U.S. Academic Research Fleet Improvement Plan 2019 Update

Report of the UNOLS Fleet Improvement Committee

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Executive Summary

The US academic research fleet (ARF) 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, the seafloor, and the sub-seafloor. Planning with respect to the composition and capabilities of this fleet has been an on-going process through the University-National Oceanographic Laboratory System (UNOLS) for over four decades. UNOLS planning guides the nation's fleet modernization and reconfiguration, helping to see that fleet infrastructure continues to evolve to stay well-matched to research and training priorities, and considers the support capacities and concerns of US Federal agencies and others supporting research at sea.

This Fleet Improvement Plan – a document updated every 4-5 years – serves as an analysis of the academic research fleet utilization and support over recent years, with extrapolations into the near future based on projected research directions. The Plan is also a synopsis of the aspirations of the research community – those who generate and utilize data provided by the fleet – regarding how that community would like to see the fleet configured, while at the same time considering reasonable expectations for fleet support. The Plan also acknowledges significant contributions to academic research and training supported by vessels and other resources that are not part of the academic research fleet coordinated by UNOLS. Examples include NOAA ships, the polar research ships of the US Antarctic Program (USAP), marine research supported on US Coast Guard icebreakers, and privately-owned vessels conducting federally supported research.

During the next decade, important renewal events for the ARF now underway include mid-life refits and enhancements to extend the service lives of three Global Class ships, and the construction of two new Regional Class ships, with a third planned. The academic fleet in 2025 is envisioned to provide 16 ships of diverse capabilities. However, unless present long-term fleet renewal plans are modified, the size of the UNOLS ARF could further decrease as a result of retirements of some ships and the potential for a decline in the funding. Changes are also likely in the NOAA, USAP, and Coast Guard fleets, all of which have potential for impacts on academic research and training.

Operational realities and a current lack of a plan for fleet renewal beyond 2024 make it imperative that the UNOLS community establishes an extended timeline and activities plan to maintain a vibrant and technologically advanced fleet. Therefore, the major forward-looking recommendations of this Fleet Improvement Plan call for the UNOLS community to:

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

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. In 2019, FIC will release redefined Global Class Science Mission Requirements (SMRs) as a 'live' document to be revisited as future research and training missions become better elucidated. An assessment of the demand for, operational costs of, and unique missions of present global vessels compared to the Ocean Class RVs Neil Armstrong and Sally Ride will also be conducted to help further develop the SMRs.

- **Support developing plans to renew and utilize the capability of Coastal/Local Class vessels as components of the Academic Research Fleet**

Efforts to raise state and private funds are critical to support the construction of these vessels. Federally-funded near-shore science programs and partnerships that provide stable utilization 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 those making 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, which also provide essential training for students, early-career scientists, and vital technical staff.

- **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. UNOLS assistance with planning for the present and future USAP research ships will also help see that those ships best support a broad science community. Research at high latitudes is critical to understanding and predicting ocean conditions globally. Shared technical resources, training, and operations between the academic research fleet and US icebreakers and USAP ships are essential for most efficient and effective high-latitude sampling and supply missions.

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AGOR	Auxiliary General Purpose Oceanographic Research Vessel
ARF	Academic Research Fleet
AUV	Autonomous Underwater Vehicle
BIOS	Bermuda Institute of Ocean Sciences
BOEM	Bureau of Ocean Energy Management
CLIVAR	Climate Variability and Predictability
CTD	Conductivity/Temperature/Depth
EPA	Environmental Protection Agency
FIC	Fleet Improvement Committee
FIP	Fleet Improvement Plan
FOY	Full Optimal Year
GeoPRISMS	Geodynamic Processes at Rifting and Subducting Margins
GLOBEC	Global Ocean Ecosystem Dynamics
GO-SHIP	Global Ocean Ship-based Hydrographic Investigations Program
IODP	International Ocean Discovery Program
ISC	Inner Space Center
LDEO	Lamont-Doherty Earth Observatory
LUMCON	Louisiana Universities Marine Consortium
MATE	Marine Advanced Technology Education
NASA	National Aeronautics and Space Administration
NNA	Navigating the New Arctic
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
RCRV	Regional Class Research Vessel
ROV	Remotely Operated Vehicle
RV	Research Vessel
SCD	Subduction Cycles and Deformation
SIO	Scripps Institution of Oceanography
SkIO/UG	Skidaway Institute of Oceanography/University of Georgia
SMR	Science Mission Requirement
T-AGs	US Navy Oceanographic Survey Ships
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
USAP	US Antarctic Program
USCGC	US Coast Guard Cutter
UW	University of Washington
WHOI	Woods Hole Oceanographic Institution

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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, the seafloor, and the sub-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 be maintained only 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, and training of the next generation of oceanographers and expert technicians. The University-National Oceanographic Laboratory System (UNOLS) is the body of such experts who advise the US Federal agencies that support science at sea on academic research fleet (ARF) improvement and new acquisitions. The UNOLS Fleet Improvement Committee (FIC), a standing committee of UNOLS, has the mandate to assess the number and mix of ships in the ARF 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 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 become outdated.

The FIC migrated to a web-based UNOLS Fleet Improvement Plan (FIP) in 2015 to maintain a current, informative and forward-looking plan for updating UNOLS facilities. The 2015 Plan is linked to supporting documents and past plans, and can be revised and re-adopted by the UNOLS community more easily. The web-based format is expected to be most useful for maintaining a coordinated national oceanographic fleet in the service of ocean-related, societal needs. In 2019, this plan is retitled the "Academic Research Fleet Improvement Plan" to reflect the Fleet's operations and its future.

The US ARF includes those vessels operated by UNOLS member institutions that are subject to the UNOLS scheduling process, safety requirements and inspection standards. ARF vessels may be owned by NSF, Navy, or member institutions. The ARF is a component of the Federal Oceanographic Fleet, which includes the ARF plus T-AGS, NOAA vessels, USCGC *Healy*, and the US Antarctic Program (USAP) ships RV *Nathaniel B. Palmer* and RV *Laurence M. Gould*.

1A. Why Is Maintaining a Modern Academic Research 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'; older ships may have low demand and the technological enhancement costs for older ships may be prohibitive.

OCEANOGRAPHIC SHIPS ARE NECESSARY TO:

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

Figure 1. The Importance of the Oceanographic Fleet. The RV *Sikuliaq*.

In this 2019 version of the Academic Research Fleet Improvement Plan, the current and projected make-up of the ARF is examined and compared to assessments of what the US scientific community will need and be able to support in coming decades. Need, affordability, and economic return are functions of societal priorities, which evolve with changing events, changing technology, and expanded knowledge or research directions.

A principal guiding 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 ARF to decadal science priorities supported by the National Science Foundation (NSF) is the National Research Council's *Sea Change*: 2015-2025 Decadal Survey of Ocean Sciences.

NSF is establishing programs in 2019 to support "10 Big Ideas," including "Navigating the New Arctic" and "Mid-Scale Research Infrastructure." The first program will establish an observing network of mobile and fixed platforms and tools across the Arctic to document and understand the Arctic's rapid biological, physical, chemical, and social changes. Current Arctic observations are inadequate for enabling discovery or simulation of the processes underlying Arctic system change or to assess their environmental and economic impacts on the broader Earth system. These activities will necessarily require research vessels and additional vessels with ice capabilities. The infrastructure funding may support some of the logistics of Arctic activities requiring research vessels.

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, industry, 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 is now understood to dominate life in the oceans (Zhao et al., 2013), to a presumed megavolcano, TAMU Massif, found below the Pacific Ocean and characterized by seismic reflection studies from the RV *Marcus G. Langseth* in 2010 and 2012 (Sager et al., 2013). Further research using ARF facilities have shown this to be part of the seafloor spreading process (Sager et al, 2019).

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 (Gruber et al., 2019; Brietburg et al., 2019, respectively). Additionally, there is the need to understand and forecast the response of ocean ecosystems to climate change and associated elemental cycles, as well as extreme weather events, and natural or human-caused disasters. For an example of the latter, the April 20, 2010 explosion of the *Deepwater Horizon* drilling platform in the Gulf of Mexico, pulled together US scientists and engineers on ARF vessels with advanced underwater tools (remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs) and submersibles), sensor technologies for tracking the oil plume and estimating how much material was spewing into the Gulf, assessing contaminant dispersal patterns, and tracking marine mammals in the vicinity of the spill.

Vessels of the ARF are also used for a range of geophysical studies targeting geohazards associated with earthquakes, tsunamis, and landslides as well as for studies of deeper earth properties. For example, several ships from the ARF were used for the innovative Cascadia Initiative experiment, to deploy and recover underwater seismometers for multi-year time periods spanning an entire tectonic plate offshore western North America. Scientists are using data from this experiment to understand the deep structure beneath the Juan de Fuca plate and the Cascadia subduction zone, which last ruptured in a magnitude 9 earthquake in 1700 AD and may rupture again in the coming <100 years (e.g. Hawley et al., 2016; Morton and Bilek, 2015).

1B. The Current US Academic Research Fleet

In 2018, eighteen vessels of various sizes and capabilities make up the US academic research fleet, with operations shared by 14 institutions or regional consortia. The ARF is made up of vessels operated by UNOLS member institutions that are subject to the UNOLS scheduling process. This composition is not stagnant and over the past decade many changes in the fleet have occurred to both improve capabilities and control costs. ARF vessels are owned by NSF, the Navy, or they are institutionally owned (Table 1). UNOLS provides advice to the Coast Guard for the purpose of enhancing facilities and science aboard their icebreaker fleet (currently two vessels). There are significant contributions to academic research and training supported by vessels and other resources that are not part of the ARF, but are coordinated by UNOLS. In addition to marine research supported on US Coast Guard icebreakers, other examples from the US Federal Research Fleet include NOAA ships, the polar research ships of the USAP, and privately-owned vessels conducting federally-supported research. The UNOLS scheduling process takes into account agency-supported research on non-ARF ships. For example, NSF has on occasion substituted its USAP-leased RV *Nathaniel B. Palmer* for the Global Ocean Ship-based Hydrographic Investigations Program (GO-SHIP), which originally requested an ARF Global Class research vessel for a non-polar region GO-SHIP cruise.

In part because of its multi-agency oversight, size and diversity, the ARF 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 a 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 participants 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*
- *platforms for a variety of training activities, for the next generation of ocean-going scientists and technicians.*

Table 1. The 2018 Academic Research Fleet Composition.

Ship/Class	Owner	Operator	Length-Over-All (m [ft])	Delivered (y)	Projected End of Service (y)
Global Class					
RV *Thomas G. Thompson*	Navy	UW	84 [274]	1991	2036
RV *Roger Revelle*	Navy	SIO	84 [274]	1996	2041*
RV *Atlantis*	Navy	WHOI	84 [274]	1997	2042*
RV *Sikuliaq*	NSF	UAF	80 [261]	2014	2045
RV *Marcus G. Langseth*	NSF	LDEO	71 [235]	1991	2020
Ocean/Intermediate Class					
RV *Kilo Moana*	Navy	UH	57 [186]	2002	2032
RV *Neil Armstrong*	Navy	WHOI	73 [238]	2015	2045
RV *Sally Ride*	Navy	SIO	73 [238]	2015	2046
RV *Endeavor*	NSF	URI	56 [184]	1976	2021
RV *Oceanus*	NSF	OSU	54 [177]	1976	2020
RV *Atlantic Explorer*	BIOS	BIOS	51 [168]	1982	2026
Regional Class					
RV *Hugh R. Sharp*	UDel	UDel	44 [146]	2005	2035
Coastal/Local Class					
RV *Robert Gordon Sproul*	SIO	SIO	38 [125]	1981	2023
RV *Pelican*	LUMCON	LUMCON	35 [116]	1985	2020
RV *Walton Smith*	UMiami	UMiami	30 [96]	2000	2030
RV *Savannah*	SkIO/UG	SkIO/UG	28 [92]	2001	2031
RV *Blue Heron*	UMinn	UMinn	26 [86]	1985	2025
RV *Rachel Carson*	UW	UW	22 [72]	2003	2033

**RV Revelle and the RV Atlantis service-life extensions are anticipated after completion of the mid-life refit programs to begin in 2019 and 2020.*

The ship class categories of the ARF are generally prescribed by Science Mission Requirements (SMRs) and by basic design elements such as vessel payload and endurance, which in practical terms together relate closely to vessel length. One responsibility of the FIC is to review class definitions and revise SMRs periodically to reflect current mission priorities.

1C. The Federal Agencies Supporting Science at Sea

UNOLS has had as its primary mission the safe, efficient, and comprehensive support of US ***federally-supported*** research at sea, since it was established in 1971. The composition of the ARF has been designed with this objective as the first priority. The US Federal agencies that support science at sea are the National Science Foundation (NSF), Navy, 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.

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, observational, and training requirements. The ships necessarily vary 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 addition of RV *Sikuliaq* for improved capability for research at high latitudes and, to investigate key issues in these critical ice-covered regimes. Another example is the present construction of Regional Class Research Vessels to advance coastal and regional oceanographic research and training with cutting-edge platforms that provide scientists and educators access to the coastal marine realm, where societal dependence and infrastructure and living resources are dependent on wise resource use.

Figure 2. The Federal Agencies That Support Research. The diversity of Federal Agencies that support research conducted from the ARF. UNOLS itself does not fund research.

The common objective of most vessel use, however, is to support basic research and training on topics in physical, chemical, biological, and geological oceanography, or in related disciplines in ocean, atmospheric, and earth sciences that require observations from a floating platform or access to moored facilities. These topics largely reflect the programmatic makeup of the Ocean Science Division (OCE) of the National Science Foundation, which is the largest source of funds

for the fleet, supporting almost 60% of use in recent years (2009 – 2018). 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-ARF vessels have become more common in recent years, at least in some oceanographic sub-disciplines, such as ocean engineering, and for research in unique 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, the Ocean Exploration Trust, and soon the Norwegian based REV Ocean, which will operate the 183-m ship Research Expedition Vessel (REV) due to launch in 2021, (https://www.sciencemag.org/news/2018/11/norwegian-billionaire-funds-deluxe-deep-ocean-research-ship). On a smaller size, examples of state institutions or consortia 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-ARF vessels of various sizes (including Louisiana Universities Marine Consortium (LUMCON) and Woods Hole Oceanographic Institution (WHOI)). The UNOLS Research Vessel Operators Committee (RVOC) Safety Committee is writing a guidance document to assist in evaluating a particular vessel to determine if that vessel falls within the legal US Coast Guard framework governing a class of vessels designated as research vessels. This document (under development), titled "Guidance Document - Contracting for a research vessel outside of the ARF," provides detailed guidance, check lists, a cruise plan example, and a flow chart for determining proper research vessel charters.

Figure 3. Private Research Vessels. RV *Falkor,* of the Schmidt Institute of Oceanography, in the northern Gulf of Mexico.

Private donors, as identified above, and organizations such as the David and Lucille Packard Foundation with funding for the Monterey Bay Aquarium Research Institute and the Moore Foundation for shore-based microbial studies, can be generous supporters of oceanographic expeditions.

Some of the larger scale, non-ARF ventures emphasize public outreach and immediate sharing of data. Because of this general tendency, many projects aboard non-ARF research vessels are technology-driven projects involving new instrumentation that produces visually appealing data or video opportunities. 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 vessel owners often welcome the extra utilization opportunities.

A survey of scientists with experience of non-ARF expeditions indicates that in general these vessels can be accommodating and generally safe, but may lack basic necessities such as meals, linens, Internet, medical expertise and shore-support equipment.

There have also been concerns about the use of UNOLS-designated assets on non-ARF vessels (e.g., UNOLS supported assets are used on US polar vessels). Issues can be financial, accessibility (scheduling), or fairness (priority). Scheduling and pre-cruise planning with a non-ARF vessel may be organized and done well in advance, but sometimes the platforms become unavailable with short notice, leaving a science party with unexpected and unrecoverable expenses, e.g., travel and shipping costs. Operators of non-ARF vessels also may not have the experience and capability for foreign customs clearance and permitting, and often have little experience with oceanographic operations. Laboratory space may be insufficient, and such vessels may not be equipped with instrumentation generally expected by US oceanographic researchers.

While all non-ARF vessels may not be suited for expected oceanographic research capabilities, the larger dedicated research vessels operated by private foundations or academic consortia, on the water or in construction, are developing excellent track records consistent with the ARF. The ARF, nonetheless, continues to have many attributes that bring ocean scientists primarily to UNOLS for use and scheduling of vessels for research at sea.

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

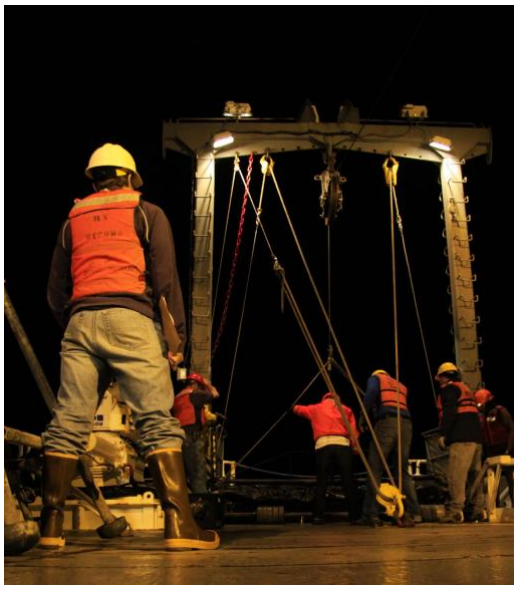

Figure 4. Night Operations. 24/7 work.

Oceanographic ships support increasingly complex, multidisciplinary, and multi-investigator research programs with 24-7 operations (Fig. 4). This requires increased support from specialist marine technicians during day and night operations, and increasingly for telepresence capabilities and high bandwidth communications. The advantages of this connectivity are many (as discussed in section 1F below), but the presence of oceanographers cannot be entirely replaced by long-distance participation. Their presence, fully immersed in the scientific process and day-to-day life at sea, leads to discovery and transformative ideas. "We see with our mind's eye" wrote Fryer et al., (2002) when making a case for rebuilding the human-occupied submersible *Alvin*. Being present from preparation to execution is a privilege, and one that UNOLS is dedicated to preserving with the highest research capabilities available. Many types of oceanographic sampling and/or sample processing and analysis cannot

be done without trained scientists actively involved. One of the main goals of fleet improvement is broadening the suites of information routinely collected at sea, and then making this information readily available to those at sea and colleagues on the shore.

1F. Training and Outreach aboard the Academic Research Fleet

An important, continuing aspect of ARF operations overall that merits increased attention as an area for future, potential multi-agency support is in the arena of training – for undergraduate and graduate students, for marine technicians, and for young career professionals.

UNOLS works with funding agencies and vessel operators to provide a variety of activities aimed at developing skills for students, early career scientists and chief scientist training. Since the beginning of the Chief Scientist Training Cruises in 2011, there have been 21 cruises on 11 different vessels through 2018. The vessels range from global vessels, intermediate ships, and regional and local ships. A recent example is the Chief Scientist Training cruise on the RV *Atlantis* with *Alvin/Sentry* in December 2018 to the East Pacific Rise with 10 berths dedicated to primarily new scientists and post docs. The Chief Scientist Training Workshops reached 215 participants for 2011-2017, for which there were 250 ship time requests submitted (Fig. 5).

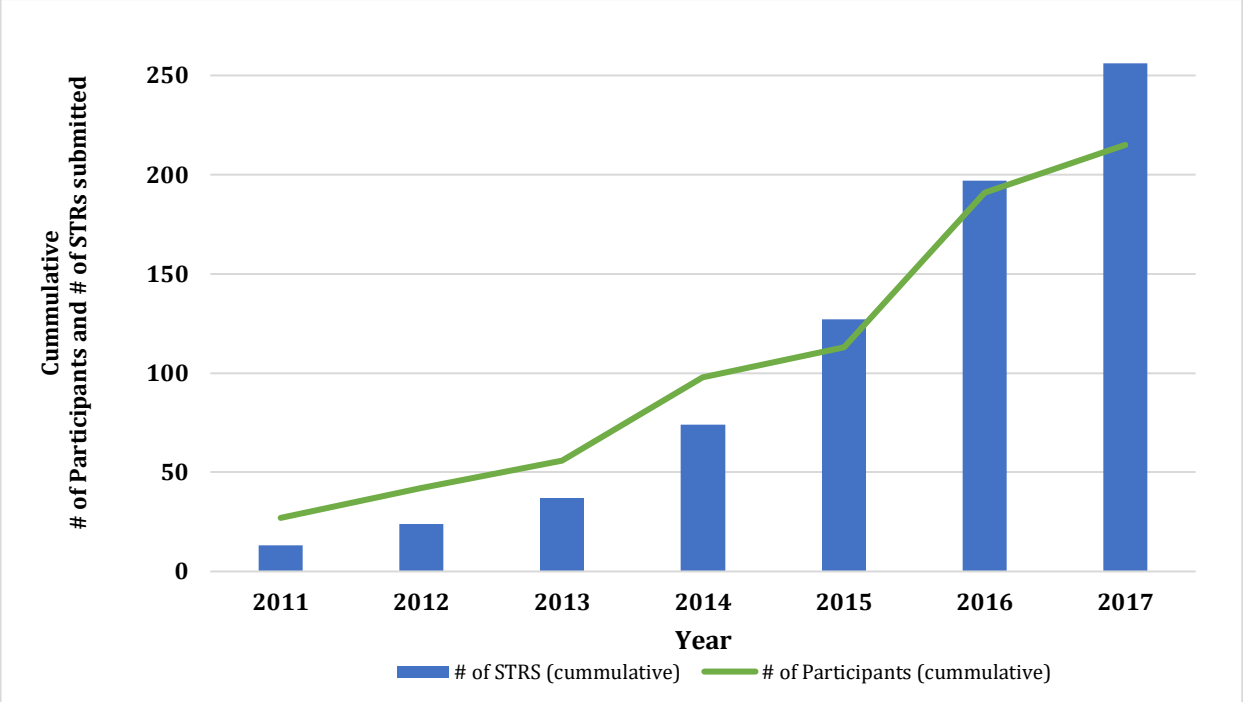

Figure 5. Chief Scientist Training Workshop. Chief scientist training workshops cumulative participants and ship time requests submitted.

The NSF supports the STEM-SEAS (Science, Technology, Engineering and Math Student Experiences Aboard Ships) Program. STEM-SEAS aims to provide ship-based 6-10 days at-sea exploratory experiences for undergraduates from diverse backgrounds. The STEM-SEAS cruises

utilize ARF vessel repositioning transits that would have otherwise gone unused, making the best use out of the at-sea time. Since the program began in 2016, STEM-SEAS has completed nine cruises and taken 85 students to sea (through March 2019). The goal for diversity is working with more than half the participants being non-Caucasian, e.g., African-American, Asian-American, Hispanic, Native American or Alaska Native, and Pacific Islander.

Non-agency funding has also been made available at a number of UNOLS institutions, e.g., the University of Rhode Island/Graduate School of Oceanography, the University of Washington, Woods Hole Oceanographic Institution, and Scripps Institution of Oceanography. For example, the Rhode Island Endeavor Program (RIEP) allocates funds from the State of Rhode Island for competitively funded activities aboard GSO's RV *Endeavor* for teacher training and as a catalyst for developing cutting-edge technologies. In accordance with the terms and conditions of the Charter Party Agreement between UW and ONR, UW has committed to funding 45 days per year of academic research time on RV *Thomas G. Thompson*. This time supports UW students participating in research programs on RV *Thompson* and other ARF vessels to complement UW classes by taking students to sea. WHOI has raised a substantial endowment to support days on the RV *Neil Armstrong*, in support of research and student training, including an annual "student"-led expedition. At Scripps Institution of Oceanography, the University of California Ship Funds Program uses institutional and philanthropic support to enable seagoing projects for graduate and undergraduate classes, as well as for independent research by students and early-career faculty.

A major UNOLS resource is the cadre of well trained, highly experienced marine research technicians. Each expedition is outfitted and staffed based on the stated scientific requirements, the labor contributions to the measurement program expected from the scientific party, and the expected daily workload at sea. UNOLS marine technicians are key contributors to these seagoing scientific endeavors. The MATE/UNOLS Long Term Internship program was developed to help graduating or recently graduated students who have expressed interest in becoming a Marine Technician. The 6-month program is designed to give the intern in-depth at-sea experience to help him/her gain the technical experience to be hired as a Marine Technician in the ARF. The Summer At-Sea Internship program provides community college and university students with essential on-the-job experiences, where they can develop the knowledge and skills necessary to become employable in the marine science workforce. Internships last from 2-10 weeks. Shorter internships are geared toward students considering a marine technical career, while longer internships are filled by students who have taken relevant course work. These programs have placed more than 250 students onto cruises on the ARF.

Many UNOLS operators stand dockside at their institutions or elsewhere for 'Open House' events open to the local community. These events often exceed 1000 participants. For example, the RV *Atlantis* was dockside in San Diego in December 2018's "Deep-Sea Exploration in the 21st Century" for tours of the vessel and its related submarines and conversations with early career marine scientists. The RV *Pelican* has been dockside in New Orleans many times for national science association meetings, including the Association for the Sciences of Limnology and Oceanography, American Geophysical Union, and the Ocean Sciences Meeting (which

includes the two aforementioned societies and The Oceanography Society). The RV *Pelican* also holds "Meet the Fleet" open houses in its home port of Cocodrie, LA, and in Baton Rouge, LA on the Mississippi River, joined with legislative activities, and in the Intracoastal Canal in Houma, LA, the largest nearby city.

UNOLS institutions and the ARF welcome opportunities to engage with the media, radio, television, and as parts of longer documentaries. Reporters are often hosted on research cruises for their work or met dockside when a voyage returns with news-breaking research.

1G. Expanding the Reach of the Research Vessels with Telepresence

1Ga. Telepresence Operations at Sea and on Shore

High-speed Internet connectivity at sea is growing to be a significant requirement for PIs to conduct their research and communicate effectively to other researchers and a variety of audiences. Some of the most frequent complaints identified in post-cruise assessments by PIs who use academic research ships relate to the quality of satellite services for Internet bandwidth during research cruises. The UNOLS Satellite Network Advisory Group (SatNAG) was established to address some of these challenges. In addition, telepresence operations at sea are becoming more common, and as a result requests for bandwidth expansions to support telepresence are being received more frequently by HiSeasNet, one of the satellite service providers for the ARF. Many ships in the ARF have upgraded their hardware to be able to support such requests for increased bandwidth and telepresence. However, there is not yet a standard set of requirements for both on-ship and on-shore technologies and personnel to support telepresence operations, nor is there a standard protocol for requesting expanded bandwidth operations at sea. Furthermore, there is no standard protocol for training marine technicians to support telepresence activities onboard, nor for securing shore-based technical and operations support.

Shore-based science participation in remotely operated vehicle (ROV) operations through telepresence via video are part of normal operations for the programs that support the NOAA vessel *Okeanos Explorer* and the Ocean Exploration Trust's Exploration Vessel *Nautilus*. The Inner Space Center (ISC) at the University of Rhode Island Graduate School of Oceanography is the hub for shore-based telepresence operations for both ships. In addition, the ISC has supported many telepresence-enabled expeditions on academic research ships and other platforms during recent years. Some of these expeditions have employed telepresence technologies for scientific reasons, others for engineering and operational reasons, and others for broader impacts through live broadcasting for educational outreach opportunities.

1Gb. Telepresence for Science and Engineering Operations

All telepresence activities (video, audio, satellite image receiving, and real-time data transfer, to name a few) require high bandwidth operations on the vessel and with shore-based technical support. This technology effectively facilitates expanding the science party onboard to additional on-shore expedition participants and technical operations.

Figure 6. Using Telepresence for Broader Impacts. Research operations using *Alvin* and telepresence technologies.

Successful cruise operations where telepresence support has been available include autonomous underwater vehicles (AUVs), remotely operated vehicles (ROVs) and human occupied vehicles (HOVs) that were guided by shore-based teams. One example is an early career scientist training cruise onboard RV *Atlantis* utilizing *Alvin* (Fig. 6). Also onboard RV *Atlantis*, the AUV *Sentry* has mapped the wreckage site and located the voyage data recorder from the container ship *El Faro*, which was lost in a hurricane. Data from these two operations were transferred to shore for analysis and dive planning, and intercom-based voice communication was used for planning and live operations. The *Sentry*'s *TETHYS* mass spectrometer recorded more than 3500 discrete sample measurements, simultaneously tracking independent chemical parameters in real time to the RV *Endeavor* for immediate decisions on sampling design during the *Deepwater Horizon* oil spill in April 2010. Onboard RV *Sally Ride*, a shore-based PI was involved in advising the at-sea team during the deployment and testing of a ROV-based system to dig into the seafloor sediment for future seismometer deployments. Onboard RV *Endeavor*, the chief scientist was able to troubleshoot technical issues with an AUV and a tethered instrument by having shore-based engineers watch live video as shipboard technicians took the instruments apart and discussed ways to fix the issues.

1Gc. Telepresence for Achieving Broader Impacts

Providing learning opportunities through telepresence has been a common component of real-time video presence for ocean exploration, which is an effective tool to engage audiences and educate both informally outside, and formally, within the classroom. Science educators have "expedition parties" onboard research vessels to provide live broadcasting and interactive experiences with audiences at museums, aquariums, and schools. Facilities, such as the Exploratorium Museum in San Francisco and the Smithsonian Institution's National Museum of Natural History, host large audiences of public visitors, school groups, and VIP event attendees who connect live to onboard scientists, students, engineers, and educators. These activities broaden public participation and interest in ocean science. Additional impacts can be achieved using video presence to provide "inreach" (instead of outreach) to our oceanographic community. Some UNOLS/NSF-sponsored chief scientist training cruises and other early career scientist opportunities have benefited by having shore-based scientists participate as groups or individuals in the live research activities onboard ships in the ARF. This is particularly useful in showcasing the technical and scientific capabilities of national vehicle assets available to the

community, such as the National Deep Submergence Facility at Woods Hole Oceanographic Institution.

1H. 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 the primary reason for an "evolving" **Academic Research 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% 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 the capabilities for a given class of vessel should be. New designs are subject to an unprecedented level of scientific, agency, and operator scrutiny, review and oversight to ensure appropriate science capabilities, the incorporation of new technological solutions, preparation of realistic bottom-up cost estimates, and risk assessments that give a firm basis for contingency funds during construction. For example, the evolution of the Alaska Regional Research Vessel into the RV *Sikuliaq* took over 15 years, reaching 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. The manual 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 followed 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 recently delivered the RVs *Neil Armstrong* and *Sally Ride*. Similarly, NSF is presently carrying out a multi-phase process to design and construct the next generation of Regional Class Research Vessels to support oceanographic operations in areas from shallow coastal bays and estuaries to and beyond the continental rise. 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 ACADEMIC RESEARCH FLEET OF THE NEXT DECADE

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 earth sciences requires a versatile and mission-ready research fleet equipped with new, appropriate technologies for ocean and atmospheric 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 (Fig. 7).

***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?

Figure 7. *Sea Change* Report Research Priority Questions. Priority research questions for the next decade taken from the *Sea Change* report.

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 five major US research programs have needs and/or extensive plans for the use of ARF vessels during the upcoming decade: the Ocean

Observatories Initiative (OOI), US GO-SHIP [a contributor to the Climate Variability and Predictability (CLIVAR) program], the International Ocean Discovery Program (IODP), Geodynamic Processes at Rifting and Subducting Margins (GeoPRISMS), and the aligned nascent Subduction Zone 4D Observatory Initiative and GEOTRACES. Access to the ARF and emerged from the NSF 10 Big Ideas initiative. New initiatives out of GEO to support resiliency mobile ocean assets will also be relevant for the Navigating the New Arctic program that has in coastal zones (Coastlines and People, CoPe) may also make use of coastal vessels.

OOI is an observatory project covering many aspects of biological, chemical, geological, and physical oceanography at the scales of coastal, regional and global. In 2016, OOI was commissioned and accepted by the NSF for operation of both deep water and coastal observatories in the Atlantic and Pacific Oceans (See OOI Science Plan, 2005; OOI Final Network Design, 2011; OOI Scientific Objectives and Network Design: A Closer Look, 2017). The OOI Global arrays involve deployments of large moorings that require vessels with requisite large trawl winches and A-frames, and sufficient deck space for not only the moorings themselves, but the associated nodes and cabling. These requirements are expected to be met into the future with ARF Ocean and Global 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 deploy smaller equipment (by size and weight) than the global arrays so that Regional Class vessels should be able to handle both deployment and maintenance.

The US Global Ocean Ship-based Hydrographic Investigations Program (US GO-SHIP), a contributor to the Climate Variability and Predictability Program (CLIVAR), has been in operation since 1997 to examine the ocean's role in the Earth's climate variability. Its global-ranging repeat hydrography cruises have made extensive use of ARF and NOAA vessels in the world's oceans. Its science plan envisions continued hydrographic measurements (via ships) and modeling, with a significant move into examining the Arctic Ocean. Closely related CLIVAR process studies that 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 observers and modelers. Because climate is not just physically controlled, the next decade of US GO-SHIP is expected to seek interdisciplinary collaborations, and in particular it is likely that bio/ecosystem components will also be added to the GO-SHIP measurement programs. GO-SHIP 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 CLIVAR process study efforts.

The International Ocean Discovery Program (IODP) is the latest phase of the internationally supported scientific ocean drilling initiative, which in 2018 celebrated a half century of addressing important problems in climate history, global geodynamics, and the study of the "sub-seafloor biosphere." Scientific ocean drilling is responsible for the founding and evolution of the fundamental science of paleoceanography, and also for the corroboration of the theory of plate tectonics. The US has led scientific ocean drilling since its inception in the 1960s; more than 20 countries are now members. ARF vessels have played a vital role in scientific ocean drilling for

decades in the provision of seismic images, both for drill site characterization and for putting drilling results into regional and global context. IODP is presently undergoing international review for its next 5 years of operations (2019-2023), and plans are also underway for the next incarnation of scientific ocean drilling beyond 2023. ARF vessels will continue to provide survey capabilities worldwide in support of this ongoing international collaboration.

The Geodynamic Processes at Rifting and Subducting Margins (GeoPRISMS) program is an ongoing special NSF-OCE funding opportunity designed for investigations of geodynamics, earth surface processes, and climate interactions that build and modify continental margins over a wide range of timescales. The GeoPRISMS Science Program includes two broad initiatives: the Subduction Cycles and Deformation (SCD) initiative, which focuses on the processes at subduction zones, ranging from the updip limits of the accretionary wedge and incoming plate to the deep mantle and plate boundary interface, and the Rift Initiation and Evolution (RIE) initiative, which studies active rifts and rifted margins. Processes studied include the localization of continental rupture, the growth of rift zones, and the resulting structure of passive margins. Each of the initiatives has identified primary sites for focused investigations, as well as thematic studies that complement primary site studies. Dedicated funding for GeoPRISMS is scheduled to end in 2020-2022. There are plans for a new initiative, Subduction Zone 4D (SZ4D), which will complement aspects of the GeoPRISMS SCD initiative, with a focus on the processes that underlie the spectrum of hazards associated with subduction zones, including earthquakes, tsunami, volcanic eruptions, and landslides. This initiative would support multi-disciplinary, long-term observatory type investigations and will involve both marine and terrestrial 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 relevant 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 biological component of 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; 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 led expeditions across the North Atlantic Ocean in 2010-2011, throughout the equatorial eastern Pacific Ocean in 2013, to the North Pole via the Bering Strait in 2015, and on a meridional transect in the Pacific from 56°N to 20°S in 2018. The GEOTRACES program will take at least another 10 years to complete, and the US has a cruise from 20°S to the Antarctic Circumpolar Current and Chile planned for 2021, depending on funding. Thereafter, US GEOTRACES will likely begin process cruises throughout the world's oceans depending on topic but due to their highly interdisciplinary nature and resulting participation, will require Global Class research ships.

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 new navigation areas, unknown coastal hazards, and the opening of resources for exploitation. 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 indigenous populations that depend on them. Additionally, with the loss of ice, sunlight is able to 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). As a result of the increased solubility of CO2 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)

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 warmer waters adjacent to Antarctica. Changes in the position or intensity of the Southern Ocean circulation in response to global change 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 2011a).

NSF established programs in 2019 to support "10 Big Ideas," of which "Navigating the New Arctic" (NNA) is one. Arctic change, similar to Antarctic descriptions above, will fundamentally alter climate, weather, and ecosystems globally in ways that we do not yet understand but that will have profound impacts on the world's economy and security. Rapid loss of Arctic sea ice and other changes will also bring new access to the Arctic's natural resources, such as fossil fuels, minerals, and new fisheries. Research is needed to inform the economy, security, and resilience of the US, the larger region, and the globe. Inclusion of the human community is imperative. Major goals of NNA include:

- improved understanding of Arctic change and its local and global effects that capitalize on innovative and optimized observation infrastructure, advances in understanding of fundamental processes, and new approaches to modeling natural environment, social, and built systems interactions
- new and enhanced research communities that are diverse, integrative and well-positioned to carry out productive research at the intersections of Arctic social, natural, and built systems
- research outcomes that inform U.S. national security and economic development needs and enable resilient, sustainable Arctic communities.

Observing infrastructure and understanding fundamental processes will likely enlist the ARF.

Other global processes respond to a warming world and ocean. Warming oceans are attributed to increased CO2 levels in the atmosphere from anthropogenic activities, particularly from emission of fossil fuels, changing carbon and oxygen cycling, from increased CO2 dissolution in ocean waters, and worsening deoxygenation from higher water temperatures. The process of ocean acidification is clearly documented (e.g., Gruber et al., 2019; Fig. 8). One of the major elements for life, nitrogen, is increasing partially from nitrogen deposition of NOx from burning fossil fuel, but mostly from over-use of artificial N fertilizers combined with landscape change. These global changes link carbon, oxygen, and nitrogen cycling across the ocean and in coastal waters, affecting basic chemical and biological processes. Oxygen minimum zones in the open ocean have expanded by several million square kilometers, and hundreds of coastal sites now have oxygen concentrations low enough to limit the distribution and abundance of animal populations

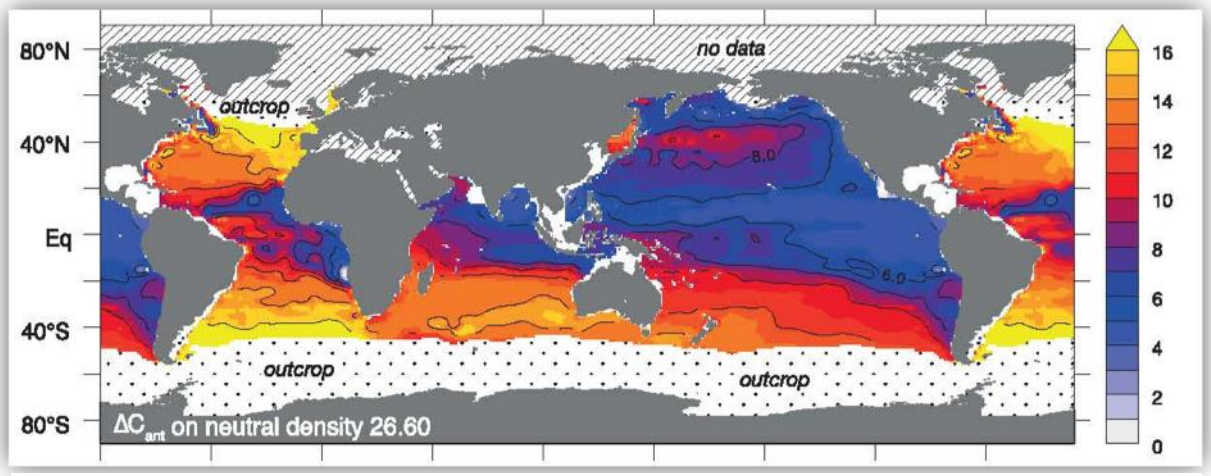

Figure 8. Distribution of the Change of Anthropogenic CO_2. Distribution of the change in anthropogenic CO_2, DtC_{ant}, between 1994 and 2007 on the neutral surface 26.60 kg m−3, representing subtropical mode waters and located around 400-m depth in the centers of the subtropical gyres (from Gruber et al., 2019).

and alter the cycling of important nutrients (Breitburg et al., 2018; Fig. 9).

The US Navy's Physical Oceanography program is organized around Directed Research Initiatives, and actively uses ARF vessels. Current research areas are:

- sub-mesoscale variability associated with fronts, jets, and eddies; internal tides, turbulence, and mixing; influence of regional variability on meso- and sub-mesoscale processes, sea strait dynamics, and the predictability of these processes
- western boundary current forcing and variability on short time scales
- the processes that govern ocean interior mixing and air-sea interaction, in particular those that govern, surface fluxes, and turbulence.

- Novel uses of existing or emerging remote, autonomous or *in-situ* instruments to understand the ocean on the scales at which the Navy operates; use of such data to improve ocean state predictions.

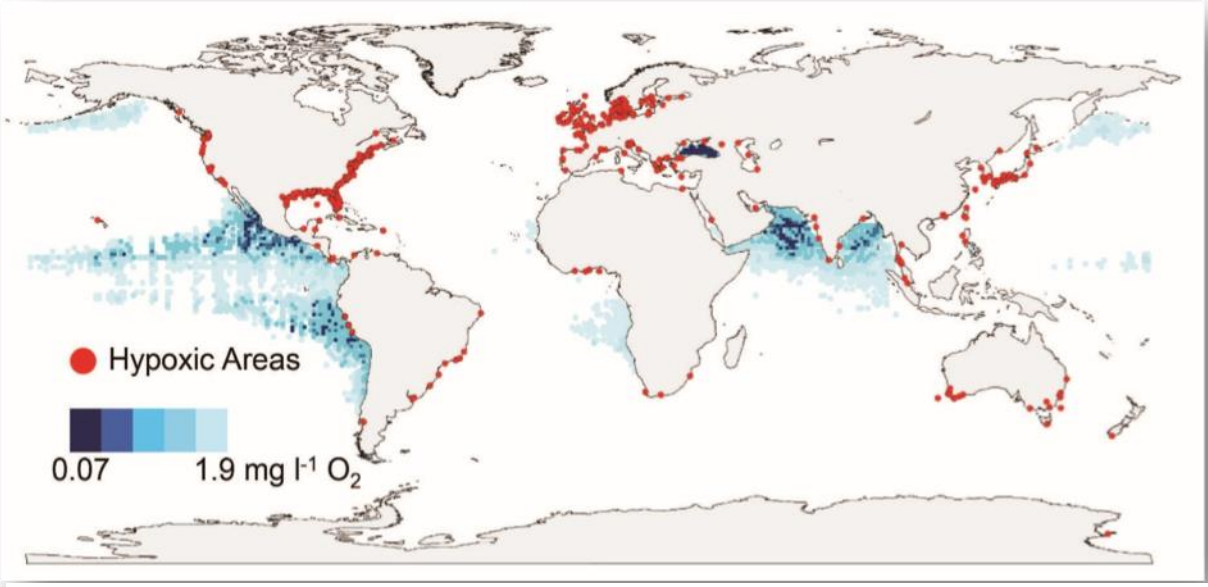

Figure 9. Oxygen Levels in the Oceans. Low and declining oxygen levels in the open ocean and coastal waters affect processes ranging from biogeochemistry to food security (with permission, Breitburg et al., 2018).

Two large NASA programs utilize ARF platforms. The North Atlantic Aerosols and Marine Ecosystems Study (NAAMES) utilizes a combination of ship-based, airborne, and remote sensing measurements that directly link ocean ecosystem processes leading to aerosol precursors, emissions of ocean-generated aerosols and precursor gases, and subsequent atmospheric evolution and processing. EXport Processes in the Ocean from RemoTe Sensing (EXPORTS) is a large-scale, NASA-led field campaign that provides critical information for quantifying the export and fate of upper ocean net primary production using satellite observations and state-of-the-art ocean technologies.

2B. Academic Research Fleet-Wide Vessel Specifications

The current and near-future academic research fleet has been equipped to meet SMRs formulated and published by the UNOLS community with scenarios of current and future vessel operations in mind (see section F1). A few ships have special purposes, e.g., RV *Atlantis* for support of operations of the Human Occupied Vehicle, *Alvin*.

Newer ships have enhanced capabilities as technologies and scientific approaches advance. The new Ocean Class RVs *Neil Armstrong* and *Sally Ride* came into service in early and late 2016, respectively, are owned by the Navy Office of Naval Research, and are operated by Scripps

Institution of Oceanography and Woods Hole Oceanographic Institution, respectively. Both vessels are Ocean Class Auxiliary General Oceanographic Research (AGOR) vessels designed to perform multidisciplinary oceanographic research worldwide, from littoral environments to the deepest ocean, from the tropics into first-year sea ice.

Two Regional Class Research Vessels (RCRVs) are under construction with oversight and eventual operation by Oregon State University and the East Coast Oceanographic Consortium, led by the University of Rhode Island. NSF solicited proposals from eligible organizations in 2019 to serve as the Operating Institution for a third Regional Class Research Vessel (RCRV-3).

In mid-2018, the decision was made by the NSF to divest itself of ownership of the RV *Marcus Langseth* by mid-2020 and to restrict facility funding for deep crustal and 3-D marine seismic operations after divestment to no more than $10M/year over an initial period of five years, due to difficulties with the financial and resultant operational model for the ship (Dear Colleague Letter). The ship is expected to continue to operate through the 2020 field season at which time, NSF plans to implement divestment activities.

> "…. NSF will make every reasonable effort to honor all existing commitments regarding awards that require the current capabilities of RV *Marcus Langseth*. ….. We anticipate the end of field commitments to be no later than mid-2020, at which time NSF will implement the activities for divestment of RV *Langseth*. ….. The Marine Geology and Geophysics (MGG) program will ….. work with the community and the UNOLS Marine Seismic Research Oversight Committee (MSROC) to identify decadal-scale solution(s) for the provision of marine seismic capabilities. Until such time as a new approach for provision of seismic capabilities is in place, NSF will continue to accept proposals that include large tuned-source, long-offset data acquisition, but access to these capabilities will need to be coordinated ….. through industry providers or international/institutional partners. …. Finally, through the time-frame of this overall transition, NSF will continue its programmatic support of other seismic acquisition capabilities (e.g., portable 2-Dimensional multichannel seismic [MCS], ocean-bottom seismometers, CHIRP systems, P-cable, etc.) ….. that can be provided by other ARF vessels, international or commercial partners, or other means ….."

In response to the NSF decision, senior and early career scientists, academic administrators, research ship operators, NSF and ONR program staff, and representatives of the commercial sector involved in ship operations and seismic data collection offshore met during April 2019 to assess viable options for maintaining U.S. academic marine seismic capabilities comparable to those available on RV *Marcus Langseth*.

After carefully evaluating the range of options, including discussion of current commercial vessel costs and availability, the workshop concluded that a general-purpose vessel (which provides the possibility of support for non-seismic operations) with seismic capabilities is more appropriate than a dedicated seismic ship.

The workshop participants proposed short-term (transitional) plans and long-term solutions:

- For the period between 2020 and ~2025, the workshop endorsed that a private entity, institution or consortium of institutions either purchases and outfits a general purpose oceanographic vessel with seismic capabilities and operates it as part of the ARF (with cross-decking and continued use of existing seismic equipment currently on RV *Langseth*), or that they take on continued operation of RV *Langseth* for up to 5 more years, with title transfer away from NSF.
- For the longer term, beyond 2025, the workshop endorsed acquisition by a private institution, conversion and operation of a general purpose vessel with seismic capabilities as part of the ARF, or, if there is not a private institution able or willing to raise funds to acquire and convert such a ship in the foreseen time frame, a long-term lease (~5 years) with a single commercial operator providing one or more vessel(s) as required to meet NSF-funded science objectives, with a contracting office at a research institution negotiating individual charters of commercial or foreign academic seismic vessels of opportunity as need arises. The workshop participants were informed that Columbia University is actively pursuing funding for the purchase of a general purpose/seismic vessel, and endorsed that activity.

The UNOLS Fleet Improvement Committee supports seeing that ship requirements are met for US academic marine seismic research. There has not yet been, however, a UNOLS evaluation of how the general purpose capabilities of the seismic ship envisioned by the workshop participants would fit into long term planning for support of non-seismic academic marine research.

The vessel class structure of the ARF 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.

Of the Global Class vessels, the RV *Thompson* is chosen for characterization (see Table 2), but the capabilities of each vary. The Global Class RV *Sikuliaq* is specialized in terms of its capacity to operate in high latitude open seas, near-shore regions and single-year sea ice, but compared to the others, has about 15-20% shorter endurance, 40% less range, 35% less scientific berthing, less total laboratory space, and lower total science load capacity.

Planning for the RCRVs has progressed from early community recommendations captured in the 1995 FIP. The evolution of the number of RCRVs began in 2014 when the OCE at NSF, in cooperation with its agency partners, asked the UNOLS FIC to re-evaluate the need for three new RCRVs to meet this decade's regional coastal requirements. FIC and UNOLS Council response was that three new, capable technologically advanced RCRVs, one on each of the East, West and Gulf coasts, were essential to support US ocean research. With the release of the *Sea Change* report, the Council kept its recommendation for three, but the National Science Board (NSB) authorized NSF in 2015 to include in future budget requests construction of only two RCRVs in agreement with *Sea Change* Recommendation 5 (Fig. 7). Subsequent Congressional funding decisions, however, provided for the construction of three RCRVs. The construction of these general-purpose vessels is expected to be cost-effective, with mostly the same design and

the same shipyard. Oregon State University will manage the construction of the third RCRV. The RCRVs will begin transition to operations, with staggered dates 2021-2022. New capabilities, and a smaller fleet overall, should foster high utilization rates.

Table 2. Vessel Specifications. Vessel particulars compared using examples from each class of the ARF (details of all vessels are available at www.unols.org).

Vessel Class:	Global	Ocean/ Intermediate	Regional	Coastal/ Local
Vessel:	RV *Thompson*	RV *Neil Armstrong*	RV *Taani*	RV *Savannah*
Dimensions				
Length overall (ft)	273	238	199	92
Length waterline (ft)	252.5	230	184	82
Beam (ft)	52.5	50	41	27
Draft (ft)	17	15	12.5	8.5
Displacement full load (LT)	3,528	2,916	1842	329
Lab and Science Spaces (fixed)				
Main Lab (ft^2)	1,700	1,023	520	308
Wet Lab (ft^2)	225	398	440	158
Hydro Lab (ft2)	480	-	-	-
Computer Lab (ft2)	600	311	-	-
Bio Analytical Lab (ft2)	340	-	-	-
Additional Labs (ft^2)	-	303	465	-
Library/Conf RM/Lounge (ft^2)	560	529	195	178
Temperature controlled lab space (ft^2)	80	102	-	-
Science Storage (ft^2)	1,400	589	165	-
Science Hazmat/Chemical Storage (ft^2)	50	57	External	-
Deck				
Aft Deck (incl staging bays) (ft^2)	4,350	3472	2220	606
CTD Staging Hanger (ft^2)	-	170	-	-
Side Rail (ft)	112	80	76	~50
Freeboard (ft)	10	7	6.5	5
Maximum Science Load (LT)	150	250	66	10
20ft Van Locations (#)	6	3	3	0
Berths				
Science/Mar techs (#)	38	24	16	17
Crew (#)	21	20	13	6
Mobility impaired (#) (within Sci berths)	0	1	1	0
Performance				
Cruise Speed (kts)	12	11	11	8.5
Max Speed (kts)	15	12	12.5	9.5
Range (nm)	12,000	11,500	5,400	2,160
Endurance (days)	60	40	21	26

Fleet modernization has also advanced with the Ocean Class AGOR 27 and 28 vessels RVs *Neil Armstrong* and *Sally Ride* entering service in early and late 2016, respectively. These ships were 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 Technology, Reporter, May 2014). NSF took delivery of the ice-reinforced diesel-electric powered RV *Sikuliaq* in 2014, now being operated by the University of Alaska Fairbanks, for use globally and in the Arctic. This important addition complements only two 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 2023) is a heavy icebreaker used primarily to support breakout of the channel to McMurdo Station for annual resupply of US Antarctic research facilities. (The *Polar Star*'s end of service date is dependent upon continued successful maintenance of aging systems.) 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 Leidos /Edison Chouest Offshore for use of the ice-reinforced RV *Nathaniel B. Palmer* (American Bureau of Shipping (ABS) Ice Class A2) and the RV *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. Through its Advisory Committee, the NSF Office of Polar Programs has initiated a study of the science mission requirements, operational capabilities, and fleet configuration needed to support future USAP research, with the report expected during 2019.

2C. Fleet Support, Utilization, and Operational Costs

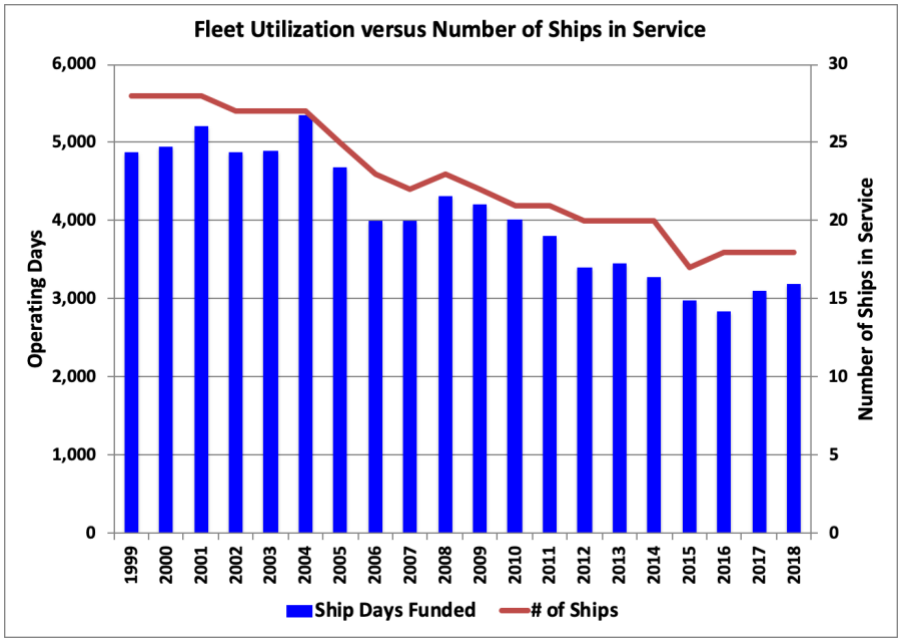

Figure 10. Fleet Utilization and Number of Vessels. Academic Research Fleet Utilization v. the Number of Ships in Service.

The 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 significant decline from an ARF of 28 vessels in 2001 to just 18 in 2018, with 17 being the projection for 2020 (Fig. 10). New vessels and retiring vessels will fluctuate at least through 2025.

Beginning in 2014, the UNOLS FIC has worked with vessel operators to revise the target number of days per year of vessel operations that are considered optimal for retaining crew, maintaining vessel equipment, and mobilizing for diverse science missions during peak periods of science demand. The Full Optimal Year (FOY) targets are ranges that reflect not just vessel class, but also vessel age, homeport, and differences in at-sea utilization caused by regional weather constraints. The average FOY ranges by class are:

- Global Class: 270-300 days
- Ocean/Intermediate Class: 220-250 days
- Regional Class: 170-200 days
- Coastal/Local Class: 90-120 days

UNOLS has worked with NSF and ONR to upgrade the Ship Time Request and Scheduling (STRS) System so that all ship activities can be accounted for within a calendar year. The importance of showing all of the activities that are necessary to support science at sea, as well as maintain a safe, fully operational fleet was recognized. The activities required to support science include the actual science operation days, outreach activities, transit days, and load and unload days. Safe operation of the vessels requires days for maintenance, general upkeep, and outfitting, as well as inspections. The new STRS features for accounting for all ship activities were introduced in 2017 and continue to be refined.

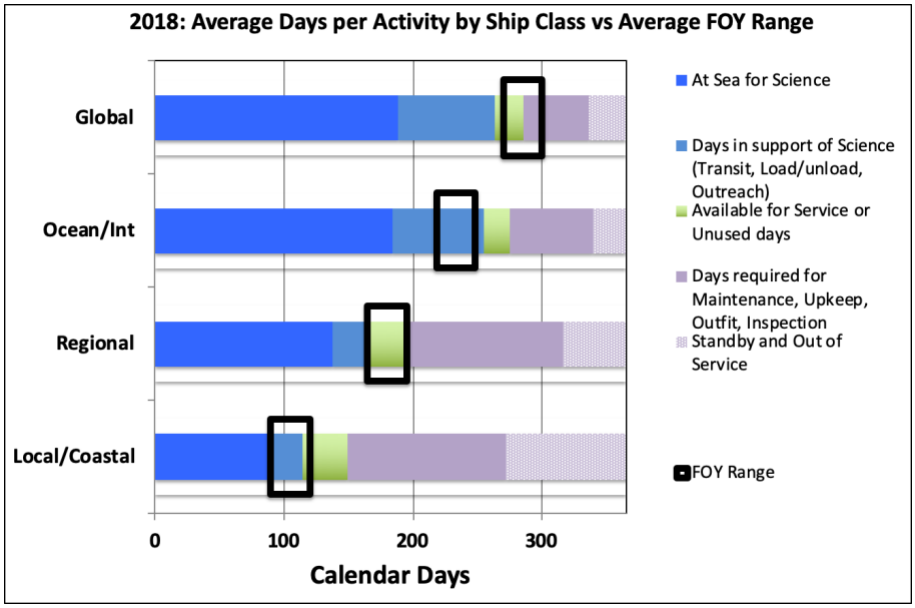

Figure 11. Fleet Activity by Class. 2018 Average Days per Vessel Activity by Ship Class versus the Average FOY Range by Class.

Beginning in 2019, vessel operators have charged for homeport loading and unloading days. Going forward, the new methodology of establishing a homeport load/unload day rate, a separate Major Overhaul Stabilization Account (MOSA) rate, and an operational rate, will provide more transparency to a ship's overall day rate calculation, and is in-line with industry practice. This will also slightly change the overall ship utilization numbers as traditionally the homeport loading and unloading days were not included in the utilization because they were not days directly charged to the user.

When all ship activities are recorded, it becomes clear that less excess capacity is available than could be perceived when only considering the time spent by each ship in science operations. For 2018 fleet operations, the average number of days devoted to each ship activity by vessel class was calculated and plotted with an overlay of the average FOY range (Fig. 11). In 2018, excess fleet capacity was not excessive, suggesting that perhaps the efforts to "right-size" the fleet to match available operation budgets better has been effective. Some extra capacity is desired to retain flexibility for rapid response operations, such as those that were needed after the Deepwater Horizon Oil Spill in the Gulf of Mexico in 2010 and 2011, and the cargo vessel *El Faro* search operation in 2017. Additional data are needed to assess capacity trends; this will continue to be a focus in upcoming years. Maintaining a balance of excess capacity within the fleet that is large enough to allow operational flexibility, but at the same time not so large as to jeopardize the ability to sustain operations, is critical. If the number of operational days and associated funded science projects decrease significantly, it is predicted that a significant erosion of the ocean science-related work force, including experienced mariners, shipboard technicians, engineers, and scientists working in different marine disciplines could occur.

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

The nation-wide planning that has led to the present and near future ARF has sought to modernize, balance, and distribute fleet assets, while matching capacity to federal sources of support. As a result, by 2025 it is projected that the ARF will contain only 16 ships, unless one (or some other number) still notional Coastal/Local Class vessels are built by entities, such as the state of California, where there are groups working to replace RV *Robert Gordon Sproul* (Fig. 12). Recent planning activities for future provisioning of seismic capabilities could also influence the composition of the ARF.

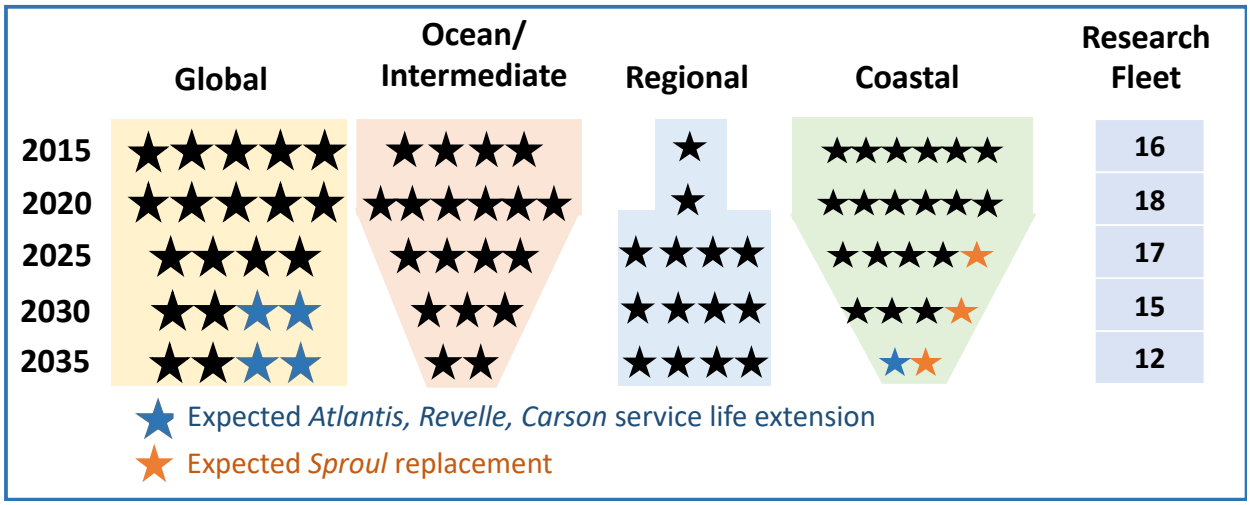

Figure 12. The Academic Research Fleet, Projections by Class.

In 2020, the Global Class vessels will be among the oldest vessels in the fleet. To extend the operability of the three AGOR-23 Global Class vessels (the RVs *Thomas G. Thompson*, *Roger*

Revelle, and *Atlantis*) to 40-45 years, ONR 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 carry out the mid-life refit/service life extension program (SLEP). RV *Thomas G. Thompson*'s mid-life refit was completed in early 2018. Follow-on funding has been approved to enable the completion of mid-life refits for RV *Roger Revelle* and then RV *Atlantis*. The RV *Roger Revelle* refit began in spring 2019 and is scheduled for completion in spring 2020. 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 also see extensive maintenance to sustain their useful life. As mentioned above, the RV *Marcus G. Langseth* is scheduled to be retired in 2020; no refit is planned for this vessel.

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 the fleet's 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.
4. How will the need for the marine seismic capability that is currently provided by RV *Marcus G. Langseth* be supported?

The science community is very concerned about investments in facilities outpacing investments in core science projects. This concern was expressed, and trends documented in the *Sea Change* report released by the NRC. While UNOLS fully agrees that 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 needed 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 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 observation 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 two or more ARF vessels in the time span of 2025-2036 (Table 1 and Fig. 12). These realities, and a current lack of agency commitment for fleet renewal beyond 2024, make it imperative that, starting with this ARF Improvement Plan, the UNOLS community establishes an extended timeline and activities plan to maintain a vibrant and technologically advanced fleet. The Fleet Improvement Committee has initiated this process by drafting Science Mission Requirements for Global Class vessels.

3B. Projections of Fleet Operations Costs

To assess the operational cost of the academic research fleet over the next decade under a scenario guided by recent trends, the UNOLS Office and FIC compiled three-year average (2016-2018) costs (including marine technician budgets) and operating days for each existing vessel, and computed average annual budgets, average numbers of operational days, and average day rates. These averages were applied to assess future costs as new ships are added to the fleet and existing vessels are either retired, continue to operate, or enter the yard for refit according to current planning (Fig. 13). 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., RCRVs are projected to operate 180 days per year). Further assumptions were:

- All estimates are given in 2018 dollars without inflation factors.
- RV *Thompson* average is based on part of 2016 and 2018 (the ship was out of service for mid-life refit from mid 2016 through 2017.)
- The University of California will continue to operate a coastal vessel after the RV *Sproul* is retired.
- RV *Kilo Moana* was out of service for repairs in 2016, at 50%.
- First year of service for RV *Armstrong* was 2016 and a partial year, at 50%.

- First full year of service for RV *Sally Ride* was 2017.
- Retirements for RV *Oceanus* and RV *Endeavor* are staggered to occur in 2020 and 2021, respectively, before the RCRVs enter service.
- RV *Barnes* retired at the beginning of 2018 and was replaced by RV *Rachel Carson* in spring 2018. RV *Rachel Carson*'s 2018 day rate is used for the projection.
- RV *Langseth* will end service life in 2020.
- RV *Atlantic Explorer* will retire in 2026.
- RV *Blue Heron* will retire at the end of 2025 and Pelican at the end of 2021.
- RV *Revelle* and RV *Atlantis* will 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. (RV *Revelle*: 25% in 2019 and 75% in 2020. RV *Atlantis*: 50% in 2020 and 2021).
- Mid-life refits for RVs *Atlantis*, *Revelle*, and *Thompson* extend their service lives past 2030.
- RV *Taani* will enter service in 2022, RV *Resolution* in 2023, and RCRV-3 in 2024.
- The day rates for RV *Taani*, RV *Resolution*, and RCRV-3 are based on best-guess estimates prior to delivery and are subject to change once real operating costs are available.

Figure 13 compares cost projections to a target budget set at $115 million in 2018 dollars, calculated using the $98.5 million target from 2014 with a 4% annual increase applied. In 2014, the target 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 ARF should be required to manage costs within expected infrastructure budgets from 2019 to 2030. The planning that has gone into "right-sizing" the ARF over the past decade has already anticipated the amount of investment the Federal agencies can reasonably make to maintain this fleet.

Another projected outcome is that the ARF will experience a slight decrease in available capacity in 2021 as Pelican is retired and the RCRVs transition into service. This suggests the end of service life of Pelican may need to be extended into 2022. By 2024, these projections anticipate a stable fleet utilization (> ~3000 operational days) as all three global AGOR 23 Global Class vessels return to full service and three new RCRVs enter into operations. This number of operational days is much lower than in the 1990s and 2000s (Fig. 10).

Demand for research vessel time is typically thought of as science-driven, with agency ship support budgets a co-contributor. Well-reviewed proposals requiring sea work timed with adequate funds to support the required sea days lead to well-used ships. However, the availability of appropriate facilities can also be a factor. For example, the addition of the ice capable RV *Sikuliaq* to the fleet has made it possible to support new research programs in the rapidly changing high northern latitude regions of the ocean, drawing support from ONR and NSF's Office of Polar Programs (OPP) - thus augmenting support from traditional NSF ocean science core programs. It will be important to see if these science interests build and sustain – as many predict – seeing that, as illustrated in Fig. 14 under the assumptions that led to Fig. 13, operating the RV *Sikuliaq* may require the largest single-ship fraction of the overall fleet budget (~12%) by 2024.

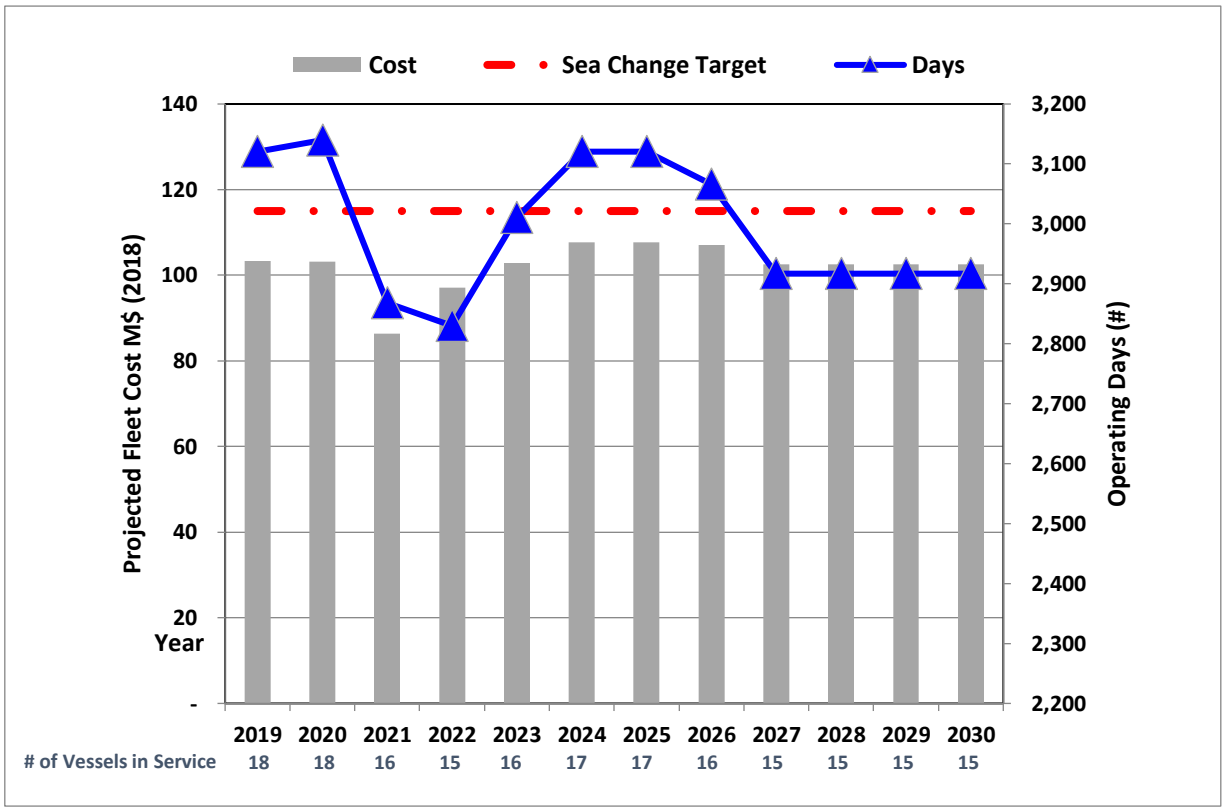

Figure 13. ARF Projected Costs, Vessels and Operating Days. Projected costs, operating days and ships in service in the Academic Research Fleet (see text for assumptions leading to these projections) compared to the *Sea-Change* report's target value.

A much different scenario is faced by the US marine geophysics community, where NSF is in the process of divesting support for the one-of-a-kind seismic-capable RV *Marcus G. Langseth*. There is community demand for continued seismic-related research. With NSF unable to continue full ship support, new models are being considered to provide the required ship time, such as cooperation with industry or foreign partners, perhaps cutting overall costs to the federal agencies.

On a positive note, the new RCRVs are expected to be beneficial to NOAA, BOEM and state programs regionally. These partners already support the majority of the operational days of the RV *Pelican,* and their multi-purpose mission profiles are expected to diversify and eventually cover the entire Gulf of Mexico, in collaboration to understand the Gulf of Mexico as a system. The data presence capabilities of the RCRVs are also expected to attract new users for work in all US coastal areas.

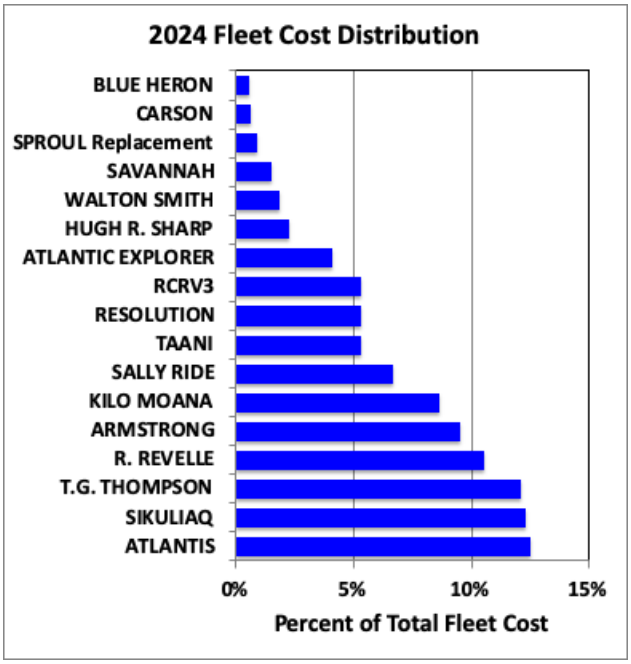

Figure 14. Fleet Cost Distribution. Estimated distribution of fleet costs in 2024 under the utilization assumptions described in the text.

The critical alignment between the ARF and decadal ocean science research priorities requires a fine balance. Under present federal budgets, greater fleet utilization with the present fleet is feasible only if NSF acts to shift funding away from other infrastructure programs to support basic OCE research, seeing that the ARF is the most essential and responsive element to a wide portfolio of ocean science programs. The optimistic and healthiest scenario would be an increase in NSF's overall budget. However, even under flat funding scenarios, by "right-sizing the fleet," greater fleet utilization will follow core science funding. Caution must be paid, however, to the fact that research vessels cannot be taken out of and put back into service at the whim of federal budgets or science demand.

Science needs and the budgets to address them are widely thought to be imbalanced at this time. After a long period of decreasing expectations, if marine research were to regain a higher priority in terms of fiscal support, would the ARF be capable and ready? It is crucial that the nation plan for the research vessels needed to meet future directions.

3C. Projections for Polar Programs

Given the rapid changes taking place at both poles, and their global consequences into the future, it is highly likely that the demand for ice-capable research vessels will increase. Although, as projected above, the RV *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 OPP 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. Specifically, the annual

resupply that enables much of the USAP on-Continent research has depended for many years on heavy icebreakers opening a shipping channel through the ice to McMurdo Station, which is then used by resupply vessels to gain wharf-side access to the station. From McMurdo, supplies and fuel are used directly or are flown to South Pole Station and the USAP's various remote field locations. The US Coast Guard has completed this icebreaking mission for many decades, but only with increasing difficulty in recent years. USCGC *Polar Star*, the only remaining US heavy icebreaker, has become increasingly difficult and costly to keep in service. No other US icebreaking vessels have the icebreaking capacity required. Until April 2019, there was no assurance that after 2023 the US would have heavy icebreakers capable of supporting McMurdo resupply, but a Coast Guard contract awarded at that time now provides for detailed design and construction of at least one heavy polar icebreaker, with completion scheduled for 2024. Under present timetables and planning, the US Coast Guard medium icebreaker *Healy* - a science-oriented ship - will be retired after 2029, with no Coast Guard science icebreaker to replace it.

Although design and outfitting plans for the new Coast Guard heavy polar icebreaker are not yet completed, Coast Guard presentations indicate the ship is expected to have multi-mission capabilities, including some basic science support, but without the full ARF-like science support provided by the *Healy*. 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. Although the newly-announced Coast Guard heavy icebreaker program somewhat changes the underlying premise, 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, 2007)" 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 the US Antarctic research agenda and policy; number two on the list is "US icebreaking capability (lack of assured access)," since that time likely to be addressed by the new heavy Coast Guard icebreaker, and number eight is "*Gould* and *Palmer* (aging with long replacement cycle)."

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 SMRs, one of which is for ice-breaking capability equivalent to PC-3, e.g., USCGC *Healy*. With construction costs for such a ship expected to be very high, and operating expenses to exceed the sum of those for the two present USAP ships, in the flat budget environment of 2018, NSF continues to engage the science and technical communities for input to make decisions on the path ahead. During 2018-2019, a subcommittee of the NSF OPP Advisory Committee analyzed previous studies, listing and prioritizing the SMRs for USAP ships, discussing feasible courses of future action. UNOLS assistance with planning for the present and future USAP research ships will help see that those ships best support a broad science community. Research at high latitudes is critical to understanding and predicting ocean conditions globally. Shared technical resources, training, and operations between the ARF and

US icebreakers and USAP ships are essential for most efficient and effective high-latitude sampling and supply missions.

Design, construction, and operation of research ships working in polar regions must deal with the impacts of the International Code for Ships Operating in Polar Waters (or Polar Code), which is an international regime adopted by the International Maritime Organization (IMO) in 2014. The Code sets out regulations for ships in the polar regions. The Polar Code covers the full range of design, construction, equipment, operational, training, search and rescue, and environmental protection matters relevant to ships operating in the polar regions. The Code applies to any ARF ship operating in those waters, not just those intended for high latitude operations such as RV *Sikuliaq* or the US Coast Guard icebreakers.

3D. A Decade for Green Technologies

The UNOLS Council began a discussion of environmental sustainability of the academic research 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 ARF 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 operations 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 among 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 first 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.

Two subsequent Green Boats and Ports workshops have been held; one in 2016 at the Graduate School of Oceanography, University of Rhode Island, and the most recent in 2018 hosted by Oregon State University in Portland, OR. These have continued to inform the community and facilitate discussion of goals and options.

The RCRVs of the ARF are 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 ARF 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 RV *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 ARF offers 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 or hydrogen-fueled engines 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* report 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 ARF vessels offer the best technologies available for cutting-edge science, training the next generation of ocean-going scientists and technical experts, and cost-savings through efficiencies and agility to complete diverse missions safely. Expansion of the general oceanographic and exploratory capabilities outside the ARF is inefficient for the nation and should be dissuaded. A more advantageous scenario would be the channeling of multiple agency funds into ARF vessels to lower overall day rates.

The UNOLS Fleet Improvement Committee (FIC) should take a proactive role in learning of and assessing new and shifting operational requirements for US academic marine science support, and see that these are incorporated into relevant planning documents, such as the ARF Improvement Plan and the Science Mission Requirements (SMRs) for various research vessel classes. For example, what would be the ship facility and personnel support shifts associated

with an increase in launch, operation, and recovery of autonomous and semi-autonomous aerial, surface, and underwater observation devices? This would include regular inquiries to scientists, technicians, and operators, followed by "touch ups" to the relevant "living" planning documents.

4. Conclusions and Recommendations

4A. Recommendations for Fleet Renewal Activities

In the United States, Federal infrastructure funding and UNOLS planning, scheduling and oversight activities underlie successful ocean science research proposals that request research ship time. The purpose of this document is to explain and outline the continuing 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 stronger partnerships among 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 the next decade:

1. Operational realities and a current lack of a fleet renewal plan beyond 2024 make it imperative that, starting with this ARF Improvement Plan, the UNOLS community establishes an extended timeline and activities plan to maintain a vibrant and technologically advanced fleet. The Fleet Improvement Committee has initiated this process with drafting Science Mission Requirements for Global Class vessels.
2. As per funded plans, maintain and improve the existing capabilities of critical UNOLS Global Class vessels by completion of mid-life refits/service life extension programs for the RVs Roger Revelle and Atlantis. These investments that would extend the useful operability of these vessels to 40-45 years should be made over the next five years and planned sequentially so to minimize scheduling impacts. RV 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*.
3. Assure full US investment in the construction, outfitting, and management of three 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. These NSF-owned vessels will contribute to the diversity of the ARF - being designed and equipped to conduct a broad spectrum of science mission scenarios. Dedicated data-presence systems of the RCRVs will emphasize interactive data streaming and sensors complementary to coastal ocean observatory assets.
4. Identify and implement alternate support models for the US marine geophysical and seismic research now carried out by the RV *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. The community needs to establish a stable multi-year and multi-source funding model for its ship support that is tied to community science planning for seismic exploration and other specialized marine geophysical research.

5. Determine a course for building future federally-owned global research vessels. There are community-wide concerns that the ARF is already in need of at least one more general-purpose Global Class vessel capable of supporting large (>30) interdisciplinary science parties. With the mid-life refits of the ARF Global Class vessels well underway (as of 2019), there is no longer substantial uncertainty in the service lives of these vessels. Still, vessel lives are finite, and as of 2019 there are no new acquisition plans for the ARF 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 has started this process 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 ice-capable RV *Sikuliaq* and RVs *Neil Armstrong* and *Sally Ride*, will also be conducted to help develop the SMRs of the future Global Class.
6. Maintain the capability of Coastal/Local Class vessels as mission-ready components of the ARF. Two 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 replacing the capabilities of these vessels, and guidance provided by the federal agencies to local institutions regarding this process is also needed. Further, federally-funded nearshore science programs and partnerships could help provide consistent utilization of these assets, so that they may be applied to enhance the 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.
7. Support the acquisition of new icebreaking capabilities for science community access to high latitude oceans. UNOLS should assist efforts led largely by the Coast Guard for a new icebreaker class to help see that such ships are equipped with modern capabilities for scientific research. Furthermore, UNOLS should assist NSF efforts to provide future ship support for US Antarctic Program (USAP) marine research. The Antarctic ships are occasionally used in place of UNOLS ships by some NSF programs. UNOLS assistance with planning for the present and future USAP research ships will help see that those ships best support a broad science community. Shared technical resources, training, and operations between the ARF and US icebreakers and USAP ships are essential for most efficient and effective high-latitude sampling and supply missions.

4B. Recommendations for Fleet Improvements apart from Fleet Renewal

Because new ships entering the ARF take advantage of new and improved technology in nearly all systems, new ships are more technically complex than past vessels, placing additional support demands on operators, crew, and science support personnel. Hence, operational models and funding priorities for ship and personnel support must evolve to meet research and ship operation needs. Therefore, the US academic research fleet should:

1. Provide strong support for the electronic technicians, IT specialists, and other crew positions required to keep research vessels optimally operational. Automation is the norm, with nearly every shipboard system on new ships controlled by Programmable Logic Controllers. This high level of sophistication in basic ship systems requires appropriate philosophies in staffing the marine crew. Meanwhile all crewing requirements mandated by the regulatory agencies for basic watch-standing and emergency staffing standards must be maintained.
2. Strongly support fleet-wide coordination and communications in major technical areas of ship operation and research support, including support for centers of excellence/expertise in major technical areas where most beneficial. Work actively to improve science support 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 NORCOR (OSU's Marine Coring Facility). [Note: The R2R program provides fleet-wide management of underway data to ensure preservation of, and access to, our national oceanographic research assets. The HiSeasNet program is a satellite communications network designed to provide continuous Internet connectivity for oceanographic research ships and platforms.] UNOLS should continue to encourage incorporation of new and improved technology for communications for all vessel operations.
3. Promote active participation by users and operators in reduction of the environmental impact of ship and research operations - "going green". Environmental improvements and new technologies should be an ongoing and iterative process and must not stop with the construction of the vessel. Environmental sustainability should be adapted to fit the needs of science operations and will vary with ship class and mission.

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6. Addendums

Addendum to Section 2C: NSF 19-03 -Dear Colleague Letter

NSF 19-083

Dear Colleague Letter: An Update to the Approach for the Provision of Marine Seismic Capabilities for the U.S. Research Community

September 4, 2019

Dear Colleagues:

This Dear Colleague Letter provides updated information regarding the National Science Foundation's (NSF) Division of Ocean Sciences (OCE) support of the marine seismic community need for long-term sustainable access to seismic data collection capability. This Dear Colleague Letter supersedes NSF 18-061.

NSF/OCE is implementing the following actions to ensure continued access to capabilities comparable with those available via the R/V *Marcus G. Langseth*:

1. Operations of R/V *Marcus G. Langseth* will be extended through the end of fiscal year 2021 (September 30, 2021) when dry-docking of the vessel is scheduled. The dry-docking activity which would be necessary for continued operations will not be conducted and instead the vessel will be retired.
2. NSF is accepting proposals to PD 17-1620 for use of the R/V *Langseth* during the period October 1, 2020 to September 30, 2021 for operations in the eastern Pacific. The focus of the additional period of Langseth operations is on providing opportunities for early career researchers to develop their skills, particularly as Principal Investigators (PIs).
3. NSF seeks to avoid a hiatus in seismic research opportunities after retirement of R/V *Langseth* by facilitating access to the active source seismic capabilities available in the commercial and international sectors through two mechanisms, that are not mutually exclusive.
    a. NSF will solicit proposals in Fall 2019 for an award to establish a seismic vessel facilitator whose role will be to work with PIs in identifying potential commercial sector vessels with the needed seismic capabilities and developing contract documentation needed to support the submission of research proposals. It is expected that the facilitator will be in place before the retirement of the R/V *Langseth*.
    b. NSF will accept research proposals that utilize international vessels in parallel with proposals utilizing commercial sector vessels.

Sincerely,
William E. Easterling
Assistant Director for Geosciences