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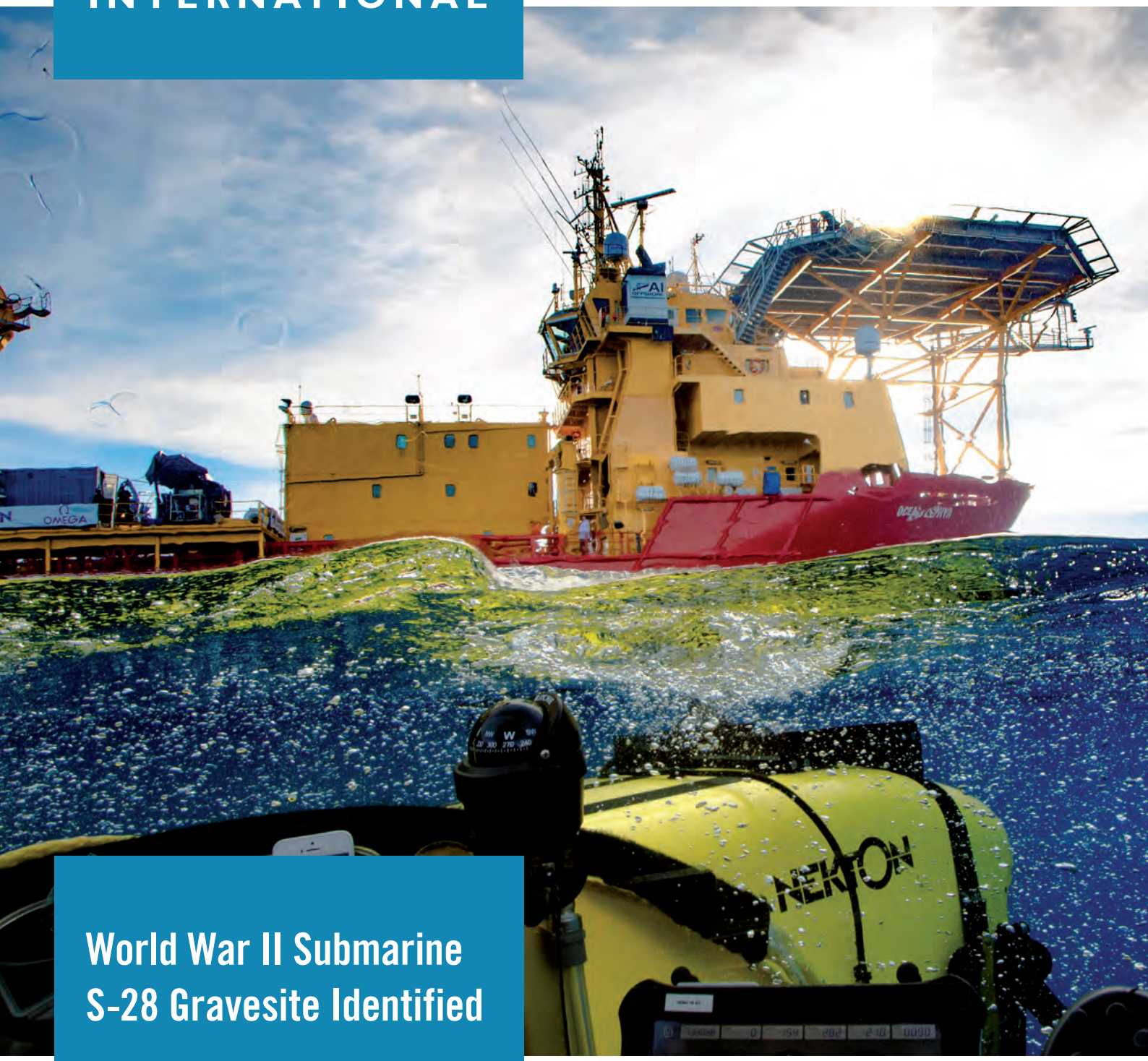

World War II Submarine S-28 Gravesite Identified

Monitoring The Ocean Cleanup Project

Live Transmissions from the Unexplored Deep

Deep down in the Indian Ocean

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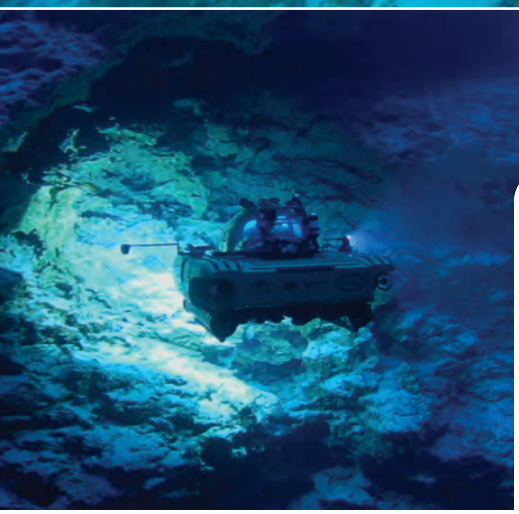

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Front cover

Live transmissions from unexplored regions deep below the Indian Ocean have underlined the role that reliable, high-speed broadband is playing at sea in expanding knowledge and promoting a more sustainable future.
Read more on page 28.


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Future Telling

▲ *Durk Haarsma.*

The future as a concept has always been something that has appealed to humankind. What will the future look like, what will we do, where will we go. In earlier centuries, a writer like Jules Verne fuelled imagination when his books were first published, with lots of the stories by this famous Frenchman coming true over the years. A more recent example is the TV-series 'Years and Years', broadcast by the BBC, portraying society by following the life of a family over the years 2019 till 2030. Quite scary to see how trends and events from now could pan out over the next decade when the authors have future-telling capacities. Sometimes the future was far away – times of slow development, sometimes catching up with the future is almost undoable – times of really fast development.

It is clear that nowadays we are in such an era of unprecedented technological progress and no one knows where it will end. Data almost always plays a role in that progress. That goes for hydrography as well. It is not so much the technology of acquiring data that is developing fast at the moment, but the possibility of gathering, combining, storing, analysing and even attributing forecasting capacity to data that will shape the nearby future of oceanography and data. Denis Hains from Canada wrote a story on Artificial Intelligence for this issue of Hydro International (see page 16). Hains doesn't foretell the future in this article but describes where we are now. Who dares to take up the challenge and predict what will happen? We are happy to receive your future telling ideas!

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director strategy & business development
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Old Fashioned or Just Safe

▲ *Cees van Dijk.*

Not long before this issue of Hydro International went to press, a major problem with Galileo, the European equivalent of the American GPS system, occurred. A few days later, the malfunctioning system has still not been corrected. It appeared to be an incident related to the Galileo ground infrastructure that resulted in a temporary interruption of the Galileo Initial Services.

Galileo is widely used by most of the commercially available receivers. Multi-constellation GNSS receivers will remain unaffected and compute position and timing using other constellations, said experts for the European GNSS Agency, the industry, the European Space Agency and the European Commission. The incident affected a wide range of users and disrupted, among others, hydrographic and oceanographic operations. It highlighted again how much we made ourselves dependent on modern technology.

This reminded me of the first trip I took on a commercial sailing ship as an enthusiastic but rather unexperienced seafarer. I embarked on the beautiful ship from a hot, dirty, and dangerous South American port. On our way to one of those pristine Caribbean islands, the old captain insisted that I should learn how to use a sextant. So every day at noon I tried my best to find our ship's position, to mark it on a paper chart and to set out a new course using a pair of compasses, a ruler and a pencil. It always felt like a small victory when I could say to the helmsman "course 256", or something similar while pointing at the ship's compass.

Although the ship was equipped with a sophisticated positioning system and a state-of-the-art chart plotter, to be able to use the instruments sailors had been using for ages, thorough knowledge of the art of navigation was vital, my captain said. "Navigation involves more than watching a screen and pushing a few buttons. All those things could be broken at the moment you most need them. As a professional seafarer, you have to bring your ship and crew to the next port or call safely without having to rely on something you can't influence."

Was my captain an old salt who was afraid of modern technology? Certainly not. He thought me a lot and I will never set sail without at least having a plan B, just in case all the navigation satellites stop functioning or be switched off.

Cees van Dijk, content manager
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Mapping the Collaboration Networks of the Future

The Alumni Team

In May 2019, the GEBCO-Nippon Foundation Alumni Team won the US$4m first prize in the Shell Ocean Discovery XPRIZE competition. For many in the team, the trip to Monaco for the award ceremony was their first opportunity to meet the colleagues they'd worked with during the past three years through countless emails and late-night Skype meetings, coordinating team activities from offices and onboard ships around the globe.

Throughout the competition, the team of graduates from The Nippon Foundation/GEBCO Postgraduate Training Program at the Center for Coastal and Ocean Mapping, University of New Hampshire (UNH), relied on this kind of virtual cooperation to advance their winning concept for efficient, safe, and cost-effective seafloor mapping. The team's entry, funded by Japanese non-profit organization The Nippon Foundation, utilized the SEA-KIT Unmanned Surface Vessel (USV) Maxlimer, purpose-built by Hushcraft in the UK, together with the Kongsberg Maritime HUGIN Autonomous Underwater Vehicle (AUV) System.

In the words of project manager Dr Rochelle Wigley from the NF/GEBCO class of 2008, USV Maxlimer acted as a "mothership", able to autonomously launch and recover the AUV and serve as a communication link during subsea survey operations. This role was extended in the second round of the competition to include Maxlimer simultaneously collecting multibeam data.

Rather than trying to "reinvent the wheel", according to 2010 graduate and team lead Dr Yulia Zarayskaya, the team pushed the boundaries of existing and proven technological solutions, deploying their complementary functionalities to optimal effect.

Not only did the Alumni Team succeed in their goal, they excelled. From an initial field of 32 international teams, only five made it through to the final 24-hour mapping challenge in Kalamata, Greece. The GEBCO-NF Alumni Team covered a greater area than any of their competitors, mapping 278km2 of seafloor and producing ten high-resolution images and eight 3D seafloor surfaces, processing data in Greece and uploading multibeam data online to be cleaned and processed by colleagues at UNH.

"We proved that a large scientific and surveying project can be realized by people spread all over the world, dispersed geographically but still working together on equipment control, data analysis and many more areas", said Dr Karolina Zwolak, a hydrographic surveyor and member of the GEBCO Guiding Committee who graduated from UNH in 2013.

Throughout the competition, the team consulted with a number of industry specialists on various elements of their entry, including data processing and mapping information systems. Wetherbee Dorshow, chief scientist at Earth Analytic, predicted that the working relationships and processes formed throughout the competition "will be very beneficial to all team members, their industrial partners and academic affiliates, and the ocean community at large."

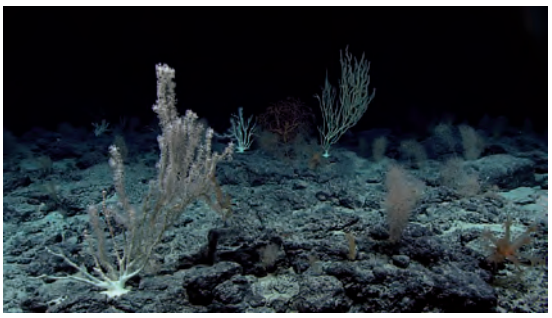
These benefits are already being felt. This year, five team members joined various stages of the Five Deeps Expedition, operating multibeam echosounders to collect bathymetric data between dive sites as part of a collaboration with The Nippon Foundation-GEBCO Seabed 2030 Project. Others are playing a leading role in coordinating the collection and processing of data for the project's Regional Centres. Since taking part in the XPRIZE, Dr Evgenia Bazhenova – from the UNH class of 2016 – has taken up the post of Seabed 2030 Data Manager at the project's South and West Pacific Regional Centre, hosted at NIWA in Wellington, while Tomer Ketter, a 2014 graduate, now works at UNH as a data analyst for the Seabed 2030 Arctic and North Pacific Regional Centre.

"I think our [XPRIZE] solution will be one of several techniques used to complete the goals of Seabed 2030," said Aileen Bohan, a consultant marine geologist from Ireland and an alumnus of the class of 2018. "I also believe our cloud-based data process will be an integral part of the GEBCO-NF Alumni, as it will allow us to process data anywhere in the world."

For the Alumni Team, their common bond of the NF/GEBCO training programme and involvement in the XPRIZE have been the perfect proving ground for both technological innovation and international scientific collaboration. As the international community looks to address the challenges of ocean exploration, conservation and marine resource management, their experience will be vital to finding and implementing the solutions that we need. ◂

▲ *The GEBCO-NF Alumni Team included 16 alumni of The Nippon Foundation-GEBCO Postgraduate Training Program at the University of New Hampshire.*

Industrial Deep-sea Mining Will Harm Ocean Floor-bed



Irreversible harm to some of the planet's most crucial ecosystems could be caused if an area of the ocean floor five times the size of the UK is mined, according to a Greenpeace report. The United Nations (UN) has issued 29 exploration licenses for companies to deep-sea mine rare metals such as cobalt that will be used in batteries as the 'green economy' grows. This 'new industrial frontier' could also result in vast amounts of carbon stored in the ocean floor being released, which could jeopardize attempts to reduce emissions, the report stated. Although commercial deep-sea mining has not yet begun, exploration licenses have been granted to countries including the UK, France, Germany, China, Korea and Russia. Without proper governance, mining could remove entire habitats and species and release toxins in areas that have been undisturbed for millennia, Greenpeace says. "The health of our oceans is closely linked to our own survival. Unless we act now to protect them, deep-sea mining could have devastating consequences for marine life and humankind," says Louisa Casson of Greenpeace's Protect the Oceans campaign. "The deep-sea is the largest ecosystem on the planet and home to unique creatures that we barely understand. This greedy industry could destroy wonders of the deep ocean before we even have a chance to study them." To date, around only 0.0001% of the deep seafloor has been explored or sampled by scientists.
Web: www.greenpeace.org.

Fugro to Support Climate Change Research in the Caribbean

▲ *Courtesy NASA/JPL/NGA.*

Geo-data specialist company Fugro is embarking on a coastal mapping project in Jamaica and Haiti to support The Investment Plan for the Caribbean Regional Track of the Pilot Program for Climate Resilience. The work, which comprises approximately 2,000 square kilometres of integrated shallow water and land-based elevation data, was awarded to Fugro by the University of West Indies Mona with financing from the Inter-American Development Bank. Fugro will accomplish the project using its Rapid Airborne Multibeam Mapping System (RAMMS). Introduced in August 2018, RAMMS delivers depth penetration and point densities for nearshore and coastal mapping. Weighing just 14kg, the compact sensor is deployed on small aircraft with limited support crew requirements. For the Jamaica project, Fugro estimates using RAMMS in place of larger conventional mapping systems will reduce CO2 emissions by 5.1 metric tons, with an overall estimated 80.5% reduction in carbon footprint as compared to a recent deployment in the same region, just 24 months ago. Fugro is currently operating the system in Jamaica. Once finalized, the data will be used to assess coastal vulnerability and conduct climate analysis related to sea-level rise, storm surges and flooding in the Caribbean.
Web: www.fugro.com.

Integrated View of Greenland Ice Sheet Mass Changes

The Greenland ice sheet is a major contributor to sea level rise, adding on average 0.47 ± 0.23mm a year to the global mean sea level between 1991 and 2015, an international group of scientists has found. The cryosphere as a whole has contributed around 45% of observed global sea level rise since 1993. Understanding the present-day state of the Greenland ice sheet is therefore vital for understanding the processes controlling the modern-day rates of sea level change and for making projections of sea level rise in the future. In a recent publication on their website, a group of scientists provided an overview of the current state of the mass budget of Greenland based on a diverse range of remote sensing observations to produce the essential climate variables (ECVs) of ice velocity, surface elevation change, grounding line location, calving front location, and gravimetric mass balance as well as numerical modelling that together build a consistent picture of a shrinking ice sheet. They also combined these observations with output from a regional climate model and from an ice sheet model to gain insight into existing biases in ice sheet dynamics and surface mass balance processes. Web: www.mdpi.com.

▲ *Courtesy Good Free Photos.*

Growth in Maritime Industry to Drive AUV-Market

▲ *Courtesy Royal Australian Navy.*

The autonomous underwater vehicle (AUV) market is expected to be valued at US$371.3 in 2019. During the course of the forecast period (2018–2027), the market is expected to register a CAGR of over 6%, according to a recent report on the AUV market by Market Research, a research and consulting firm.
AUVs are generally used in aquaculture systems for a variety of underwater tasks such as tank water monitoring in fish farming. Aquaculture production has been increasing rapidly, making fish farming one of the fastest growing industrial sectors across the world. This has been significantly contributing to the growth of the global AUV market. Moreover, AUVs are also used for the monitoring and quality control of seawater. For this, government bodies such as the US Environment Protection Agency (EPA) have implemented regulations on the use of seawater quality, which in turn is expected to fillip the demand for AUVs over the forecast period. Numerous, if not all, ocean-based or maritime industries depend on AUVs for the setting up or expansion of the respective industry. Maritime industries are expected to experience significant growth in the coming decade, owing to global economic development and increasing demand.
Web: www.marketresearch.com.

Joined Forces to Reduce Fuel Consumption

Kongsberg Maritime has formed a partnership with DOF, SINTEF Ocean and NORCE, which aims to reduce fuel consumption and greenhouse gas emissions for complex offshore operations while streamlining fleet-wide maintenance.
Enabled through sponsorship and support from Innovation Norway, the new partnership between four of Norway's most maritime organizations, will develop a new Decision Support System (DSS) for offshore vessel operations. This tool will act as the foundation for DOF to simplify operational complexity with objective measurement, ultimately enabling optimal utilization and more sustainable fleet management. Highlighting the potential of the partnership to catalyse a tangible transformation, the multi-year project is backed with Innovation Norway's largest funded offshore vessel, environmental technology project in 2018. It will be a gamechanger in how marine operational decisions are supported by providing more accurate, timely, and easily consumable information to decision-makers; from the vessel's Chief Engineer to the Chief Operation Officer based shore-side, the conglomerate expects. "The partnership is focused on building a platform for intelligent efficiency, made possible only through the integration of operational, information and communication technologies," said Eirik Mathiesen, Director of Energy Products Integration, Kongsberg Maritime. "Encompassing IoT, new smart sensors onboard will stream accurate data to the cloud-based DSS, where deep analysis with intuitive presentation and application will drive equitable and predictable operational performance. Web: www.kongsberg.com.

Only 10% of Sri Lanka's Coral Reefs Remain

Only 10% of Sri Lanka's coral reefs remain in its oceans as 90% of them have died due to pollution, illegal fishing methods and excessive climate change, according to Sri Lanka's Marine Environment Protection Authority, the country's state-owned marine protection body.

Dr Terney Pradeep Kumara, General Manager of the marine authority told the media that the island nation must take urgent steps to mark the remaining live coral reefs as 'highly protected areas'. Measures must be taken to move these live corals to deeper seas.

Kumara strongly advised the government to take urgent measures to save the remaining coral reefs which are facing potential damage due to high-temperature levels. "Therefore, we expect all government agencies, private agencies and all the environmentalists to get together and help the government declare these reefs as highly protected areas and help transfer the living corals to deep areas to keep them alive." said Kumara.

He also stated that by saving the remaining live corals, they would stay alive for decades which would help Sri Lanka attract more tourists. That would strengthen the economy and would have a positive effect on the biodiversity of the island's waters. Web: www.mepa.gov.lk.

Job Opportunities for those with Marine Backgrounds

Qualified and Experienced Seafares can now Change their Course

Do you have a marine background and are looking for a new job? Being a USV pilot could be the next step in your career, James Ives, CEO of XOCEAN explains.

His company currently has openings for USV Pilot & Surveyor positions as well as Software Engineers and plans to recruit an additional 60 employees in the next year to meet increasing market demand.

As an extensive buyer of ocean data in his previous role as CEO of a marine engineering business, founder James Ives saw a need to transform the way in which ocean data was captured. As a customer, he thought there had to be a better way to collect it and in early 2017 he established XOCEAN.

Based on the north east coast of Ireland, his company is transforming the way data is collected from our oceans using Unmanned Surface Vessels (USVs). The innovative X0-450 USV platform is designed and manufactured in Ireland where the company recently opened a new Technical Centre and 24-hour Control Room for operating its fleet of USVs globally.

The company currently has two USV systems in operation and a further eight in construction, with a target to have a fleet of 100 USVs in service within three years. The use of unmanned vessels offers significant benefits including safety with operators remaining onshore, efficiency with 24/7 operations and environmental with a USV generating approximately 1000th of the emissions of a conventional survey ship.

The services offered by James Ives' company range from seabed mapping, to monitoring the environment, to the inspection of subsea structures including subsea pipelines, offshore wind foundations and inter array cables. Recently the Irish completed over 2,000 hours of unmanned bathymetric survey off the coasts of Scotland and England as part of the UK's Civil Hydrography Programme (CHP), administered by the Maritime & Coastguard Agency (MCA).

XOCEAN has also completed acoustic fisheries surveys for Ireland's Marine Institute in the central Celtic Sea. In one such mission, the USV transited from Milford Haven to the survey location 100nm offshore and performed data collection over several days. Data from the survey was used as part of Ireland's fish biomass submission to the EU.

Using USVs, XOCEAN provides turnkey data collection services to surveyors, companies and agencies. From mapping the seabed to environmental monitoring, the platform offers a safe and economic solution to collecting ocean data.

The following is an interview with James Ives, CEO of XOCEAN, about the past, present and future operations of his company.

How did your company get started?

The Organisation for Economic Co-operation and Development (OECD), are predicting the

▲ *Operator at the cyber deck in the control room.*

▲ *James Ives, CEO of XOCEAN.*

▲ *A USV at an offshore windfarm.*

▲ *An USV can be transported to most locations to be launched.*

ocean economy to double to US$3 trillion by 2030. We believe the foundation of that growth is data.

Using USVs we provide turnkey data collection services to survey companies and agencies. Applications range from seabed surveys, e.g. multi-beam bathymetry, side scan and sub bottom profiling, to environmental monitoring, e.g. data harvesting, fisheries surveys and met-ocean data.

The traditional approach to collecting data from the oceans has been to send out a boat with a crew of people, but we do this differently using USVs that are monitored and controlled from shore. Our platform offers significant benefits including safety with operators remaining onshore, efficiency with 24/7 operations and environmental with a USV generating approximately 1000th of the emissions of a conventional survey ship.

You recently started using a special technical centre for unmanned vessels. What was the reason for doing this?

Demand for our services has grown quickly, having recently completed multiple projects for BP and over 2,000 hours of unmanned bathymetric surveys off the coasts of Scotland and England as part of the UK's Civil Hydrography Program (CHP), administered by the Maritime & Coastguard Agency (MCA). To meet market demand, we plan to increase our fleet to 100 USVs in the next three years. The opening of our new Technical Centre in Ireland is central to the company's expansion programme providing us with the space needed to service our growing fleet of USVs."

What is the function of this centre and how does it work?

The new Technical Centre and 24-hour Control Room acts as a hub for operating our fleet of USVs globally. What we offer is an over-the-horizon operation. Regardless of where in the world the project is taking place, we can monitor and operate the USVs from our base here in Ireland.

Each USV sends real-time images and situational awareness data to our Technical Centre where USV Pilots keep watch and control the vessels 24/7 via the CyberDeck platform, a highly secure cloud-based environment developed by XOCEAN. The CyberDeck also allows our USV Pilots to monitor the quality of the data being collected and to adjust both the USV and sensor parameters as required.

You have a large number of vacancies. What kind of people are you looking for to staff the operating centre?

We plan to recruit an additional 60 employees in the next year to meet increasing market demand and currently we have openings for USV Pilot & Surveyor positions as well as Software Engineers. USV Pilots are responsible for the safe navigation of the USV and controlling and monitoring the data collected during a project. We therefore look for people with marine backgrounds and qualifications, as well as those with experience working with software such as Applanix POSPAC, QINSy, EIVA NaviSuite.

You also provide training for operators. Can you tell me something more about that?

Our USV Pilots complete 100 hours of operational training at our Technical Centre in Ireland. Here, Trainee Pilots learn from our experienced USV Pilots and Survey Managers. Their training encompasses both the theory and practical application of the skills required to safely Pilot an XOCEAN USV and to monitor and control data collected. Subjects covered include USV navigation and control, survey system operation and data QC.

Seafarers are concerned about the loss of jobs in their sector. How do you view this?

The industry is growing rapidly, and we see great opportunities for seafarers in this space. Seafarers are an essential part of our service, from the technicians who service our growing fleet to the USV Pilots in the Control Room monitoring and controlling the USVs, we are always on the lookout for skilled seafarers to join the team.

What do you expect from the future of the way unmanned vessels are deployed?

We expect USVs to be deployed in a variety of ways, but increasingly used together to reduce survey time and improve efficiency, as well as spatial and temporal resolution of surveys. We see a future where a number of USVs act in a co-ordinated manner to conduct, for example, a fish-stock assessment survey or mapping highly changeable seabeds.

Which technological innovations can we expect in the coming period?

Continual improvements in enabling technologies such as computing power, battery technology, machine learning and artificial intelligence techniques, along with new developments in satellite internet technology, will lead to improved USV capabilities. Techniques and systems for integrating USVs with additional vehicles (aerial and subsea) will also lead to exciting new capabilities. ◀

Acknowledgment
This article was written in collaboration with Claire Quinn at XOCEAN.

From Water Column Analysis to Bathymetry and Seabed Classification

SeapiX Sonar – Complete Environment Monitoring

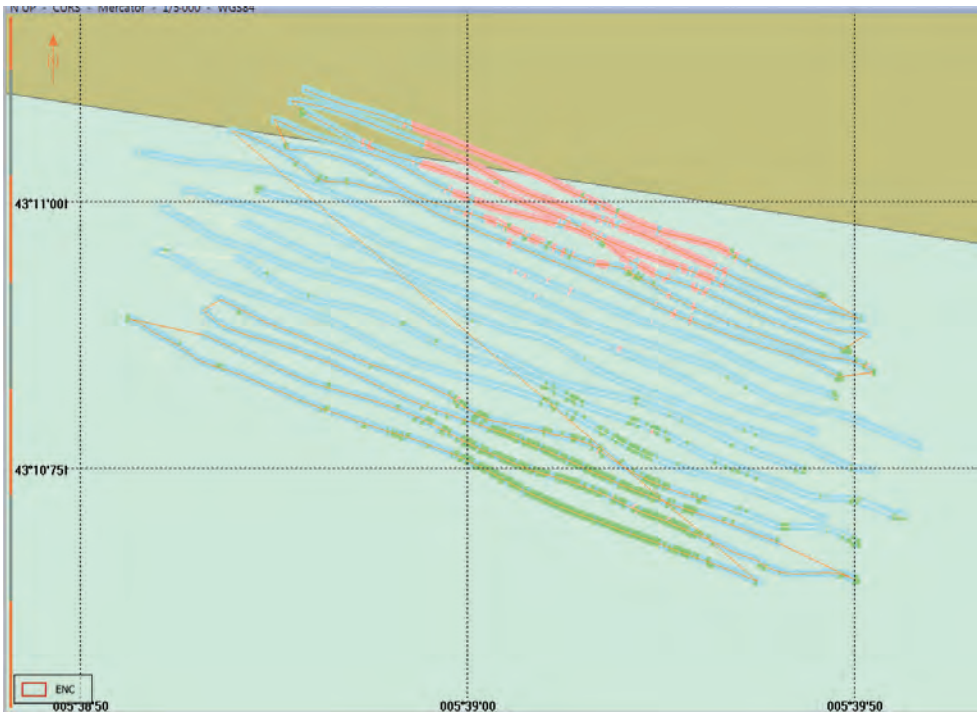
Launched in 2013 by iXblue, SeapiX, the first compact civilian system comprising a dual Mills Cross multi-beam sonar transducer, went through multiple changes to meet customers evolving needs in various fields of applications. Its latest 'seabed classification' feature offers all players working in fishing, ocean sciences, subsea construction and maritime security, a new tool to help them achieve their operations in the most efficient way possible.

THREE-DIMENSIONAL COVERAGE OF THE ENTIRE ECOSYSTEM

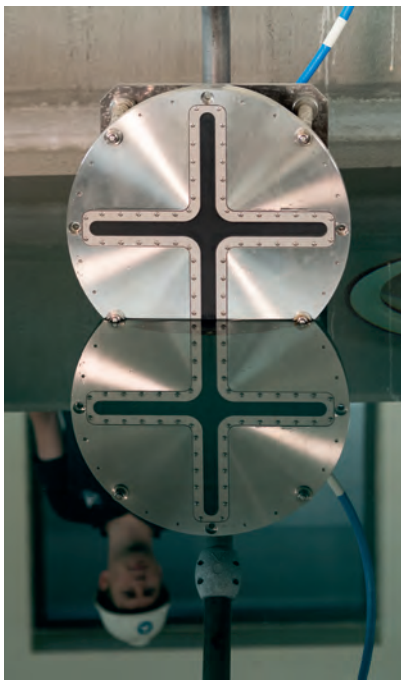
Based on military and scientific technologies, SeapiX is special in that it is equally efficient in terms of volume as it is in terms of metrology. Using a symmetrical double multibeam, the system is able to describe the information contained in a large volume of water. By generating one or more scan swathes along or across the vessel axis, the SeapiX sonar provides total three-dimensional coverage of the water column, a bathymetric profile of the seabed and a sediment identification analysis.

"SeapiX can describe the content of a volume of water up to 200 times greater than a standard sonar can in an identical analysis period," explains Christophe Corbières, Business Development Manager at iXblue. "In addition to its ability to analyse a large volume of water, the system is also an extremely reliable and efficient metrology solution for bathymetric operations and seabed classification. The resolution of the images obtained is very high – a voxel at 100 metres depth is equivalent to 0.6 cubic metres, compared with 30 cubic metres for conventional seafloor sounders. Moreover, the SeapiX sonar has the advantage of being fully stabilized by its integrated inertial unit – it moves independently of the ship's motion, which enables it to generate a guaranteed high-quality image."

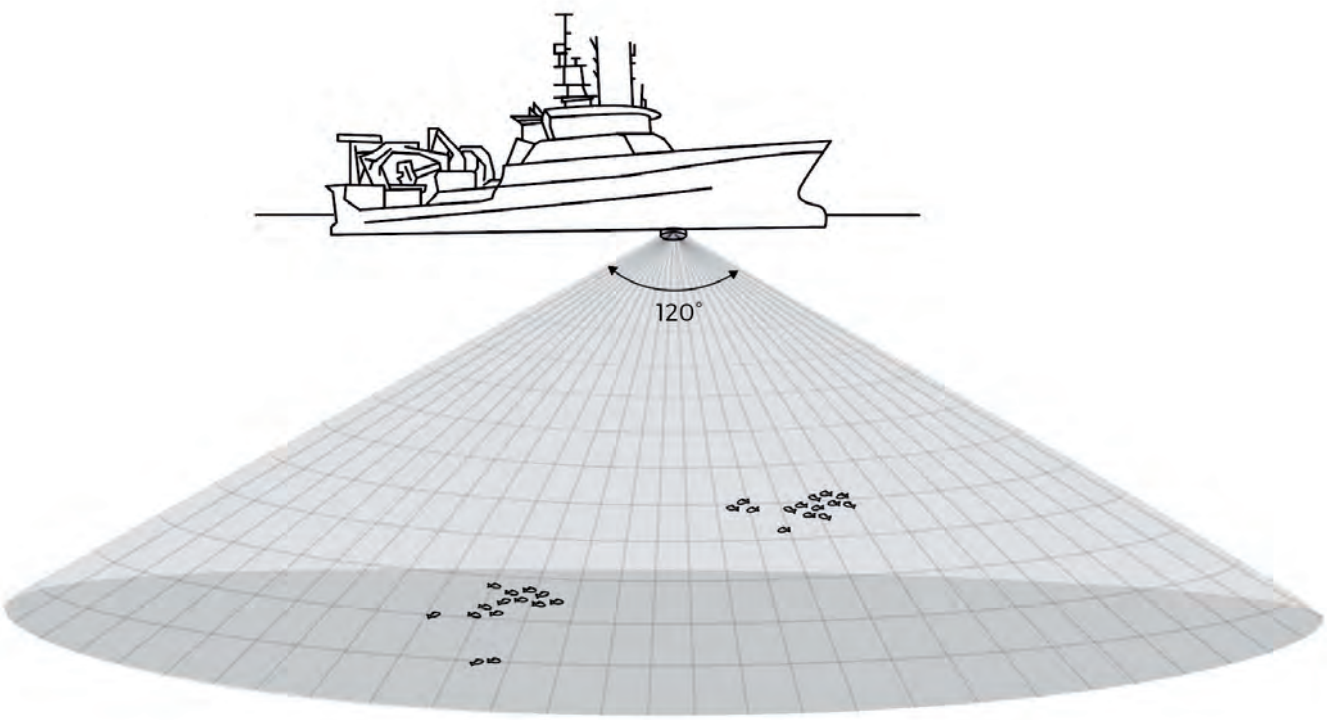
The SeapiX transducer generates several multibeam transmissions and acoustic



▲ *Seafloor classification survey performed by SeapiX.*



▲ *SeapiX 3D Multi-beam Echosounder in a calibration tank.*



▲ *SeapiX covers a volume of 120 x 120 degrees below the ship.*

processes to yield quantitative and qualitative measurements of the whole marine environment. Its multiple advanced modulation modes, including CHIRP, combined with pulse compression guarantee the highest possible detection performance, even in difficult conditions.

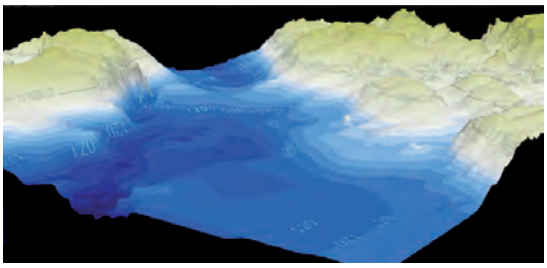
REAL-TIME SEABED CLASSIFICATION FEATURE

Another major advantage of SeapiX is its ability to provide real-time location-based data by integrating navigational, cartographic, and layers of fishery, bathymetric and sediment information without the need to use post-processing software.

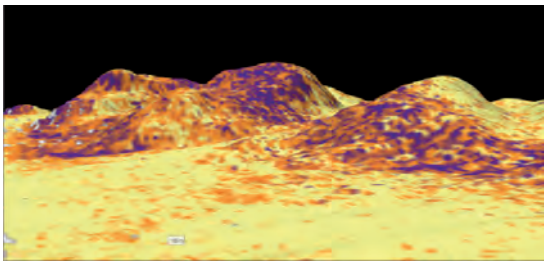
Unlike SeapiX, conventional sounders (that cover only 7°) are not able to simultaneously provide seafloor mapping as well as generate a volumetric image of the water column in front of and to the side of the vessel. Nor can they offer a full survey capacity of the entire ecosystem, including both the water column and the seabed classification. With the implementation of this seabed classification feature, iXblue brings an innovative and efficient solution to its customers, allowing for the study of the interaction between the seabed and the water column. This approach enables scientists and operators alike to get precise and localized real-time data from the entire ecosystem of the seabed morphology to the water surface.

"SeapiX's particular design offers a unique, safe and reliable operational mode for this new feature enabling real-time seabed classification from either an existing standard library stored into the system, or from a custom-made library created by the customers according to their needs," explains Maxence Rioblanc, Product Manager at iXblue. "SeapiX truly is a reliable system that is easy to use, even for non-specialists, as it does not require complex settings to work, making it accessible to all. This seabed classification feature is particularly helpful for various applications such as detection of oil or gas leaks, bottom trawling, risk assessment, MRE monitoring and environmental impact assessment, or even for volcanologists, to only name a few."

Already adopted by major shipowners and institutes worldwide, SeapiX has sparked lots of interest from customers since its launch. Featuring an extremely complex and innovative technology, the SeapiX sonar is truly unique as it combines several different capabilities that makes it the perfect solution for a wide array of uses. ◀



▲ *SeapiX multibeam swaths provide precise bathymetric measurements in real-time.*



▲ *SeapiX offers accurate seabed hardness values while bathymetry is in progress.*

Preparing for Hydrographic Artificial Intelligence Network and Systems

Success Depends on the Quantity and Quality of All Available Data

With the ever increasing and affordable availability of capacity and computing power to process and store data, the emergence of artificial intelligence (AI) in marine geomatics, ocean sciences and hydrography is palpable.

Mathematical models are very powerful, but their reliability must be validated and demonstrated using calibration points. It's the same thing for AI. It can not emulate and learn properly if it can not rely on observations that represent reality. In the commercial shipping world, AI-based technologies are about to be tested, resulting in additional bathymetry and hydrography needs that will quickly become necessary and critical.

Commercial Marine Autonomous Surface Ships (MASS) such as the "Rolls Royce-Kongsberg" are prototypes in development and will eventually be tested in Europe – Norway is a leader in the field. Many see these commercial MASS as providing for economies in terms of fuel consumption, optimization of transportation routes, reduction of greenhouse gas emissions and reduced risks to navigation by respecting many rigid and strict rules of navigation in the world.

How can commercial MASS learn, if indeed they can learn, from the charted and uncharted seabed where hydrographic data is insufficient or even absent? I suggest that the success of AI in hydrography is fundamentally dependent on the quantity and quality of all available bathymetric and hydrographic data, whether static, predictive, near real-time, or real-time (dynamic).

LACK OF BASIC DATA

In the world of ocean sciences (bathymetry and hydrography), there is a lack of basic data that meets modern technological standards. However, the data acquired with multibeam echosounders (MBES) for some decades are localized and increasingly dense and more voluminous than ever. Also, the additional data coming from MBES and specifically its multiplier effect of backscatter data signal and the Lidar and Satellite-Derived Bathymetry (SDB) multiplier effect of reflectance data signal amplify them further.

I emphasize that there is also a lot of unknown, unavailable data, and when it is known and made available, it is often non-standard and low precision. They, therefore, tend to be unused or rejected. Since AI is based on computing ability and the power of mathematics and statistics, the availability of all data, especially big data, plays a key role in computer learning, machine learning and deep learning.

RESPECTING STANDARDS

AI in hydrography will be stimulated and catalyzed by MASS. The key to success will be based on the same fundamental issue known in hydrography for a long time (i.e. associated bathymetric and hydrographic data of known

▲ *In the commercial shipping world, AI-based technologies are about to be tested (courtesy Albin Berlin - Pexels).*

▲ *AI can not emulate if it can not rely on observations that represent reality (courtesy Kordi Vahle - Pixabay).*

▲ *Commercial Marine Autonomous Surface Ships (MASS) such as the Rolls Royce Kongsberg are prototypes to be tested in Europe (courtesy Kongsberg).*

quality and respecting established standards). This represents a major challenge considering that the vast majority of the world's oceans and coastal areas have little or no modern hydrographic data of sufficient quantity and quality. However, there are several opportunities with the current technological wave that we are encountering.

To prepare for hydrographic AI, it is better to have the maximum quantity of data where the quality is KNOWN, even if it does not always meet the standards, than not having the data, or having just a little data. This is especially true in remote areas where new needs emerge.

ALTERNATIVE DATA SOURCES

In that context, promoting and adopting Crowd-Sourced Bathymetry (CSB) and the unreserved use of alternative data sources such as: Satellite-Derived Bathymetry (SDB); Airborne hydrographic Lidar; autonomous data acquisition vehicles: airborne (drones), surface and submarine; is a must, and shall even be forced and accelerated more than ever.

For hydrographic data, ideally the most accurate and exact data is needed. On the other hand, in the context of AI in hydrography, I suggest that all data, even those that are inaccurate or not precise, are of interest. Rather than being obsessed with precision and accuracy, we must accept data for which the accuracy and precision would not be sufficient for traditional standard purposes. By knowing or even 'qualifying' the precision and accuracy, this data will allow the machine and deep learning algorithms to identify areas of risk to avoid for some current and future MASS.

▲ *For hydrographic data, ideally the most accurate and exact data is needed (courtesy Roman Grac - Pixabay).*

CHALLENGES AND OPPORTUNITIES

What currently appears to be incomplete and imprecise could, in the context of AI, enable a paradigm shift in which hydrographic data reaches unexpected maturity through repetition and mathematical / statistical correlation in the future.

The emergence of AI in hydrography is full of challenges and more importantly opportunities. This is an exciting and important developing field to follow everywhere in the world and especially in the Hydrographic community. With three oceans and the longest coastline in the world, Canada should clearly have an interest in playing a pivotal role in the issue of 'How to prepare for Hydrographic Artificial Intelligence Network and Systems'. ◀

VECTOR 2019 Symposium
More than 200 participants gathered for the VECTOR 2019 Symposium, from 15-17 April 2019, in Rimouski, Canada. This event was coordinated by the Technopole maritime du Québec (TMQ) in collaboration with the Centre de la géomatique du Québec (CGQ) and the CIDCO. The author was invited as a special guest speaker on 'How to prepare for Hydrographic Artificial Intelligence (AI)'. This article is an exact of this presentation and will summarize the highlights.

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He is the Founder, President and CEO of H2i (Hains Hydrospatial Int. Inc.); the representative appointed by the United States and Canada Hydrographic Commission (USCHC) on the International Hydrographic Review (IHR) Editorial Board of the International Hydrographic Organization (IHO); member of the Board of Directors of the Interdisciplinary Center for Ocean Mapping Development (CIDCO); and he is also, member of the Canadian Hydrographic Association (CHA).
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Minimum Requirements for Munitions Detection at Sea

Submerged Munition, No Hazard Left Undetected

Munition in the sea poses a risk to the sustainable development of the ocean economy. In particular, it remains a global challenge during the construction of wind parks, pipelines and other infrastructure. To ensure high-quality performance during the execution of the necessary maritime munitions detection and clearance operations, industry experts and scientists from Germany have defined a set of requirements. Especially in the detection phase which requires the attention of hydrographical surveyors.

THE MUNITIONS CHALLENGE

Safe access to large areas of the sea floor is a prerequisite for offshore economic development. However, this ability is compromised by the presence of submerged ammunition around the globe. Over the past 140 years, ammunition entered the sea in a variety of entry modes such as naval battles, aerial bombing and mine laying. Additionally, large quantities were dumped after the Second World War. What appears unreasonable today, was considered a safe and permanent means of disposing of weapons for many decades, until the practice was eventually outlawed by the London Convention on the Prevention of Marine

▲ *Moored mine recovered in German waters (courtesy Heinrich Hirde).*

Pollution by Dumping of Wastes and Other Matter in 1975. Even today, in times of peace, naval target practice adds to the amount of munitions in the sea.

To this day, more than 1.6 million tons of both chemical and conventional (i.e. explosive) munitions remain in German territorial waters alone. As an example, Figure 1 displays a corroded moored mine which was recovered in German waters. This legacy is not only an obstacle to the offshore construction industry, it also affects sectors like coastal tourism and fishing. On top of this, it will impede deep sea mining endeavours in the future. Finally, it may pose a threat to marine life due to gradual leakage of carcinogenic TNT and its metabolites into the sea water.

QUALITY GUIDELINE

The challenge of submerged ammunition – also referred to as unexploded ordnance (UXO) – crosses borders and, accordingly, operations concerning their detection and clearance have to be conducted in various judicial areas, some of which are only weakly regulated. This issue generally concerns exclusive economic zones and international waters. The absence of an industry standard left the acting stakeholders without guidance regarding best practices, personnel qualification, technology specifications or requirements for documentation and communication.

This was the reason for the development of a new quality guideline by German key stakeholders from industry, relevant authorities and the scientific community. Over the course of two years, the 'Quality Guideline for Offshore Unexploded Ordnance Treatment' was compiled under the leadership of Leipzig University. The content of the document was defined, discussed and revised in a series of workshops and expert group meetings. Experts were given the chance to make annotations to the work in progress twice, which led to the creation of a document that genuinely represents all relevant actors. At the same time, this process of strong stakeholder involvement was set up to ensure wide acceptance of the finished guideline by the players it affects.

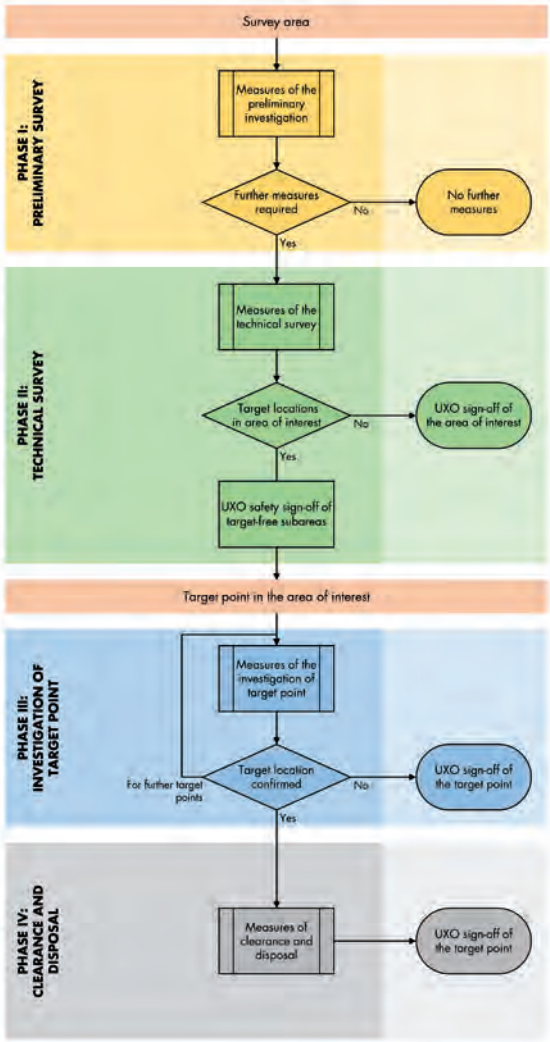
The resulting document covers the entire procedure for offshore munitions treatment which is subdivided into the phases of (I) Desk based preliminary survey, (II) Technical survey, (III) Investigation of UXO target points; and (IV) Clearance and disposal. These four phases are displayed in the flowchart in Figure 2. Phase II: Technical survey, covers the detection of potential UXO.

SURVEY TECHNOLOGIES

Magnetic and electromagnetic sensors are the survey technologies that are customarily applied during the execution of a technical UXO survey. These are supported by additionally deploying side scan sonar (SSS), multibeam echosounder (MBES) or sub-bottom profiler (SBP). As each of these sensors has certain shortcomings – the use of a single technology is insufficient. Magnetic sensors are easily supersaturated in areas where existing infrastructure or a high amount of scrap metal or geologic magnetic anomalies are present.

Electromagnetic sensors suffer from a limited range both vertically and horizontally, thereby rendering their application on larger regions or in areas covered by thick layers of sediment costly. Both SSS and MBES are only suitable during the search for exposed munition items, but does not support the detection of any targets that are buried in the sediment. In addition, they do not allow for the distinction between a UXO and a likewise shaped boulder. Finally, SBP with its very limited area coverage, can only act as an additional source of information on items that were already detected with the help of another sensor.

Consequently, multi-sensor approaches are required. In order to ensure sufficient data quality, the deployment of at least a towed array of magnetic sensors and side scan sonar is necessary. Figure 3 exemplifies an area containing numerous suspected UXO target points as measured with magnetometers. Other sensors may be added to increase information density or to compensate for the shortcomings that are mentioned above.



▲ *Procedure for offshore UXO treatment.*

▲ *Submerged .50 caliber shells from USS Arizona (courtesy Wiki Commons).*

Some areas may even unify a set of characteristics that make it impossible to guarantee the detection of all relevant munition items, even if all available technologies would be deployed.

CRITICAL SURVEY REQUIREMENTS

Due to the large variety of potentially present munitions items and consequently the potential range of their properties, a reference object for the UXO survey needs to be defined. This is the single most important decision before a technical UXO survey can be conducted. The reference object is the minimum threat item and is therefore the smallest munition item that needs to be detected during the survey. It has to be defined based on the information of numerous sources.

First, historical research (which is part of Phase I: Preliminary survey) should provide an indication on the type and degree of contamination that can be expected in the area of interest. Secondly, a hazard assessment for the surveyed area should inform on the occupational and economic risks that originate from different types of munitions. Finally, the technical limitations of the available technologies as laid out above need to be taken into account to ensure that the detection of the reference object is conducted in a manner which is technically feasible.

Other critical technical requirements that need to be defined include the desired detection depth of the minimum threat item below the seafloor, the positioning accuracy and the signal to noise ratio (with an emphasis on magnetic sensors). All other parameters, such as the line spacing, the along-track-resolution or the height of the towed system above the seabed, are defined thereafter and depend mainly on the specifications of the reference object and the detection depth.

TARGET LIST AND UXO SIGN-OFF CERTIFICATE

A technical UXO survey and the subsequent data processing and interpretation commonly result in two main deliverables; the UXO target list and the UXO sign-off certificate. Both can only be issued by competent personnel, who hold an appropriate certificate of competence for the handling of explosives.

The target list is a directory of all points within the area of interest, for which acquired survey data indicate the presence of munitions. These points are listed along with relevant information, like water depth, estimated object size and further parameters that are derived from magnetic sensors such as the total field amplitude and the magnetic moment of the measured signal. The detected target points should then be scrutinized during Phase III: Investigation of target points. If confirmed, munitions should be subjected to Phase IV: Clearance and disposal, such as the items displayed in Figure 4.

As the second output, the UXO sign-off certificate is provided for all those areas that are free of suspected target points. If the entire survey area is free of target points, a comprehensive sign-off certificate can be issued. Due to the historical background, this scenario is highly unlikely in European waters and adjacent exclusive economic zones. It is more likely that only part of the survey area is eligible for sign-off. Either way, the limitations of the sign-off certificate, such as the specified reference item, detection depth, time of the survey and the utilized survey technologies, need to be clearly communicated. Finally, it should be noted that a UXO sign-off must be based on the results of a technical UXO survey. A desk-based risk assessment cannot replace a qualified technical survey.

CONCLUSION

As submerged ammunitions continue to present an obstacle for development, the new quality guidelines inform employers, authorities, survey companies and UXO clearance specialists alike on requirements for performing the detection and clearance of munitions in the sea. While the document caters to the German legal specificities, the majority of its content is applicable to any offshore location and even to inland bodies of water.

The limitations of available technologies make the technical UXO survey a particularly intricate task. In order to collect an adequate amount of data, numerous sensors such as magnetometers and SSS need to be combined, with the aim of detecting at the least a previously defined reference object. This results in the generation of a target list and a UXO sign-off certificate, both of which are of paramount importance to the mediation of a hazard that affects the ocean economy and the marine environment alike. ◂

▲ *Salvaged munition items that are save to handle (courtesy Heinrich Hirde).*

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Clemens Kirchner has been employed as a project manager at Boskalis Hirdes since 2014. In recent years, he has been involved in the planning and execution of numerous successful offshore UXO clearance projects, utilizing various survey and clearance technologies in the German, British and Danish sector.
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Seismic Activity Data Collection on the Ocean Floor

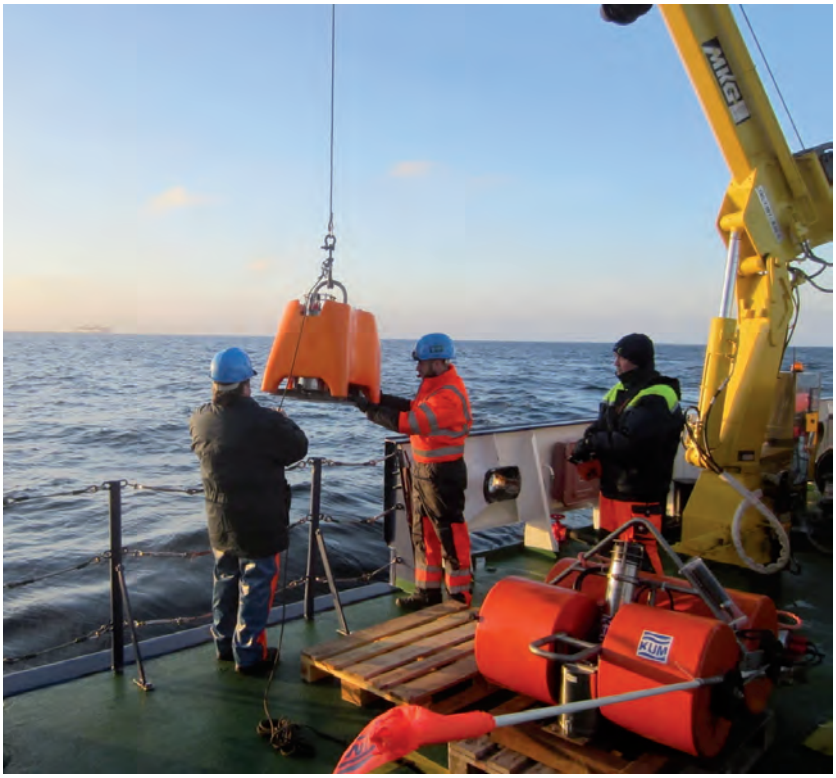
Unlike neighbouring Japan, earthquake activity is infrequent in the peninsula area of South Korea, and those that do occur tend to be low in intensity. Typically, earthquakes in this region measure between 2.0 and 5.0 on the Richter scale[1]. The record for the quake with the highest magnitude on the Korean Peninsula stood for some time, recorded as 5.3 in 1980. This was recently overtaken by a 5.8 magnitude tremor in Gyeongju in 2016 and a 5.4 magnitude tremor in Pohang, followed soon after by a 4.8 magnitude aftershock tremor. Data on these events is collected using the existing seismological observation network and tsunami warning system established by the Korea Meteorological Administration (KMA). This network is comprised of broadband seismometers, short-period seismometers and accelerometers – recording velocity and accelerations automatically and transmitting the data to processing stations. Whilst this network has been bolstered in the past couple of decades, there are limits to its reach, as well as gaps in understanding the seriousness of active faults to generate large and tsunamigenic earthquakes[2].

FORECASTING THE IMPACT OF FUTURE FAULT ACTIVITY

The three cities that have experienced these recent quakes, Ulsan, Gyeongju and Pohang, are all found in the Gyeongsang provinces, which is located in the south east of the Korean Peninsula. Whilst there have been no deaths, approximately 1,500 residents of the area were rendered homeless after the Pohang quake alone, and the cost of repair to damaged parts of the region are set to exceed US$200 billion[3].

The Yangsan Fault is classified as an active fault, and has the capacity to generate large earthquakes, while the Chugaryenong Fault (also active) is said to have caused the 2010 3.0 magnitude quake in Seoul.

Researchers employed a catastrophe model to predict the cost and damage burden that the Seoul region would experience should a 6.0 or greater magnitude tremor occur, concluding that the result would be an unprecedented and massive loss. The catastrophe model used took into account likely loss using a scientific understanding of disasters and actual building vulnerability modelled on building registration data in the region, in comparison to an actuarial model that is limited to loss estimation based on empirical data. Up to 2.76 million people could loose their lives, with the economic impact forecast up to US$2,848 billion, depending on the particular seismic characteristics of the earthquake[4].



▲ *K.U.M. is specialized in the construction of Ocean Bottom Seismometers (OBS), developed for the study of the seabed. The NAMMU OBS is very suitable for earthquake monitoring, amongst other applications.*

BUILDINGS ILL-EQUIPPED TO RESIST STRONG TREMORS

Despite the rarity of major earthquakes, the Korean Peninsula is not without its seismic events, and there are considerable concerns with the capacity of most buildings to withstand these events. Most buildings (around 75%) are not earthquake-resistant, and 93.2% of all buildings in South Korea fail to comply with seismic code requirements[5]. According to the Korea Institute of Geoscience and Mineral Resources, most of the buildings that are earthquake-resistant can only resist tremors up to 6.5 magnitudes, indicating high overall vulnerability to earthquakes. Experts like Professor

Kwang-Hee Kim of Pusan National University, has advised that South Korea is therefore considerably unprepared for natural disasters of this type[6]. Professor Kim, seismologist, has voiced concern about the potential of further strong quakes in this region, predicting tremors of around 7.0 magnitudes on the Richter scale[7]. It is essential South Korea is prepared, given that high-magnitude earthquakes will result in disastrous impacts both along the peninsula and inland.

There is clearly a need for accurate data on the seismic activity in the region that enables more in-depth observation and prediction. To achieve this objective, the KMA has established and funded an extensive, five-stage investigation that aims to analyse seismic activity and the underlying fault structure in the waters around the South Korean peninsula. This government authority has a broad purview that includes meteorological topics, natural disasters like tsunamis and earthquakes, as well as climate change. The first part of the KMA programme, led by Professor Kim, will collect data on fault structures, fault shape and prediction of seismic activity including earthquake and tsunami magnitudes, enabling prediction and preparation for the impact of such seismic events. The research team will develop a model for the underground structure, integrating this with data collected on seismic velocity. The earth's internal structures that transform or amplify seismic waves will be captured and analyzed alongside data from the existing networks, and the data used to more accurately identify and predict earthquakes.

K.U.M. OCEAN-BOTTOM SEISMOMETERS

The project team, which includes experts in tsunamis, earthquakes and coastal research, selected the Ocean-Bottom-System (OBS) manufactured by German company Umwelt- und Meerestechnik Kiel (K.U.M.), whose name translates to Environmental and Marine Engineering Keel. K.U.M. has developed products and delivered services to the marine research and maritime science sector since 1997 and the OBS seismometers are a core focus. The OBS' were purchased via Korean supplier GeoTech Systems Corp, a company that provides measurement equipment and marine related products and services, from tunnel and water surveying to ocean-related exploration equipment. OBS' have been used successfully in other studies investigating the Korean seafloor[8].

The OBS is using one of the most advanced dataloggers and has the lowest energy consumption of the systems currently available. On top of this, the OBS is equipped with a microprocessor-controlled crystal oscillator with a precision of at least 0.02ppm.

These OBS' will detect and measure sub-sea seismic movements on the South Korean peninsula to measure the displacement of water level change. The researchers selected this equipment for its ease of use, portability, robust software and continuous data collection capabilities – all of which enable straightforward operation. The team has found the devices are particularly suitable due to their compact size, given the space limitations onboard the ship. Ten devices have already been deployed and a further ten will be installed on the ocean floor in identified locations during October 2019. The OBS' will remain in place for up to two years with the team collecting data from them every six months, whereby an acoustic signal will be sent to each OBS, which will subsequently detach from its anchor and rise slowly to the ocean surface.

OUTCOMES AND IMPACTS

Major earthquake and tsunami predictions are difficult and comes down to three factors: magnitude, location and time. The choice of the K.U.M. OBS will enable observation that was previously difficult to achieve with the existing network, with Professor Kim stating that the best way to observe such phenomena is by placing instruments as close to the seismic activity as possible, including in remote locations beyond the existing network. The sensitivity, robustness and ease of use of these OBS devices make them ideal for such a mission, which will yield important data for our understanding of the active fault zones in the Korean peninsula. Intelligence gathered by these in-situ devices placed on the ocean floor has the potential to provide comprehensive data to inform planning and implementation across all stages of management for large-scale disasters, from mitigation through to preparedness, response and recovery – contributing to the reduction of risk and enabling tailored disaster management[9].

This article is brought to you by Umwelt- und Meerestechnik Kiel (K.U.M.).

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Project to Directly Measure Overturning Circulation Gives Surprising Results

Trans-Atlantic Mooring Array Changes View of Ocean Circulation

The Atlantic Ocean's overturning circulation, sometimes known as the Ocean Conveyor Belt, transports heat from the Equator northwards. It's a key mechanism in the climate system and is largely responsible for the relatively mild climate of Northwest Europe.

The ocean circulation at this latitude was measured directly for the first time by the trans-Atlantic mooring array of the Overturning in the Subpolar North Atlantic Program (OSNAP) deployed in summer 2014.
The Atlantic meridional (north-south directed) overturning circulation (MOC) consists of two main parts. In the upper layers, which are warm and saline, buoyant waters are transported northward in currents such as the Gulf Stream. In the deep ocean, which are colder and fresher, dense waters return southward. At high latitudes, the warm, saline waters of tropical origin are strongly cooled in winter, making them dense enough to sink (overturn) and form the deep return flow. Climate models predict this overturning will weaken as a result of increasing temperatures and input of freshwater from the Greenland Ice Sheet and the Arctic. As a consequence of this reduced sinking, the ocean circulation and its heat transport could weaken as well. It is therefore crucial that we observe and understand the ocean circulation system.

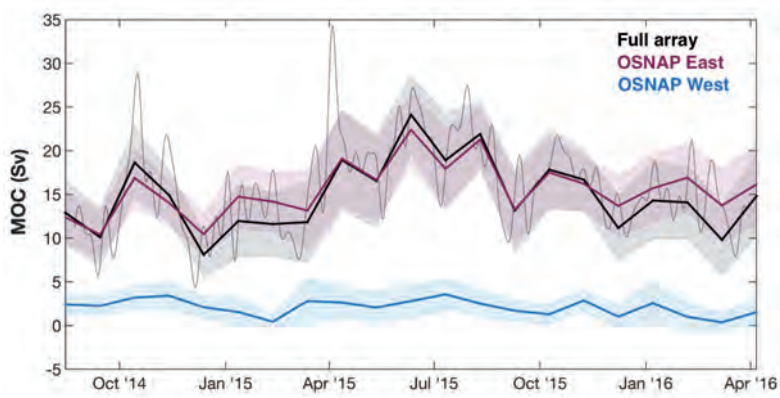
OBSERVING ARRAY

The OSNAP array includes 53 ocean moorings deployed at depths from 150 to 4200m. These moorings are organized in two legs. The western leg covers the Labrador Sea between Canada and Greenland, while the eastern leg extends from Greenland to Scotland across the Irminger Sea, Iceland Basin and Rockall Trough (RT). Each mooring is outfitted with instruments that measure current speed and direction as well as temperature (T) and salinity (S). The Royal Netherlands Institute for Sea Research maintains five moorings on the western flank of the Mid-Atlantic Ridge, with a total of four Acoustic Doppler Current Profilers, 18 current meters, 20 hydrographic (T&S) instruments and eight thermistors (T). The other moorings are maintained by institutes from the USA, UK, Germany, Canada and France. An ocean glider, operated by the USA and China, contributes hydrographic measurements around the Rockall-Hatton Bank.

FIRST DEPLOYMENT

The OSNAP array was first deployed in 2014 by a set of research cruises from the different institutions starting in May and ending in August. Since then, moorings have been recovered and redeployed in the summers of 2015, 2016 and 2018, with the next recovery and redeployment planned for summer 2020. Each recovery and redeployment of the full array typically require three to five research cruises, up to one month long, combining teams of scientists, technicians and students of the various institutions.

The moorings are placed over the steeper topography where the boundary currents are strongest. Over flat topography, the flow is mainly driven by the pressure gradient over the basin, which is derived from the tall moorings at either side of these basin. The pressure gradient data is combined with satellite data on surface currents and the hydrographic data from autonomous Argo floats and the glider in order to get full fields of velocity, temperature and salinity. The 15 minutes to hourly measurements of the moored instruments, merged with the ancillary data, are reduced to 10 and 30-day averaged volume, heat and freshwater transports over the full array. A contribution of shallow, wind driven (Ekman) transport is derived from atmospheric reanalysis.



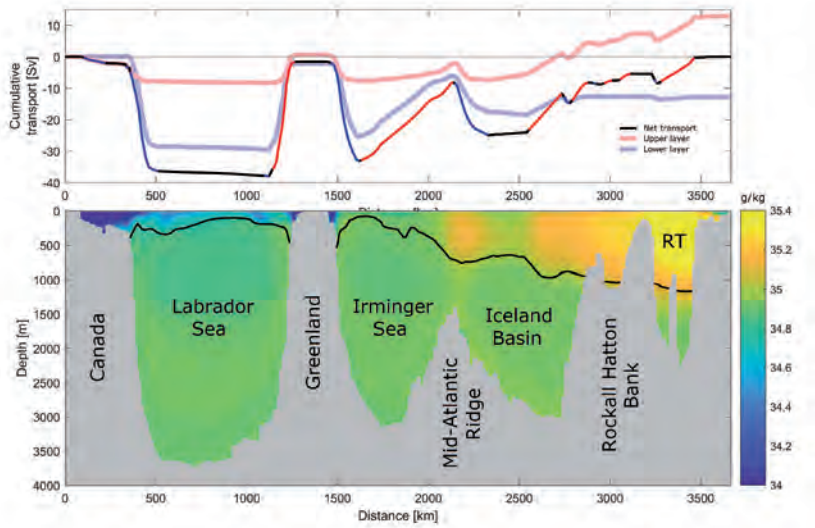
▲ *Time series of volume transport through OSNAP. Black, blue, and red lines represent the 30-day mean estimates from the full section, OSNAP West, and OSNAP East, respectively. Shading indicates uncertainty in the 30-day means. Thin gray lines show the 10-day lowpass filtered daily means for the full OSNAP section.*

FIRST RESULTS

The first two years of measurements show the structure of the overturning circulation through the OSNAP array (figure 3). Through OSNAP West it shows southward transport, mainly of dense water, along the Canadian shelf compensated by northward transport of dense water along the west Greenland shelf. The resulting net flow over this basin is small. In OSNAP East there is a strong southward flow of dense water along the East Greenland shelf, a broad but weaker northward flow of dense water over the western flank of the Mid-Atlantic Ridge and again mostly southward flow in the Iceland Basin.

Overall, this results in a net southward flow of dense water. In the upper layers, the largest contribution to the northward transport is by the warm, saline North Atlantic Current in the Rockall Trough and Iceland Basin. The integrated net transport over the full array is zero because of the assumption of a mass balance (water does not accumulate on either side of the array).
These first two years of measurements give a mean overturning transport of 14.9 Sverdrup (1 Sverdrup/Sv is 106 cubic metres per second) and a mean heat transport of 0.45 Peta Watt (0.45 1015 Watt). These numbers will serve as validation for the transports simulated by global climate models.

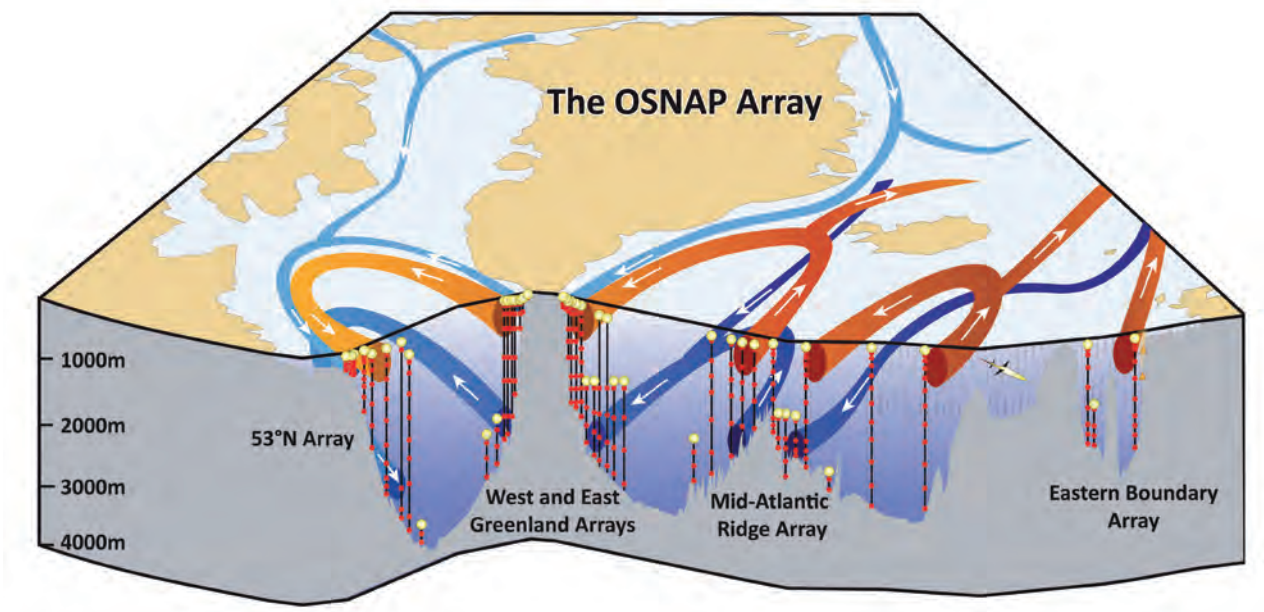
The 10 and 30-day averaged transport give insight into the variability of the meridional overturning circulation. This time series highlights the difference between the transport through OSNAP West and East (figure 4). Both the total transport and its variability is dominated by the contribution of the transport through OSNAP East while the contribution of OSNAP West is fairly stable and considerably smaller.



▲ *Top: Integrated transport accumulated eastward starting at the western edge of the array (black line), with areas of northward/southward transport color coded red/blue. The upper (light red line) and lower (light blue line) MOC limbs are shown separately.*
Bottom: Mean salinity (colored, with scale at the right-hand side) calculated from Argo and OSNAP data from August 2014 to April 2016. The thick black line denotes the potential density surface (27.66 kg/m3) that separates the MOC upper and lower limbs.

CHANGE OF VIEW

The small contribution of OSNAP West to the overturning circulation is surprising due to the fact that most of the cooling and sinking of surface waters takes place specifically in this area west of Greenland. In cold winters, waters have been observed to mix down to



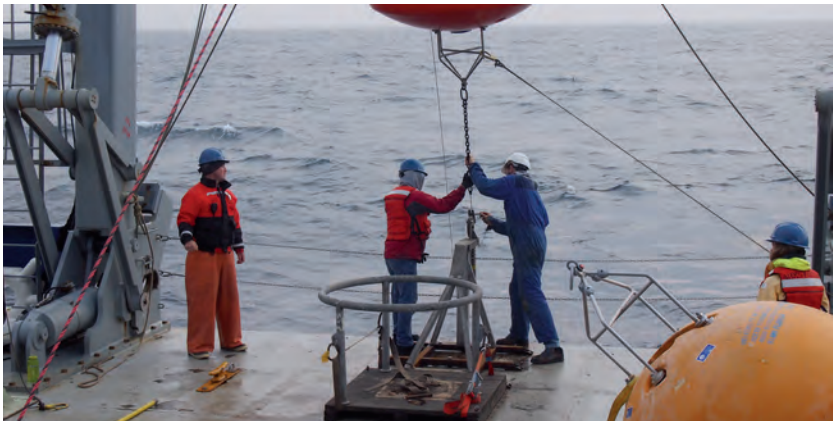
▲ *The OSNAP array. Warm surface currents (red) and cold deep and polar currents (dark and light blue) are schematically indicated. Moorings are drawn as vertical lines, with a top buoy in yellow and instruments along the cable in red. (Credit Penny Holliday, NOC)*

2,500m depth, much deeper than any mixing observed east of Greenland. In fact, the winter of 2014-2015 was one of these strong winters.

Many model and paleoceanography studies have focused on this mixing depth as an indicator of past, current and future overturning circulation strength. However, it appears that most of these newly sunk waters have a long residence time in the basin and do not directly feed into the boundary current. In OSNAP East, on the other hand, the continuous northward transport of buoyant waters in the North Atlantic Current and southward transport of deep, dense water results in a much larger net overturning transport while most of the actual transformation between these density classes likely takes place north of this line.

FUTURE RESEARCH

The OSNAP arrays are planned to remain in the water in order to study changes and trends on longer time scales. How the circulation and its heat transports depend on transformation processes east and west of Greenland, which will be studied in detail. Future goals are also to determine how the overturning circulation relates to the transport of other parameters, such as nutrients and carbon. ◀



▲ *A buoy with ADCP of a NIOZ mooring being recovered on the RV Neil Armstrong in summer 2018. (Photographer Roos Bol)*

Marieke Femke de Jong studied meteorology and physical oceanography at Utrecht University. She did her PhD on the circulation of the Irminger Sea at the Royal Netherlands Institute for Sea Research (NIOZ), after which she moved to the USA to do research at the Woods Hole Oceanographic Institution and Duke University. She is now back as a scientist and a principal investigator in OSNAP at the NIOZ.
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Exploring the World's Most Unknown and Least Protected Ocean

Live Transmissions from the Unexplored Deep

Live transmissions from unexplored regions deep below the Indian Ocean have underlined the role that reliable, high-speed broadband is playing at sea in expanding knowledge and promoting a more sustainable future.

Increasing our knowledge of the marine fauna that populate the depths and the physical systems governing ocean behaviour is essential for a scientific community seeking to better understand climate change and assist political strategies to protect the underwater environment.

The remote setting creates challenges for scientists in what are increasingly collaborative endeavours, involving multi-disciplinary teams that are disparately located. Furthermore, researchers are often using advanced instruments that have never before been deployed in the field; if something goes wrong, troubleshooting can be a drawn out and frustrating process.

DECENT COMMUNICATION

Until recently, a major aggravating factor has been the lack of decent communication when a research vessel is situated at a remote oceanic

▲ *Omega is raised after a successful dive.*

outpost. However, advances in satellite infrastructure and the associated onboard equipment such as antennas and terminals mean ships can now communicate in real-time allowing shore-based partners to follow the excitement of a mission as it happens.

The extent to which connectivity can transform science missions at sea is abundantly clear in the Nekton Mission, which among other things is marrying communications with innovations in AI and Big Data to accelerate exploration and conservation of the Indian Ocean – the world's least explored and least protected marine zone.

BASELINE OF MARINE LIFE

The initial expedition in the First Descent series took place off the Seychelles in 2018. Despite having an ocean territory of 1.37 million square kilometres, little research has been undertaken beneath scuba depth (30m). A primary goal of the expedition – and those to follow – is to help establish a baseline of marine life and measure the state of the ocean, with particular focus on the bathyal zone (200m to 3000m) – depths richly populated with fish and other marine fauna.

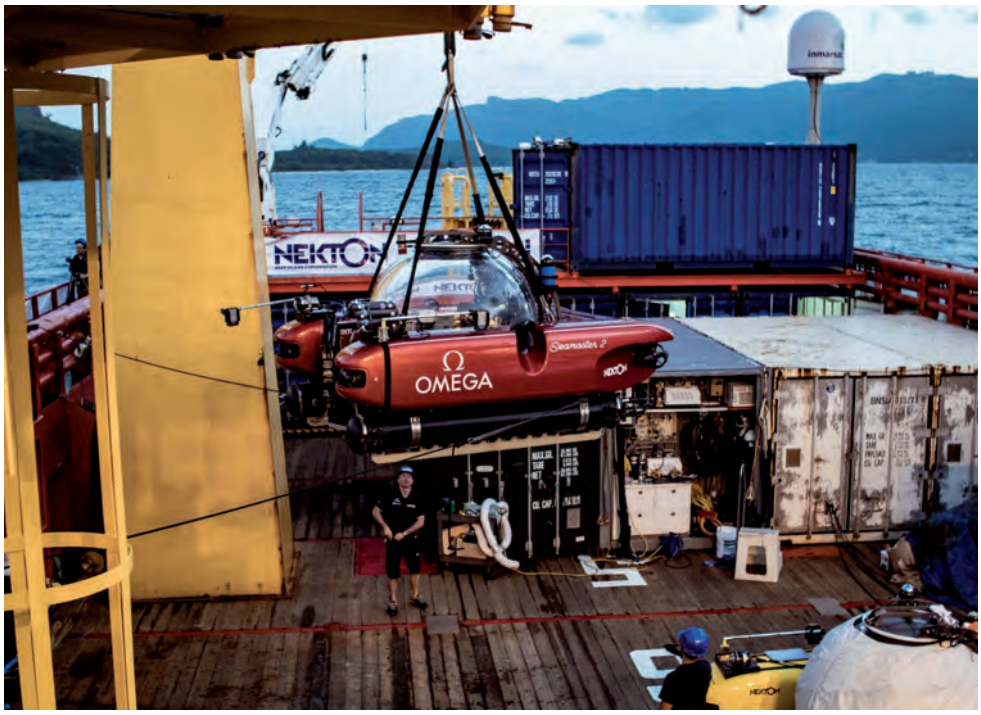
The submersibles and remotely operated vehicles involved in the Nekton Mission bristle with an array of research, sampling, survey and video technologies, including 15 different camera systems that will enable scientists to create the first 3D maps of newly discovered deep sea ecosystems.

LIVE AUDIO AND VIDEO

Inmarsat's Fleet Xpress maritime broadband service delivers enough performance and reliability to allow live audio and video streaming between vessels and the shore, important for both research and outreach activities. High throughput makes it easier to transmit and share large datasets, while the ability to deliver real-time updates matches expectations for the hyper-connected audiences of today, raised on accessing media on-demand.

In fact, sharing footage taken from the subsea cameras in real-time is an integral part of the project – and not just among fellow specialists. Images have been distributed live by media outlets including Associated Press along with a series of live subsea programmes produced by Sky News and Sky Atlantic. At one point, pictures were even beamed to the giant screens positioned above the concourses of London's major railway stations, offering commuters a live 'feed' to events unfolding deep beneath the waves on the other side of the world.

▲ *Mike Pownall and Denise Swanborn control the multi beam.*

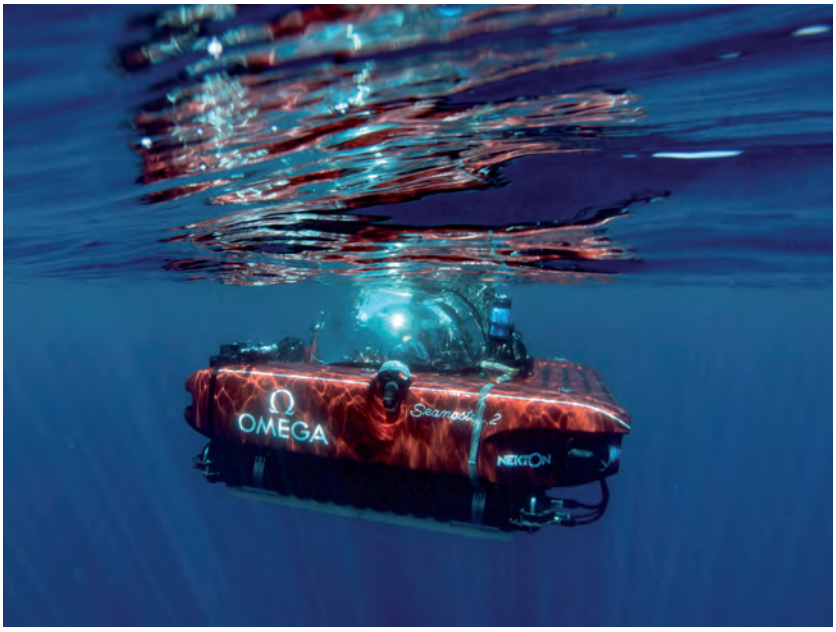


▲ *Omega craned aboard the ‚mothership'.*

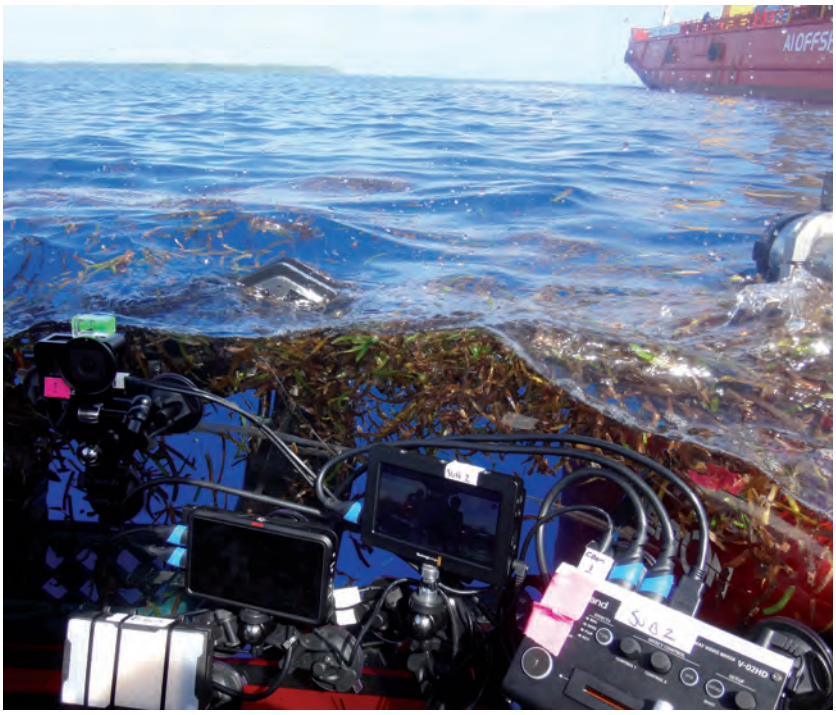
HOW IT WORKS

Inmarsat's VP for Offshore Energy, Eric Griffin, explains how the technology worked "The mothership for the mission, Ocean Zephyr, was fitted with two high-power SAILOR100 GX antennas supplied by Cobham SATCOM that were configured to run simultaneously. One was dedicated to getting broadcast quality images back to broadcasters, while the other was reserved for data transfer and operational communications."

Today such outreach is vital. Effective engagement with the public often ranks highly in the mission statements of universities and research bodies because public funding demands demonstrating value-for-money to taxpayers. Again, for research tours that are privately funded, commercial sponsors can be keen to advertise by association.



▲ *Omega floating underwater near the surface.*



▲ *The submarine entering the water.*

COMBINED CAPABILITIES

"Cobham's partnership with Inmarsat that provides Fleetbroadband connectivity for the Volvo Ocean Race is perhaps the most recognized example of how our combined capabilities deliver outstanding results for any organization aiming to widen reach and expand audience engagement," says Matt Galston, sr. Director Global Market Strategy and Development at Cobham. "The Nekton team's use of Fleet Xpress and SAILOR 100GX High Power terminals raises the bar, succeeding not only in audience growth, but also in bringing the global scientific community right on board the ship, enabling real-time collaboration to improve mission outcome and better understand our constantly changing planet."

But livestreams are also invaluable to scientists who cannot participate in person, whether due to restrictions on numbers, insufficient funds or time to go to sea. With a satellite-enabled link, everyone can watch. The enhanced connectivity can help the onboard team respond to the unexpected or unknown.

EMPIRICAL DATA

The fact is that empirical data remains the backbone of research, wherever the recipient is located. By allowing large volumes of raw data to be speedily shared among the scientific community, the high-throughput of Inmarsat Fleet Xpress can help accelerate research. Shore-based research teams can then set about analysing the data while the mission is still underway, and report back to the ship if they spot something that merits follow-up.

"This is a real game-changer," comments Griffin. "Before the arrival of Fleet Xpress, scientists would seldom have the chance for real-time interaction. They wouldn't get their hands on the data until after the ship returned home. If it turned out to contain something special, they would have to cross their fingers and hope it wouldn't be too long for a return visit. That could be a wait of several years, and even then, the vessel might not head to exactly the same spot."

ARTIFICIAL INTELLIGENCE TOOLS

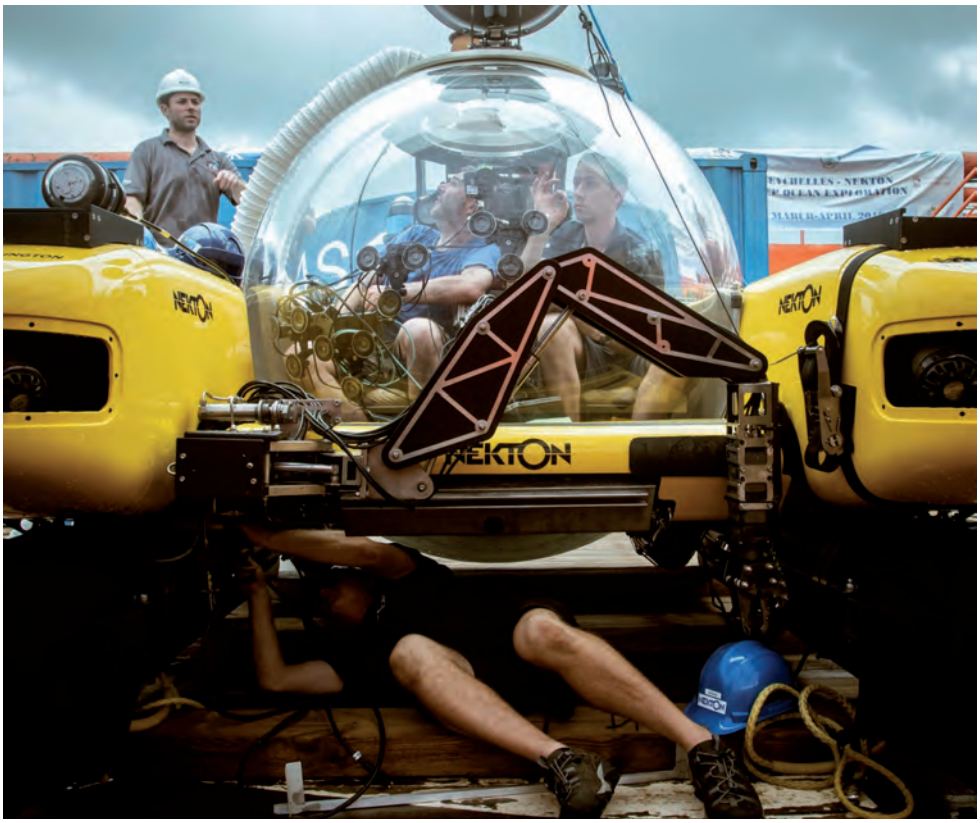
Meanwhile, the potential of the Nekton Mission continues to unfold. Nekton has teamed up with the University of Oxford to develop artificial intelligence tools, for example, to accelerate analysis and publication. Data will be made available through OCTOPUS – Ocean Tool for Public Understanding and Science – to provide a holistic and dynamic view of the changing state of the Indian Ocean, its biodiversity and human impacts.

Better connectivity can also increase participation. Improved real-time communication opens the door for experts from developing nations to join the scientific exploration of the oceans. In fact, promoting local engagement is one of the Nekton Mission's broader objectives.

OPPORTUNITIES FOR MARINE SCIENTISTS

The project organizers made sure to create opportunities for marine scientists based in the Seychelles to participate in all aspects of the expedition. This eye to capacity-building is intended to foster the leadership, tools, skills, knowledge and networks needed to empower long-term sustainable ocean governance at a local level.

Together with datasets and research findings emerging from the expedition, this inclusive



▲ *Checking and preparing the Kensington Deep.*

▲ *Last inspection before diving to the deep.*

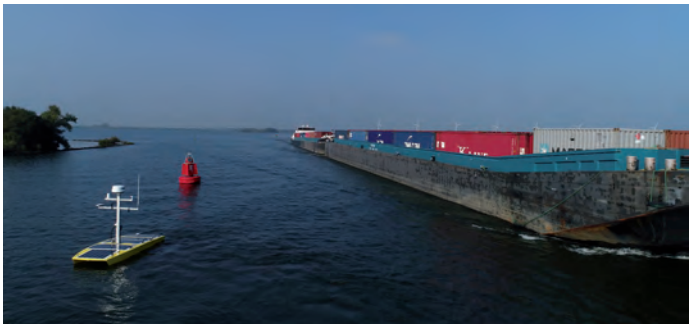
approach is intended to support the Seychelles implement a Marine Spatial Plan, which will see around one-third of its national waters protected as part of building a sustainable Blue Economy. This is important because the way the Indian Ocean changes in the coming decades will profoundly affect the lives, livelihoods and wellbeing of the 2.5 billion people living in the region. ◀

Nekton and it's Missions
Nekton's Missions combine scientific research, capacity development, ocean governance and public engagement and all of this work is co-developed hand in hand with host nations. Nekton is an independent not-for-profit research institute working in collaboration with the University of Oxford and is a member of the Blue Prosperity Coalition. Web: nektonmission.org.

Mark Warner is Marketing & PR Director at Inmarsat Maritime. He has over 18 years' experience in the maritime industry and is a University of Plymouth alumnus, holding an MSc in International Logistics and a BSc in Maritime Business & Law. Warner has served five years as Chairman of the Plymouth Nautical Degree Association.
✉ mark.warner@inmarsat.com

Year Long Survey Programme

Aquatic Drones executes a year-long survey programme for inspection & monitoring of bathymetry, maritime construction & water quality on the Dutch river IJssel for the Dutch Ministry of Infrastructure & Water Management (Rijkswaterstaat). Marine Contractor Boskalis will inspect a pumping station to lower risks for divers.

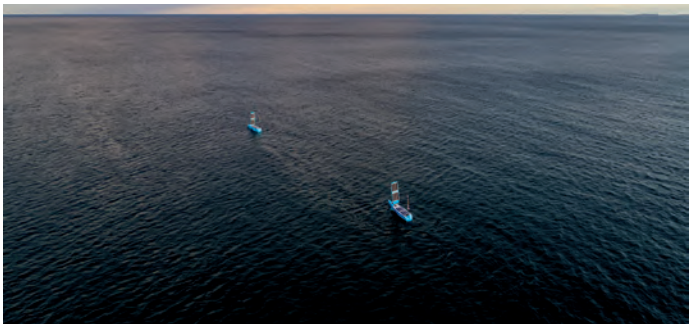


Portable USV

Clearpath Robotics has designed Heron, a portable, mid-sized surface vessel. The catamaran design includes anti-fouling thrusters, a shallow profile, and built in GPS for easy access positioning data. This unmanned surface vessel features a payload bay for mounting submerged sensors or equipment on deck.

Two Fit in a Container

Ocius is working with the University of NSW robotics department to build an intelligent network of autonomous persistent Unmanned Surface Vessels. The 18' version has a 300kg payload capacity and can fit in a 20' shipping container and be launched from a conventional boat ramp.



Three Different Hull Lengths

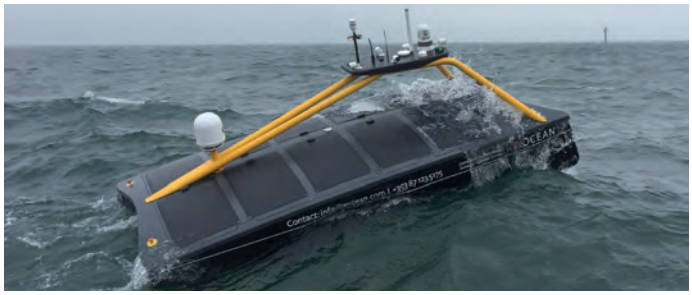
This Accession from Unmanned Survey Solutions provides a modular solution for the USV market. One vessel with three different hull lengths. Specifically designed to meet the challenges of surveying in the nearshore and offshore environments, it has a base length of 3.5m with optional additional hull sections to create 4.25m and 5m variations.

Waterjet USV

The 1.6-metre-long SL40 is a waterjet hydrographic survey USV, manufactured by OceanAlpha. It can carry 15kg of survey instrument making it an economical USV platform for smaller-sized multibeam echosounders like R2Sonic 2020 MBES.

Hybrid Power Plant

XOCEAN's XO-450 USV offers unmanned 'Over the Horizon' operations using satellite communications. Applications range from seabed surveys (e.g. multibeam bathymetry, side scan, sub bottom profiling) to environmental monitoring (e.g. data harvesting, fisheries surveys, metaocean data). The platform features a fully automated hybrid power plant with 18 days endurance.

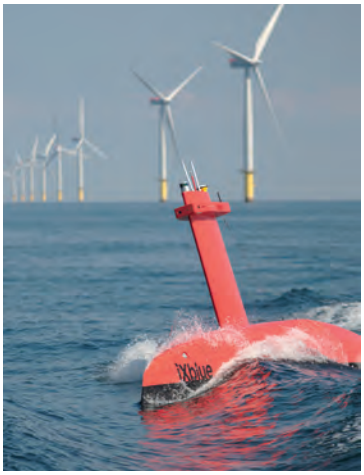


USV for Rent

Kongsberg Maritime's Aberdeen based rental office has taken delivery of a GeoSwath USV to add to their rental pool. The 1.8m long USV is fitted with a 500kHz GeoSwath system giving simultaneous bathymetry and side scan data in a wide swath to IHO SO44 1a standard.

Hydrodynamic and Resilient

One year after iXblue launched DriX, it has built a track-record in the energies and survey industries and validated its early design: hydrodynamics, autonomy and resilience. In parallel, DriX was enhanced with a deployment system, a fitted transport container and multiple upgrades to improve communication range and user interfaces.

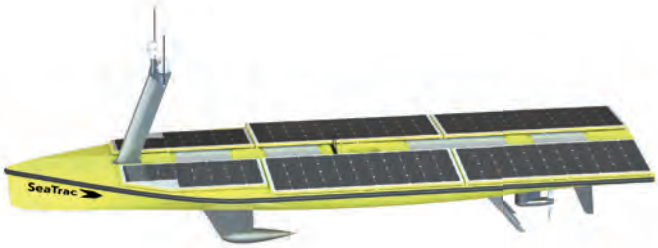


Compact and Easily

The Otter USV, manufactured by Maritime Robotics, is a compact vehicle that is easily transported and deployed. The Otter can access places that larger boats and ships struggle to reach, such as small lakes, rivers and water reservoirs. Its four battery packs allow it to operate up to 20 hours at 2 knots.

Solar Powered USV

The SeaTrac SP-48 by SeaTrac Systems is a multi-purpose long-endurance solar powered USV for real-time ocean observation and data collection missions. With its large power and payload capacity, the SP-48 can be customized with best-in-class sensors, operated from near shore to open ocean for commercial, defence and scientific applications.



Designed for Shallow Water

SeaRobotics introduces the SR-Surveyor M1.8, a next generation portable survey system. It was designed for shallow water survey. It collects two frequencies of sidescan imagery, high resolution swathe bathymetry, Lidar point clouds and discharge measurements simultaneously. Tightly integrated control autonomy, data acquisition, and processing make for safe operation and streamlines workflow.

Product News Editor's Pick

We have chosen 11 USVs (more product details can be found on Geo-matching.com). In our next issue we will focus on underwater positioning. Please send us your news about product innovations or technical developments (product name, high-resolution product image, description, informative not commercial, no direct links to your website, max. 50 words, Geo-matching URL). Please send your news before 15 October.

Discovered by the Lost 52 Expedition Team

World War II Submarine S-28 Gravesite Officially Identified off Oahu

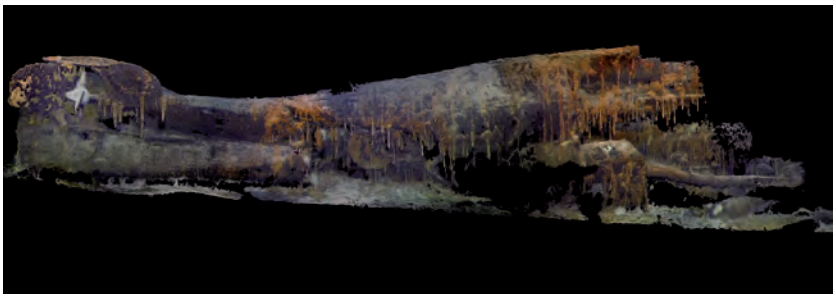
After almost 75 years utilizing advanced imaging technology, Ocean Explorer Tim Taylor and his Lost 52 Expedition Team officially discovered the final resting place for the 49 Sailors of the U.S. submarine S-28 (SS-133) off Oahu, Hawaii. The U.S. Navy recently validated the identity of the wreck, which Taylor located in 2017.

The 4 July 2019 marks the 75th anniversary of the submarine loss, which was conducting exercises at the time she disappeared. "The discovery of the USS S-28 as part of my 'Lost 52 Project' continues to honour the men, their mission and their memory. It is important that they not be forgotten and that future generations recognize their invaluable sacrifice for our country and the world", said Taylor.

"Identification of a Navy gravesite is something Naval History and Heritage Command's Underwater Archaeology Branch takes great care in doing," said Sam Cox, Director of Naval History and Heritage Command. "After an exhaustive review of the data provided by Tim Taylor's team, we can positively identify the wreck as S-28."

▲ *The U.S. Navy recently validated the identity of the S-28.*

▲ *Remains of the WW II submarine S-28.*



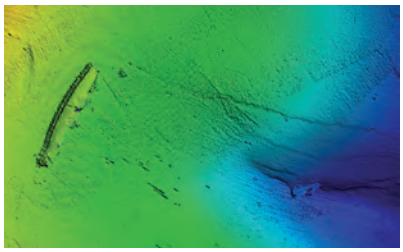
▲ *Another picture of the S-28.*

Tim Taylor is a renowned ocean explorer, expedition leader, and underwater robotics expert who has spent twenty-nine years exploring the oceans. He has collaborated with noted geologists, marine biologists, archeologists, coral and shark scientists. His research vessel Tiburon was the platform for numerous scientific expeditions that included work with the Hawaiian Undersea Research Laboratory, Mote Marine Lab, Scripts, University of Miami, NOAA, National Geographic, National Science Foundation, and the US Navy. Taylor was inducted as a fellow in the Explorers Club in 2004 for his discovery of Sherwood Forrest, the sanctuaries cornerstone reef in the Florida Keys National Marine Sanctuaries.

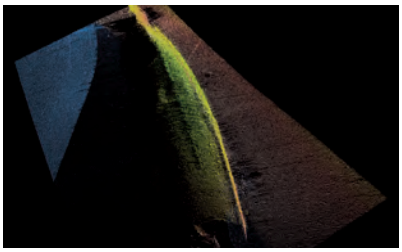
In 2008, Taylor received the Explorers Club 'Citation of Merit' for his contributions to exploration. Over the past decade, his focus has been on the utilization of robotic technology in underwater expeditions. He pioneered a 1,500-metre deep AUV search for submerged cultural resources spanning three years and 1,800 square miles. His recent discoveries include three US WWII Submarines – The USS R-12, USS S-26 and the recently added USS S-28 discovered near Oahu, Hawaii, in 8,700 feet of water with 49 servicemen entombed.

He and his wife Christine Dennison are the recipients of the Brazil Navy League's Medal-of-Honour and have been awarded the Brazilian Navy's distinguished title of 'Honorary Submariner' for their discovery and ongoing

▲ *The Kongsberg Maritime's Hugin AUV.*



▲ *Bathymetric Lidar of the S-28.*



▲ *Bathymetric Lidar of the S-28.*

research work of the USS R-12. To date, they have discovered the final resting places of 129 US Navy servicemen and two Brazilian officers.

Taylor has been profiled in the London Financial Times, The New York Times, Bloomberg News and is a regular contributor on FOX, CNBC, BBC, CBC and CNN as an ocean technology and robotics expert. He is President of Tiburon Subsea Services specializing in supplying autonomous underwater robotics and founder of Ocean Outreach, home of the 'Lost 52 Project' dedicated to educating the next generation of ocean advocates.

"… we now know the final resting place of our shipmates."

The ongoing multi-year project is supported by STEP Ventures, who are dedicated to continuing the work of the 'Lost 52 Project' and shares its commitment to preserving and honouring the legacy of the lost WWII submariners and the bravery of the sailors for future generations.

FIRST WORLD WAR

The keel of USS S-28 (SS-133) was laid down in April 1919, just months after the end of the First World War. Commissioned on 13 December 1923, the S-Class submarine spent 16 years taking part in various Navy exercises in the Caribbean and eventually the Pacific.

When Pearl Harbor was attacked on 7 December 1941 she was being overhauled at Mare Island Naval Shipyard outside of San Francisco, California. She was one of several S-boats put into service in World War II and was initially sent to Alaska to defend the Aleutians against a possible Japanese invasion. By mid-November, S-28 arrived at Pearl Harbor and for the next seven months trained in the waters around the island.

ANTISUBMARINE WARFARE

On 3 July 1944, S-28 embarked on an antisubmarine warfare training exercise off the coast of Oahu, Hawaii. During the training, communication became sporadic and the boat sent her last communication to the Coast Guard cutter Reliance in the evening of 4 July. The Navy's search of the area did not reveal the location of the submarine and two days later, a diesel oil slick appeared in the area. Later, a Navy Court of Inquiry could not determine the cause of the loss. During her service in WWII, she completed six war patrols and earned one battle star.

"We're thankful for the care and attention Tim and his team took in locating the wreck. Because of their efforts, we now know the final resting place of our shipmates. This discovery helps to ensure their service will always be remembered, honoured and valued and we hope provides some measure of closure to their families," continued Cox.

S-28 (SS-133) rests in approximately 8,700 feet of water, which made locating the ship at the time impossible due to technological limitations of the era. After such an initial discovery, archeologists conducted exhaustive research to ensure its identity. In the case of S-28, the location at which it was discovered offered a key clue to its identity.

ADVANCED PHOTOGRAMMETRY

Following World War II, the U.S. tested ordnance and scuttled U.S. and Japanese ships in the vicinity of the wreck site. Records indicated that her sister ship, USS S-35, had been scuttled in that same area. Finding the subtle differences between the two series of S-class submarines demanded some technical expertize and analysis. Through Taylor's research, paired with historical archives, the Naval History and Heritage team were able to positively identify the wreck comparing design differences. Records revealed the hulls had uniquely different cowling covers on the forward bow planes.

The investigators also considered some likely superstructure modifications and the probability that deck guns were removed from the S-35 before it was scuttled as possible indicators. Ultimately, however, the cowlings provided the evidence the team needed to make the final confirmation. "The differences in external configurations are minimal on these 100-year-old submarines, but the cowlings are a distinct indicator," states Taylor.

Taylor's team utilized advanced photogrammetry to create imaging that allows them to research the site long after they have returned to the dock. The data produced by their expedition was key in helping to confirm that they were looking at the S-28 and not the S-35.

The Lost 52 Expedition 2017 deploys state-of-the-art deep water autonomous underwater vehicles (AUVs) as well as remotely operated vehicles (ROVs). Tim Taylor has a reputation for working with the latest in undersea technology and with the top specialists in underwater exploration. ◀

The Lost 52 Project is a long-term exploration and underwater archeological project that is documenting and preserving the story of the Lost 52 WWII Submarines, leaving a foundation of knowledge for future generations. Building on our current discoveries, ocean exploration and underwater robotics expertize, our team is organizing, executing and managing expeditions with the goal to discover and survey as many of the lost 52 US WWII submarines as possible.
Information: www.lost52project.org.

Laser Calibration of Hydrophones

Metrology Project to Protect the Marine Environment

The following is an overview of the metrology development carried out under the EURAMET UNAC-LOW project. This includes the support of the wider purpose of protecting the marine environment for our future.

There has been significant growth in the demand for underwater noise recording equipment. This is due to greater awareness of human effects on the oceans and a motivation to maintain a good environmental status for prosperity. The Marine Strategy Framework Directive (MSFD) was published in 2008 and updated in 2012 to provide guidance on how low frequency noise should be monitored in the ocean (Van der Graaf and Ainslie et al.).

QUANTIFY NOISE

A laser has been used in this work to measure acoustic pressure in a chamber containing a hydrophone. By dividing the voltage from the hydrophone by the acoustic pressure, a sensitivity rating is obtained for the hydrophone over a range of low frequencies. This type of primary calibration is vital to quantify noise in absolute terms. By applying this calibration to noise recorders, the long-term monitoring of large hydrographic areas becomes possible.

One such example of noise monitoring is the Joint Monitoring Programme for Ambient Noise in the North Sea (European Union INTERREG project, see May/June issue of Hydro International). Their work uses a combination of underwater noise recordings, with source and propagation modelling to map noise across the entire North Sea using a relatively low number of stations. Providing traceability to these acoustic measurements helps make robust decisions about low frequency noise levels in the ocean.

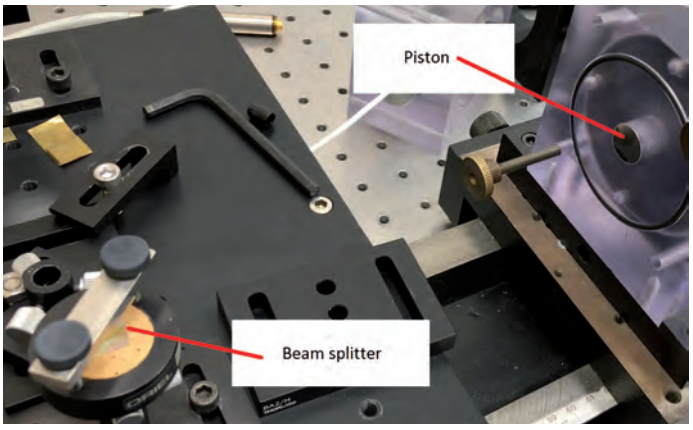
CALIBRATION SERVICE

Where important decisions are to be made based on sound pressure level, it is necessary to calibrate hydrophones and recording systems. Where measurements span, for example decades, this traceability provides confidence in the observations so that long term trends can be inferred correctly. The National Physical Laboratory (NPL) provides this sort of calibration service not only for cabled hydrophones, but also for underwater recording systems.

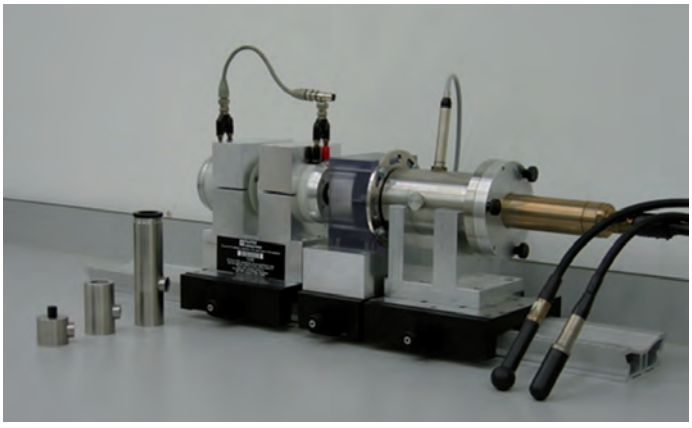
This article reveals how NPL, through a special measurement set up, traces the acoustic pascal to the wavelength of laser light, which in turn helps provide a robust measurement infrastructure. The laser pistonphone is one of a number of low frequency hydrophone calibration techniques identified in the International Electrotechnical Commission standard for hydrophones (IEC 60565-2006).

APPLYING THE PRESSURE

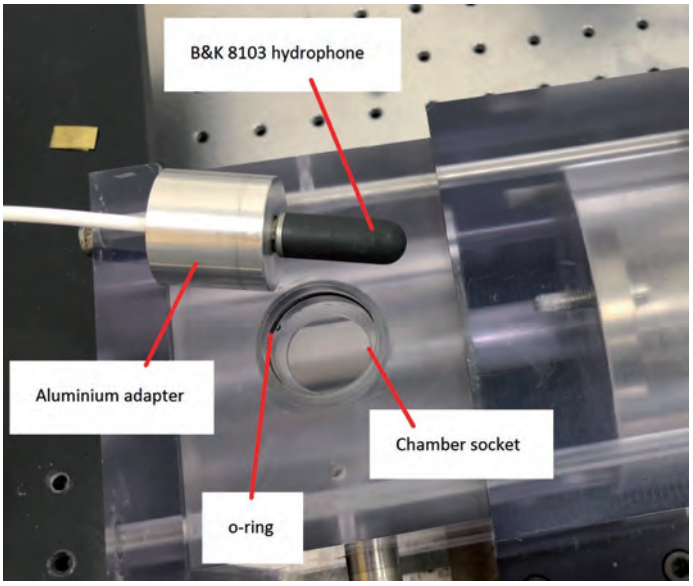
A pistonphone is an acoustic calibration device that generates pressure by driving a circular piston into a closed volume of fluid (a chamber). Knowledge of the thermodynamic properties of the fluid in the chamber can be used to relate a change in volume to a change in pressure. The laser pistonphone uses a Michaelson interferometer to measure the displacement of the piston.



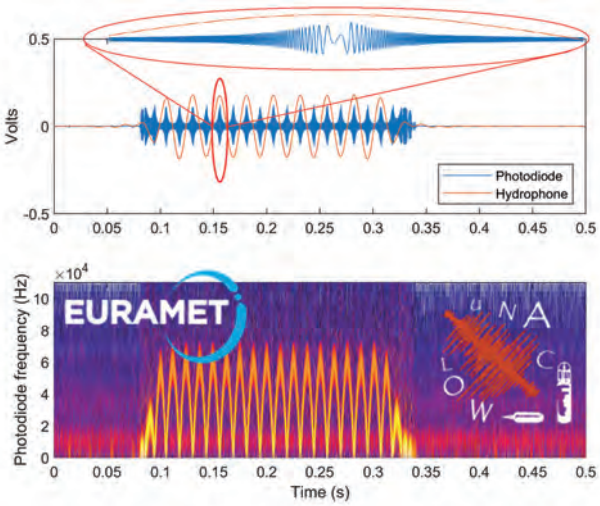
▲ *Fig 1: Piston with chamber removed showing beam-splitter as part of a Michaelson interferometer. The front face of the piston is optically flat to reflect the laser light.*



▲ *Fig 2: Comparison chamber for transferring the primary calibration to other devices, such as underwater noise recorders.*



▲ *Fig 3: Chamber fitted with socket to house the hydrophone in the chamber.*



▲ *Fig 4: Photodiode and hydrophone signal at 40Hz. The spectrogram reveals the chirp-like nature of the photodiode signal.*

Figure 1 shows the piston with the chamber removed. The laser shines through the beam splitter, through a glass window into the chamber and onto the polished face of the piston. Figure 2 shows the chamber fitted to the piston, with a socket cut for the hydrophone. The volume of the hydrophone has the effect of reducing the volume of the chamber.

Figure 3 shows the equipment used for transferring the primary laser pistonphone standard to other devices, such as noise recorders. By exposing the noise recorder and primary-calibrated hydrophone to the same pressure, the sensitivity of the noise recorder can be determined.

RESULTS

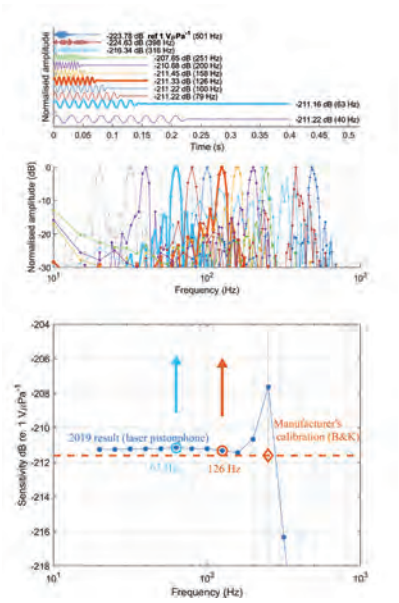
Figure 4 shows the photodiode signal from the interferometer together with the waveform received on the hydrophone. The rate of fringe-crossings is proportional to the scalar speed of the piston. This causes the photodiode signal to chirp, as can be seen in the spectrogram.

The calibration results for the type B&K 8103 hydrophone are given in Figure 5 (top) which shows the time traces of the tonebursts captured on the hydrophone cable. The toneburst signal is faithfully recreated up to 158Hz. However, above this frequency, propagating modes in the chamber and vibrations in the jig distort the hydrophone waveform.

Figure 5 (middle) shows the spectra for the individual tonebursts with the MSFD 63 and 126Hz frequencies highlighted in bold. Figure 5 (bottom) shows the hydrophone sensitivity results plotted as a function of frequency with the original manufacturers calibration marked on at 250Hz.

CONCLUSION

The laser pistonphone is a valid means for low frequency calibration of hydrophones which can be exploited for underwater noise recorders. The technique is demonstrated in the range 20 to 158Hz and consequently offers traceability for noise recorders used to monitor annual trends in the 63 and 125Hz bands, as identified in the MSFD Guidance. This NPL service helps users standardize across multiple pieces of equipment and multiple deployment sites so that low frequency noise can be evaluated over a large hydrographic area. ◀



▲ *Fig 5: Example results showing hydrophone sensitivity at the MSFD-identified frequencies.*

Acknowledgement
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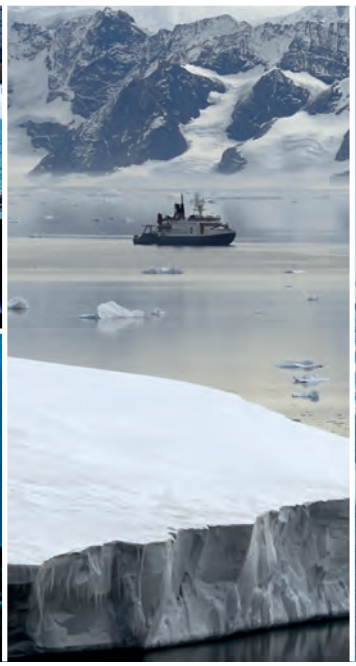


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The Ocean Cleanup Project

Ocean Cleanup's passive drifting system, also known as System 001, or 'Wilson', was deployed in the Great Pacific Garbage Patch, located roughly midway between California and Hawaii for 116 days. A team of scientists and experts researched any possible environmental impact of the system.

With the aim of protecting the environment from the negative impacts of persistent plastic pollution, we have to try and predict the effects of our actions on nature. To thoroughly assess potential impacts of this technology, and to identify mitigation measures aimed at reducing or eliminating any significant environmental impact, we voluntarily conducted an Environmental Impact Assessment (EIA), in collaboration with an independent party (CSA Ocean Science, USA). In addition to the EIA, an Environmental Management Plan (EMP) was established to ensure proper monitoring of the environment surrounding System 001.

In preparation for the environmental monitoring campaign, The Ocean Cleanup team and mission partners received several theoretical and practical training sessions with experts from the NOAA Fisheries Science Center in San Diego, The Marine Mammal Center in Sausalito, and The Bird Rescue Center in Santa Rosa (all in California, USA). These training sessions focused on the recognition of marine animals and understanding their behaviour as well as instruction on data collection procedures. Additionally, the team received training for handling and rescue procedures for distressed or entangled marine animals.

MONITORING EFFORTS

Starting from the System 001 launch date, The Ocean Cleanup staff and independent observers of Seiche Group Ltd. performed daily monitoring of the environment surrounding the barrier during the towing of the system, offshore installations, and deployment operations. These monitoring efforts were conducted using visual observations at and below the surface with acoustic monitoring. Remotely Operated Vehicles and GoPro cameras were used to spot marine animals that could be moving in the proximity of the system. These inspections included the observation of protected species

▲ *Survey vessel Maersk Launcher and the System 001 in operation.*

(marine mammals, birds, sea turtles), fish and plankton communities. The aforementioned activities were performed as part of the routine daily inspection, using different methods depending on weather conditions.

The scientists and engineers aboard the vessel would review the collected footage and data on a daily basis to ensure that any critical impact would be quickly addressed. A deeper analysis of all collected data has been performed since then with the scope of understanding System 001's behaviour, performance, and impact on the environment, while situated in the ocean environment.

DRONE TESTING

To test how drones record the system, and to collect visual data of the system in its complexity, many aerial photos were taken of System 001. The imagery was used to monitor plastic accumulation as well as animal presence around the system. We could also track the shape and behaviour of the system with this footage. Using these high-resolution photos, we created a mosaic to give a scope of how the monitoring was conducted.

RESULTS

Visual observations have shown that marine mammals and other marine animals have passed in the vicinity of System 001. The animals remained in the area from minutes to days (the latter exclusively for birds) before diving in deeper waters, swimming away, or flying away in other directions, after which, these animals were not spotted again. No critical interaction was observed between the animals and the three-metre underwater screen, nor with the closing lines used for shaping the system.

PROTECTED SPECIES

In total, there were 63 sightings of protected species, most taking place during tow near the coast, and the remainder occurring during monitoring in the patch – 62 marine mammals were spotted: of these, 52 whales (including 5 humpback whales, 1 fin whale, and 1 adult sei whale), 7 pinnipeds (including 3 California sea lions), 2 marine fissipeds were identified, and 1 unknown marine mammal. One recorded species was an unidentified sea turtle.

Several species of birds were also recorded including: albatross, osprey, storm petrel, tropicbird, sanderling and booby shearwater. Small groups of dolphinfish, yellowtail, red snappers, sardines, pilot fish, and other fish species were recorded swimming in the vicinity of the system. Fish presence was also well observed in close proximity to ghost nets and plastic debris (including those encountered far from the system). In some cases, frogfish and other pelagic fish were found taking shelter inside nets and plastic debris.

PELAGIC AND NEUSTONIC PLANKTON

We did not observe any recurring accumulations of pelagic and/or neustonic plankton. One recording, during uncommon weather conditions (wind < 1 knot, still waters, following heavy storms), a small accumulation of Vellela vellela (< 100 count) occurred around and on top of the plastic debris collected by the barrier. This aggregation remained visible for a limited time period (< 6 hours); most Velella dispersed when wind speeds increased. Phytoplankton Neutrally buoyant eggs were never observed floating on the surface and analyses of the Chlorophyll a concentration in the water did not suggest any phytoplankton abundance within the system, compared to open waters.

BIOFOULING

Once the system was recovered in Hilo Bay, Hawaii, a full characterization of the system's biofouling was performed by volunteers of the Division of Aquatic Resources (DAR). Soft biofouling (i.e. green algae) and hard biofouling (i.e. gooseneck barnacles) occurred on various

▲ *Part of the System 001 at sea.*

▲ *Floating plastic ‚cought' by the System 001.*

locations of the system, primarily on those permanently immersed in water. Scaly rock crabs were also found on the system.

CONCLUSION

During the four-month environmental monitoring campaign of System 001, we did not observe any substantial interference with System 001 and the ocean ecosystem and/or marine life; nor did we observe any entanglement or entrapment of marine animals or protected species. All observed species in the proximity of the system were able to freely swim around and underneath the system. Impact on plankton species and macrofauna communities was far lower than anticipated in the EIA.

LIMITED DATA

It is important to note that the open ocean and, more specifically, the Great Pacific Garbage Patch are largely unstudied; hence, limited data

▲ *A ghost net is brought aboard the Maersk Launcher.*

was available when preparing our EMP. Being a first-of-its-kind deployment, we knew that performing a comprehensive monitoring of the ocean environment would be challenging and that it would require ad hoc adaptations and improvements. Overall, these observations did give us greater confidence in the EIA, considering its results projected minimal risk; while on-site monitoring confirmed and lowered this expected risk. Some lessons learned from these monitoring efforts have now been incorporated into the EMP, but as always, we welcome additional suggestions and feedback.

Further research is needed in order to gain a greater understanding of the environment and the possible impacts and benefits of our technology in use; necessitating our team to return to the patch and reinstate monitoring efforts. That said, we hope these initial observations provide a greater scientific knowledge of the GPGP ecosystem.

We look forward to returning to the North Pacific and resuming our tests as well as our environmental monitoring programme while continuing to work with the scientific community throughout these processes. ◀

▲ *Maersk Launcher surrounded by System 001.*

Monitoring by the Numbers

Figures summarizing the at-sea monitoring efforts of System 001:

- 1,045 hours of visual and acoustic monitoring for protected species (including marine mammals, sea turtles, and various birds), over a total of 141 days, of which ± 1012 hours of direct visual observation and ±32 hours of Passive Acoustic Monitoring (PAM)
- 200+ visual inspections performed over the 116 days of System 001 in operational configuration (U-shape). Of which:
- 150 drone flights – each drone flight would carry a 4K camera live-streaming and recording at low and high altitudes
- 56 manned inspections with a support vessel – while engineers and biologists would conduct direct visual observations of the system and the waters within and around it, they would also record above- and under-water footage
- 49 days of remotely operated monitoring carried out via the AutoNaut, Unmanned Surface Vessel (USV), using wave motion to precisely and silently move within and outside the system.
- 5 M3i+ Ecosounder buoys were connected to the system in the operational configuration to continuously monitor potential fish aggregation as far as 200 metres below the surface.

The Ocean Cleanup would like to thank Terra Drone Europe for providing the necessary training for creating aerial imagery in an offshore environment.

Francesco Ferrari obtained his Master's Degree in Marine Biology at the Universitá Politecnica delle Marche, Italy. After completing his studies in 2014, he joined The Ocean Cleanup to work on the ecological side of ocean plastic debris removal. He participated in multiple offshore expeditions and has coordinated the collection and analysis of plastic samples from the Atlantic and the Pacific Ocean. He is now the Environmental Monitoring Coordinator, leading the efforts in ensuring the environmental safety of The Ocean Cleanup technology.

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