New England Aquarium Research Vessel Retrofit Project XA-97172701-0

Final Report

November 5, 2008

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ABSTRACT

In May 2008, the **New England Aquarium (NEAQ)** retrofit its marine research vessel, the *Galatea*, with a diesel oxidation catalyst (DOC) emissions reduction system. The retrofit project was managed by M.J. Bradley & Associates LLC.

Through a competitive bidding process, the Aquarium procured the particulate matter (PM)-targeted DOC device, which was specified to provide a minimum 25% PM reduction and 80+% reduction of carbon monoxide (CO) and volatile organic compounds (VOC), when used with the *Galatea's* standard No. 2 distillate fuel, with nominal sulfur content of 350 parts per million. The winning bidder was MIRATECH Corporation, which provided its SP-IQS-16-05-L1 diesel oxidation catalyst (DOC) module packaged in a rugged stainless steel housing designed for the marine environment. The module was designed to be installed downstream of the *Galatea's* existing muffler.

The device was installed in a new enclosure on the main deck of the vessel, above the engine compartment. Installation took place during a scheduled project to replace the vessel's main deck.

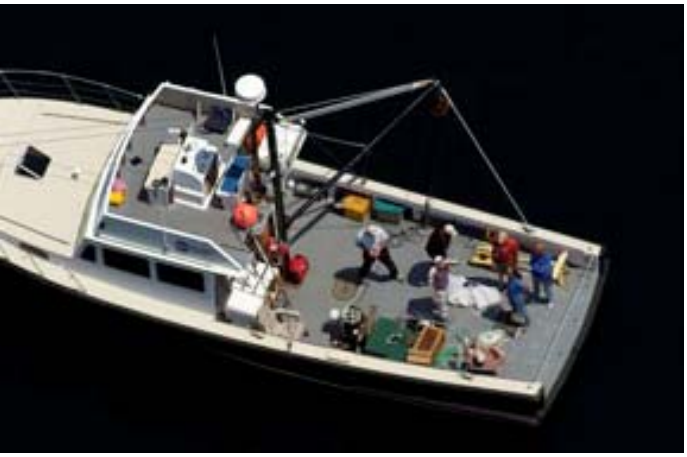
Since installation of the DOC the vessel has continued to be used in its normal research program, primarily tracking right whales off the coast of Maine and Massachusetts, with no problems or maintenance issues.

Emissions testing conducted in September 2008 confirmed that the DOC device reduces carbon monoxide (CO) emissions by 87% on the ISO 8178 E3 Emissions Test Cycle used by the U.S. Environmental Protection Agency for marine engine emissions certification testing. In addition, the percentage of total NOx emissions that were nitrogen dioxide (NO_2) increased from 5% to 21%, indicating that the DOC catalyst was very active. Emissions testing under other programs has shown that these results correlate to a PM emissions reduction of 20% or more.

Acknowledgements

Funding for purchase and installation of the retrofit device was provided by U.S. EPA Region 1. Additional funding for technical project management and emissions testing was provided by the Northeast States for Coordinated Air Use Management (NESCAUM), the Northeast Diesel Collaborative (NEDC), and the Massachusetts Department of Environmental Protection (MassDEP).

The New England Aquarium would like to thank EPA, NESCAUM, NEDC, and MassDEP for funding this project, and acknowledge the contributions of Scott Kraus and Thomas Balon towards making this project a success.



Founded in 1969, the **New England Aquarium** is a global leader in ocean exploration and marine conservation. The Aquarium is one of the premier visitor attractions in Boston, with over 1.3 million visitors a year, and is a major public education resource.

Vision and Mission

The Aquarium is redefining what it means to be an aquarium: combining education, entertainment and action to address the most challenging problems facing the ocean. Through a wide variety of educational programs and conservation initiatives, we make a lasting impact globally.

At the New England Aquarium, we are committed to engaging and educating the public through our exhibits in Boston—but also in taking an active role in the world. Today, we see many threats facing the oceans—including overfishing, climate change, pollution and habitat loss. Our commitment is to build awareness and find innovative solutions through our marine conservation and research.

www.neaq.org

M.J. Bradley & Associates LLC
A Climate Change Capital Group Company

M.J. Bradley & Associates is an environmental consulting firm with a national reputation for helping clients balance environmental goals with business objectives, as well as for demonstrating advanced low emission vehicle technologies. By providing clients with high-quality information and services, and facilitating collaboration, MJB&A assists private and public sector clients in meeting the challenges posed by changes in environmental and energy law and policy, energy markets, technology and business climate.

MJB&A has two offices, an Energy & Environmental Policy Group in Concord, MA and a Technical and Transportation Services Group in Manchester, NH. The Environmental Policy group consults in the fields of energy and environmental policy, electric generating technologies, greenhouse gas policy, and stakeholder groups.

The Transportation Services Group participates in a variety of project areas, with a concentration in advanced vehicle and optimized combustion system technologies. Projects include strategic analysis, feasibility studies, economic and life cycle cost analyses, emissions testing, emissions inventory development, technology assessments, and management of prototype deployments and retrofit programs for a wide range of vehicle types, including transit and school buses, construction equipment, locomotives, and marine vessels.

www.mjbradley.com

The *Galatea's* Mission: *Coastal Oceanography and Conservation Research*

Right Whales

The critically endangered North Atlantic right whale is one of the rarest whale species in the world. Once heavily hunted, the North Atlantic right whale has not recovered from the pressure of historic whaling. Less than 400 of these whales remain. Vulnerable to vessel strikes and entanglement in fishing gear, this species suffers mortality from human activities. Its recovery is threatened by low reproduction, habitat loss, disease and environmental contaminants. Solutions to reduce human impact on right whales exist, but implementation remains a challenge. The New England Aquarium's program is the longest running and most comprehensive North Atlantic right whale research and conservation initiative in the world. NEAQ is working to conserve this critically endangered whale through various programs. The *Galatea* is used to conduct surveys for right whales throughout the Gulf of Maine.

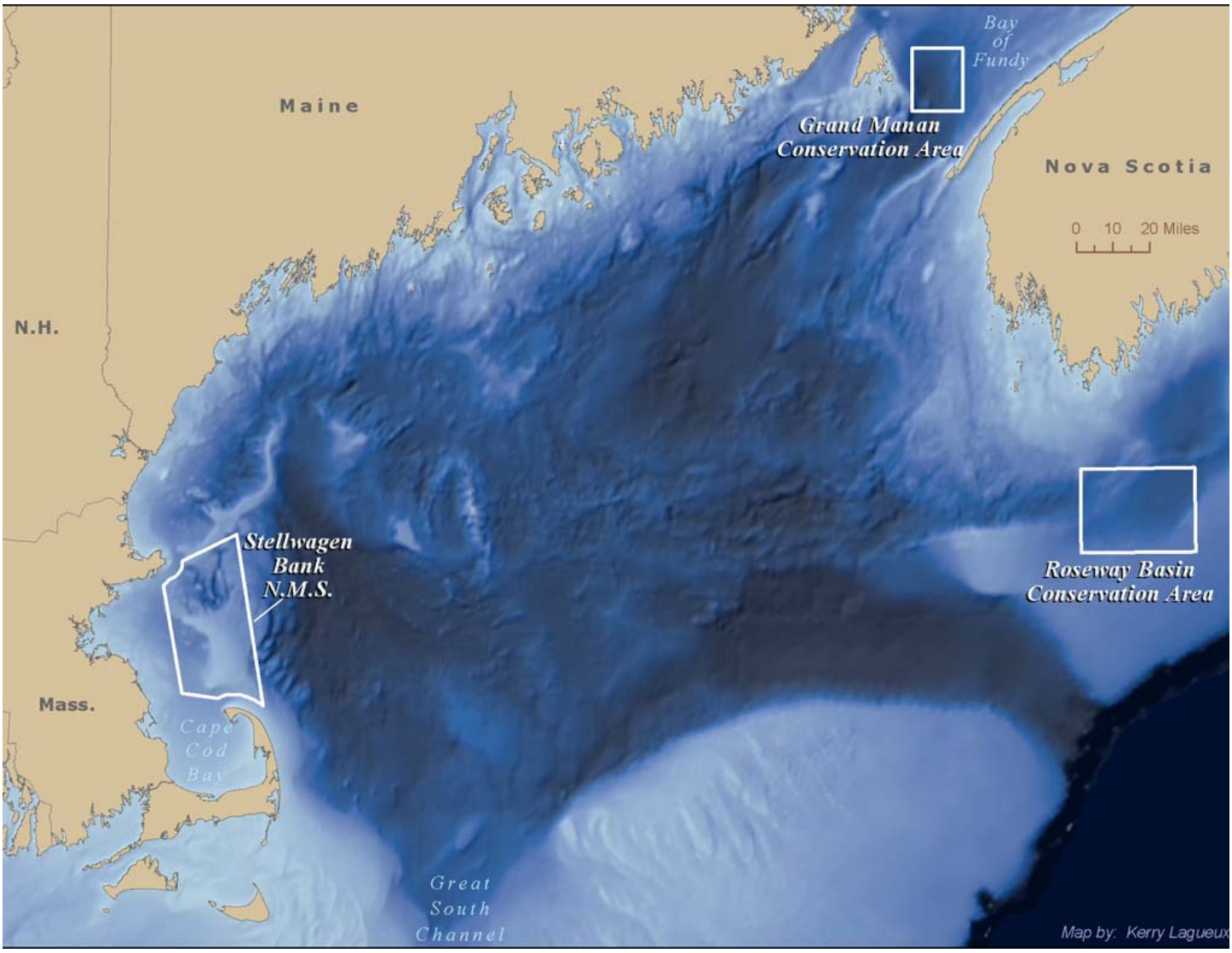
Census of Marine Life

We are studying the distribution of cetaceans, seabirds, pelagic fish, euphausiids and zooplankton over Platts Bank in the Gulf of Maine to determine

the conditions and ocean processes that concentrated prey there and to examine foraging behavior. Our preliminary findings indicate that euphausiids were the primary prey for most large predators and that internal wave passage stimulated upward movement and concentration of euphausiids. The *Galatea* is being used to conduct whale, dolphin, and seabird surveys simultaneously with oceanographic sampling designed to evaluate the physical processes that trigger aggregations of food and predators.

Effects of Offshore LNG Terminals on Marine Life

The New England Aquarium is engaged in a 5-year study of the biological impacts of the liquefied natural gas (LNG) exclusion zone around the deepwater ports established off the entrance to Boston Harbor. We are investigating bottom and mid-water fauna inhabiting or traversing the deepwater port areas to determine whether the port construction and operations bring forth conspicuous biological changes; whether the port infrastructure and operations (e.g., 8-day on-site residence periods for LNG tankers) act as an attractant or a repellant for mobile marine animals; and whether the lack of bottom trawling in the designated ports areas leads to improvements in seafloor integrity (e.g., biodiversity and abundance of benthic fauna). The *Galatea* is the primary research vessel for these activities.



North Atlantic Right Whale *Eubalaena glacialis*	
Size	Up to 55 feet long and 80 tons
Diet	Zooplankton, copepods
Lifespan	At least 70 years; possibly 100 years or more
Habitat and Range	North Atlantic, usually from Nova Scotia to Southern Florida. Calving grounds are off the southeastern U.S. with feeding grounds off New England and Canada.
Predators	Orcas and large sharks occasionally may hunt calves, but adults have no predators other than humans.
Family Life	Females do not give birth until the age of 9 or 10, after which they will give birth to a single calf every 3-5 years after a 12-14 month gestation. Calves are completely dependent on their mothers for about a year. Right whales usually migrate alone, or as a mother-calf pair, but are found in large groups on feeding grounds.

The *Galatea*

The *Galatea* is a 46 foot Jarvis designed lobster-type vessel used for marine research. It's 538 hp four-stroke diesel engine was installed in 1999.

The *Galatea* typically accumulates approximately 300 hours of engine operation, and burns 4,000 gallons of diesel fuel, annually.

The *Galatea* currently burns No. 2 distillate fuel with nominal sulfur content of 350 parts per million.

The *Galatea* is flagged in Boston, MA. It is used by marine researchers sponsored by the New England Aquarium; research activities typically take place off the coast of Maine and Massachusetts, but the vessel travels throughout New England. The Galatea is also used in collegiate education programs with the University of Southern Maine and Boston University.

M/V Galatea	
Engine Manufacturer	Deutz
Power Rating	538 HP
EPA Certification	Tier 0 (Euro 2)
Drive System	Single Propeller

Typical Role of the *Galatea*

Every summer and fall, large numbers of right whales congregate in the Northwest Atlantic Ocean to feed and breed. The New England Aquarium operates a seasonal field station out of Lubec, Maine, on the coast of the Bay of Fundy between Canada and the United States.

On every good-weather day, the Aquarium surveys the local right whales from the *Galatea.* The primary goal is to record the sighted whales with digital cameras, and incorporate the photographs into the North Atlantic Right Whale Catalog. Scientists also collect biopsy and fecal samples., which are used to determine the genetic relationships between individual whales, their hormone levels and their relative health.

The Aquarium also conducts annual boat-based surveys in the Great South Channel which is a major commercial shipping and fishing area near Cape Cod that is also considered critical habitat for North Atlantic right whales.

The waters within the Great South Channel are extremely productive, and support an incredible density of marine life, including North Atlantic right whales. Many of the right whales that visit the Great South Channel are often not seen again for the rest of the year. This means that our sightings from the Great South Channel may be the only known sightings for some right whales alive today.

EPA Cat 1 Marine Engine Standards (g/kwh)		
Certification Level	NOx +THC	PM
Tier 1	10.0 *	NA
Tier 2	7.2 **	0.30 **
Tier 3	5.4 **	0.12 **
Tier 4 (Engines > 600 kw only)	2.0	0.04

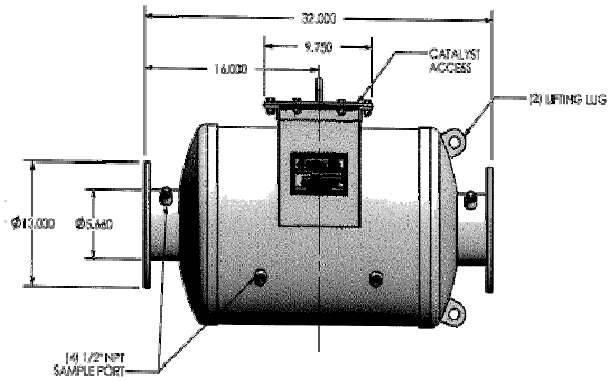
** For engines with maximum operating speed of 1800 RPM*

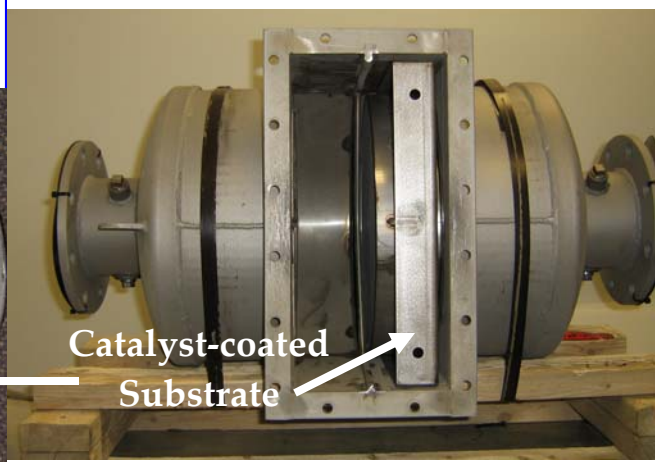
*** For engines with displacement of 0.9 - 1.2 m^3 per cylinder*

Retrofit Diesel Oxidation Catalyst

The heart of the diesel oxidation catalyst is a flow-through metal foil substrate coated with a proprietary precious-metal catalyst. In the device used for the *Galatea*, this substrate is packaged in a rugged stainless steel enclosure and is accessible via a plate on the side of the enclosure.

The enclosure is designed to be installed in the exhaust system of the vessel. As engine exhaust flows through the channels of the substrate, the catalyst coating promotes the oxidation of carbon-containing exhaust components, at temperatures as low as 150°C. Carbon monoxide (CO), volatile organic carbon (VOC) compounds, and particulate matter (PM) in the exhaust are all reduced, as the carbon is oxidized to carbon dioxide (CO_2).





EPA Marine Vessel Emission Standards

In 1999 the U.S. Environmental Protection Agency adopted the first numerical emissions limits for new commercial marine engines, denoted as "Tier 1" and "Tier 2" standards. The Tier 1 standards were applied beginning with engine model year 2004 and only set limits on NOx emissions, with the allowed level varying depending on engine speed (RPM).

The more stringent Tier 2 standards were first applied in Model year 2007. In addition to setting lower limits on NOx emissions, the Tier 2 standards introduced PM limits for the first time. Tier 2 standards vary by engine size (horsepower and displacement) as well as whether the engine is similar to a land-based construction engine (Category 1) or a locomotive engine (Category 2).

In March 2008, EPA adopted even more stringent Tier 3 and Tier 4 standards for new engines, which phase in between model year 2009 and 2017 depending on engine size. The most stringent Tier 4 standards apply only to engines larger than 600 kw (800 hp).

The Tier 4 requirements also specify that beginning in October 2008, older engines larger than 600 kw must be "upgraded" to reduce their PM emissions by 25% when they are remanufactured or rebuilt. To meet this requirement many vessels will have to be retrofit with emission control devices, and the installation of a diesel oxidation catalyst on the *Galatea* demonstrates the effectiveness of the technology in marine applications.

Retrofit Installation

The *Galatea's* original muffler was mounted in the engine compartment, below the main deck, behind the engine. It had duel inlets from the engine's exhaust manifolds and a single outlet to a vertical exhaust stack. The vertical exhaust stack was bolted to a flange on the muffler and was routed through the deck just behind the cabin. To preclude casual contact with the hot exhaust, the stack was insulated between the top of the deck and the top of the cabin. The top of the exhaust pipe is approximately six feet above the cabin roof.

The DOC was designed to be bolted to the top of the existing muffler. It is mounted in a wooden enclosure on top of the main deck, just behind the cabin. The enclosure occupies approximately four square feet of deck surface.

The device itself is wrapped in an insulating blanket inside the wooden enclosure, and the enclosure has a small vent to allow heat to escape.

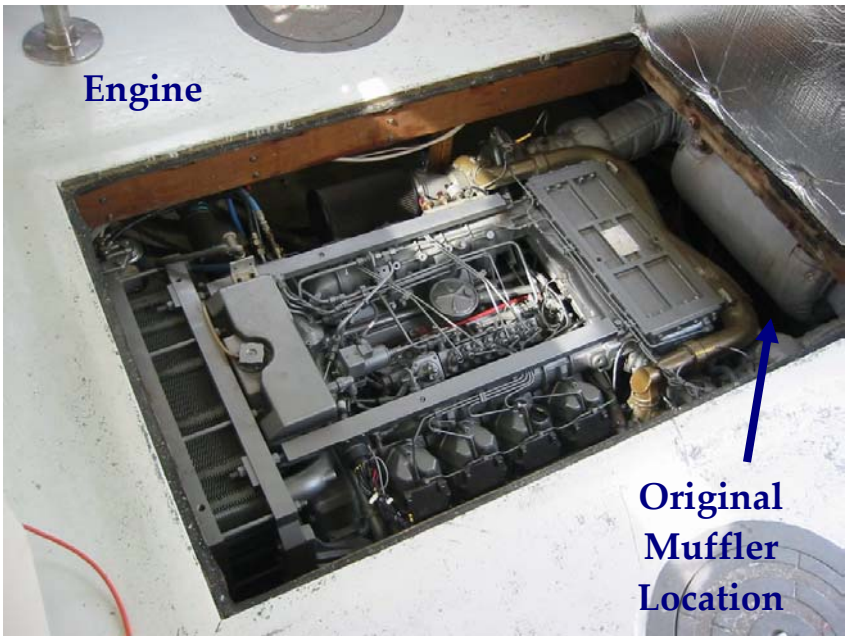
The original insulated exhaust pipe was bolted to the outlet (top) of the DOC, and it rises above the cabin as in the original design.

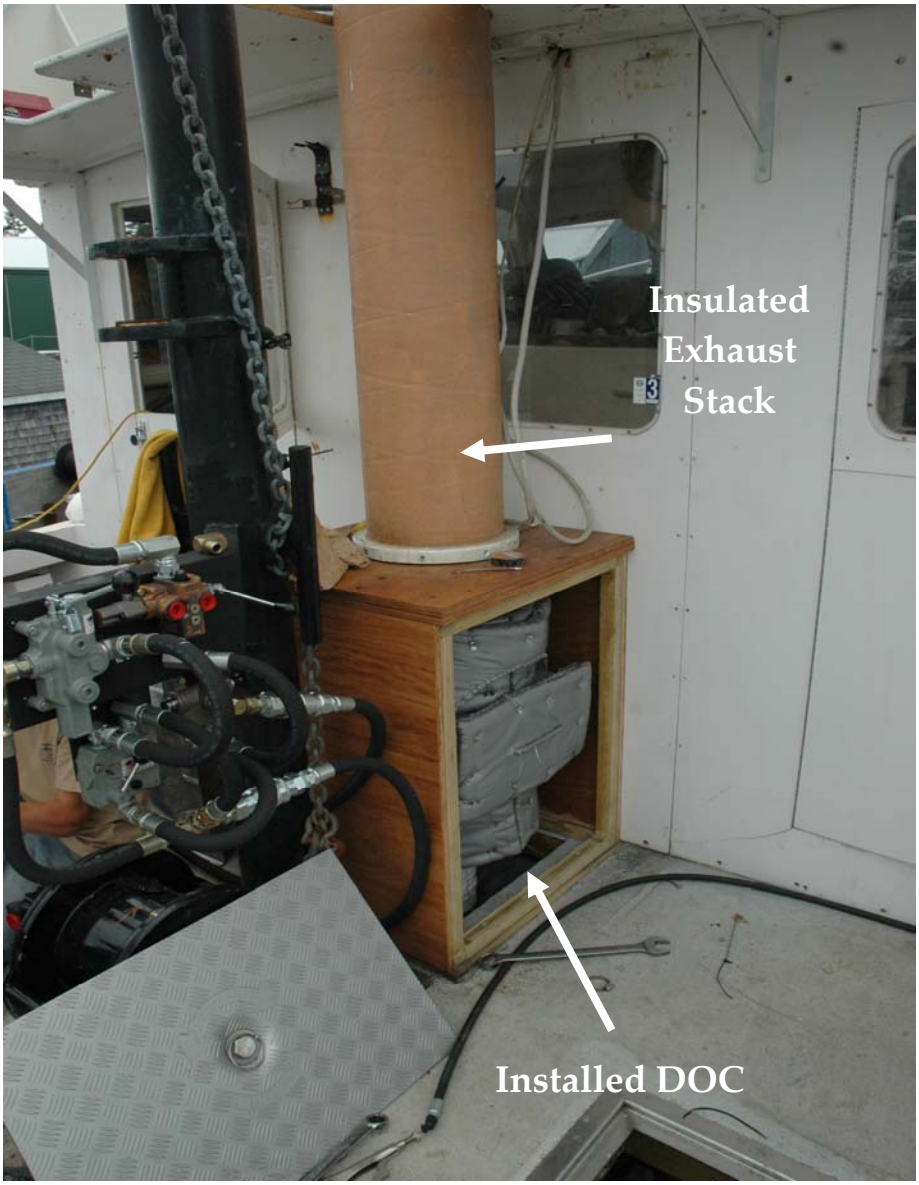
Installation was easy and straight-forward; no modifications were required to the original exhaust piping, and all original parts were re-used. The only fabrication required was the new wooden enclosure on the deck.

The DOC is easily accessible, though it is not expected that access will be required frequently. DOCs are passive devices with no moving parts, and they typically do not require any routine maintenance, other than inspection and potentially cleaning after about 8,000 hours of operation.

The DOC was installed during a previously scheduled vessel overhaul, during which the *Galatea's* main deck was replaced.


NEA
Original Muffler


Engine
Original
Muffler
Location


Insulated
Exhaust
Stack
Installed DOC

Emissions Testing

Emissions testing was conducted on board the *Galatea* on September 29, 2008. During the test, weather conditions were partly cloudy with seasonable temperatures and fairly calm waters. Testing was performed in the inner harbor part of Boston Harbor, mostly within Quincy and Dorchester bays.

Testing was conducted at various engine speed (rpm) points to replicate the ISO 8178 E3 Emissions Test Cycle used by EPA for marine engine emissions certification testing. The E3 cycle includes four distinct engine power modes: 25%, 50%, 75%, and 100% of rated power. On a prop-driven vessel this corresponds to 63%, 80%, 91%, and 100% of maximum engine speed. The E3 cycle rpm points were approximated by visual indication of the engine tachometer.

Testo 350-XL Emissions Analyzer

Emissions Probe in Outlet Port (post-DOC)

During testing emission concentrations in the raw exhaust were measured with a Testo 350-XL portable emission analyzer system. This type of device is typically used for stack testing of industrial boilers.

At each engine load point, data were collected at a 1 hertz rate for several minutes, with the sample probe inserted both before and after the DOC. The sample probe was inserted into sampling ports in the DOC housing that are located upstream (inlet) and downstream (outlet) of the catalyst module, to measure pre-DOC and post-DOC conditions. The

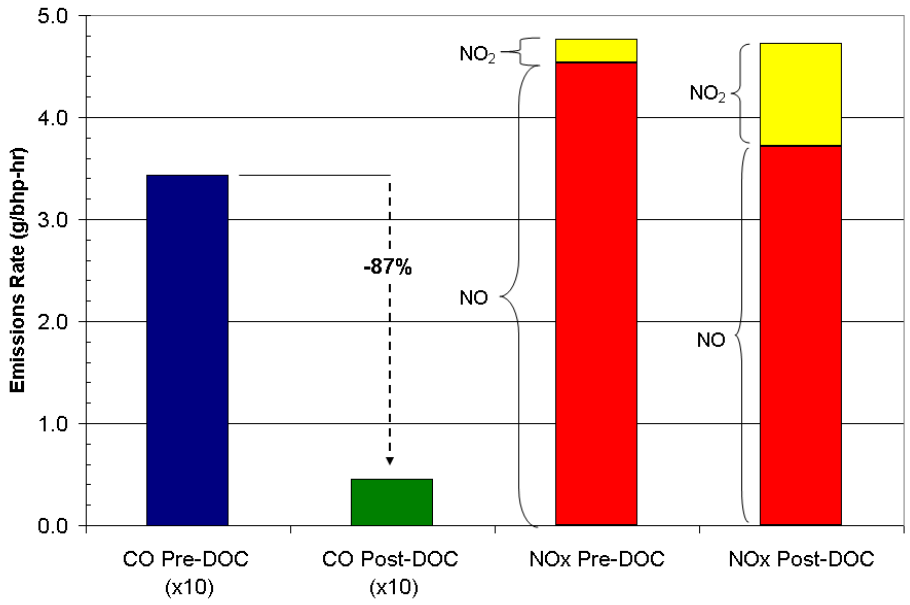
Testo 350-XL readings typically stabilized after 30—60 seconds at the start of each sampling event and remained fairly consistent throughout the remainder of each event. The data presented here are averages of the stabilized concentration data, converted to a gram per brake horsepower (g/bhp-hr) value for inclusion in the E3 test cycle computation.

To calculate E3 cycle emissions rates, measured steady-state emissions rates at the different engine load points were combined using pre-determined weighting factors, as shown in the table on the next page.

Emissions Probe in Inlet Port (pre-DOC)

The Benefits

The emissions analyzer used for emissions testing did not have the capability to directly measure PM or VOC emissions from the *Galatea*. Instead, carbon monoxide (CO) was measured, along with nitrogen oxides (NO and NO_2). Prior testing in different programs has shown that significant reductions in CO concentrations post-DOC correlate well to PM reductions in the expected range of 20—25%. In addition, an increase in NO_2 concentrations post-DOC are indicative of good catalyst activity since NO is oxidized across the catalyst along with carbon compounds.



As shown in the table below, CO emissions were reduced across the DOC by 81-96% at all engine load points except idle. At idle CO emissions were reduced by 30%. This was not unexpected given the lower exhaust temperature at idle. On average CO was reduced by 87% over the E3 emissions test cycle.

Pre-DOC, NO_2 comprised only 5% of total NOx emissions, while it increased to 21% post-DOC.

The significant reductions in CO emissions and the increase in NO_2 emissions across the catalyst both indicate that the DOC is working as intended and it is likely that PM emissions are being reduced by at least 20% as a result of retrofit of the *Galatea*.

Test Results—Carbon Monoxide Emissions

Engine Power	Engine Speed	E3 Cycle Weighing Factor	Pre-DOC		Post-DOC	
			Emissions Rate g/bhp-hr	Weighted g/bhp-hr	Emissions Rate g/bhp-hr	Weighted g/bhp-hr
0%	Idle	0.00	1.38	0.000	0.965	0.000
25%	63%	0.15	0.47	0.070	0.018	0.003
50%	80%	0.15	0.37	0.056	0.033	0.005
75%	91%	0.50	0.30	0.152	0.048	0.024
100%	100%	0.20	0.32	0.065	0.063	0.013
		E3 Test Cycle Emissions Rate		0.343		0.045
				E3 Cycle Emissions Reduction		87%


New England Aquarium
GALATEA