CaCO_3$ mineral suppression (Mathis 2011). Shrinking summer ice cover in the Arctic is spurring oil and gas exploration, and emergence of a seasonally ice-free Northwest Passage will mean more commercial shipping through the Arctic.

In the Antarctic, pteropods are showing greater shell dissolution (e.g., Bednaršeck et al. 2013). Antarctic krill, a key pelagic species that supports many of the higher trophic level animals of the Antarctic, e.g. whales, seals, and penguins, appear to be sensitive to ocean acidification. It has recently been suggested that, due to pH sensitivity of krill eggs, acidification of important krill habitats of the Weddell and Haakon VII Seas may make these areas "high-risk" areas for krill by 2100 and that the Antarctic krill population could collapse by 2300 (Kawaguchi et al. 2013).

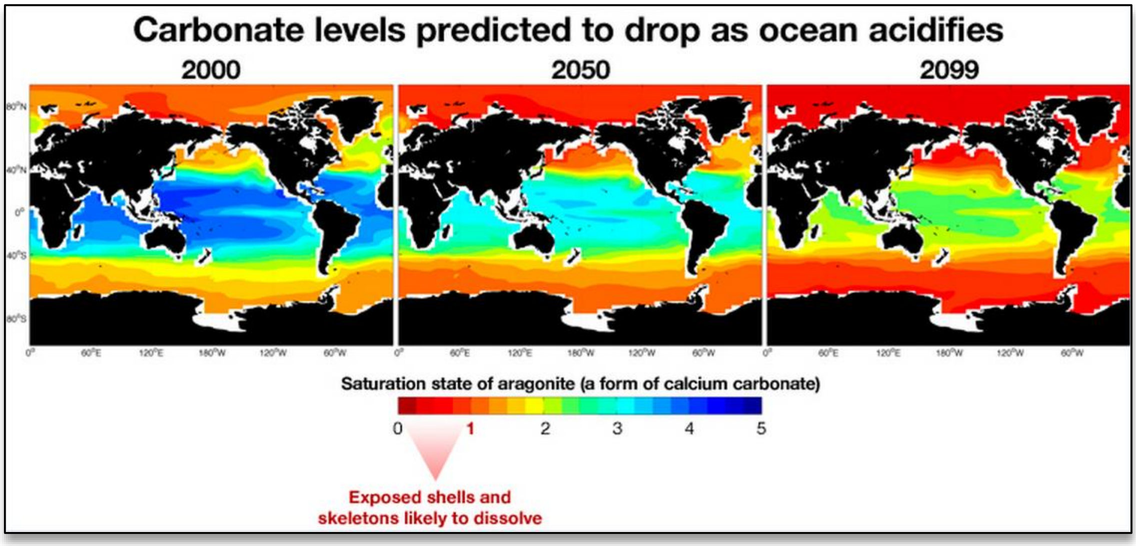

Fig. 7: Ocean acidification and sea ice loss are predicted to impact the polar oceans greatly in future decades. Figure From Winner, C. (2010, January 8) *The Socioeconomic Costs of Ocean Acidification.* Retrieved From https://www.whoi.edu/oceanus/feature/the-socioeconomic-costs-of-ocean-acidification.

Southern Ocean circulation is tied to global climate. Driven by the continuous westerly winds around Antarctica, the eastward flowing Antarctic Circumpolar Current and the associated upwelling of deep waters from all of the oceans brings warm waters adjacent to Antarctica. Changes in the position or intensity of the Southern Ocean circulation in response to global change could increase the rate of ice shelf loss and accelerate sea level rise. Research questions and plans to address these Antarctic issues and similar issues for the Arctic have been summarized by science committees in (SEARCH 2001) and (NRC 2011).

2B. Fleet-Wide Vessel Specifications

The current and near-future UNOLS fleet has been equipped to meet SMRs formulated and published by the UNOLS community with scenarios of current and future vessel operations in mind. A few ships have special purposes, e.g., R/V *Marcus G. Langseth* that is equipped for active source marine seismology, and newer ships have enhanced capabilities as technologies and scientific approaches advance. The vessel class structure of the UNOLS fleet accounts for a diversity of missions that establish particulars such as payload, speed, and endurance. Table 2 illustrates some of these differences by highlighting a general-purpose vessel from each class including the anticipated Regional Class Research Vessels (RCRVs).

Table 2. Vessel Particulars Compared Using Examples from Each Class in the UNOLS Fleet. Complete fleet specifications are available for viewing.

	Class:	Global	Ocean	Regional	Coastal
	Vessel:	*Thompson*	*Neil Armstrong*	*RCRV*	*Savannah*
Dimensions					
Length overall (ft)		273	238	193	92
Length waterline (ft)		252.5	230	178	84
Beam (ft)		52.5	50	41	27
Draft (ft)		17	15	12.5	8.5
Displacement full load (LT)		3,528	2,916	~1488	351
Lab and Science Spaces (fixed)					
Main Lab (ft^2)		1,700	1,023	510	308
Wet Lab (ft^2)		225	398	350	158
Additional Labs (ft^2)			311	420	
Library/Conf RM/Lounge (ft^2)		560	529	180	178
Temperature controlled lab space (ft^2)		80	102	-	-
Science Storage (ft^2)		1,400	589	220	-
Science Hazmat/Chemical Storage (ft^2)		50	57	-	-
Deck					
Aft Deck (incl staging bays) (ft^2)		4,350	1,870	2350	606
CTD Staging Hanger (ft^2)		-	303	-	-
Side Rail (ft)		112	80	70	~50
Freeboard (ft)		10	7	6	5
Maximum Science Load (LT)		150	250	50	10
20ft Van Locations (#)		6	3	3	0
Berths					
Science/Mar techs (#)		38	24	16	17
Crew (#)		21	20	13	5
Mobility impaired (#) (within Science berths)		0	1	1	0
Performance					
Cruise Speed (kts)		12	11	11	8
Max Speed (kts)		15	12	12	9
Range (nm)		12,000	11,500	5,100	2,400

Endurance (days)		60	40	21	10

Planning for the RCRVs has progressed from early community recommendations captured in the 1995 FIP. In 2014 the Division of Ocean Science (OCE) at NSF in cooperation with its agency partners asked the UNOLS FIC to re-evaluate the need for three new RCRV's to meet this decade's regional coastal requirements. FIC's response was that three new, capable technologically advanced RCRVs, one on each of the East, West and Gulf coasts, are essential to support US ocean research. The UNOLS Council then came to the same recommendation after soliciting community input. The question was taken up again in March 2015 after the release of the *Sea Change*, and once more the UNOLS Council made the case in a letter to NSF that three RCRVs are needed and their operations are affordable within future budget projections. None-the-less, in May 2015, the National Science Board (NSB) authorized NSF to include in future budget requests construction of only two RCRVs in agreement with *Sea Change* Recommendation 5. This Fleet Improvement Plan therefore looks ahead with the expectation of the acquisition of only two RCRVs unless the funding of ocean research nationally increases above 2015 projections. These general-purpose vessels will be cost-effective. This cost effectiveness, new capabilities and a smaller fleet overall should foster high utilization rates. The project management and design of the RCRV has passed a Preliminary Design Review and awaits separate MREFC funds appropriation to begin construction. NSF plans to include the RCRV project in a FY 2017 MREFC budget request, leading to these vessels becoming operational in 2021-2022.

Fleet modernization is also advancing with the Ocean Class AGOR 27 and 28 vessels *Neil Armstrong* and *Sally Ride* going into service in early and late 2016, respectively. These ships have been designed to handle heavy loads and be fully operational with advanced SONAR systems in Sea State 4, with dynamic positioning relative to a fixed position in Sea State 5 with a 35-knot wind and 2-knot current (Marine Tech, Reporter, May 2014). NSF took delivery of the ice-reinforced diesel-electric powered R/V *Sikuliaq* in 2014, now being operated by the University of Alaska Fairbanks, primarily for use in the Arctic. This important addition complements only 2 other US agency owned vessels capable of supporting research in ice-covered Polar Regions. US Coast Guard Cutter (USCGC) *Polar Star* (122 m, commissioned in 1976 with projected end of service life in 2022) is a heavy icebreaker used primarily to support breakout of the channel to McMurdo Station for annual resupply of US Antarctic research facilities. The USCGC *Healy* is a medium icebreaker commissioned in 1999. *Healy* is used primarily for scientific research in the Arctic and can carry a science party of up to 52. Projected end of service life for *Healy* is 2029.

NSF has a long-term Antarctic Support Contract (ASC) with Lockheed Martin/Edison Chouest Offshore (ECO) for use of the ice-reinforced *Nathaniel B. Palmer* (ABS Ice Class A2) and the R/V *Laurence M. Gould* (ABS Ice Class A1) for research in the Antarctic. Projected end of service lives for these vessels are 2022 and 2027, respectively.

The Coast Guard has initiated planning for the design and construction of a new heavy polar icebreaker, meant to replace ships such as the *Polar Star*. However, the timing and execution of ship construction is uncertain, and there is no agency stepping forward to support having science capabilities as part of the design. Planning at this stage includes developing a formal mission-need statement, a concept of operations, and an operational requirements document. The Coast Guard's proposed FY2016 budget requests $4 million to continue initial acquisition activities, and in August 2015 President Obama proposed moving up the date for completing the first replacement icebreaker to 2020. Although science users by and large have not been consulted at this time to provide recommendations for the scientific capabilities of the proposed vessel, it is fully consistent with the UNOLS mission to support icebreaker modernization for greater science access to areas with heavy ice cover.

2C. Fleet Support, Utilization and Operational Costs

The recent reality of academic research fleet operations in the US is that budgetary constraints across the Federal agencies combined with escalating costs of new regulations, fuel, crew salaries and repairs has led to a forced reduction in the utilization of ships to support ocean science projects. This trend affects all vessel classes and has led to a striking decline from a UNOLS fleet of 28 vessels in 2001 to just 17 in 2015 (Fig 8).

In 2014 the UNOLS FIC worked with vessel operators to revise the target number of days per year of vessel operations that are considered optimal for retaining crew,

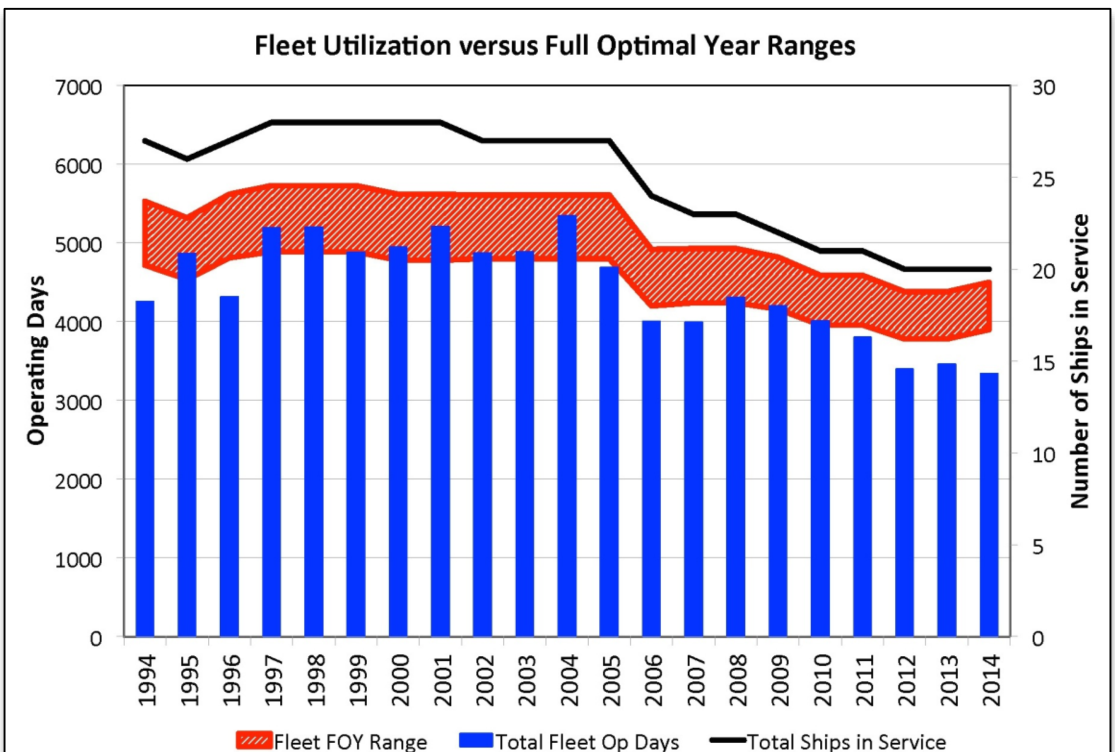

FIG. 8: UNOLS FLEET UTILIZATION VS. FOY RANGES: 1994 TO 2014.

maintaining vessel equipment and mobilizing for diverse science missions during peak periods of science demand. It was recognized that these Full Optimal Year (FOY) targets should be ranges that reflect not just vessel class, but also vessel age, homeport, and differences in at-sea utilization caused by regional weather constraints. As a result, the capacity of the current UNOLS fleet is less than calculated by earlier metrics, but the fleet is still below optimal utilization (Fig. 8). Some extra capacity is desired to retain flexibility for rapid response operations such as were needed after the Deepwater Horizon Oil Spill in the Gulf of Mexico in 2010 and 2011. However, if the number of operational days and associated funded science projects continues to fall, it is estimated that this will significantly erode the ocean science-related work force including experienced mariners, shipboard technicians, engineers and scientists working in different marine disciplines.

2D. Maintenance of Facilities: Near Future Upgrades to the Fleet

The nation-wide planning that has led to the present and near future Academic Research Fleet has sought to modernize, balance and distribute fleet assets while matching capacity to federal sources of support. As a result, by 2020 it is projected that the UNOLS fleet will contain only 15 ships, unless two (or some other number) still notional coastal/local class vessels are built by entities such as the states of Washington and California where there are groups working to replace the R/Vs *Clifford Barnes* and *Robert Gordon Sproul*, respectively (Fig. 9).

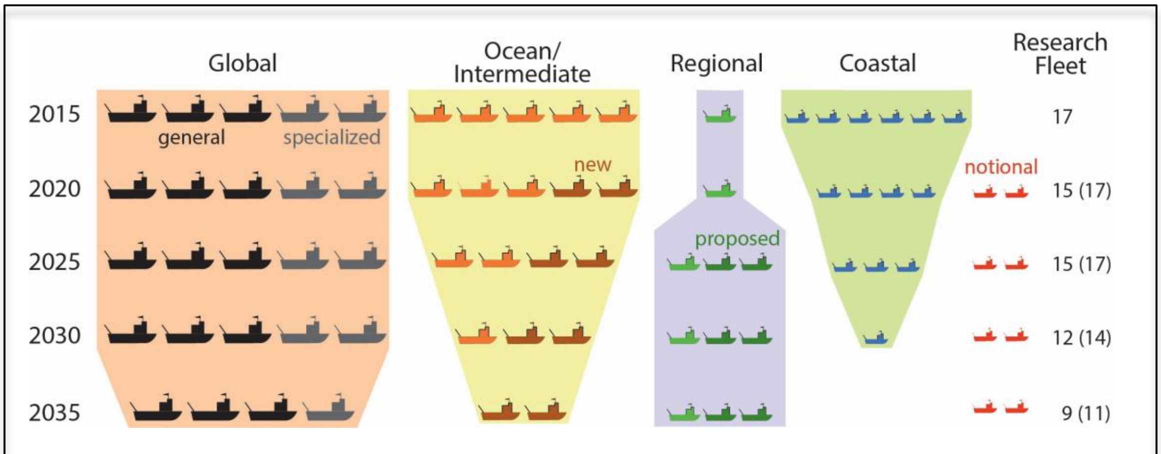

FIG. 9: UNOLS FLEET PROJECTIONS BY CLASS. IN THIS FIGURE THE GLOBAL R/VS *ATLANTIS* AND *MARCUS G. LANGSETH* ARE PORTRAYED AS "SPECIALIZED" VESSELS BECAUSE THEY CARRY SPECIAL EQUIPMENT TO SUPPORT THE OPERATIONS OF THE HUMAN OCCUPIED SUBMERSIBLE, *ALVIN*, AND MARINE SEISMICS, RESPECTIVELY. THE *ATLANTIS*, HOWEVER, REGULARLY PERFORMS GENERAL OCEANOGRAPHIC OPERATIONS, AND IS THE ONLY FULLY MULTI-PURPOSE UNOLS GLOBAL VESSEL WITH A HOME PORT ON THE ATLANTIC COAST.

In 2020 the Global Class vessels will be amongst the oldest vessels in the fleet. To extend the operability of three of these (the AGOR-23 class of *Thomas G. Thompson, Roger Revelle* and *Atlantis*) to 40-45 years, the Office of Naval Research has initiated a program to complete extensive mid-life refit overhauls. These highly capable vessels, with their large flexible work decks and laboratory spaces, extensive berthing, advanced over-the-side handling systems, and combination of excellent sea-keeping and station-keeping capabilities, are essential to supporting deep-water oceanographic research and for taking large integrated science expeditions to sea. Congressional funding has been received to start the mid-life refit/service life extension program (SLEP) at the end of 2016 with R/V *Thomas G. Thompson.* Follow-on funding must be approved to enable the completion of mid-life refits for R/V *Roger Revelle* and then R/V *Atlantis*. The core work will include repowering each ship so that engines, generators, motors etc. are reliable and more efficient. Upgrades will also be made to hull, mechanical and electrical systems, alarms and monitoring, ship controls, navigation, firefighting, potable water, ballast and seawater piping, sewage, heating, ventilation and air conditioning (HVAC), habitability, ballast water treatment, lighting, and internal communications. Science support equipment such as A-frames, cranes and hydro-booms will see extensive maintenance to sustain their useful life.

The questions that remain for the UNOLS community are:

(1) If the refit and construction plans contained in present fleet projections are realized, will the fleet be fully capable of meeting the next decade's science requirements?
(2) Can its operational costs be met without increases to research and related activities funding?
(3) Are other changes in the fleet make-up recommended? Fleet viability requires ships with near optimal schedules to minimize day rates and retain crew who move to other jobs during layups. Fleet viability also requires continuing investment in new science equipment and maintenance of equipment by skilled technicians.

The science community is very concerned about investments in facilities outpacing investments in core science projects. This concern has been expressed and trends documented in the *Sea Change* report released by the NRC (http://nas-sites.org/dsos2015). While UNOLS fully agrees a balance in funding needs to be restored to core science programs, these programs also cannot address the enormity of priority science questions without a well-maintained and fully operational research fleet.

To avoid erosion of expertise in all technical and scientific marine disciplines, additional federal resources that will stimulate innovation in a wide science base while also bolstering the fleet need to be appropriated. One avenue for such investment is through new programs that focus on coastal and inland waterway areas vulnerable to sea-level rise and rapid environmental change such as the Great Lakes, US estuaries and inner shelf regions. Programs such as GLOBEC and the Coastal Ocean Processes (CoOP) program supported by NSF and NOAA in the late 1990s and early 2000s are lacking today. Vessel operations in support of regional and coastal programs with diverse sampling needs have historically increased the number of institutions with shore facilities and expertise valuable to all of fleet operations. In addition, the coastal/local vessels needed for such federally-funded programs receive considerable institutional and state funding in support of educational and pilot research programs, and they are usually available for rapid response missions such as sampling oil spills or algal blooms, or recovering damaged buoys, gliders and other coastal observatory equipment.

3. Fleet Renewal Considerations for 2025-2034

3A. Facilities Projected to Retire 2025-2034

The standard service-life projection for research vessels is 30 years. Under this model, and even with some modest extensions made possible by mid-life refits, the US can expect to retire five or more UNOLS vessels in the time-span of 2025-2034 (Table 1). The ships with the greatest uncertainty in their projected service lives are the AGORs 23-25 (*Thompson*, *Revelle* and *Atlantis)* because of the yet-to-be-determined extent and effectiveness of their planned mid-life refits. These realities and a current lack of agency commitment for fleet renewal beyond 2024 make it imperative that, starting with this FIP, the UNOLS community establishes an extended timeline and activities plan to maintain a vibrant and technologically advanced fleet.

3B. Projections of Fleet Operations Costs

To assess the operational cost of the UNOLS fleet over the next decade under a scenario guided by recent trends, the UNOLS Office and FIC have compiled three-year average (2012-2014) costs (including marine technician budgets) and operating days per each existing vessel, and computed average annual budgets, average numbers of operational days, and average day rates. These averages have then been applied to assess future costs as new ships are added into the fleet and existing vessels are either retired, continue to operate, or enter the yard for refit according to current planning (Fig. 10). Since day rates usually diminish as the number of operational days increase (at least after reaching a threshold number of days), it is recognized that these numbers are not rigid or independent. Projected operating costs for new vessels were based on anticipated day rates provided by operating institutions and the assumption that each new research vessel will have schedules at their FOY minimum estimate (e.g., *Sikuliaq* is projected to operate 270 days per year, *Armstrong* and *Ride* 250 days). Further assumptions were:

- All estimates are given in 2014 dollars without inflation factors.
- First year of service for *Armstrong* will be in 2016 and a partial year, at 75%
- First year of service for *Sally Ride* will be a partial year in 2016, at 25%.
- The first year of service for each RCRV will be a partial year of approximately 2 months, or 17% of the year.

- Retirements for *Oceanus* and *Endeavor* are staggered to occur at the end of 2019, and 2020, respectively, before the RCRVs enter service.
- *Barnes* retires at the end of 2016, *Sproul* at the end of 2018 and *Pelican* at the end of 2020 accorded to existing NSF service life recommendations with no replacements factored in at this time.
- *Thompson*, *Revelle*, and *Atlantis* will all receive mid-life refits taking each ship out of service for approximately 12 months. Operating costs were reduced in these years to reflect out-of-service time.

Figure 10 compares cost projections to a target budget set at $98.5 million in 2014 dollars that was calculated using the 2014 Total Fleet Operating Cost minus 5% of NSF's 2014 Annual Operating budget. This target is in accordance with one of the *Sea Change* recommendations. The result suggests that no further down-sizing of the academic fleet

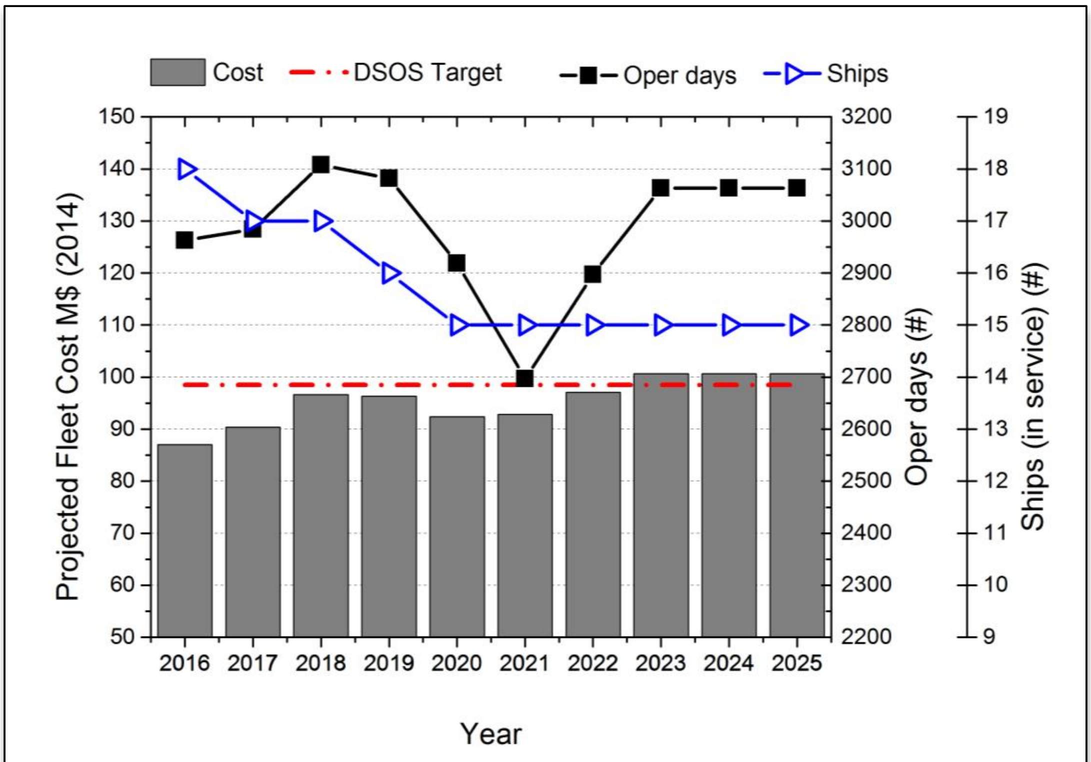

FIG. 10: PROJECTED COSTS, OPERATING DAYS AND SHIPS IN SERVICE IN THE UNOLS FLEET (SEE TEST FOR ASSUMPTIONS LEADING TO THESE PROJECTIONS).

should be required to manage costs within expected infrastructure budgets from 2016 to 2025. The planning that has gone into "right-sizing" the academic fleet over the past decade has already anticipated the amount of investment the federal agencies can reasonably make to maintain the academic research fleet.

Another projected outcome is that the fleet will experience a dip in available capacity in 2021 as *Endeavor* and *Pelican* are retired and the RCRVs transition into service. This suggests the end of service lives of *Endeavor* and/or *Pelican* may need to be extended into 2021. By 2023 these projections anticipate a stable fleet utilization (~3063 operational days) as all three global AGOR 23 class vessels return to full service and two new RCRVs enter into operations. This number is much lower than in the 1990s and 2000s (Figure 8).

Factors that are expected to affect demand are first, the addition of the ice capable R/V *Sikuliaq* to the fleet presents an extraordinary new platform equipped for new research programs in the rapidly changing high latitude regions of the ocean as well as non-polar waters. Initial programs are drawing support from ONR and NSF's Division of Polar Programs (PLR) - thus augmenting support from traditional core programs. The US CLIVAR program and the US Navy in particular have interest in understanding and predicting conditions in the Arctic Ocean, including a desire to forecast the presence or absence of sea ice at a variety of lead times. Fig. 11 illustrates that under the assumptions that led to Fig. 10, the R/V *Sikuliaq* may require the largest fraction of the overall fleet budget (~12%) by 2024. However, with 1) the urgency of changing ocean conditions in ice-covered areas and 2) this ship's new capabilities, persistent funding sources should be a reality.

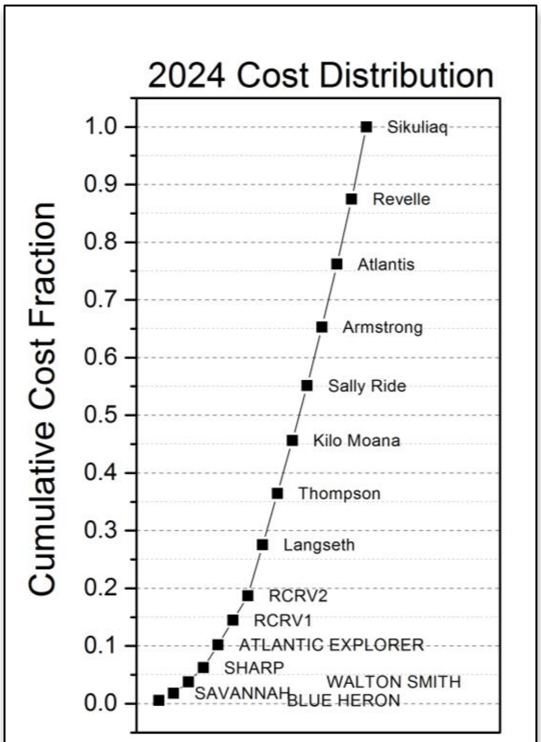

FIG. 11. ESTIMATED DISTRIBUTION OF FLEET COSTS IN 2024 UNDER THE UTILIZATION ASSUMPTIONS DESCRIBED IN THE TEXT.

Second, the UNOLS community is on the verge of new models whereby industry and foreign partners may be served by the UNOLS fleet, cutting overall costs to the federal agencies. This approach is being implemented first with the seismic R/V *Marcus G. Langseth* and should make it feasible to continue to operate *Langseth* with <180 federally supported days per year. (Figures 10 and 11 assume 178 days per year, but they also use a day rate for *Langseth* that is higher than any other vessel in the fleet). Under a new operations model for *Langseth* that will also include multi-year programs in specific ocean basins (OCENEWSLETTER announcement 2015), its day rate and overall cost to the federal agencies should be reduced in future years.

Third, the new RCRVs are expected to be highly beneficial to NOAA, BOEM and state programs regionally. These partners already support the majority of the operational days of the R/V *Pelican*, and their multi-purpose mission profiles are expected to diversify and eventually cover the entire Gulf of Mexico in collaboration with Mexico and possibly Cuba to understand the whole Gulf of Mexico as a system. The telepresence capabilities of the RCRVs are also expected to attract new users for work in all US coastal regions.

Lastly, the critical alignment between the academic fleet and decadal ocean science research priorities is likely to drive greater fleet utilization if NSF acts to shift funding away from other infrastructure programs to support basic OCE research. Of all of NSF's major infrastructure assets, the academic research fleet is the most essential and responsive to a wide portfolio of ocean science programs. The healthiest scenario would be an increase in NSF's overall budget. However, even under flat funding scenarios, greater fleet utilization should follow greater core science funding.

3C. Projections for Polar Programs

Given the rapid changes taking place at both poles and their global consequences, as we go into the future it is highly likely that the demand for ice-capable research vessels will increase. Although, as projected above the *Sikuliaq* is expected to be in high demand to fill some of this need, every US icebreaker currently in service is expected to be retired by 2030.

The Presidential Memorandum 6644 and Presidential Decision Directive NSC-26 mandate that NSF's Division of Polar Programs fund and manage US research in Antarctica and the Southern Ocean, as well as a US geopolitical presence. McMurdo Station is the central location for supply of most US research in Antarctica and most supplies are delivered to McMurdo by ship. Significantly, after 2023 the US will have no heavy icebreakers capable of McMurdo resupply and no icebreakers of any type after 2029.

However, National Security Presidential Directive (NSPD) 66/Homeland Security Presidential Directive (HSPD) 25 states that the US Arctic policy includes scientific monitoring and research into global environmental issues and investigation of the extended continental shelf and boundary. The projected lack of ice-capable research vessels has been noted by the NRC: "…the loss of US icebreaker capability may become an issue of national security and competitiveness in future years (NRC, 2007a)" and "The United States should continue to project an active and influential presence in the Arctic to support its interests" (NRC 2011b). Likewise, the Antarctic Blue Ribbon Panel Report (2012) lists 11 "single-point failure modes" for US Antarctic research agenda and policy; number 2 on the list is "US icebreaking capability (lack of assured access)" and number 8 is "*Gould* and *Palmer* (aging with long replacement cycle)". Finally, in 2010 NSF requested that UNOLS review and update a 2006 report on needs and requirements for a new US Polar Research Vessel (PRV). That report (UNOLS, 2012) documents the needs for a new PRV and lists the science mission requirements, one of which is for ice-breaking capability equivalent to PC-3, e.g. USCGC *Healy*.

3D. A Decade for Green Technologies

The UNOLS Council began a discussion of environmental sustainability of the academic fleet at a meeting at Moss Landing in the winter of 2009. In 2010, UNOLS adopted as one of its annual goals the objective of making the present and future UNOLS fleet more environmentally sustainable. A UNOLS representative (Bruce Corliss/URI) attended a Global Green Ship Conference in Baltimore, MD in 2011 that focused on large commercial vessels and operators to gather relevant information and make contacts with marine environmental experts. In January 2012, a UNOLS-sponsored workshop entitled "Greening the Research Fleet" was held at Duke University to develop sustainability guidelines for oceanographic research vessels. The meeting included presentations from marine architects, designers, builders, related private businesses and representatives of the federal government and foreign research vessel operators. The topics that were covered during the workshop included: Port Sustainability, Emerging Technologies, Propulsion and Fuel, Energy Monitoring and Conservation, Ship Design, Recycling, Certification, Compliance and Noise Pollution.

A second workshop entitled **Green Boats and Ports for Blue Waters** was held in April 2014 at the Graduate School of Oceanography, University of Rhode Island and supported by private contributions and UNOLS. This two day national workshop was a follow up to the first workshop and facilitated communication between academia, governmental agencies, and private industry involved in the environmental sustainability of ships, boats, and ports. Participants exchanged information and developed sustainability recommendations for the operation of existing and future ships and construction of future ports and other marine facilities. A number of conclusions or suggestions came from the two workshops:

- Advances in environmental sustainability will result not only from the adoption of new and innovative technology, but from changes in the culture of operations. UNOLS needs to promote active participation by users and operators in "going green".
- Environmental improvements and new technologies should be an ongoing and iterative process and not stop with the construction of the vessel.
- Environmental sustainability must be adapted to fit the needs of science operations and will vary with ship class or mission.

The workshop concluded with a plan to hold the **3rd Green Boats and Ports** workshop in the spring 2016 at the Graduate School of Oceanography, University of Rhode Island and tentative funding for the workshop has been committed. The proposed RCRVs of the UNOLS fleet are also being designed with a number of green-ship alternatives in the areas of the hull coatings, propulsion system (e.g., variable speed generators), auxiliary systems (e.g., waste heat recovery), pollution control (e.g., biologic marine sanitation device, EPA Tier 4 engines), and outfitting (sustainably sourced, environmental friendly materials).

Reluctance to move the academic research fleet rapidly into new technologies and alternative fuels is based largely on concerns about unknown failure points, supply limits and hidden costs in new operational models that could disrupt ship schedules. To overcome these barriers, much can be learned from private industry and trials at the local level such as tests using 100-percent renewable diesel fuel in SIO research vessels starting with *Robert Gordon Sproul* in 2014. In addition to the benefit of being renewable and nearly carbon-neutral, renewable biodiesel results in cleaner emissions, thus improving air quality relative to fuels derived from petroleum. The coastal/local class of UNOLS vessels offer practical candidates for expanding Green Ship alternative programs. As new coastal/local vessels are designed, technologies with potentially low carbon emissions such as hybrid battery power plants should be evaluated for their viability under various operational scenarios.

3E. Future Support Options for Ship Acquisition and Operational Requirements

The present system of support for academic research ship acquisitions and operations in the US is highly successful. This system does not need to be changed but would be less vulnerable and more adept at meeting scientific needs with a greater infusion of federal support stemming from multiple agencies. Federal agency leaders need regular briefings on Ocean Science facilities and timelines for fleet renewal to keep these plans in the pipeline and in balance with basic science programs. This is consistent with recommendations of the *Sea Change* and the goals of the Interagency Working Group on Facilities and Infrastructure (IWG-FI). New UNOLS documents will need to illustrate to facility reviewers and planners that UNOLS vessels offer the best technologies available for cutting edge science, cost-savings through efficiencies and agility to complete diverse missions safely. Expansion of the general oceanographic and exploratory capabilities outside the UNOLS fleet is inefficient for the nation and should be dissuaded. A more advantageous scenario would be the channeling of multiple agency funds into UNOLS vessels to lower overall day rates.

4. Conclusions and Recommendations

4A. Recommendations for Fleet Renewal Activities

In the United States leading ocean science research proposals request research ships that are available because of federal infrastructure funding and UNOLS planning, scheduling and oversight activities. The purpose of this document is to explain and outline the next stages of fleet planning. Other priorities that inherently guide this plan are that the costs of infrastructure do not outpace support for science programs, and that greater partnering between federal agencies, state, industry and foreign interests be developed to benefit infrastructure (*Sea Change* Report 2015). Given these mandates, the UNOLS FIC recommends six parallel directives for fleet renewal during 2016-2025:

1. Maintain and improve the existing capabilities of critical UNOLS global class vessels by completion of mid-life refits/service life extension programs for the R/Vs *Thomas G. Thompson*, *Roger Revelle* and *Atlantis*. These investments that should extend the useful operability of these vessels to 40-45 years should be made over the next 5 years and planned sequentially so to minimize scheduling impacts. The R/V *Atlantis*, in particular has two essential roles: 1) as the only general-purpose oceanographic global class vessel with a homeport on the Atlantic coast and 2) as the supporting vessel for the operations of the deep human-occupied submersible *Alvin*.

2. Assure full US investment in the construction, outfitting and management of two next generation RCRVs for general-purpose oceanographic studies to support current and future scientific demand primarily on the East and West coasts and the Gulf of Mexico. The operations and maintenance costs of two new RCRVs are projected to be affordable under current budget scenarios, and acquisition of a third RCRV remains of high priority if overall national funding of ocean science increases significantly above 2014 levels. These NSF-owned vessels will contribute to the diversity of the UNOLS fleet - being designed and equipped to conduct a broad spectrum of science mission scenarios. Dedicated telepresence systems of the RCRVs will emphasize interactive data streaming and sensors complementary to coastal ocean observatory assets.

3. Assess alternate funding models for the R/V *Marcus G. Langseth*, the fleet's global vessel that is specialized for 2D and 3D seismic surveys and Ocean Bottom Seismometer installations and capable of many general oceanographic operations. Seismic surveys provide essential information for basic geophysical research and they support scientific ocean drilling operations. In light of its scientific importance weighed against its significant operational costs, *Langseth* needs to operate under a stable multi-year and multi-source funding model that is tied to community science planning for seismic exploration and general-purpose oceanography as appropriate.

4. Determine a course for building future federally-owned global research vessels. There are community-wide concerns that the UNOLS fleet is already in need of at least one more general purpose global vessel capable of supporting large (>30) interdisciplinary science parties. Until the mid-life refits of the AGOR-23 class vessels are completed, there is uncertainty in the service lives of the R/Vs *Thompson*, *Revelle* and *Atlantis*, and no new acquisition plans for the UNOLS fleet after the RCRVs. An activities timeline is needed that will lead to the acquisition of new general-purpose global class ships during the decades of the 2030s and 2040s. FIC will establish the start of this timeline in 2016 with a detailed restructuring and redefinition of global class Science Mission Requirements (SMRs). An assessment of the demand for, operational costs of, and unique missions of present global and ocean vessels including the new ice-

capable R/V *Sikuliaq* and R/Vs *Neil Armstrong* and *Sally Ride* will also be conducted to help develop the SMRs of the future global class.

5. Maintain the capability of coastal/local class vessels as mission-ready components of the UNOLS Fleet. Three of the fleet's coastal/local class vessels will reach the end of their service lives in the next 2-5 years. Efforts to raise state and private funds are critical to replace the capabilities of these vessels, but more proactive support and guidance provided by the federal agencies to local institutions regarding this process is also needed together with new federally-funded nearshore science programs and partnerships that provide consistent utilization so these assets may be applied to enhance understanding of processes in areas vulnerable to sea-level rise and environmental change such as the Great Lakes, US estuaries and inner shelf regions. Coastal/local class vessel operations have historically consumed <5% of the total fleet budget, while providing platforms for regular repeat sampling programs and rapid response capabilities needed in certain areas. New coastal/local vessels need to be designed with advanced sensor systems appropriate for the nearshore coastal ocean. Coastal/local vessels are also practical platforms for green-vessel designs such as the use of hybrid propulsion systems.

6. Support the acquisition of new ice breaking capabilities for science community access to the high latitudes. UNOLS should assist efforts led largely by the Coast Guard for a new icebreaker class that is equipped with modern capabilities for scientific research.

4B. Recommendations for Fleet Improvements apart from Fleet Renewal

Because new ships entering the UNOLS fleet are more technically complex than past vessels, some changes are needed in operational models and funding priorities. Therefore the US academic research fleet should:

- Reinforce the understanding that electronic technicians and IT specialists are necessary crew positions to keep new research vessels operational. Automation is the norm and nearly every new shipboard system is controlled by Programmable Logic Controllers. This higher level of sophistication in basic ship systems requires new philosophies in staffing the marine crew. These positions are in addition to crewing requirements mandated by the regulatory agencies for basic watch-standing and emergency staffing standards.

- Establish more centers of excellence/expertise in major technical areas throughout the fleet. These centers should be charged with working actively to improve performance and provide quality control in critical areas such as over-the-side handling equipment (e.g., winches and wires), sonars (e.g., ADCP and multibeam), unmanned aircraft and vehicle systems, and telepresence. Existing centers or teams that already prove the value of such a model are the Rolling Deck to Repository (R2R), the HiSeasNet program, and the Marine Sediments Sampling Group (MARSSAM).

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