

## Trained Fish for Littoral Protection: Mine detection & Defense “Swimmer” Defense

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Long before tragic bombing of the USS Cole while stationed in Yemen, which killed 17 sailors, the US Navy has been investigating ways to better protect ships from attack while in foreign harbors. Of particular concern are defense against underwater mines, and “swimmers” - people or trained aquatic life intent on planting explosives on or near a ship’s hull.

The Office of Naval Research has several ongoing programs [1] investigating the use marine mammals (dolphins, seals and sea lions) to serve in such a protective role. While these animals offer several advantages, including high intelligence / trainability, and in some cases special sensing capabilities (e.g. dolphin sonar), they have several serious drawbacks as well. These include:

- Environmental Sensitivity – they can only operate in a narrow range of water temperature and quality
- Limited Operating Envelope – they can operate to a certain depth and stay underwater for a limited length of time.
- Independence – they sometimes refuse to follow their training
- High maintenance – they are difficult to care for, requiring lots of room to exercise. It is especially hard to transport and house them on a ship.
- Animal Welfare Concerns – Ethical issues associated with confining and risking the lives of sentient marine mammals.

Our experience training various species of fish to do lots of different tricks suggest fish could be trained to seek, locate and (if necessary) manipulate objects on and under the surface of the water, such as mines and “swimmers”. We've been amazed at what fish have been able to learn using the same techniques of positive reinforcement and shaping employed to train marine mammals. These results are demonstrated on the ‘Fish School’ web site [2].

The ability our fish have demonstrated to fetch objects from the bottom of the tank seems particularly germane for ship protection applications. Clearly dolphin sonar has the advantage of being able to penetrate the ocean floor to some depth to detect mines, and more easily distinguish mines from rocks based on their sonar return. But to their advantage, having fish resident on a ship / sub would seem more tractable, and they could stay under water hunting & patrolling for longer periods of time. Furthermore, fish live in a variety of habitats, ranging from the warm tropics to the frigid polar regions. So fish can potentially cover a wider range of water temperatures and qualities than marine mammals. Overall, the idea of using trained fish ship protection while entering or inside foreign harbors has substantial merit.



Bomb damage to the hull of the USS Cole

To balance dolphin's sonar sensing abilities, there is a lot of evidence that fish have quite extraordinary sensory capabilities as well. Some fish have very good eyesight and might be capable of such discrimination. But vision is unlikely to be too most effective, since mines can be buried or camouflaged.

Olfaction would seem like a much more promising candidate. Some fish have a very acute sense of smell and might be able to sniff out explosives like dogs do.

*"Fish have a very sensitive sense of smell. How sensitive? They can detect concentrations of chemicals as low as one part per trillion. That's the equivalent of one ounce of chocolate syrup in a million railroad cars full of milk. Salmon can detect smells from the waters where they were born from hundreds of miles away [and obviously home on it via their sense of smell]." [3]*

Perhaps most intriguing, many types of fish, including sharks, rays, catfish, sturgeons have an amazingly well developed ability to detect tiny electric fields.

*"As early as 1917 scientific studies had revealed that a number of animals including fish, demonstrated responses to the presence of tiny electric fields in their environment. Some of the earliest work was done on catfish which turned out to be very electrically sensitive. Scientists, PARKER and VAN HEUSEN, tested blindfolded catfish in an aquarium. When glass or inert rods were inserted into the tank, there were no reactions. However, when metal rods were inserted, there were immediate reactions. With some metals, the catfish would swim to the rods and with other metals they would swim away. The reactions came from galvanic reactions between the metals and the water. Later the same scientists created the same reactions with induced electricity instead of the rods.*

*By the 1950's hundreds of fish were classified and ranked by their degree of response to an anode (electrical) reaction. It was learned that many fish have the capability to sense the electrical impulses given off by other fish and some can even sense the tiny voltage gradients created by ocean currents and river water movements in the presence of the earth's magnetic field. All fish have a reaction to an electrical field but it differs.*

*Some fish are unique in that they have special cells on their body surface that are electro receptors. These nerve cells have the specific capability of reading electric signals. Sharks, rays, sturgeon and catfish are some of the better known species of this type. Not only are they attracted by an anode reaction but they will use their electro receptors to find prey hidden or buried in the mud or sand. They can sense the electrical nerve discharges of their target.*

*An interesting series of tests on sharks were run by a scientist named KALMIJN in 1971. He successfully demonstrated that sharks and rays use electro sensors to find prey buried in sand. He buried live flatfish. When sharks were stimulated to feed, they would go to the exact spot in the sand and dig out the flatfish. Kalmijn then substituted a charged wire electrode for the flatfish. The sharks would tenaciously dig to the electrode and return time and time again even though they found no prey." [4]*

This suggests it might be possible to train certain types of fish to discriminate between mines and other natural and man-made objects using the unique electrical signature of mines.

John Galloway, the Navy's littoral and mine warfare program executive officer, has pointed out the importance and some of the challenges of littoral (shallow water) operations [5]. According to Galloway:

*"Buried mine detection remains one of the toughest problems out there."*

The description of sharks detecting and digging up buried electrodes seems particularly applicable to this challenging problem.

*Defending ships against enemy swimmers also remains a priority, Galloway said. "Swimmer defense for a ship is important," he said. "It still remains a very difficult problem."*

*Detecting divers is not easy with other clutter and environmental challenges in an area, Galloway said. Galloway also mentioned a need for non-lethal maritime weapons. The Navy is seeking the capability to intercept vehicles in a way that would "not kill people if they really do not have a bad intent," he said.*

If trained sharks were employed, defense against enemy swimmers, either by generating fear (non-lethal) or direct attack (potentially lethal) might be relative straightforward!

Launching and recovering both robots and marine mammals from a ship or sub at sea remains a challenge. According to Galloway:

*We did some testing to be able to launch and recover these vehicles from a submarine," he said Nov. 7 at a defense industry conference in Vienna, VA. "That's still a daunting problem."*

One could imagine transporting medium-sized trained fish in modest-sized tanks (few hundred gallons) on-board a sub, and inserting the fish into the theater of operation via torpedo tubes.

Galloway continues:

*The Navy is looking to shorten the time needed for detection and engagement in the mine neutralization sequence.*

We've been quite successful at training fish to move and manipulate objects. This suggests to me they might be helpful in the mine neutralization sequence, as well as mine detection. Finally, Galloway concludes:

*The Navy wants to reduce manpower and moved toward greater autonomy with this capability.*

Quite clearly, if fish could be trained to perform the detection and some of the neutralization effort, mine clearance required much less human involvement than is currently required.

Overall, it appears there may be a very good match between the Navy's need for more effective littoral defense and the ability of fish to be trained to perform complex sensory / motor behaviors.

We at Fish School would be interested collaborating with Naval researchers to investigate the viability of using trained fish to address the grave risks US military personnel face when stationed in foreign harbors.

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**References:**

[1] *Naval Mine Warfare: Operational and Technical Challenges for Naval Forces*. Committee for Mine Warfare Assessment, Naval Studies Board, National Research Council. 2001. ISBN-10: 0-309-07685-4

[2] <http://www.fish-school.com/gallery.htm>

[3] <http://www.fish.state.pa.us/water/fish/senses.htm>

[4] <http://www.protroll.com/blkbox7.html>

[5] Littoral and Mine Warfare Office Outlines Key Needs for Industry, *Inside the Navy*, November 27, 2006