MARINE MAMMAL PROGRAM

Everyone is familiar with security patrol dogs. You may even know that because of their exceptionally keen sense of smell, dogs like beagles are also used to detect drugs and bombs, or land mines. But a dog would not be effective in finding a sea mine. Sea mines are sophisticated, expensive weapons that are designed to work in the ocean where they can sink ships, destroy landing craft, and kill or injure personnel. Sea mines are made so that they cannot be set off easily by wave action or marine animals growing on or bumping into them. If undetected, sea mines can be deadly, destructive weapons.

But just as the dog's keen sense of smell makes it ideal for detecting land mines, the U.S. Navy has found that the biological sonar of dolphins, called echolocation, makes them uniquely effective at locating sea mines so they can be avoided or removed. Other marine mammals like the California sea lion also have demonstrated the ability to mark and retrieve objects for the Navy in the ocean. In fact, marine mammals are so important to the Navy that there is an entire program dedicated to studying, training, and deploying them. It is appropriately called the **Navy Marine Mammal Program** (NMMP).

Member of Alliance of Marine Mammal Parks and Aquariums

"The Navy's Marine Mammal Program is an accredited member of the Alliance of Marine Mammal Parks and Aquariums, an international organization committed to the care and conservation of marine mammals. Accreditation by the Alliance means this facility meets or exceeds all the standards of excellence for marine mammal care, husbandry, conservation and education."

Libraries
Home
About Us
Animals
Fleet Systems
Frequently Asked Questions
Health Care
Internship Opportunities
Research Programs
Training

ANIMALS

The development, training, veterinary care and research facility that supports today's Navy Marine Mammal Program is centered in the Biosciences Division at SSC Pacific. The Navy's work with marine mammals has been ongoing for many years, beginning in the late 1950s when the Navy began to study the unique attributes of marine mammals such as the hydrodynamics of the dolphin. By understanding how dolphins move in the water, perhaps the Navy could improve torpedo, ship and submarine designs. Soon the Navy realized that dolphins would be valuable assistants to Navy divers working in the open ocean. Unlike human divers, dolphins are capable of making repeated deep dives without experiencing "the bends," or decompression sickness. They also found that dolphins and sea lions are highly reliable, adaptable and trainable marine animals that could be conditioned to search for, detect and mark the location of objects in the water.

In the early days of the program, various marine mammal species were considered including: killer whales, pilot whales, belugas (white whales), Steller sea lions, grey seals and fur seals. Other animals were used in various studies pertaining to locating personnel from downed aircraft and creating effective shark deterrents to protect them until they could be rescued. As the animals were assessed for their capabilities, much about their basic biology was learned

FREQUENTLY ASKED QUESTIONS

What species of marine mammals are used by the Navy?

In the early years of the Navy's Marine Mammal Program, several marine mammal species were investigated and considered for their sensory and physical capabilities. Today, the Navy cares for, trains, and relies on two species: the bottlenose dolphin (Tursiops truncatus) and the California sea lion (Zalophus californianus). Both of these species are known for their trainability, adaptability, and heartiness in the marine environment. The Navy also has two white whales, or belugas (Delphinapterus leucas), that have been subjects in a number of research projects and are currently on breeding loan.

Why does the Navy use marine mammals?

The Navy currently relies on dolphins and sea lions to help protect lives and naval assets for two major reasons: 1) their sensory capabilities and 2) their diving capabilities. Dolphins naturally possess the most sophisticated sonar known to man. Mines and other potentially dangerous objects on the ocean floor are acoustically difficult targets to detect, especially in murky or dark water. The dolphin's biosonar system is unmatched in its ability to make accurate detections. The sea lion has excellent low light vision and underwater directional hearing capabilities. Sea lions are not only adept at locating objects in challenging conditions, they also have the ability to maneuver in tight spaces and can go onto the shore if necessary. Both species of animals can make repeated deep-water dives without suffering the effects of decompression sickness or "the bends" as humans do. One sea lion, two handlers, and a rubber boat searching for objects on the ocean floor can effectively replace a full-sized naval vessel and its crew, a group of human divers, and the doctors and machinery necessary to support the divers operating onboard the vessel.

Is the Navy exempt from following regulations for the keeping of marine mammals?

No. The Navy is subject to all federal laws regarding the protection and humane treatment of marine mammals. These include the Marine Mammal Protection Act (MMPA) and the Animal Welfare Act (AWA). Under the MMPA, the Department of Commerce/NOAA Fisheries is responsible for pinnipeds (other than walruses) and cetaceans in the wild; the Department of the Interior is responsible for walruses, sea otters, polar bears, manatees, and dugongs. The AWA is administered by the Department of Agriculture and ensures the humane care and treatment of marine mammals in aquariums, zoos, and research facilities. The Navy is responsible for meeting all requirements of these laws regarding acquisition, care and treatment of its marine mammals, and not only meets but exceeds them and leads the industry in many cases. Congress has provided the Navy with exemptions to a few specific requirements in support of national security, but none related to the care and well-being of the animals.

Does the Navy train its dolphins for offensive warfare, including attacks on ships and human swimmers or divers?

No. The Navy does not now train, nor has it ever trained, its marine mammals to harm or injure humans in any fashion or to carry weapons to destroy ships. A popular movie in 1973 ("The Day of the Dolphin") and a number of charges and claims by animal rights organizations have resulted in theories and sometimes actual beliefs that Navy dolphins are assigned attack missions. This is absolutely false. Since dolphins cannot discern the difference between enemy and friendly vessels, or enemy and friendly divers and swimmers, it would not be wise to give that kind of decision authority to an animal. The animals are trained to detect, locate, and mark all mines or all swimmers in an area of interest or concern, and are not trained to distinguish between what we would refer to as good or bad. That decision is always left to humans.

Does the Navy ask the dolphins and sea lions to do dangerous things?

The dolphins locate and mark the location of sea mines which are designed to be set off by large ships, not aquatic animals. In the swimmer detection program, dolphins and sea lions move so quickly and

with such accuracy that human swimmers in dark or murky waters are located and marked before they know what has happened. Once the marking has been completed, the animals are removed from the area before mines are disarmed or swimmers are apprehended by trained security forces. Marine mammals are actually in more danger from sharks, and wild marine mammals are put in much more danger by people who feed them (which is why it is illegal).

Why have there been so many rumors about the NMMP over the years?

Several decades of classification of the program's true missions of mine-hunting and swimmer defense, led to media speculation and animal activist charges of dolphins used as offensive weapons, speculation and charges that could not be countered with facts due to that classification. Additionally, fantasy is often times more interesting than reality. With declassification of the missions of the program in the early 1990s, the Navy has repeatedly and openly discussed those missions, but rumors are not easily forgotten, and there are those who continue to actively promote them.

In response to charges that the program abused the animals, the presidentially appointed Marine Mammal Commission investigated the program in 1988 and 1990. The Commission reported that the allegations were not only false, but that the Navy's care of its marine mammals was "exemplary."

How do the marine mammals protect the general public and military personnel?

They detect, locate and mark mines so human divers can deal with them appropriately before they damage or sink military or civilian ships, and they can also detect and mark enemy swimmers who pose a threat to people, vessels, and harbor facilities.

Have the Navy's marine mammals ever been used to help in other ways?

Yes. The most significant use of the Navy's marine mammals has been to teach us more about them in research that has generated over 800 publications in the open literature. The more we know about

marine mammals, the better we can protect them. With the added advantage of working with animals trained to operate in open water without restraint, Navy as well as visiting scientists have learned many things about marine mammals that we might still not know otherwise.

Who sets the care standards for the animals in the NMMP?

An instruction from the Secretary of the Navy requires that the Navy's "marine mammals will be provided the highest quality of humane care and treatment." While it is important to us to have those words in writing, meeting them comes very naturally to the managers, trainers, scientists, veterinarians, engineers, and all other personnel working with and around the animals. The NMMP facilities in San Diego are state-of-the-art, including the food storage and preparation facilities, animal enclosures, and veterinary medical facilities. Regularly scheduled physical exams, balanced diets, an extensive database of health records, the training of husbandry and other behaviors, monthly briefs to all personnel on animal care topics, and a high level of professionalism mixed with genuine compassion all contribute to the health and welfare of the animals.

How are animals moved to and from remote deployment sites?

Over short distances, animals are trained to either swim alongside a small boat or to ride in the boat itself. For long distance trips, animals can be transported by sea in large naval vessels or by air in planes or helicopters. For these trips, sea lions ride in specially designed enclosures and are kept cool, wet, and comfortable. Dolphins are placed in fleece-lined stretchers that are suspended in fiberglass containers filled with enough water to comfortably support the weight of the animal. On these long transports, a veterinarian oversees the comfort and health care of all the animals while each animal is constantly monitored by an experienced trainer or handler. Upon arrival at their destinations, animals are housed in temporary facilities that are much like those in San Diego. In addition, a portable veterinary clinic

accompanies the animals to provide veterinarians with everything they need to care for the health of the animals.

I still have some questions about the NMMP, who do I contact?

Please direct any further inquiries to the SSC Pacific Public Affairs Office at (619) 553-2717.

FLEET SYSTEMS

In the Fleet's operational Marine Mammal Systems (MMS), the Navy uses dolphins and sea lions to find and mark the location of underwater objects. Dolphins are essential because their exceptional biological sonar is unmatched by hardware sonars in detecting objects in the water column and on the sea floor. Sea lions are used because they have very sensitive underwater directional hearing and exceptional vision in low light conditions. Both of these marine mammal species are trainable for tasks and are capable of repetitive deep diving.

Some of the objects the animals find are expensive to replace. Others could present a danger to Navy personnel and vessels. The dolphins and sea lions work under the care and close supervision of their handlers and are generally trained for a particular operational capability called a "system." (The term "system" is engineering jargon for a collection of personnel, equipment, operations processes, logistics procedures, and documentation that come together to perform a specific job.) However, animals may be crossed-trained for more than one system to better serve the needs of the Fleet. The term "mark" (MK for short) is military jargon for a type of thing within a category. There are 5 marine mammal systems called MK 4, MK 5, MK 6, MK 7, and MK 8. MK 4, MK 7, and MK 8 use dolphins, MK 5, which uses sea lions, and MK 6 uses both sea lions and dolphins. These human/animal teams can be deployed within 72 hours of notice and can be rapidly transported by ship, aircraft, helicopter, and land vehicles to potential regional conflict or staging areas all over the world. They regularly participate in major Fleet exercises. These animals are released almost daily untethered into the open ocean, and since the program began, only a few animals have not
returned.


WHALER
Johnson

All Fleet systems are assigned to the Explosive Ordnance Disposal Group ONE (EODGRU ONE), where the mine hunting systems (MK 4, MK 7, and MK 8 MMS) are assigned to Explosive Ordnance Disposal Unit Mobile Unit (EODMU ONE). MK 5 is assigned to SSC Pacific and MK 6 is assigned to Navy Explosive Ordnance Disposal Mobile Unit THREE (EODMU THREE). SSC Pacific supports these Fleet systems with replenishment marine mammals, hardware, training, personnel, and documentation.

Mine Hunting Systems

Enemy sea mines have been responsible for 14 of the 19 Navy ships destroyed or damaged since 1950. That is why the Navy created the mine hunting systems. The mine detection systems are MK 4, MK 7, and MK 8 MMS. In the operation of these systems, a dolphin waits to receive a cue from its handler before it begins to search a specific area using its biological sonar called echolocation. When a dolphin echolocates, it emits a series of clicks that bounce off an object and return to the dolphin, allowing a dolphin to construct a mental image of the object. The dolphin reports back to its handler, giving one response if a target object is detected and a different response if no target object is detected. If a mine-

like target is detected, the handler sends the dolphin to mark the location of the object so it can be avoided by Navy vessels or dealt with by Navy divers.

MK4 Marine Mammal System

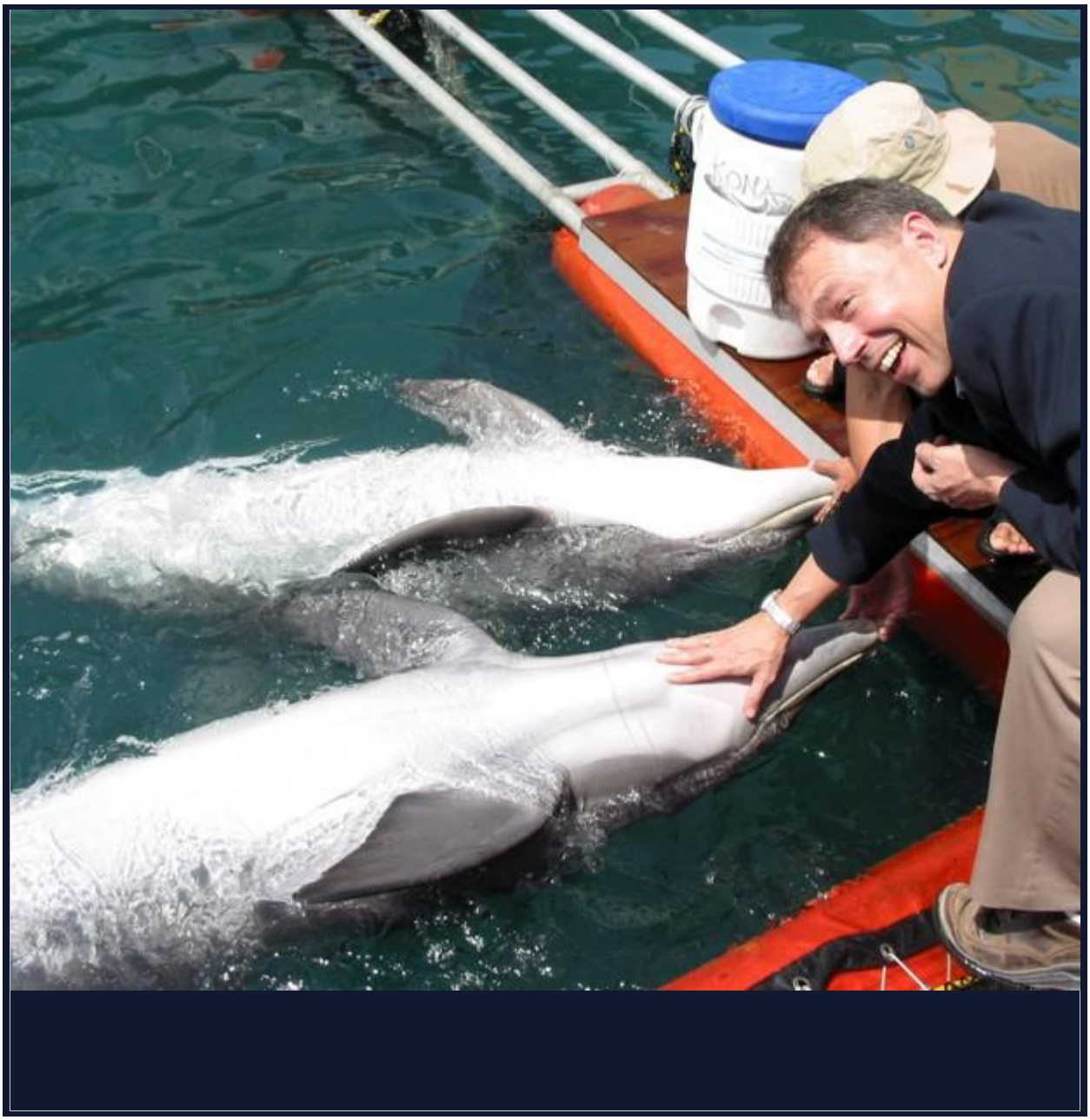
The MK 4 MMS uses dolphins for detecting and/or marking the location of sea mines that are tethered off the ocean bottom. These deep-water mines are easy targets for the dolphin's highly effective echolocation. The MK 4 MMS offers reliable and effective mine detection, classification, and marking capabilities in areas that are highly cluttered or where rough seabed, high marine growth, and other complex acoustic conditions hamper the performance of Navy hardware systems.

MK7 Marine Mammal System

In the MK 7 MMS, dolphins are trained to detect and/or mark the location of mines sitting on the ocean bottom or buried in sediment. The dolphins are sent out after the first troops have gone into the area. They help to clear a wider path of safety for additional troops and equipment.

MK8 Marine Mammal System

MK 8 MMS is a human/dolphin team that allows troops to quickly identify safe corridors for the initial landing of troops ashore. MK 8 MMS operates with a low profile in very shallow water.



Force Protection

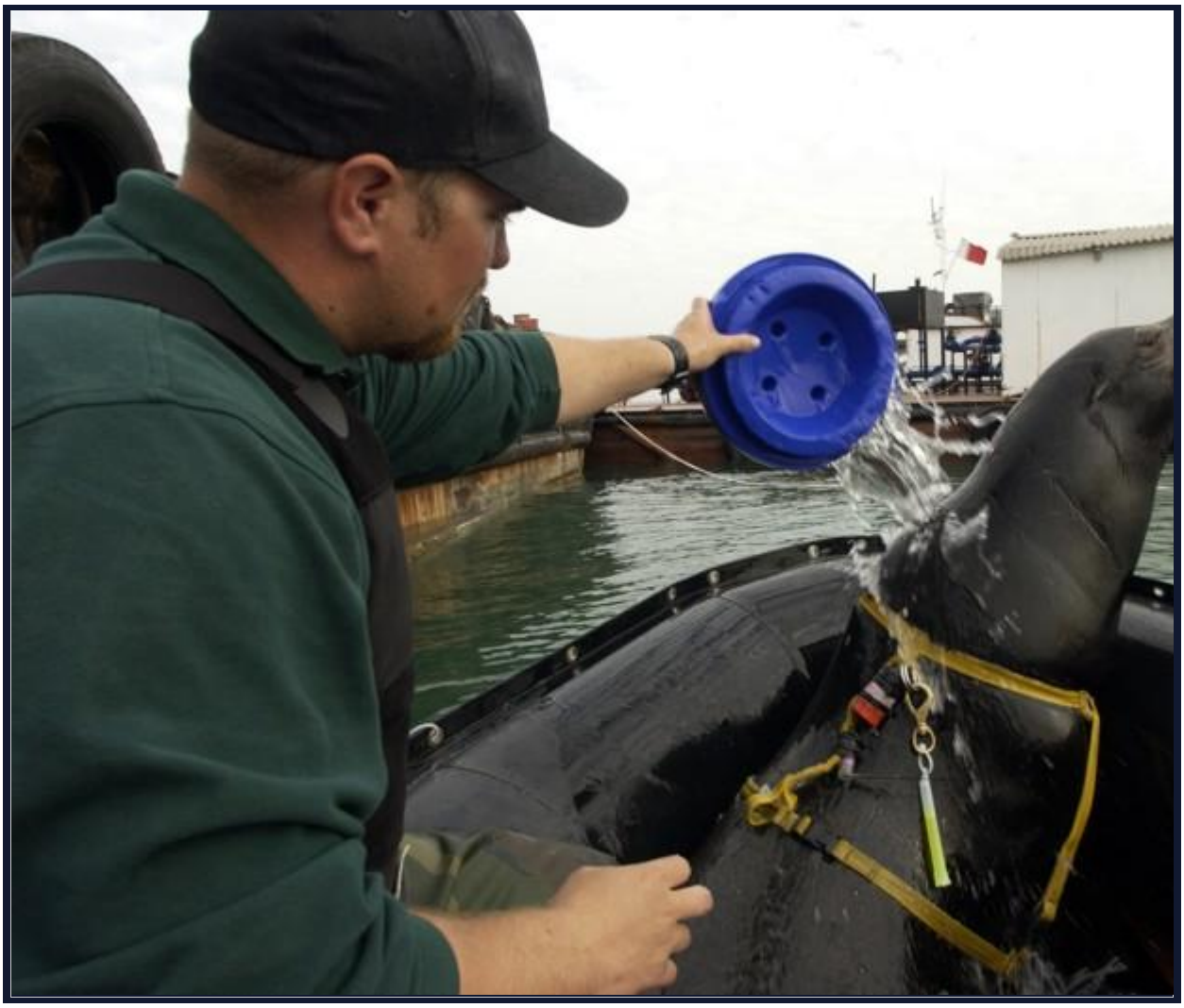
While dogs work as effective sentries on land, dolphins and sea lions cannot be outmatched as sentries in the water. In the MK 6 MMS, dolphins and sea lions effectively protect piers, ships, harbors, and

anchorages against unauthorized swimmers, SCUBA divers, closed-circuit divers, and swimmer delivery vehicles.

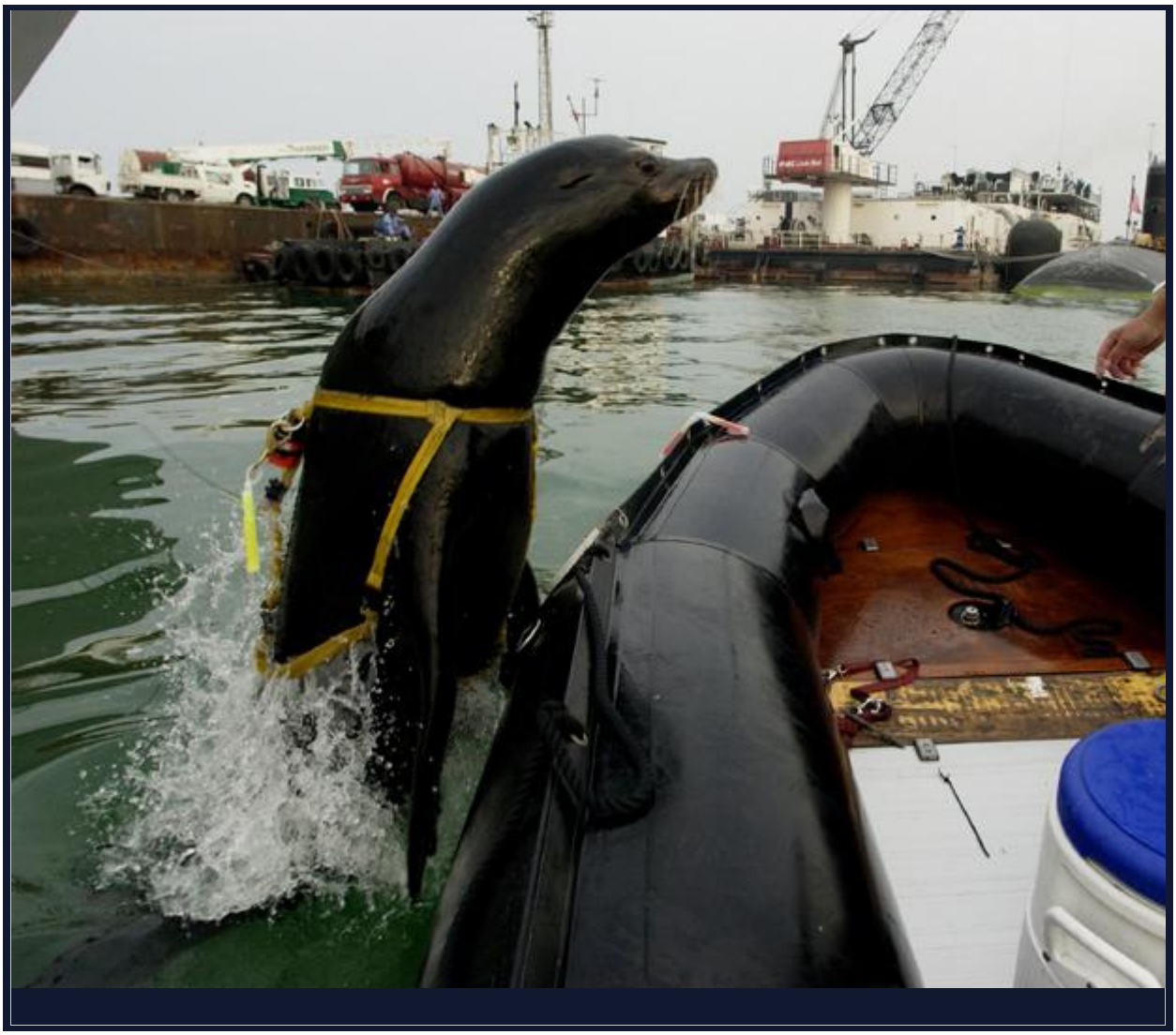
MK 6 MMS was first operationally deployed with dolphins during the Vietnam War from 1971 to 1972 and Bahrain from 1986 to 1987.

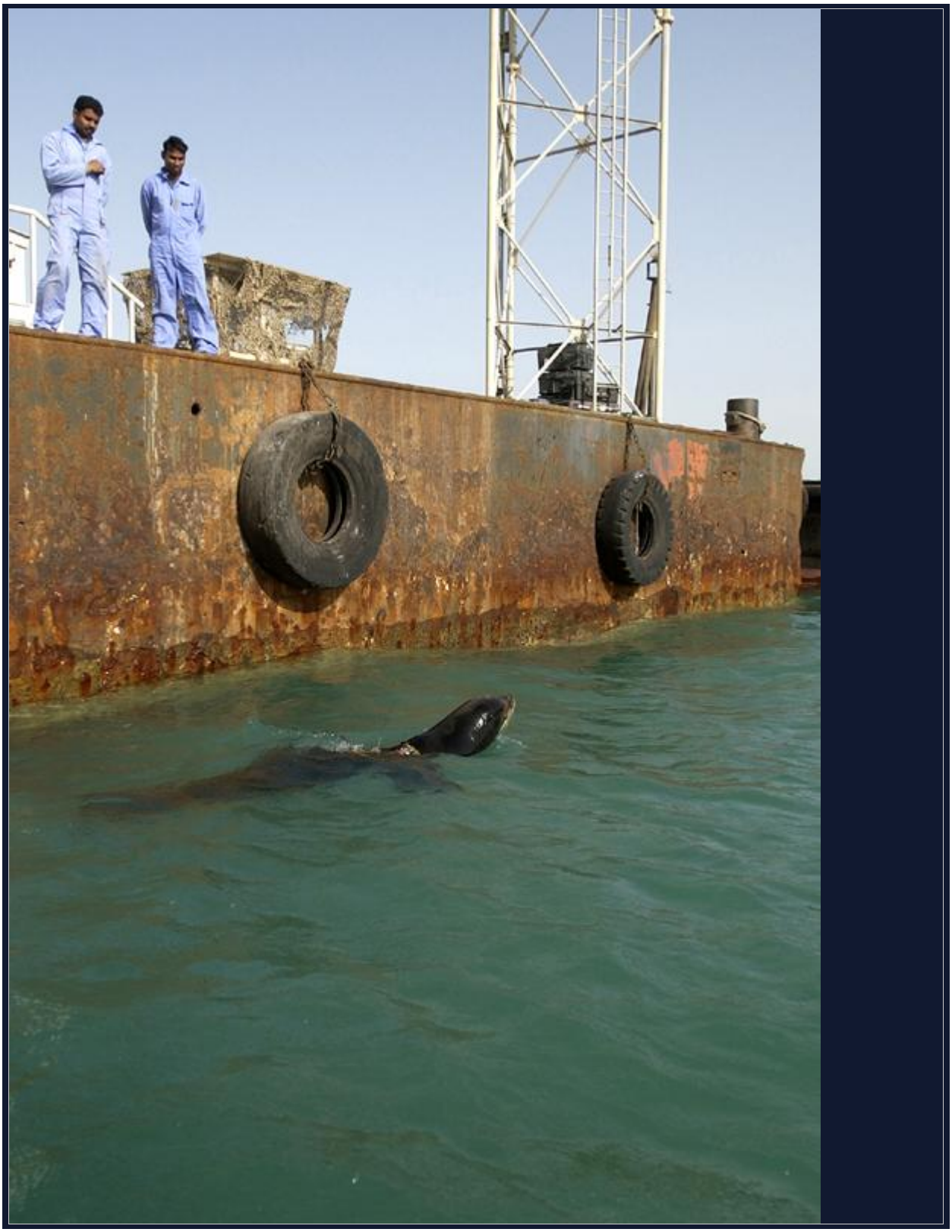
MK 6 has now been expanded to include specially trained sea lions to locate water-borne intruders and suspicious objects near piers and ships that pose a possible threat to military forces in the area. They have been shown to be effective under and around ships, piers, and in open water.

The sea lions were deployed to Bahrain as part of the effort to support missions under Operation Enduring Freedom.




SEA PRINCE



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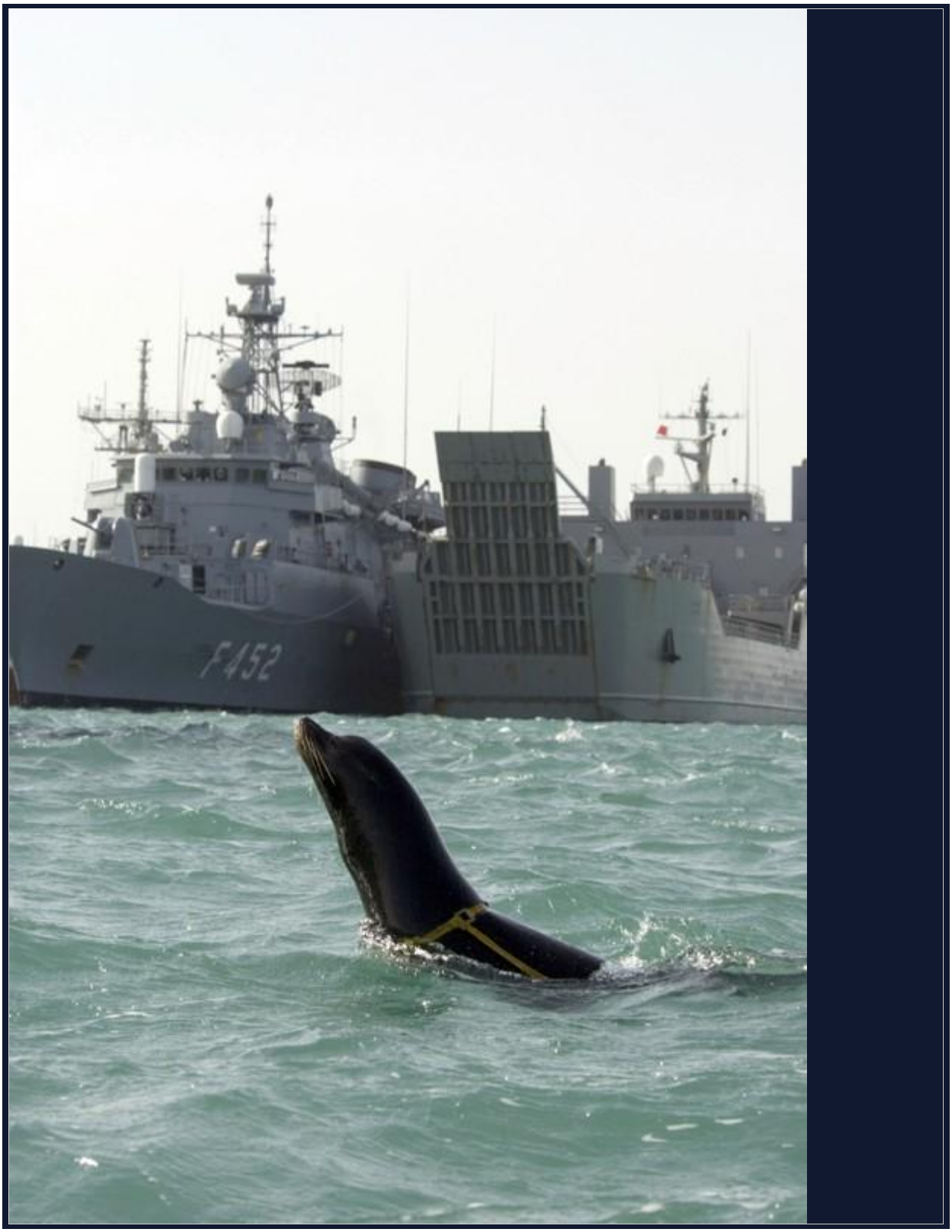
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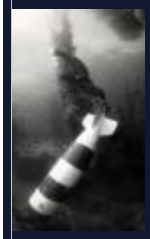
All MK 6 sea lion photos courtesy Navy NewsStand. Search for 'sea lion'.

Object Recovery

The Navy uses hardware and unarmed instrumented test equipment that may be launched from ships or dropped from planes into the ocean. Traditionally, these items were recovered by human divers. However, humans are restricted to short periods of working time on the bottom and can also be hampered by poor visibility, currents, and the requirement for surface support. To meet this need, the Navy developed the MK 5 "QuickFind" Marine Mammal System (MMS).

QuickFind



The MK 5 "QuickFind" system first demonstrated its capabilities when it recovered an ASROC (Anti Submarine Rocket) MK 17 from 180 feet of water in November of 1970. The MK 5 MMS became operational in 1975 and uses California sea lions to locate and attach recovery hardware to underwater objects such as practice mines. Some of these mines are equipped with a device called a pinger that sends out a tone to help the sea lion locate them. For this, the sea lion may have to dive to depths of 500 feet or more. The QuickFind system consists of a small rubber boat, a sea lion, and two or three handlers. When the boat arrives at the recovery site, the sea lion is sent over the side and given a bite plate to which an attachment device is mounted. The sea lion locates the object by using its exceptional low light vision and directional hearing to locate the undersea object. A strong line tied to the bite plate is payed out from the boat as the sea lion swims down and attaches the device. To be sure the connection is complete, the sea lion tests it by pulling back on the bite plate a few times. The sea lion then releases the bite plate and returns to the boat for a well-deserved reward of fish while the recovery vessel pulls the object to the surface.

The MK 5 "QuickFind" system provides an inexpensive method to recover submerged objects. Cost analyses have shown that this system is much less expensive for recovery than the use of dive teams or remotely operated vehicles (ROV). The sea lions' natural swimming ability makes it ideal for working in this environment and they are not hampered by decompression times. Their speed and agility allow them to recover objects much quicker than the mechanical options. The MK 5 MMS has also located submerged vehicles in a lake and had the opportunity to recover victims (dummies) in a simulated airplane crash.

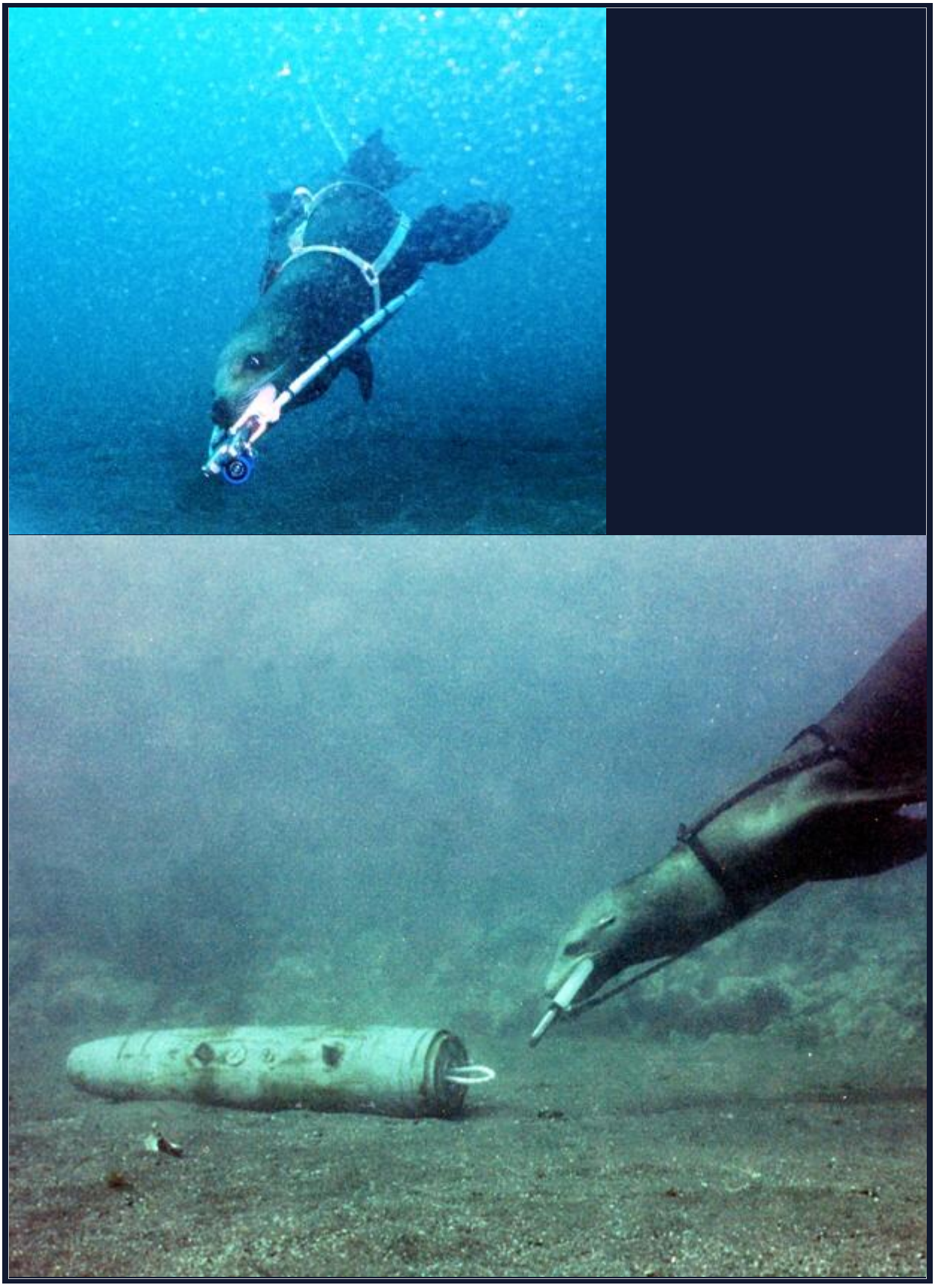
As of 1 October 2005, SSC Pacific has taken over the daily operations of MK 5 after many years of being part of EODMU THREE.

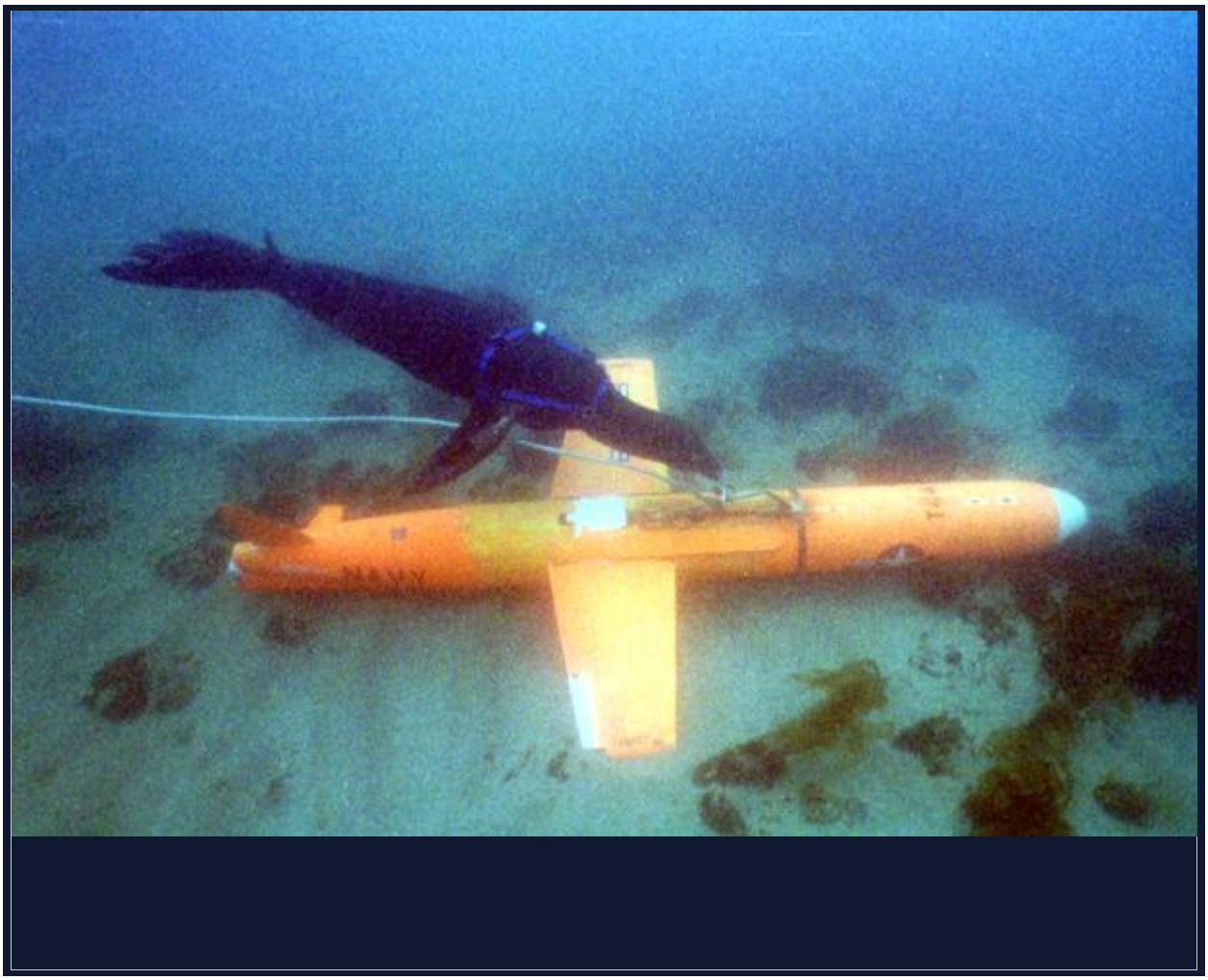
Requesting Services

The use of the MK 5 "QuickFind" MMS to recover objects is not limited to Navy assets. The system is available for tasking from any branch of the armed forces or RDT&E labs. In most cases the cost for employing MK 5 is limited to travel and per diem expenses. To request the recovery services of the MK 5 "QuickFind" MMS please download and fill out the following request form:

- QuickFind Services Request Form.doc
- QuickFind Services Request Form.txt

Email the completed form or any other inquiries to QuickFind@spawar.navy.mil.

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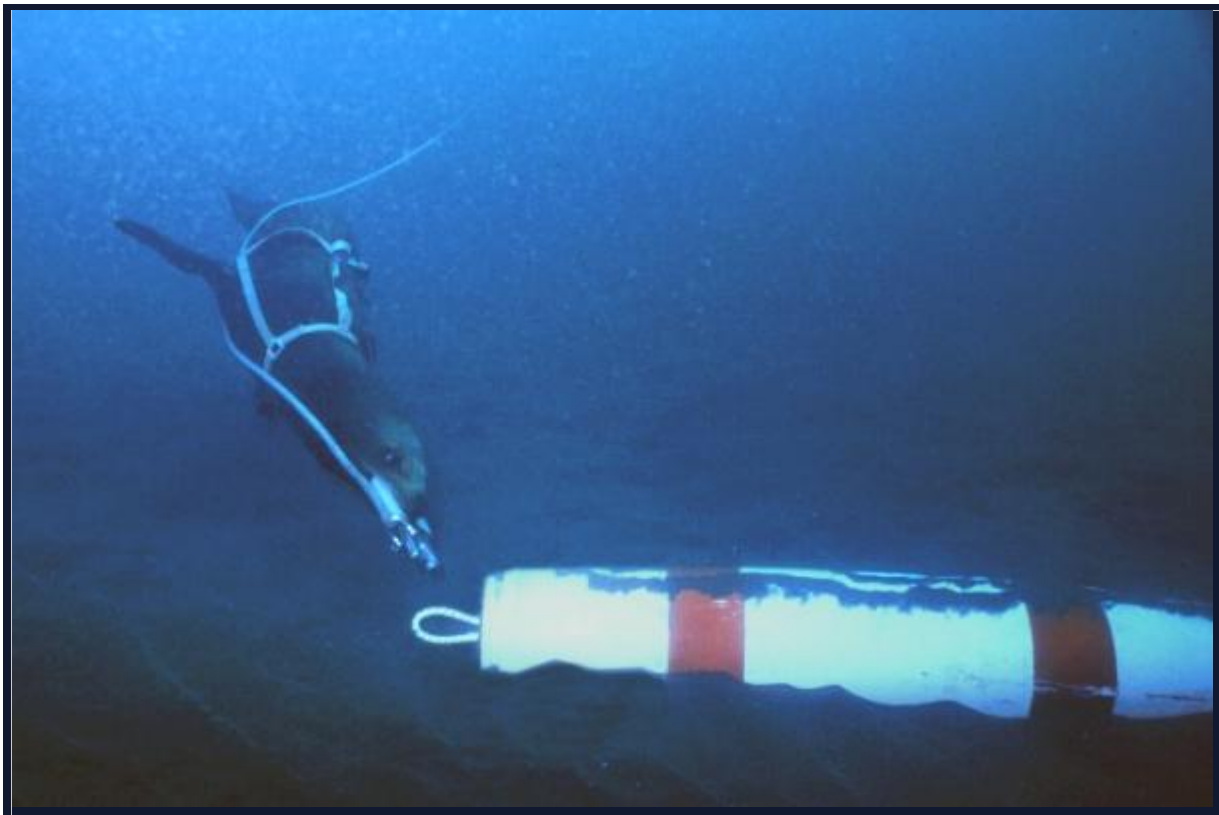


Fleet Support

Animal Production

The Spares Program provides back-up animals for all the systems in the Fleet to help maintain uninterrupted mission readiness. Not only are the spares animals trained the advanced skills they will need to replace an animal that has been taken out of the Fleet, they are also on call, ready to step in at any time to fill in for another animal that is temporarily unavailable or to fill the needs of an expanded mission. It is in the Spares program that new technologies and training techniques are innovated and validated to ensure that the Marine Mammal Program always maintains the highest caliber product.

Technical Representative

Marine mammal handlers in the Fleet participate in a course of study that includes marine mammal husbandry, training, and systems operations. Each Fleet system is also supported by an experienced

civilian marine mammal trainer called a technical representative. Technical representatives are essential personnel and an integral part of the Fleet systems. They provide support and expertise during daily operations, as well as deploying with the systems on military exercises and operations. They also act as a liaison between the Fleet and the NMMP to ensure that the Fleet's needs are being met and that the highest level of animal care is maintained.

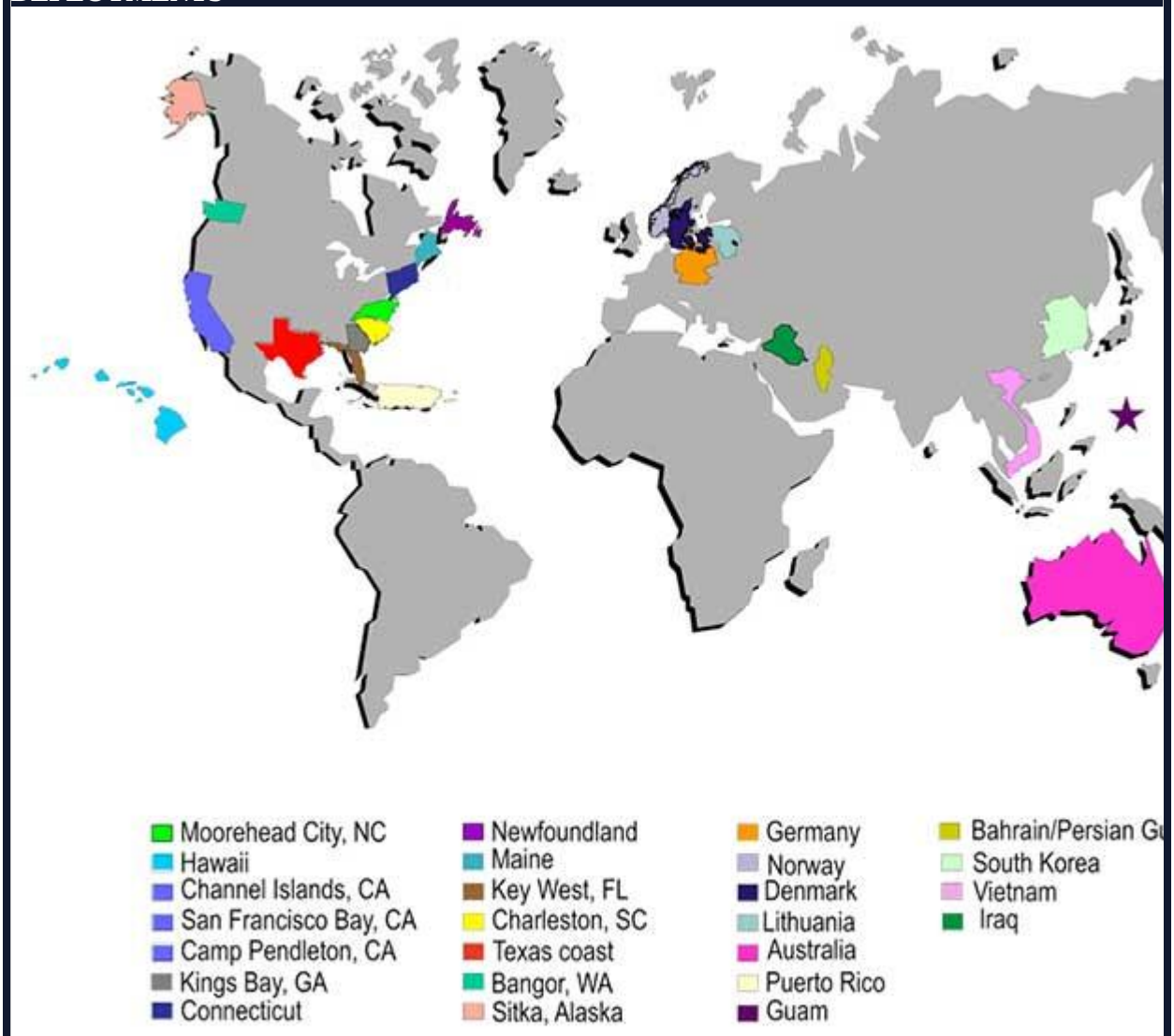
Systems Engineering

An expert team of talented engineers maintains continual vigilance on hardware to ensure the efficiency and safety of current hardware and enhance the operational capabilities of the system through new designs of existing equipment and the development of new hardware.

Maintenance Depot

The Marine Mammal Program has a materials and equipment storage and maintenance facility known as the Depot to provide Fleet equipment needed for operation of marine mammal systems. The personnel at the Depot have years of experience with the program. They provide an efficient means of helping the Fleet to prepare for an exercise or operation and ensure that all the equipment is properly maintained to enhance mission readiness.

DEPLOYMENTS



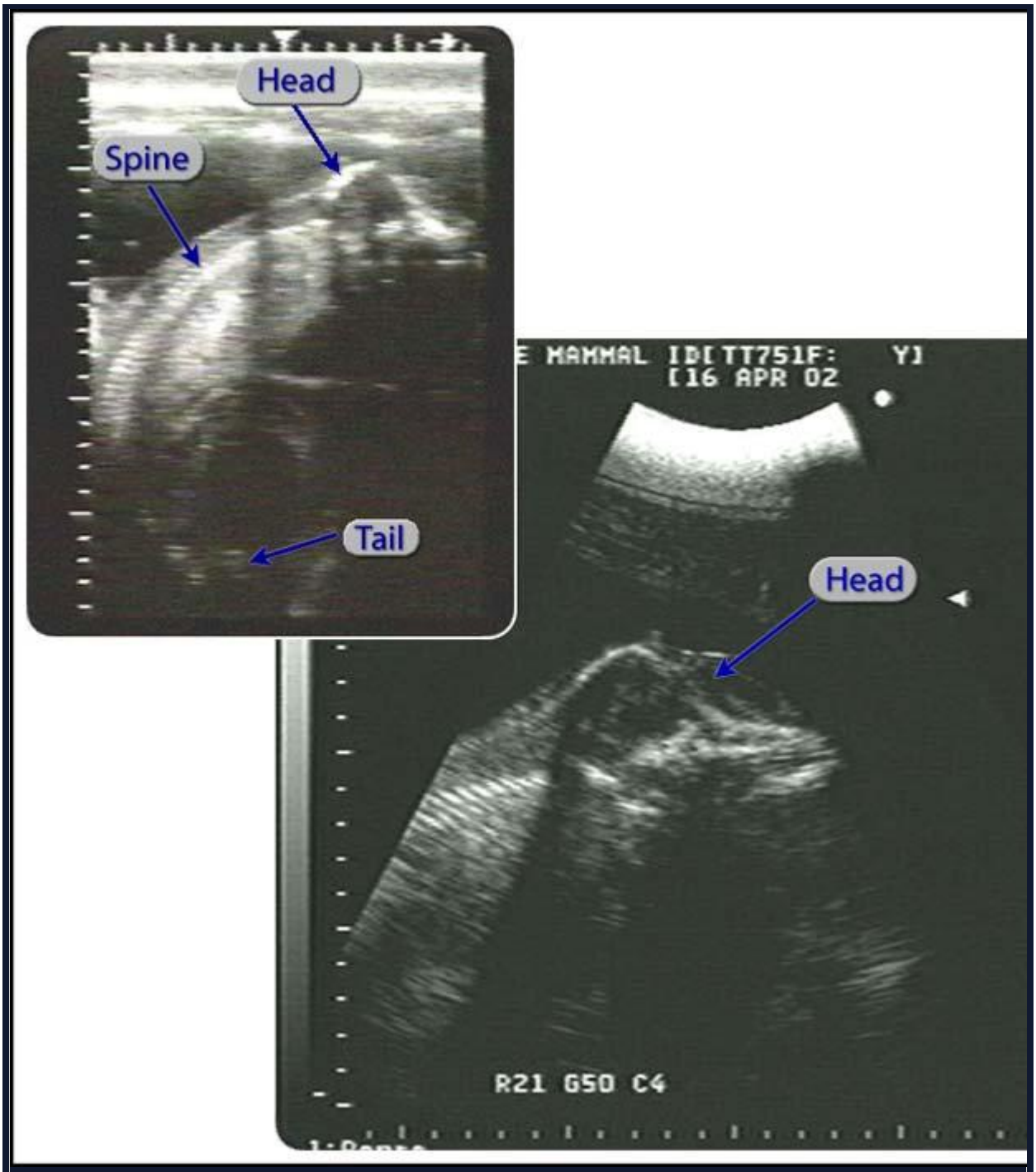
HEALTH CARE

Maintaining the health of the Navy's marine mammals is central to the Navy Marine Mammal Program's mission and focus. A full-time staff of veterinarians, veterinary technicians, and biologists ensures that necessary care and management processes are in place to provide for all the health needs of the animals. A veterinarian and a veterinary technician are on call around the clock, 7 days a week. The NMMP is in strict compliance with all statutory requirements, DoD requirements, and federal laws regarding the proper care of the animals.

The primary focus of the health care program is to keep the marine mammals healthy and fit for duty. Cutting-edge marine mammal health care techniques and technologies are actively evaluated and developed. Research to support the health of the animals incorporates fields such as immunology, virology, epidemiology, microbiology, toxicology, and vaccination development. In this regard, the Navy continues its time-honored tradition of being an important National resource for the study of marine mammal nutrition, medicine, physiology, and ecology.

The NMMP is accredited by the Association for Assessment and Accreditation of Laboratory Animal Care International (AAALAC). AAALAC is a nonprofit non-regulatory organization that promotes high standards of animal care and use, improves laboratory animal well-being, and enhances life sciences research through accreditation. It is a non-governmental independent organization that monitors and ensures strict animal care standards throughout the world. Membership is voluntary so it shows a level of care that is exceptional and over and above what is required by law. It includes a triennial site visit and a comprehensive review of all procedures and performance for the care and handing of the animals. The 2002 re-accreditation letter to the NMMP noted: "The Council commends you and your staff for providing and maintaining an excellent program of laboratory animal care and use."

Preventive Medicine



A crucial aspect of animal health care is that the animals are conditioned to cooperatively participate in routine examinations, including blood draws and ultrasound scans. As leaders in the field of marine mammal medicine, the NMMP actively collaborates with investigators to find ways to improve the understanding of marine mammal health and physiology. Our student programs offer exciting and novel

learning opportunities. Through such efforts, the NMMP continues to be an important part of the future of marine mammal medicine.

The Navy takes great pride in providing the finest possible veterinary care to its marine mammals. The cornerstone of our animal health care program is preventive medicine. This includes routine physical examinations, nutrition and sanitation oversight, extensive data collection and management, deployment support, and development of advanced clinical technology.


COLE

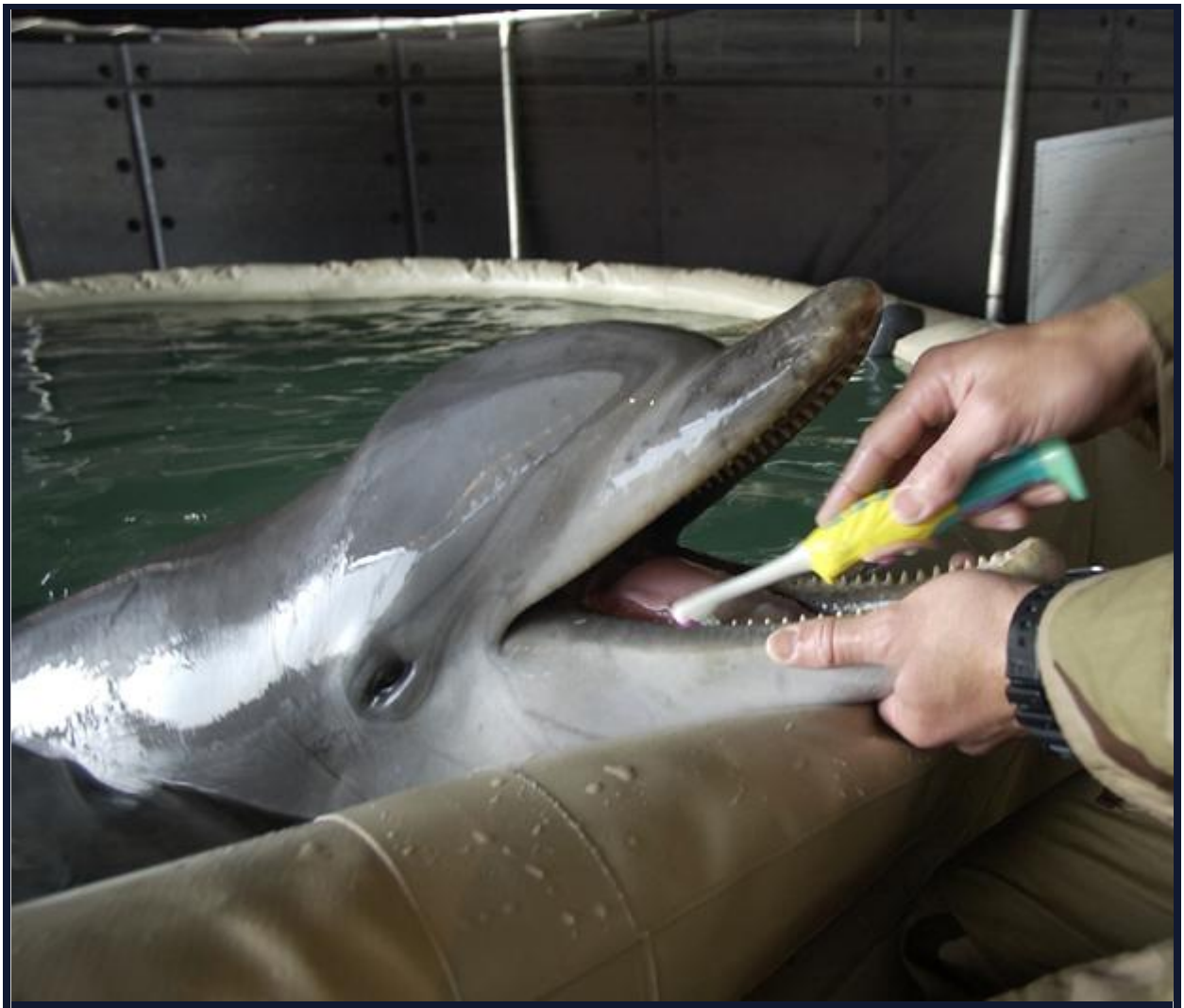


Photo courtesy Navy News Stand. Search for 'dolphin'.

U.S. Army Veterinary Staff

In addition to civilian veterinary staff, there has always been a U.S. Air Force or Army officer veterinarian assigned to the NMMP as well as supporting corpsmen or veterinary technicians. In April 1980, the Veterinary Corps Branch of the U.S. Army was appointed as the DoD executive agent for veterinary services and one detachment is assigned to the NMMP. They are an integral component of the NMMP animal health care system.


U.S. ARMY


94-45072

RESEARCH PROGRAMS

Research Programs

From the beginning of the Navy Marine Mammal Program (MMP), scientific research has been conducted to support the development of systems and technology and to gain a better understanding of the animals. The more we know about marine mammals, the better we can protect them. As a result, the MMP is the single largest contributor to the literature on marine mammals (over 1000 technical publications). This research, conducted by both staff and visiting scientists, has covered a broad spectrum of topics including hydrodynamics, sensory systems, anatomy and physiology, health care, behavior, reproduction, telemetry, open sea operations, and environmental ecology. This work is facilitated by well-trained animals that can participate in research in ocean pens, pools, or open water.

All of the animal research at the MMP has always been conducted under the oversight of an Institutional Animal Care and Use Committee (IACUC) that reviews all proposals for scientific value and validity, and to ensure safe keeping of the study animals. Our research is currently focused on several major areas with the continuing goal of safeguarding our forces at sea, responsibly protecting the marine environment, providing our animals with the best health care possible, and understanding marine mammal bioacoustics. Following are samples of some of the work underway.

Animal Health

To ensure the ongoing health and overall longevity of our animals, a major effort is made to explore and improve marine mammal medicine and care. Today veterinary techniques take advantage of animals cooperatively participating in routine medical examinations that involve the drawing of blood and the use of endoscopy and ultrasound scans to monitor the condition of each animal. Conducting research to detect, treat, and prevent infectious and metabolic diseases

and determining the unique clinical needs on aging animals are critical to the health and operability of the Navy dolphins and sea lions. The MMP is also committed to the development of advanced technologies to determine population baselines and to diagnose and treat disease. Combining the extensive animal health database maintained by the NMMP and the frequent deployment of animals around the world, NMMP scientists are also investigating the possibility of our dolphins acting as environmental sentinels to monitor the condition of the world's oceans.

Marine mammal hearing

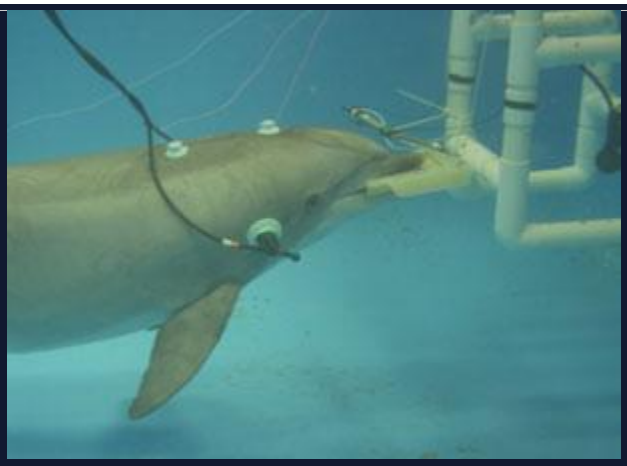
Sound is more effectively transmitted through water compared to light; as a result, marine mammals have evolved hearing abilities that allow them to exploit sound for communication, navigation, finding and capturing prey, and avoiding predators. Bottlenose dolphins and other odontocetes (toothed whales) are some of the most sophisticated listeners in the animal kingdom. Both dolphins and sea lions have ultrasonic hearing — they can hear sounds at frequencies above the range of human hearing. Dolphins can hear up to approximately 160 kHz (eight times higher than humans), with best hearing sensitivity between 40 kHz and 80 kHz. Their ability to detect and classify sounds in noisy environments is unrivaled by any human-made listening device. Sea lions can hear sounds up to about 40 kHz and have good underwater directional hearing.

Because these animals rely on sound to such a great extent, hearing impairment due to aging or environmental noise has the potential to adversely affect their performance and overall fitness. As a result, hearing tests have become a regular part of each of our animal’s physical examinations. The techniques developed to test their hearing have also been used to test animals at other marine facilities and to opportunistically test wild animals. The accumulation of this knowledge has been paramount in developing mitigation measures to protect marine mammals from harmful noise.

Behavioral (psychophysical) hearing tests

Testing human hearing is straightforward — an audiologist gives verbal instructions for taking the hearing test; for example, “sit quietly and press a button when you hear a tone”. We can’t give marine mammals complex verbal instructions on how to participate in a hearing test. Instead, operant conditioning techniques and positive reinforcement are used to train animals to perform a specific action, such as whistling, barking, or pushing a paddle, when they hear a tone. The amplitude of the tone is then adjusted, and the animal’s responses recorded, to determine the quietest sound that can be heard at a particular frequency. This is called the hearing threshold. This task is a type of psychophysical procedure — a way of conducting measurements to relate sensory perception to the measurable properties of a stimulus. Psychophysical hearing tests are also called behavioral tests, since the tasks require the animal to perform a specific behavior in response to the sounds. Behavioral techniques such as these have been used at the MMP since the late 1960s to determine hearing sensitivity and evaluate auditory system function in a variety of marine mammals, including dolphins, sea lions, and belugas. These techniques are very straightforward and intuitive — we are essentially “asking” the animals if they can hear a sound. The methods also produce reliable data, but can be very time consuming — it can take several months to train an animal to participate in a behavioral hearing test.

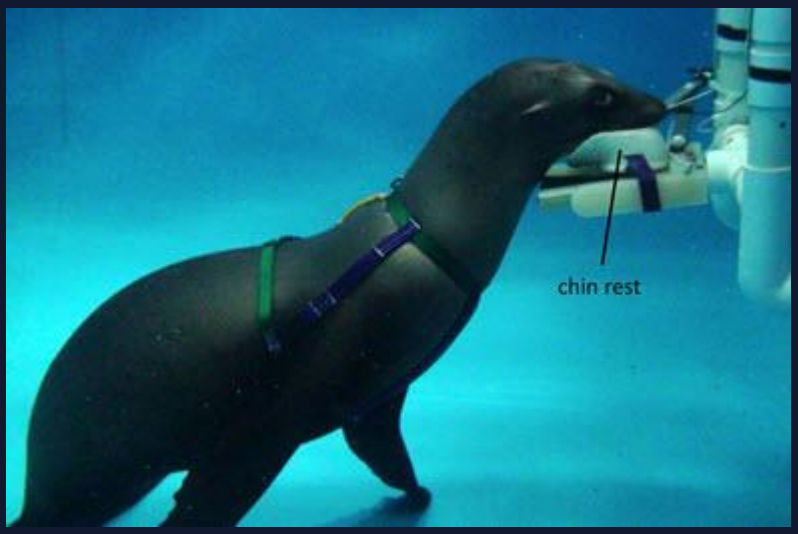
Behavioral hearing tests at the MMP are performed underwater in San Diego Bay or a quiet test pool. In-air testing is normally performed in an acoustically-treated room. Regardless of test environment, the experiments utilize a “listening station,” often constructed of PVC pipe. The listening station provides a fixed location for the hearing test and enables the sound levels to be accurately measured. The hearing tests are controlled using custom software to generate hearing test tones, and record and analyze the behavioral responses.



A bottlenose dolphin participating in a hearing test in a quiet pool. The PVC listening station contains an underwater sound projector to generate the hearing test tones and a hydrophone to monitor the sounds in the pool. The dolphin is positioned on a neoprene-covered "biteplate" to ensure that she is in the calibrated sound field.

A trainer prepares to begin a hearing test trial with a bottlenose dolphin in San Diego Bay. The dolphin is wearing a "jawphone" — an underwater sound projector embedded in a suction cup placed on the lower jaw. This is the site for high-frequency sound reception in dolphins.

A California sea lion participates in an in-air hearing test. Sounds are presented to the sea lion using headphones. The sea lion indicates that he is ready for the next trial by resting his chin on a tennis ball mounted on the listening station.



A sea lion participates in an underwater hearing test in a quiet pool. To accommodate sea lions, the dolphin listening station is modified by mounting a "chin rest" over the biteplate.

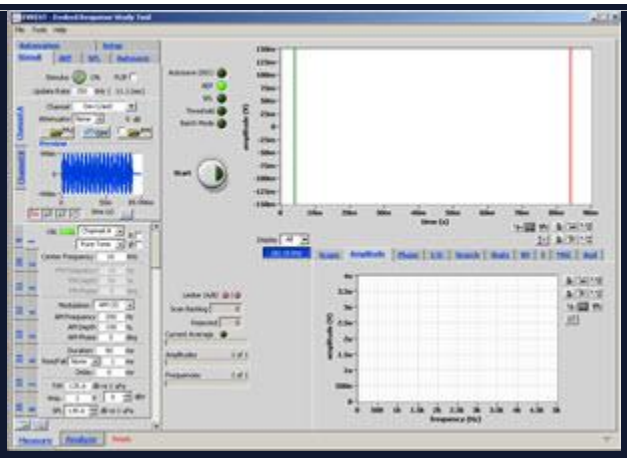
Electrophysiological hearing tests

In addition to behavioral methods, electrophysiological techniques can be used to assess hearing in marine mammals. Electrophysiological methods rely on the measurement of auditory evoked potentials (AEPs) — small (tens of nanovolts to microvolts) changes in the electrical activity of the brain produced when an animal hears a sound. Because the AEPs are automatically generated by the brain, this technique is ideal for individuals not specifically trained for behavioral hearing tests or for whom access is limited; for example, stranded and/or rehabilitating animals. Some AEPs are unaffected by attention and sleep, and can therefore be measured in sedated animals. AEPs are measured in marine mammals using electrodes placed on the head, similarly to the way AEPs are measured in human infants. The amplitude of the sound stimulus is then manipulated while the resulting AEPs are measured to find the hearing threshold — the quietest sound level that produces a measurable AEP.

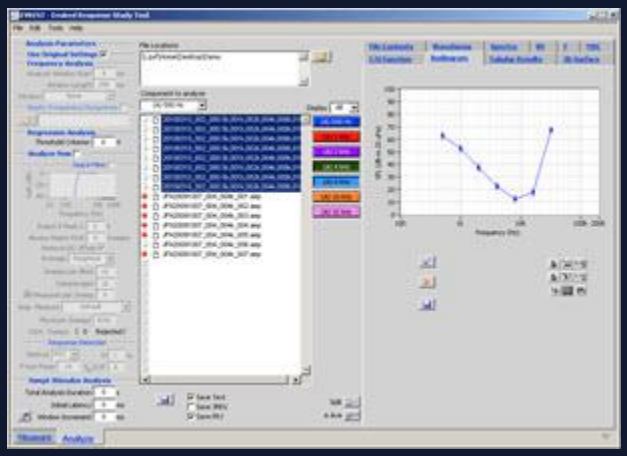
AEPs can be measured using a variety of sound stimuli. One of the more commonly employed stimuli is a sinusoidal amplitude modulated (SAM) tone. The SAM tone has become a popular stimulus because it has relatively limited frequency content (so the measurements can be attributed to specific hearing frequencies) and it produces an AEP that can be objectively analyzed using statistical techniques. Using SAM tones modulated at different rates also allows hearing ability to be simultaneously assessed at multiple frequencies. At the Navy MMP, dolphin hearing has been simultaneously tested at nine frequencies and sea lion hearing has been simultaneously tested at seven frequencies in each ear (14 total). To date over 100 dolphins have been tested, revealing suspected effects of age, gender, and certain antibiotics on their hearing abilities. The relationships are similar to what is seen in people; for example, dolphins tend to lose their hearing as they get older, just like we do, and the males hear a little worse than the females. These data form an important complement to clinical physical exams and provide key information for animal trainers and clinicians. The data also provide important population-level parameters that help us understand what is “normal” hearing for marine mammals of different ages and life histories.

Dr. Jim Finneran at the MMP has developed a rugged, portable system for AEP measurements called EVREST (EVoked REsponse Study Tool). EVREST combines a rugged laptop computer with a custom software application designed for recording and analyzing auditory evoked potentials. With EVREST, a user can generate and calibrate up to 16 sound stimuli, measure evoked responses, and analyze and store data. EVREST has been used to measure AEPs in a variety of marine and terrestrial animals, including sea horses, fish, bottlenose dolphins, rough-toothed dolphins, harbor porpoises, a beaked whale, pilot whales, orcas, California sea lions, Steller sea lions, a harbor seal, Northern elephant seals, grey seals, and 11 species of non-human primates.

The EVREST hardware is centered around a rugged laptop computer with data acquisition capabilities and custom software. Gold-cup surface electrodes embedded in soft suction cups are placed on the head to measure the brain's responses to tones. The sound projector is embedded inside a larger suction cup and placed on the dolphin's lower jaw.



Screenshot of the EVREST software showing some of the options for generating sound stimuli.

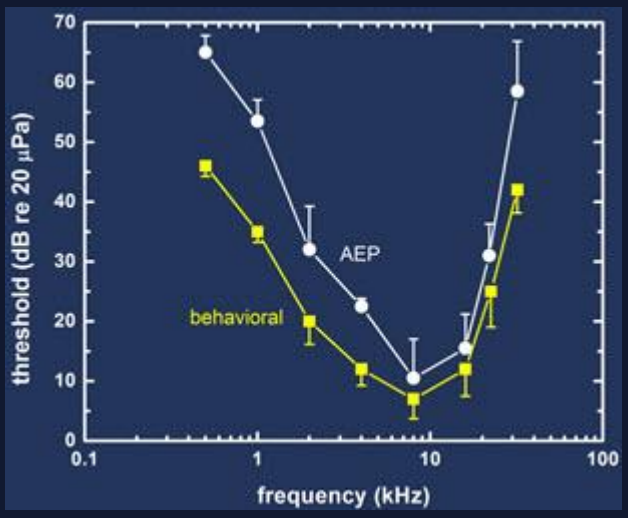


Screenshot of the EVREST software showing the options for analyzing AEP data. The curve at right shows sea lion hearing thresholds simultaneously measured at seven frequencies, from 500 Hz to 32 kHz.

AEP hearing tests with dolphins are often conducted with the animals "beached" out of the water onto foam mats. Having the dolphin out of the water makes the AEPs easier to measure and allows the procedure to be performed simultaneously with physicals or other clinical care. For in-air measurements, jawphones are used to present the hearing test tones to the dolphins. Surface electrodes measure the brain's responses.

AEP measurements on a stranded beaked whale at a rehabilitation facility. AEP methods can be used to evaluate the hearing of stranded animals, to assess the suitability of animals before release, and to better understand why the animal stranded.

Hearing tests being performed on an adult male Northern elephant seal at Año Nuevo State Reserve.



The unique capabilities of the MMP to conduct both behavioral and AEP tests with the same individual have also allowed AEP results to be validated against the more universally accepted behavioral data. This graph compares hearing thresholds measured in a California sea lion using behavioral and AEP methods. AEP thresholds are typically elevated compared to behavioral thresholds but accurately represent the shape of the audiogram — a plot of the hearing threshold versus sound frequency.

Effects of noise on marine mammal hearing

MMP scientists also use behavioral and electrophysiological methods to study more complex auditory mechanisms such as auditory masking and noise-induced hearing loss. Masking occurs when a sound affects the ability to hear another, typically simultaneous, sound. People can experience auditory masking in environments such as restaurants or clubs where the background noise levels are elevated, making it difficult to hear others during conversation. Noise-induced hearing loss is formally called a noise-induced threshold shift. A noise-induced threshold shift is an elevation in hearing threshold after exposure to noise that persists after the cessation of the noise. People can experience noise-induced threshold shifts after exposure to noisy environments such as factories or rock concerts, after operating loud power tools or firearms, or listening to loud music through ear buds. If the hearing thresholds return to normal after a noise-induced threshold shift, the shift is called a temporary threshold shift (TTS). If the thresholds do not return to normal, and some permanent hearing loss remains, the remaining shift is called a permanent threshold shift (PTS).

TTS experiments at the MMP with dolphins, belugas, and sea lions have provided critical data to better understand the effects of noise on marine mammals. These studies compare hearing thresholds measured before and after exposure to various sounds to determine the amount, if any, of TTS and the time required for recovery. The studies are similar to those conducted with people to determine safe exposure levels for people working in noisy environments. The resulting data are widely used by the Navy and others to predict and mitigate the effects of man-made noise on marine mammal hearing.

A bottlenose dolphin participates in a TTS study in a pool. The three suction cups on her head and back contain surface electrodes used to measure auditory evoked potentials (AEPs). She also wears hydrophones mounted on suction cups near her ears to measure the noise exposure.

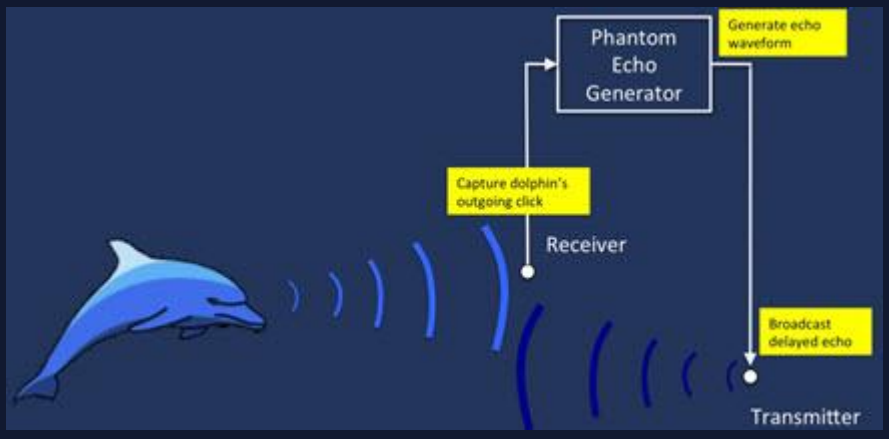
Echolocation

Dolphins have highly sophisticated, natural sonar (biosonar) that allows them to detect objects in the most complex acoustic environments. By echolocating — emitting high-frequency pulses called “clicks” and listening to echoes returning from underwater objects, dolphins can acoustically “see” their aquatic environment in amazing detail. The dolphin's biosonar system has yet to be matched by any manufactured device.

Early dolphin biosonar studies used trained dolphins to detect and discriminate various underwater objects (“targets”), like small spheres and cylinders. The object size, distance, material composition, and background noise were manipulated and the dolphin’s echolocation clicks and performance measured to learn about the capabilities of the biosonar system.

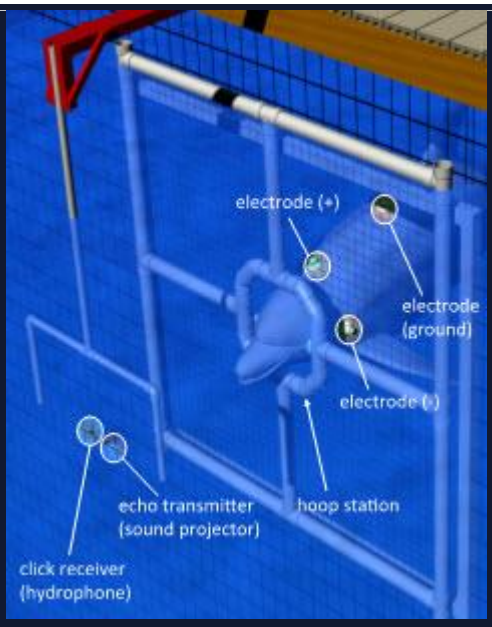
More recent studies utilize “phantom targets” or “phantom echoes”. In these studies, there is no physical target; instead, a hydrophone is used to record the dolphin’s emitted click. The click is then used to electronically create a simulated echo based on the characteristics of some physical object. The echo waveform is scaled in amplitude, delayed in time, and broadcast to the dolphin

using an underwater transmitter. In this fashion, each click emitted by the dolphin results in an echo, although there is no actual physical target. The advantage of using phantom echoes is that they can be manipulated in ways that would be difficult or impossible with physical targets.

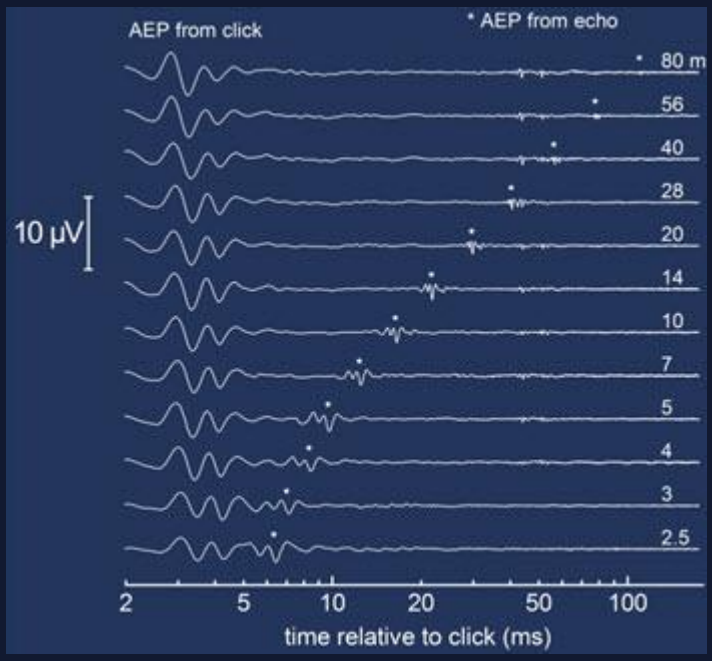


Operation of the phantom echo generator. The presence of an underwater object is simulated by capturing the dolphin's emitted echolocation clicks, then broadcasting delayed signals that resemble the echoes from distant targets.

As sound travels from a source it is naturally attenuated — this means that the echoes from underwater objects get smaller and smaller as the distance to the object increases. To help compensate for this natural change in echo strength with target range, dolphins have evolved several mechanisms, collectively referred to as "automatic gain control". To study automatic gain control in dolphins, MMP scientists combine echolocation studies with AEP measurements. The AEPs can be measured in response to both the dolphin's emitted click and the returning echo. AEPs can also be measured in response to external sounds to map changes in hearing sensitivity that occur with changes in target range.



Schematic of a dolphin participating in a phantom echo detection task while wearing surface electrodes embedded in suction cups for AEP measurements. The hoop station ensures that the dolphin's position is consistent between trials relative to the sound projector and hydrophone.



Auditory evoked potentials (AEPs) measured from a dolphin during an echolocation task with the target range from 2.5 m to 80 m. The AEP caused by the dolphin's own emitted click can be seen between 2–6 ms. The AEP from the echo occurs with an increasing time delay relative to

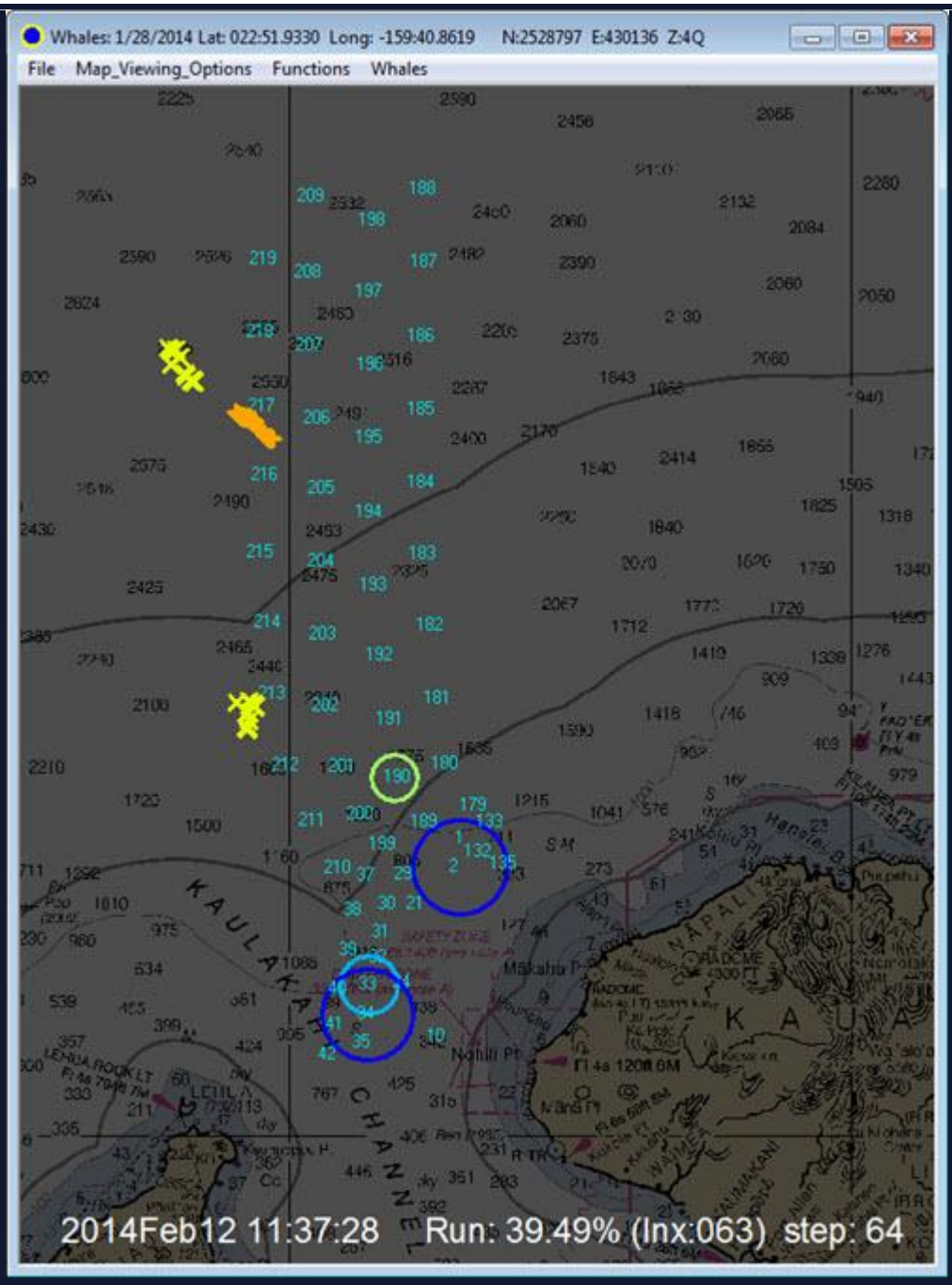
the click — as the range increases it takes longer for the click to reach the target and the echo to travel back to the dolphin. We can learn about automatic gain control mechanisms by examining the rate at which the AEP amplitudes change with target range.

Passive acoustic monitoring for whales

Passive acoustic monitoring (PAM) in underwater environments refers to the use of acoustic sensors (hydrophones) to monitor for underwater sounds of interest. In our case, the sounds of interest are the sounds emitted by whales, natural environmental sounds(e.g., rain), and man-made sounds like active sonar. PAM methods can work in real-time or on previously recorded acoustic data. The techniques can be automated, but at the present time PAM methods are often manually intensive.

MMP scientists have been analyzing acoustic recordings from US Navy hydrophones at the Pacific Missile Range Facility (PMRF) instrumented underwater range, located off the west coast of Kauai, Hawaii, since 2002. The PMRF range includes over 200 hydrophones used to track underwater objects in support of US Navy undersea warfare training. Over 40 of the hydrophones can detect low frequency baleen whale calls, such as the 20-Hz pulses emitted by fin whales. Efforts at the Navy MMP have focused on analyzing existing PMRF data to detect, classify, and localize marine mammal species known to frequent the area and to estimate species' densities. The techniques that have been developed can also be applied to acoustic data from other areas. Algorithms exist to automatically detect, classify and in many cases localize the following species of cetaceans: Balaenoptera borealis (sei), B. brydei (Bryde's) and B. physalus (fin); Balaenoptera acutorostrata (minke) and Megaptera novaeangliae (humpback); and the Ziphiidae family of beaked whales. Further data processing can be used to localize individual baleen whales, determine beaked whale foraging group dives, estimate species' densities and analyze in conjunction with US Navy mid-frequency active sonar (MFAS) training for monitoring the behavioral effects on marine mammals.

Concentrated data collections from PMRF are also obtained during focused research efforts and before, during and after select US Navy training events involving surface ship MFAS such as the AN/SQS-53C sonar (on destroyers and cruisers) and the AN/SQS-56 sonar (on frigates). Automated PAM algorithms were developed and tuned to detect and localize these active sonar signals to aid in analysis of potential marine mammal behavioral effects due to MFAS activity. The data collections during MFAS training allow estimates of the levels of MFAS that marine mammals are exposed to by utilizing standard acoustic propagation modeling software such as the US Navy's Personal Computer Interactive Multi-sensor Analysis Tool (PCIMAT). Estimates of received sound levels are currently being made not only for animals localized using PAM methods but also collaboratively with other researchers conducting animal tagging and marine mammal observations on board US Navy surface ships and aerial platforms.



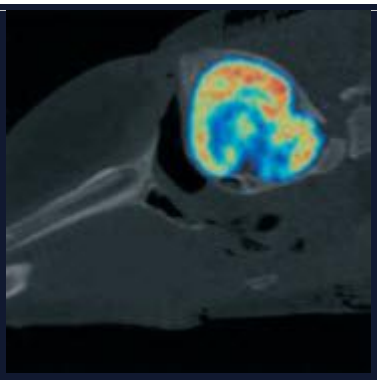
Sample of graphical user interface showing three species of marine mammals detected and localized at the Pacific Missile Range Facility off Kauai, Hawaii on 12 Feb 2014. Approximate locations for the 62 hydrophones utilized in the analysis are indicated by blue numbers. Two individual minke whales indicated with the yellow X symbols and one fin whale indicated with the orange + symbols – these are repeated localizations over the 75 minute period of time from 10:22 to 11:37 GMT. Three beaked whale

foraging dives detected and indicated by colored circles: one dive at hydrophone 190 indicated with one circle, one dive at hydrophone 2 indicated with one circle and one dive detected by hydrophones 33 and 34 indicated by two circles. The circles' diameters and colors are coded in proportion to the number of FM foraging clicks detected in the ten minute period 11:27-11:37 GMT.

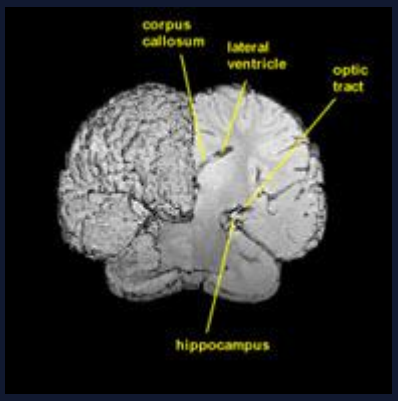
Medical imaging of auditory processes in dolphins

Dolphins have enlarged auditory processing centers within the brain, which reflect their ability to echolocate — to use high frequency biosonar for the purposes of navigation and foraging — and to efficiently process sound. In addition to their biosonar, dolphins also use sounds within the human range of hearing for communication (such as whistles). The two different types of sounds, and studies of the reception of those sounds, has led to the speculation that dolphins have a dual sound reception/processing system – one for dealing with lower frequency whistles, and another for processing the ultrasonic pulses associated with echolocation.

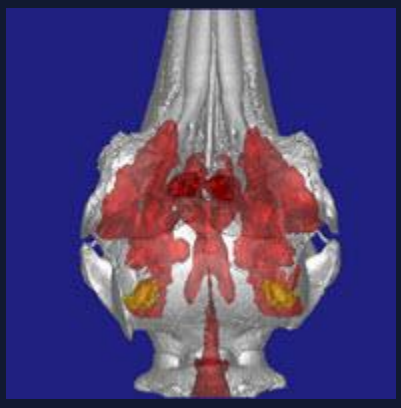
In an ongoing effort to understand how dolphins and other toothed whales process sound, MMP scientists study the anatomy and auditory physiology of dolphins in vivo, through the use of biomedical imaging techniques. The use of computed tomography (CT) and magnetic resonance imaging (MRI) permits the anatomy of living dolphins to be studied non-invasively and in detail. The use of single photon emission computed tomography (SPECT) and positron emission tomography (PET) permits physiological processes, such as regional rates of blood flow and tissue metabolism, to also be studied. The merging of structural and functional imaging data permits physiological processes to be tied to specific anatomical sites and provides a better understanding of auditory processing. To date, the effect of sleep on cerebral blood flow, the normal metabolic activity of the brain, and the effect of sounds on auditory processes within specific regions of the brain have been studied in dolphins through biomedical imaging methods.



The metabolic activity of the dolphin brain as determined from the registration and fusion of PET and CT images.



The anatomy of the dolphin brain as determined through MRI.



The relationship of reflective air spaces (red) to the ear bones (yellow) and skull (white) of the bottlenose dolphin as determined via CT.

Research internships

Opportunities periodically exist for student interns to assist with data collection and analysis for bioacoustics research. For more information, visit the Internship Opportunities [LINK TO http://www.public.navy.mil/spawar/Pacific/71500/Pages/Internship.aspx].

Sample publications

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TRAINING

Ever since the Navy realized the amiability of dolphins and sea lions and their potential for working in the sea with human partners, the Navy Marine Mammal Program has relied on the proven techniques of operant conditioning, emphasizing the use of positive reinforcement (correct responses are rewarded while incorrect responses are ignored) to train its animals. The early history of the NMMP coincided with the adaptation and growing use of those techniques among marine mammal trainers and has made a large contribution to pioneering and developing methods commonly used in the industry today.

Training is an important element of a Navy animal's life. In addition to achieving the remarkable behavioral feats the animals perform in the open ocean, training also supplements husbandry and care practices, and provides the mental and physical stimulation that contributes to overall health and welfare.

INTERNSHIP OPPORTUNITIES

The Marine Mammal Program offers two types of student internships at the Navy marine mammal facility in San Diego:

- Animal Care and Training
- Veterinary Medicine

Interested students are chosen from all over the country to participate in these voluntary internships that provide valuable exposure and experience in various aspects of marine mammal training, husbandry, and research.

Animal Care and Training Internship Program

In the Animal Care and Training Internship Program, students provide support to Navy Marine Mammal Program Staff while getting a dynamic educational experience in the field of marine mammal care and training. The internship program is designed to give undergraduate students hands-on experience with marine mammals. Students will be responsible for a number of support tasks with dolphins and sea lions throughout the course of the internship. These responsibilities will include diet preparation, sanitation, and equipment and facility maintenance. Interns may also have the opportunity to assist the marine mammal training staff in husbandry and open ocean training. In addition, they will provide support to the animal care staff in animal physicals and assist with a number of different marine mammal research projects. Lectures and field trips will also be conducted throughout the term to enhance the learning experience. It is particularly suited for juniors and seniors in fields such as biology, zoology, marine science, animal behavior, psychology, and veterinary science. This is a volunteer program and students must commit to 40 hours per week for 16 consecutive weeks.

Veterinary Medical Externship

The Veterinary Medical Externship is designed for veterinary students, preferably during their senior level or fourth year at an accredited veterinary college. Four students are selected each year to participate in the 4-6 week externship; only one student is on-site at a time. During this time, they are given the opportunity to observe and participate in various clinical activities under the direction of the veterinary staff. In addition, they are expected to select and complete a clinical project in marine mammal medicine during their stay.


Johnson

The internships are voluntary, and students are responsible for their own transportation and housing arrangements. Students must be U.S. citizens in U.S.-accredited schools within the United States.

Students interested in the Animal Care and Training internship are encouraged to send a resume, letter of intent including career goals and reasons for wanting the internship, an unofficial or official copy of their transcripts, proof of medical insurance, proof of U.S. citizenship, and a minimum of three letters of recommendation from professors or employers to the address below.

Students interested in the Veterinary Medical Externship should also send a letter to the address below. This letter should include reasons for wanting to participate in the program and dates of availability. It is

recommended that applicants list at least three prioritized availability dates. In addition, students must submit a curriculum vitae, two letters of reference, and proof of U.S. citizenship.

Attn: Coordinator of Volunteer Opportunities

Space and Naval Warfare Systems Center Pacific, Code 71510

53560 Hull Street

San Diego, CA 92152

Or fax it to (619) 553-2678.

For further information about any of the Navy Marine Mammal Programs internships, please send an email to nmmp_intern@spawar.navy.mil.