Ocean Noise Pollution
Quieter Alternatives to Common Sources
Draft Only – Do Not Cite

1.0 Overview

Perhaps the greatest obstacle in the mitigation of ocean noise pollution is that it has only recently been identified as a problem. Heretofore, with the exception of "silent submarines," there has been no particular incentive to design "quiet" into ocean technology. As a result, all human generated sources of ocean noise are either as loud as they can be, or as loud as they need to be.

Now that ocean noise pollution has increased to alarmingly dangerous levels, the significant challenge is that mitigation of the noise will require noisemakers to change their behavior. It will require modifying or abandoning technologies that are mature, "accepted" practices, and it will demand that we proceed with caution so that our "solutions" don't become the threats of the future.

The dominant sources of ocean noise pollution are:

- Military operations, including communication, surveillance, navigation, transportation and "ordinance" (explosives).
- Ocean seismic exploration and mapping.
- Commercial cargo vessels including propulsion, hull coupled mechanical noise and navigation sonar.
- Petroleum and minerals extraction, including drilling and mining operations.
- Marine based civil engineering projects such as bridge building.
- Offshore industrial processes such as factory boats and Liquefied Natural Gas plants.

Each of these sources produces an array of noises that compromise various environments in the sea – from ports and harbors, to coastal waters, to the deep sea.

The various noises can be categorized by frequency – from 'low' to 'high,' and by "form" – from 'impulse' to 'continuous.' These categorical distinctions are set by the intended purpose of the noise and also frame the range and extents of their biological impacts.

For example; low frequency signals tend to travel long distances and penetrate deeply into the surroundings, so they are used for long distance communication. Low frequency noises can interfere with low frequency biological sounds such as the communication and navigation signals of migrating whales. On the other hand, higher frequencies attenuate rapidly over distance but yield fine detail at close range, so they are used for high resolution imaging and close range, high speed communication sonar. These higher frequency signals can interfere with short range biological sounds such as bio-sonar. The current evidence suggests that marine animals are more subject to physical damage due to mid frequency communication sonar than lower or higher frequency sonars.

2.0 “Intentional” and “Incidental” noise

Noises can also be categorized as ‘intentional’ and ‘Incidental.’ Intentional noises are signals that are generated for a specific purpose such as sonar and seismic impulse blasts. Incidental noises are noises that happen as a result of some activity, such as propulsion, mechanical and construction noises.

This distinction is useful because mitigating intentional noises requires either modifying or abandoning functional, useful technologies, whereas mitigating Incidental noises may only require quieting down the particular noise source.

3.0 Mitigation of Incidental noise

The main sources of Incidental noise include the transport noises of vessels – or “shipping noise,” and the noise of marine engineering projects such as bridge building, underwater construction, and more recently, offshore processing plants such as the cooling operations for Liquefied Natural Gas (LNG) plants.

3.1 Mitigation of shipping noise

The most widespread source of Incidental noise is produced by the noise of vessels plying the seas. There are in excess of 85,000 commercial vessels in the water, perhaps as may as 40,000 in service at any time. These vessels travel across the sea and along the coasts in designated “shipping channels” centered around commercial ports and harbors, thus the noise is more concentrated in theses areas.

Commercial vessels accounts for an overall increase in ocean noise of over 10dB (ten times louder) since 1964. The ‘bright side’ of this is that even if we doubled the entire commercial fleet and it would only double the global noise (not multiply it by 10). The challenge is that while the overall level may not increase substantially from where we are now, as human populations spread out, the noise is spreading out as well, polluting larger areas farther away from the current concentrations.

The two main causes of noises from shipping are the noise of propulsion and noises from hull mounted equipment. A secondary concern is the hydrodynamic noise (turbulence), caused by hull friction and drag from equipment mounted on the outside of the hull.

Mitigating propulsion noise can be assisted by modifications in propeller design. While propeller designs are always being “tweaked” for better performance, new drive technologies, such as electrical, hydraulic, variable pitch and “vortex drive” technologies promise to significantly reduce propeller noise (see www.paxscientific.com).

Hull mounted equipment transfers mechanical energy into the hull, which then radiates the noise into the surrounding sea. Mitigation of this noise can be accomplished by mounting noise generating equipment on sound absorbing or resilient mounts, reducing noise energy transfer into the hull.

Hull friction and turbulence is aggravated by biological fouling of the hulls from barnacles and vegetation. Unfortunately chemical mitigation is also a marine pollution source and is increasingly being restricted by law, so periodically vessel hulls need to be mechanically cleaned. Because hull friction also compromises the efficiency and fuel economy of a ship, incentives to clean hulls is driven by the increasing price of fuel.

The challenge with mitigating existing shipping noise is that the ships already in service typically have an expected service life of 30+ years, so any modifications or changes designed to improve their noise will require retrofitting working vessels – at a greater expense than designing noise mitigation on new vessels. On the other hand, incorporating acoustical design practices into new ship designs can significantly improve vessel noise, and over time, decrease the contribution of shipping noise to the overall noise level of the sea.

3.2 Mitigating construction noise

The sources of construction noise include pile driving, and typical materials handling noise such as impact fastening noise and component friction during assembly of marine structures.

Heretofore there has been no incentive to mitigate marine construction noise, but recent bridge construction projects in San Francisco Bay brought up complaints by local residents who were subject to pile driving noise transferring from the bedrock into the structures of their homes. The pile driving also yielded high fish mortality around the construction operations.

This gave rise to noise research on marine construction that yielded a number of good mitigation techniques. One was the use of “bubble curtains” around pile driving operations. This technique decreased the radiated noise to a safer level for the resident fish.

During the research an important characteristic of pile driving noise was also revealed: Noise profiles of driving steel piles was significantly more damaging to fish than the same approximate noise volume of pile driving using concrete piles. This difference seems to be a product of the fast rise times, “ringing” and frequency spectrum of the steel pile driving, as opposed to the slower “thud” and narrower frequency spectrum of the concrete piles. Thus, mitigation of pile driving noise in sensitive areas can include the use of different piling materials, and “damping” the pile driving mechanism where required.

Materials handling noise can also be ‘dampened’ or attenuated by handling procedures. Noise mitigation of handling procedures can be devised to quiet down other types of Incidental construction noise.

3.3 Mitigating offshore industrial processes

Large industrial processes by nature create noise. If these processes involve the ocean, it will transfer that noise into the surrounding sea. Ocean water is often used for cooling during power generation in coal/oil powered as well as nuclear powered plants. Ocean water cooling is also used in Liquefied Natural Gas (LNG) plants while compressing natural gas. The biological sensitivity of subject areas should be incorporated into the implementation of any offshore enterprise. Noise criteria can be designed into the facility using common, existing noise and vibration attenuating technologies.

4.0 Mitigation of Intentional Noise

Intentional noises fall into three categories:

- Sounding signals used to explore and define the dimensions of the sea.
- Communication signals used to convey information underwater.
- Acoustic Harassment Devices" (AHD's) used around aquaculture and fishing enterprises to discourage marine mammals from preying on commercial food stock operations.

Sounding signals include impulse sounds to plumb the structure of the ocean floor, and navigation and ranging sonar used for depth sounding, fish finding and other navigation purposes. Sounding sonars are also used for reconnaissance and locating submerged vessels and objects. The frequency regimes of sounding sonars range from low frequency pulse explosions every 5 – 20 seconds, to high resolution sonar signals – typically up to 80 kHz, depending on the job, the required range, and the required resolution.

Communication signals are used for vessel to vessel communication, submarine communication, vessel to "Unmanned Autonomous Vessel" (UAV) control, "Remotely Operates Vessels (ROV's) and submerged equipment to surface communication modems. The frequency regimes of communication sonars range from 5 Hz – 300 Hz for long distance submarine communication sonars (such as Low Frequency Active Sonars) up to 30 kHz of short range communication sonars.

Acoustic Harassment Devices are by definition designed to annoy marine mammals (and perhaps other marine animals as well). There are AHD's specifically targeted to prevent fish from fouling intakes to hydro-electric plants and seawater cooled equipment intakes, as well as noises specifically designed to keep "net predators" away from aquaculture and fishing operations.

'Intentional noises" are deliberate, so they can be easily controlled by the noisemaker. But because they are designed for specific purposes, noisemakers are compelled to optimize their noise making objective and are typically reluctant to attenuate their noises based exclusively on biological concerns – particularly if mitigation compromises the performance of their operations.

4.1 Mitigation of "Sounding" signals.

Sounding signals are often "just as loud as they need to be" because creating louder sounds only creates additional noise that the sounding receiver needs to sort out. Driving louder signals is also typically more costly. The dominant mitigation strategy for sounding sensors then is to devise ways of sensing and resolving quieter sounds. Getting better resolution from existing and quieter signals requires more sensitive receivers, and more accurate “metrics,” which are capable of integrating and resolving useful signals out of a field of noise. Improvements in these technologies are increasing resolution as a matter of course.

The challenge is that without noise regulations, there is little incentive to create quieter systems, thus if the choice is between getting better resolution using an existing signal with better metrics, or maintaining existing resolution by lowering the signal and using better metrics, the metrics will be employed but the signal will not be decreased.

Accomplishing the “sounding” objectives using non-acoustic means is another mitigation strategy. These means can include using electromagnetic, ferromagnetic thermal or optical sensor systems. The practicality of these various strategies depends on the various energy profiles and composition of the subject target.

4.1.1 Seismic Exploration

While some of the seismic work being done in the ocean involves tectonic mapping (for earthquake and “tsunami” risk assessment), most of the seismic work is done for petroleum and minerals surveys. Of course the logical systematic mitigation for petroleum industrial noise would include using less petroleum, but in lieu of rational energy conservation measures, new and improved technologies must be developed.

This has already occurred to some measure. The current use of “airguns” to create a seismic impulse is a vast improvement over the earlier “tossing dynamite over the transom” technique. Operators familiar with the earlier ‘dynamite technique’ report that these operations were always accompanied by flocks of seagulls, who would follow the boats around, feasting on the carnage of dead fish floating up to the surface after the blasts.

While this type of catastrophic biological impact is no longer evident during airgun operations, there is ample evidence that airgun blasting compromises habitat and damages marine organisms. Airgun blasting involves serial runs of explosions every few seconds, lasting throughout the day, for weeks to months on end. The signals are generated at the surface, and while the airgun arrays aim the impulses downward, they can also be heard for hundreds to thousands of miles away, depending on the location and size of the operation. Even without the same ‘instantaneous evidence’ of dead fish that dynamite blasting causes, it is precautionary to assume that airgun blasting would have a negative synergistic impact on marine animals.

One way of limiting the reach (and required power) of these signals would be to generate signals closer to the target. This would help localize acoustical spread throughout the sea and eliminate the need to penetrate the water column twice (up and down) with an impulse. Unfortunately due to the physics of the environment, using bottom mounted signal generators is currently not practical.

A variation on this strategy would be to mount the receivers on the bottom. This strategy would improve resolution and thus theoretically allow for a decrease in impulse signal level. This strategy may prove more practical, but nonetheless represents a significant expense to the already strapped oil and gas developers.

A second strategy would involve towing multiple receive arrays from more than one vessel. Currently the airgun arrays and the sensor arrays are towed behind a single vessel. This facilitates send and receive timing because the entire operation is traveling on the same platform. With new, cost effective global positioning and synchronization systems, multiple receive arrays can be towed from two or more vessels. The multiple receive signals can be synchronized and co-processed, yielding higher resolution results and thus allow the use of quieter send signals.

A non-acoustic targeting strategy is currently being developed that uses electromagnetic (EM) pulses to distinguish differences in substrate materials. This technology can help hone in on oil deposits, though it does not yield the resolution required for successful oil field mapping. The advantage is that electromagnetic surveying will allow operators to hone in on likely deposits, limiting the required range of acoustical based testing. Unfortunately, we do not know if or how EM testing will impact the electromagnetic sensing systems of various sea animals. (We know that elasmobranches have sensitive EM sensors, but are currently unaware of this perception mode in other marine animals.

Another non-acoustic targeting strategy involves thermal mapping. This is a low resolution prospect, but thermal properties of oil deposits (and other tectonic properties) can be extracted and correlated from satellite and high altitude thermal maps.

These non-acoustic technologies are always being improved, though currently the dominant incentive for technological improvement is economic. Enforceable legislation limiting the environmental impacts of ocean noise will give industrial concerns added incentives to improve exploration and extraction technologies.

4.1.2 Mitigating navigation noise.

The word "sonar" is an acronym derived from "SOund Navigation And Ranging" so much of what we are familiar with in sonar technologies are navigation signals. Navigation systems include underwater beacons, depth sounders and submerged obstacle avoidance systems. Typically these systems operate in the 1kHz to 50kHz range. Individually they are not necessarily loud, and their range is limited by their higher frequencies. Due to the long history of using these types of signals for "fish finding" there is currently little concern for their effects on marine organisms, though due to the increased use of these signals from recreational, commercial and industrial users, further research into the effects of these signals on marine animals would be warranted.

The use of underwater beacons dates way back in maritime history with the use of submerged bell buoys that humans could hear through the hulls of their boats. These devices would give mariners an audio warning of some treacherous submarine features before they sailed down upon them. Currently various navigation beacons are being placed in high traffic and high use areas to help sea pilots locate and situate their surface vessels much in the manner that radio beacons help airplane pilots navigate around airways and landing fields. They are also being mounted to underwater equipment to help locate them during use.

The increased reliance on global positioning systems (GPS) in modern navigation should decrease dependence on certain types of underwater beacons. Equipment mounted beacons will always have a place in marine enterprises, particularly as we rely more on AUV's to get the work done.

4.2 Mitigating communication noise.

Communication noise falls under two categories; communication or control of equipment, and communication with other humans. These categories fall into two classes; non-military communication (including commercial/industrial communication and academic research), and military communication. These categories include many of the same technologies, but the class distinction is important because the class objectives are significantly different.

The non military objectives include 'cost effectiveness' which includes deploying systems that are adequate for the job. The military objective is not so constrained. The military needs systems that are "battle hardened" and "well margined," and they have the capacity and resources to make noises that are much louder. Due to the military role in society, they are also more challenging to legislate. (Due to these distinctions, this paper will examine military noise sources and mitigation objectives in a separate section below.)

While communication signals are increasing in number and acoustic density throughout the oceans, the types of signals are also changing significantly. Until recently communication signals were mostly "analog" signals – chirps, bleeps and frequency modulated (FM) signals. In many cases these analog signals were similar to biological signals produced by marine animals. Recent digital technologies have introduced communication signals that are unique to human enterprises and heretofore have not been found in biological environments. These new signals have wave shapes and rise times that marine animals are not adapted to and thus pose a significantly greater risk to marine animals.

Another recent development is the increasing use of lower frequencies to communicate over long distances. Systems such as ATOC (now NPAL)[1] and Low Frequency Active Sonar (LFAS). Using frequencies from 5 Hz to 300 Hz, very loud signals can be projected thousands of miles across ocean basins.

4.2.1 Mitigating "digital" communication signals.

The best way to mitigate digital communication signals is to examine the problem and limit the use of these signals. Analog signal technologies can be employed that yield the data rates and/or resolution of digital signals without the risk. Existing technologies such as FM, "spread spectrum" and "time correlation" techniques can be enhanced with faster

[1] The ATOC (Acoustic Thermography of Ocean Climate) program was subsumed by the North Pacific Acoustic Lab Acoustic Thermometry program.

computer processing, software enhancements, more accurate synchronizing systems, and global position systems.

4.2.2 Mitigating non-military communication noise

Communication noise includes underwater communication to and from equipment such as unmanned autonomous vessels (UAV"s), oil well-heads and other remotely controlled submersible equipment. Until recently most of these systems were tended by a live crew at the surface, and the required communication distances were in the range of a few miles. These applications were well served by lower volume and higher frequency signals and required a range of only a few miles.

Increasingly, UAV's and remotely controlled equipment are becoming more autonomous, operating unattended and at greater distances from surface modems. Some of these systems communicate by way of moored radio communication buoys that uplink to satellites. Other UAV systems include "sea gliders" that collect data while submerged, surface to up-load the data to satellites, then re-submerge to continue the mission.

Various types of UAV's are increasingly being deployed; some operating in concert with as many as eight "sister vessels" communicating through underwater acoustic networks. These technologies are being developed largely without examination of the biological impacts that they might incur. This development is increasing the density of communication noise, and the longer range requirements of UAV are bringing the signal frequencies down and volumes up.

The growth in these signals is yet another field where the global ocean noise floor is increasing – unregulated by any law or enforcing organization. These systems are being deployed without examining the impacts that their sounds may have on marine animals. A strong mitigation strategy will require understanding the extents of the problem, designing solutions, and legislating accordingly.

5.0 Military Communication

> "In the First World War, the vessel of dominance was the Destroyer. In the Second World War it was the Aircraft Carrier. In the 21st Century, the vessel of dominance is the Submarine"
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> - From a US Navy global security statement.

Perhaps the greatest challenge to the global ocean noise problem is the militarization of the entire ocean. In prior times naval operations were defined by strategic locations of national interest and the "Theaters of War." In our times the entire planet is considered "a strategic location," and the idea of "Theaters of War" is being replaced by the idea of "Global Security."

From an ocean policy perspective the challenge lies in getting national governments and their navies to cooperate in biological conservation of the global commons. Often these cooperative measures are perceived by the national navies as an impediment to their strategic and tactical missions.

Much of the current and growing ocean noise problem is growing out of the reliance on submarines. Until the last few decades of the 20th century, militaries often relied on a "show of strength" to prevent conflict. The shift to submarines marks a significant change in global military strategy. The dominant characteristic of any submarine is that they are surreptitious, so the time-tested "show of strength" has been replaced covert operations and surveillance.

As a class, tactical, "attack" sonar communications technologies tend to be more invasive and environmentally damaging than strategic and defensive technologies.

5.1 Submarine Communication

The operational challenge of submarine communication is that while being in continuous contact with their national commanders, submarines need to remain concealed. Until recently global submarine communication depended on radio contact. Because seawater is largely opaque to radio waves, submarines would either surface to get their mission directives, or drag long surface antennas to stay in contact by way of low frequency radio communication (while traveling at a concealed depth).

Also until recently submarine operations were often attended by support vessels; ships, planes and helicopters that would be in the "general vicinity" of a submarine, maintaining contact through penetrating Extra Low Frequency (ELF) electromagnetic communication, or acoustical contact. This is no longer acceptable because the attending vessels betray the location of their respective submarine operations. Additionally, surreptitious radio communication has been thwarted by surveillance satellites with magnetic sensors that could "see" submarines or their antennas from space. The situation is aggravated by the "moments notice" requirements of instantaneous military readiness that require submarines to be in continuous contact with their command.

The world navies are addressing this liability with the use of low frequency active sonar (LFAS) that allows communication to submarines over large distances. In this strategy communications vessels can transmit acoustical to submarines over hundreds to thousands of miles using very loud, long wavelength acoustical energy. While this technology exposes the broadcast platform, it does not reveal the receiving submarine. Because of the broadcast distances involved, the broadcast vessel can stay well out of harms way.

Of course the idea of being in continuous communication at 'stealth depth' with LFAS seems like a great idea to a submariner. Unfortunately, the idea of saturating millions of cubic miles of ocean with low frequency noise seems like a lousy idea to anyone interested in the bio-acoustic health of the sea. One clear mitigation objective for surreptitious communications is to localize communication signals while maintaining the stealth of the submarines. This can be accomplished in a number of ways.

Increasingly the use of small Unmanned Underwater Vessels (UUV's) allow a submarine to be attended by small, undetectable communications platforms that serve as communications relays between radio satellite communications and undersea acoustic or Extra Low Frequency (ELF) electromagnetic communications.

A second strategy is to deploy arrays of sonobuoys in strategic areas that accomplish this same task without the propulsion needs. A third strategy is to lay an array of stationary sea bottom transponders wired to land based communication facilities that communicate to submarines on a localized “call and query” basis.

Other issues of military communication system noises are similar to those addressed in sections 4.2 “Communications Noise” above. The differences are cast under the rubric of military might and tenacity. Characteristic of this is the use of acoustic “jamming” signals in areas of military engagement.

In any hostile marine environment where naval vessels are deployed, there will be many types of communication and navigation signals blasting away. These include strategic communication and navigation signals as well as tactical ‘jamming’ signals. These jamming signals are used to overpower enemy sonar communication, and maim or kill any hostile humans or animals (e.g. trained dolphins) that may be in the water. This creates an extremely loud soundfield around any navy fleet operations that is acoustically toxic.

Mitigating communication and navigation noise in a battlefield may seem mute, given that habitat conservation is not a high priority during armed conflict. But there are good strategic reasons for quieting down strategic and tactical communications. Some compelling reasons include avoidance of hostile long range torpedoes that can hone in on mid-range and high frequency sound sources.

Another compelling reason is that some of the developing technologies such as “time correlation” techniques could theoretically be so quiet as to be below the ambient noise floor. These technologies depend on accurate synchronization of the send and receive platforms, and lower cost stable clocks are making accurate synchronization more achievable. This characteristic yields a number of valuable benefits: If the signal is at or below the ambient noise floor, it is difficult to identify and intercept. These technologies lend to surreptitious communications because even if the signal is identified, unless the receiver is “time synchronized” to the communication clock, there is no way that the communication can be intercepted. Of course the third benefit is that the signals can be so quiet that they would not disturb the bio-acoustic environment.

5.2 Submarine Surveillance

There are two sides of submarine surveillance; finding hostile submarines, and concealing “friendly” submarines. Finding submarines currently relies on a number of surveillance technologies: Ocean based surveillance includes both active and passive sonar. Other technologies are used above water. These are deployed from either reconnaissance airplanes or surveillance satellites. Of all of the surveillance techniques, only active sonar poses a bio-acoustic threat, so it is worth reviewing the array of surveillance technologies to understand the field, and perhaps tease out systematic alternatives that are environmentally more benign.

5.2.1 Passive Surveillance Sonar

The difference between “passive” and “active” sonar is that passive sonar involves just listening to the environment, whereas active sonar involves sending an acoustic signal out into the environment and listening to its propagation or reflections.

Passive sonar is the most benign. The objective of passive sonar is to identify and locate sources of underwater noise. Man made sounds, both intentional and incidental can reveal much information about their sources. A vessel can easily be identified by the type of noises it creates; the number of propellers, its velocity, auxiliary equipment, sonar types, and other aspect of a vessel will reveal the purpose and intent of an ocean craft. There are a number of techniques that have been successfully used for decades that can accurately identify and pinpoint noise sources throughout the oceans.

These systems include stationary or “fixed system” arrays, and deployable arrays. Working together, along with other surveillance and reconnaissance technologies deployed by the U.S. Navy, this system is called the “Integrated Undersea Surveillance System (IUSS). The IUSS is an outgrowth of, and includes the SOSUS system developed in the 1950’s and successfully used since then. Improvements in sensor technology, processing techniques like “steered phased arrays,” and in resolving algorithms have kept these passive technologies honed and current. Continued advances in these passive systems offers the most promising mitigation for military active surveillance sonar.

Another passive system is the deployable Multi Line Array Systems. These are deployed in a few configurations, including the Surveillance Underwater Reconnaissance Towed Array Sonar System (SURTASS), stationary Vertical Line Arrays (VLA’s) and submarine towed arrays such as the TB-29 and ‘Acoustic Rapid Commercial-Off-The-Shelf (COTS) Insertion’ (ARCI) systems. In another configuration the Advanced Deployable System (ADS) is a theater-deliverable acoustic surveillance system that can provide continuous acoustic coverage over vast ocean areas of ocean for extended periods.

One inherent beauty of passive systems is that as navies develop and use them, the need for active systems decreases. This in turn decreases the overall noise contribution of the active systems in the ocean environments. This in turn improves the definition and accuracy of the passive systems because the passive systems do not have to resolve signals through a field of arbitrary sonar noise. Meanwhile, as the sonar soundscape quiets down, active systems become more of a strategic liability because they become “spotlighted” by their own noise.

To thwart the effectiveness of the passive sonar technologies, submarines are being deigned with quieter propulsion systems. The strategic question remains is whether the passive listening systems can keep up with the quieter submarine propulsion and hull technologies. But if submarines continue to use active sonar for navigation and communication, the question of quieter propulsion systems loses some of its relevance.

5.2.2 Active Surveillance Sonar

Active sonar involves sending a signal out from a platform and listening to how it propagates or reflects off of the surrounding environment. As in non-military navigation and ranging sonar (section 4.1.2), the frequency typically ranges between 1 kHz and 50 kHz, though specialized systems extend down to a few Hz and well above 100kHz. The military is not cost constrained, and thus can easily produce sonar signals thousands to hundreds of thousands of times louder than any natural sound found in the sea in any frequency range. Thus military active sonar poses the probably highest threat to the ocean bio-acoustic environment.

Mitigation of active surveillance sonar, like communication sonar, involves improving receivers, software, and resolving algorithms. For example; Multi Line Array Systems in conjunction with active signals can improve resolution. An improvement on the Multi Line Array can be realized by deploying multiple receive platforms, synchronized to a common clock and spatially synchronized by GPS systems. While the processing power to achieve this is high, the computing capabilities are well within our grasp.

The challenge of mitigating active sonar surveillance is that unless there is some incentive to quiet down the signals, the tendency will be to improve resolution without regard to volume. This was revealed to me in a comment made by Bob Gisner from the Office of Naval Research (ONR) a few years back. He suggested that when better performance is derived by improving the receivers and “metrics,” the signal levels will also tend to increase to improve resolution. His comment implies that there would be no incentive for navies to limit noise if increasing noise would also increase performance – regardless of the actual performance requirements of any system.

5.2.3 Non-sonar submarine surveillance systems

Advances in sky-based surveillance systems dramatically improve the possibilities of seeing hostile vessels. Airplane mounted Magnetic Anomaly Detection (MAD) systems have been used since WWII. Since 1959 MAD systems have been deployed on the P-3 Orion Anti-Submarine Warfare aircraft. The current revision of the P-3C also uses an infrared detection system, is coordinated with a distributed sonobuoy reference system (communicating with 20 sonobuoys simultaneously) and can simultaneously communicate with four different satellites. As such, the plane serves as an integrated, multi-spectrum surveillance coordination platform that resolves passive and active sonar (from the sonobuoy array), magnetic anomalies, thermal information (from the infrared sensors) and surveillance data from the satellites. This complimentary and integrated surveillance platform allows a deep view into the ocean that few ‘current technology’ submarines can evade.

Satellite surveillance technologies are also increasing in sensitivity, and new technologies are being employed that can “see” submarines down to a significant depth. These systems include MAD systems, infrared sensors, Synthetic Aperture Radar (SAR) and laser surface scanning technologies. These technologies have the combined capability to see submerged vessels to a depth of 300 – 600 feet, depending on weather, surface conditions, and the disturbance signature of the target vessel.

This depth conforms to the operating envelope of a majority of the existing hostile submarines. While U.S. nuclear submarines can operate deeper than 600 feet, these greater depths pose a high operating risk (due to crushing pressures). Vessels that are built to handle these depths are very expensive to produce and are uncommon in all but the most advanced western nations. For example; China is currently attempting to build a nuclear submarine that can handle these depths, (Type 094) but according to published intelligence, they have yet to achieve their goal.

5.3 Mitigation of Military Ocean Noise Summary

A review of global military strategies of all nations indicates that many nations are not supporting their submarine fleets due in large part to the high cost. The US and Europe are mostly driving the Submarine strategy and have established military dominance of the sea at this time. While this does not decrease the risk of any single hostile act occurring, current and developing surveillance technologies that can identify and locate hostile submarines while preserving the bio-acoustic health of the ocean.