Surveillance and Enforcement of Remote Maritime Areas (SERMA)

Surveillance Technical Options

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Executive Summary

Some of the most pristine marine ecosystems remaining on earth are in remote areas far from human population centers, both within national jurisdiction or beyond, on the *high seas*[*]. Unfortunately even these areas are under pressure from the effects of human activities. Recognizing this, many countries have begun to manage activities in remote maritime areas as well as seeking to conserve areas of high ecological value through the establishment of marine protected areas. In recent years some very large offshore protected areas have been established within national EEZs and in addition some are now also being established on the high seas, through the efforts of several international organizations. Without effective enforcement however, these remote managed areas will remain no more than paper management plans and paper parks.

Surveillance and enforcement is more challenging in large, remote areas than for near-shore MPAs as they are often far from populated land, and therefore difficult to reach with traditional manned patrols, radar or other short-range monitoring tools. Advanced technologies have been used successfully for surveillance of large areas, and there is great potential for expansion; however an associated response by law enforcement personnel is still essential to confirm and prosecute violations. Combining surveillance technologies into a single enforcement package has considerable cost-saving potential and is emphasized throughout this report. Additionally, the obvious and targeted presence of law enforcement reduces attempted infractions since there is a perceived significant risk of being caught.

This document reviews and evaluates a range of existing technological options for the surveillance of remote marine managed areas. Some of these technologies are currently in use by fisheries management agencies; some are currently the purview of groups like the military or security agencies; and others have hitherto been unexplored for such purposes. As commercial fishing (regulated or otherwise) is the single greatest pressure to most remote marine ecosystems, followed by vessel-based pollution, we pay particular attention to technologies for the monitoring of such activities. The paper initially discusses surveillance technologies for cooperative vessels; that is, those that are participating in a managed activity where monitoring systems are obligatory. The majority of the paper however describes the range of sensors and platforms that can be applied to the more challenging task of monitoring non-cooperative vessels.

Surveillance technologies alone are insufficient to ensure compliance, but they are a necessary component. This first paper in the series does not look at questions of integrating surveillance technologies into an enforcement regime; neither does it consider issues improving compliance. These are clearly key issues, and we anticipate giving these issues the space they deserve in subsequent publications.

[*] "high seas" refers to the water column beyond a state's inland waters, territorial sea, archipelagic waters, exclusive economic zone, and generally is beyond 200 nm from the coast.

Table of Contents

Acronyms

AIS: automatic identification system

AUV: Autonomous Underwater Vehicle

CHRISS: compact high resolution imaging spectrograph sensor

COMINT: communications intelligence

DARPA: Defense Advanced Research Projects Agency

ECDIS: electronic chart display and information system

EEZ: Exclusive Economic Zone

ELINT: ELectronic Signals **INT**elligence

EMS: electronic monitoring system

EU: European Union

FLIR: forward looking infrared

FMC: fisheries monitoring centre

GMDSS: global maritime distress and safety system

GPS: global positioning system

GT: gross tonnage

HFSWR: high-frequency surface wave radar

IMO: International Maritime Organization

IR/UV: infrared/ultraviolet system

IUU: illegal unreported and unregulated fishing

LEAF: Laser Environmental Airborne Fluorosensor

LFS: Laser Fluorosensor

LRIT: long range identification and tracking

MDA: maritime domain awareness

MMSI: maritime mobile service identity (number)

MWR: scanning microwave radiometer

NATO: North Atlantic Treaty Organization

NM: nautical mile (1.852 kilometers; 1.15078 statute miles)

OTH: over-the-horizon radar

RACON: Radar beacon

REAP: rapidly elevated aerostat platforms

RFMO: regional fisheries management organization

SAR: synthetic aperture radar

SLAR: Side-Looking Airborne Radar

SOLAS: Safety Of Life At Sea convention

UAV / UAS: Unmanned Aerial Vehicles / Systems

USV: Unmanned Surface Vehicles

US: United States of America

USCG: US Coast Guard

VMS: vessel monitoring system

Surveillance and Enforcement of Remote Maritime Areas (SERMA) Surveillance technical options paper

Introduction

Remotely-located or open ocean marine areas include some of the last remaining near-pristine habitats; from the vibrant reefs of the central Pacific to rich seamount spawning grounds, many of these areas support high levels of biodiversity and productivity. Unfortunately, like so much of the oceans, even these remote areas are under threat from human activities such as pollution, anthropogenic climate change, and destructive fishing practices. Unless these threats are addressed, these ecosystems may suffer irreversible damage. Recognizing these threats, many countries and multinational groups have begun to manage and conserve areas of high ecological value, most notably by the establishment of marine protected areas. In addition to areas under national jurisdiction, the World Summit on Sustainable Development, the United Nations General Assembly, the CBD Conference of Parties and the OSPAR Commission, amongst others, have established goals to protect significant and vulnerable ecosystems in the high seas within the next few years (we recognize that protecting high seas areas involves complicated legal issues, but these will not be addressed in this document).

Some very large and remote MPAs have been established in recent years; the Phoenix Islands Protected Area (410 500 km^2) and Pacific Marine National Monuments (224 311 km^2) for example, and these present a much greater management challenge than smaller coastal areas. By definition, ‘remote’ areas are far from population centers, and therefore difficult to reach with manned patrols, or other traditional short-range monitoring tools. However, without effective implementation of protective measures, remote managed areas will be no more than ‘paper parks’. Effective surveillance is critical to enforcement of violations, and increasing compliance with regulations. Some advanced technologies have been used successfully for surveillance purposes, but there is great potential for expansion, although these technologies do not negate the need for active law enforcement presence.

This document reviews and evaluates a range of existing technological options for the surveillance of remote marine managed areas. Some of these technologies are currently in use by fisheries management agencies; some are currently the purview of groups like the military or security agencies. As illegal fishing is the single greatest threat to most marine protected areas, followed by vessel-based pollution, we pay particular attention to technologies for the monitoring of such activities.

The technologies are arranged by the different types of sensors (radar, acoustic etc) that are available, and the platforms (e.g. aircraft, surface vessel) that can be used to support them. Sensors are further subdivided into cooperative (those in which the vessels are compliant in the surveillance) and non cooperative options (that observe vessels without their permission), with the former dealt with initially as these constitute a smaller category. Sensors may also be combined into customized packages for specific platforms; examples of such systems are described at the end of the section.

We recognize that surveillance technologies alone are insufficient to ensure compliance, but that they are a necessary component. This first paper in the series does not look at questions of integrating surveillance technologies into an enforcement regime; neither does it consider issues of promoting better compliance. These are clearly key issues, and we anticipate giving them the space they deserve in subsequent publications.

Cooperative sensor systems

Cooperative systems are those in which only participating vessels are monitored[1]; for example, fisheries Vessel Monitoring Systems (VMS) can only observe those vessels which 'cooperate' by carrying transceivers. Cooperative systems are also sometimes referred to as voluntary or participatory systems. Despite these terms however, their use is usually a legal requirement for participation in a fishery. This means some vessels participate unwillingly, and may interfere with onboard surveillance systems. Nonetheless, the level of information cooperative systems provide make them a valuable surveillance tool.

Vessel Monitoring System (VMS)

The Vessel Monitoring System (VMS) is one of the most widespread cooperative surveillance tools currently in use in the area of fisheries management. A comprehensive report on VMS is available from the UN FAO[2]; much of the following information is summarised from there.

Vessels using a VMS system carry a transceiver unit (transmits and receives signals) that transmits its GPS coordinates via a communications satellite to a monitoring station on shore (figure 1). Currently VMS uses satellite GPS technology that provides position data within 10 m resolution from anywhere on the globe. While there are currently no binding global agreements regarding the use of VMS, most Regional Fisheries Management Organizations (RFMOs) as well as many States have mandated its use on larger commercial fishing vessels (flagged to and/or fishing in the waters of the State). VMS units cost approximately US$1000-4000 each with operating costs of a few hundred dollars a year; this relatively low cost and ease of operation has facilitated its widespread use. The cost to operating agencies for a Fisheries Monitoring Centre (FMC), which typically exists at the national or RFMO level, is between US$50 000 – 500 000[3]. The VMS data are usually only reported to the vessel's flag State or the EEZ coastal State, and few arrangements exist for data sharing. The South Pacific Forum Fisheries Agency[4] and recently the EU[5] are exceptions to this rule. In areas beyond national jurisdiction, enforcement of VMS regulations is the responsibility of flag states, though this may be administered through the RFMOs.

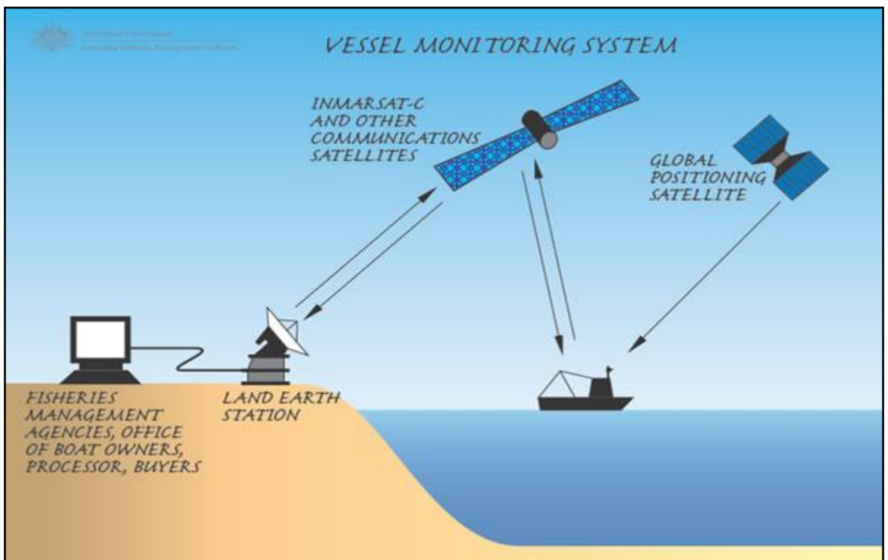

Figure 1: Graphic showing the communication steps involved with a vessel monitoring system. Image courtesy Australian Fisheries Management Authority

VMS itself only monitors the position, and in some cases speed, while saying nothing about vessel activity (newer processing software can infer, but not verify, some types of fishing activity). Most potential violations detected by VMS need to be corroborated by direct observation (e.g. enforcement patrols or shipboard observations). This is especially true in areas with more complex regulations (e.g. certain types of fishing allowed but not others)[6]. VMS data has been integrated with other information such as electronic catch reports, boarding and inspection information, permanent vessel data and so on, by fisheries management agencies at the national or RFMO level. While this combined approach is useful, the variety of data types and formats makes information sharing more difficult, and can raise potential confidentiality-related issues.

Despite its capabilities, VMS does not help with IUU fishing; as it is a cooperative system, and does not monitor non-participating vessels. Vessels can also evade VMS regulations by registering with states which do not require its use, are not members of RFMOs that require its use, or which require VMS use but lack the will or capacity to enforce regulations. Vessels may also tamper with their VMS and disable the equipment, jam signals, or broadcast false position data. In response, some states (such as the US) regulate the types of VMS unit permitted, allowing only 'tamper-resistant' models. To overcome the problems associated with false signal transmission, the EU's Galileo satellite navigation system (similar to the GPS) will use encrypted signals so that it will be more difficult to 'fool' Galileo-based VMS.

Though GPS coverage is continuous, VMS units typically report vessel position to the FMC every 1-2 hours. The low reporting rate can complicate enforcement as a two hour window can be sufficient for fishing vessels to make quick illegal forays into restricted areas. At bottom-trawling speed, in two hours a vessel could pass as far as 5.6 nautical miles (nm) inside a restricted area undetected, resulting in a need for extensive 'buffer zones' of 6 NM or more around sensitive areas[7]. A simple increase in reporting rate would greatly ameliorate this problem[8]. At a cost on the order of US$0.07 per transmission, increasing reporting rate from once per 2 hours to once per 0.5 hours would increase annual operating costs* by ~ US$500, from US$168 to US$672 per vessel.[9] More frequent VMS reporting would provide much better information not only for enforcement but also for many other fisheries management purposes, such as better understanding of where bycatch species are being encountered, and what areas are economically important to fisheries.

Figure 2: Electronic monitoring systems include on board video cameras that record deck activity such as gear deployment and recovery, and catch sorting.

Electronic Monitoring System (EMS)

Electronic monitoring refers to the use of on-board video recorders, sensors, and data processors to record the activities on board a vessel (figure 2). In the last few years, several pilot studies have used EMS for fisheries monitoring purposes, mostly in Canada, New Zealand, and the US Alaskan, West Coast and New England fisheries. EMS technology is reaching the operational stage and its capabilities make it a potentially useful observation tool. In 2008 the US National Marine Fisheries Service commissioned a comprehensive report[10] on the state of this technology, and the following technical information is summarized from this document.

* Assuming 200 days at sea per year.

EMS utilizes one or more digital video recorders to cover various parts of a fishing vessel, usually the areas where gear is deployed and retrieved, and where fish are brought on board and/or processed; multiple cameras can cover the same area for more thorough observation. Sensors are also placed on hydraulics, winches, and other fishing-related equipment. These sensors record data almost continuously as long as the vessel is underway, feeding it into an onboard processor or 'control box' which stores the data and integrates it with GPS position information. Sensors can detect when fishing activity is taking place, and can be programmed to turn on the video recorders. Video taken at rates of around 5 frames per second during fishing activity and gear retrieval can potentially provide information on the species and sizes of fish caught, handling of bycatch, and so on.

EMS equipment is fairly rugged and reliable, and can provide continuous recording of vessel shipboard activity. One great drawback is that EMS does not provide real-time information; the volume of data generated is too large to transmit, so recordings must be retrieved and examined after a vessel returns to port. Nonetheless, EMS can act as a deterrent and has some advantages over at-sea human observers. EMS provides a permanent record that can be revisited for further analysis; it is continuous (i.e. it does not need to sleep); and it can visually cover multiple areas of operation simultaneously. While the data still have to be interpreted by humans, this can be done more consistently and objectively than on board ship, with observers of various experience and temperaments. The logistical requirements for a vessel to carry EMS are simple – a small amount of deck space and a power source, as opposed to a berth on the ship. Finally, EMS is approximately one third of the cost of an observer; for example, in the British Columbia ground-fish fisheries, EMS costs ~$150 per sea-day, discounting up-front equipment costs, versus ~$550 for an observer. However, while EMS is less costly than human observers, its cost is still considerable. At $8000-10 000 for installation and $150 per sea-day per vessel, the cost of widespread EMS implementation and operation could be millions of dollars.

The large quantity of video and other data generated by EMS have to be processed to check for violations. Monitoring anything more complex than the most basic presence or absence of fishing activity, e.g. catch processing or bycatch handling, is beyond the power of automated software and requires processing by a trained human analyst. Depending on the activity being monitored, processing times range from 10-60% of actual activity time. While this is more efficient than on-board observers, a large number of staff hours would be needed to process EMS data from a large fleet. Furthermore, unlike for satellite imagery (see below) the manpower required will increase more or less in direct proportion to number of vessels monitored.

EMS use could pose legal challenges as well. Privacy and proprietary data issues related to the use of observers are only exacerbated by the nature of EMS, and questions of sovereignty and flag-state responsibilities further complicate matters when in international waters. While there is some precedent for the use of observers in international fisheries[11], no similar EMS arrangements are known to have been attempted in areas beyond national jurisdiction or on a broad scale. Finally, EMS is a cooperative system that is extremely vulnerable to tampering, even more so than VMS. EMS components such as video cams are necessarily exposed, and the system is dependent on the vessel's on-board power supply; preventing tampering is thus a practically insoluble engineering problem. Furthermore, there are indirect ways to reduce the effectiveness of the video monitoring, such as pre-sorting catch before it is recorded on video. Because of this, a strong compliance structure is necessary to prevent cheating from undermining the entire EMS-based system.

In summary, the primary advantage of EMS is the ability to monitor a vessel's activity, while being more reliable, compact and cheaper than observers and thus more practical for widespread coverage of fishing fleets, especially for those that otherwise would require observers. No other existing surveillance technology can achieve such detailed, continuous coverage. However, because EMS does not provide real-time surveillance, it may be difficult to minimise the impact of violations as they occur. As such, for protected areas that would be readily damaged by fishing activities, EMS is best used not as a standalone surveillance tool but in concert with (near) real-time technologies.

Electronic logbooks

The use of electronic logbooks is increasing as a means of capturing information on vessel location, and electronic logbook software is marketed by a number of companies[12]. The logbook records vessel location at pre-determined intervals, and allows the ship personnel to input information at each interval in the form of text messages. This allows regulatory agencies to reconstruct the history of a trip, but their effectiveness depends on the accuracy of the information logged by the vessel crew. This may limit their usefulness for comprehensive surveillance; however, the detailed information they can provide allows for very close monitoring of cooperative vessels, especially if used in conjunction with VMS and/or EMS.

The use of electronic logbooks is expanding as their advantages are recognized by fishing fleets and regulatory agencies. The EU fisheries electronic logbook legislation Council Regulation 1966/2006[13] will come into effect in 2011, and will apply to EU fishing vessels > 15 m in length. Article 1 of the regulation obliges masters of EU fishing vessels to record by electronic means, information related to fishing activities, that they are currently required to record in a logbook. This is not real-time information, as it is only reported after a vessel returns to port. It can be used to reconstruct fishing vessel movement and activity similarly to EMS, but without visual confirmation. Australia[14], Canada and the US are also implementing the use of electronic logbooks in their fisheries.

Automatic Identification System (AIS)

The Automatic Identification System (AIS) is "a shipboard broadcast system that acts like a transponder, operating in the VHF maritime band"[15]. AIS-equipped ships broadcast a wealth of information, including position (to GPS accuracy), navigational information (heading, speed, rate-of-turn, etc.), ship identity (MMSI no., call-sign, name, type of ship, etc.), and so on. This information can be received by other ships, aircraft, or terrestrial base stations, and displayed on electronic chart data. Originally intended to help avoid ship collisions, AIS has a far higher reporting rate than other systems like VMS, from once every 6 minutes down to every 2 seconds. However, its range is currently limited to ~20-100 nm (but see spaced-based AIS below).

Like VMS, AIS is a cooperative system, with all the difficulties that entails. However, AIS has the weight of an international body and convention behind it. Under regulation 19 of chapter V of the Safety of Life at Sea (SOLAS) Convention, the IMO requires all ships above 300 gross tonnes to carry AIS class A transponders[16] (smaller vessels may voluntarily carry class B AIS transponders, which transmit less information than class A transponders but still including position, vessel type and identification, speed and heading). Approximately 70 000 ships worldwide are equipped with class A AIS. The cost of AIS ranges from US$600 for a class B unit to US$5000 or more for a class A unit[17], considerably less than when AIS use was first mandated.

The primary use of AIS is navigational safety and collision avoidance, as originally intended under SOLAS. However, the obvious power of AIS in monitoring maritime traffic has attracted the attention of many navies and coast guards worldwide. AIS data from various sources (coastal stations, buoys, aircraft, etc.) is increasingly being used to achieve maritime domain awareness (MDA). Research is also underway by NATO[18] and other groups on integrating AIS data with direct observation systems. In addition to the information currently broadcast by AIS, the system architecture of AIS transmission includes several currently unused data slots. These slots could be used to transmit additional information, such as an 'on/off' read from sensors placed on hydraulic fishing equipment like those used in EMS. AIS could therefore be fairly easily integrated with other methods of monitoring a vessel's activity.

Thus far, there has been fairly little interest in the use of AIS for remote monitoring, due to two major limitations. First, relatively few non-merchant vessels are required to carry AIS – less than 1% of the estimated 1.3 million decked fishing vessels worldwide are class A, AIS-equipped. Second, the limited range of traditional AIS signals makes monitoring remote locations impractical; however strategically placed receivers can offset this limitation. For example the Department of Fisheries and Oceans (DFO) in Canada are testing mobile AIS installations, including an offshore unit deployed on the top of an oil platform that can reputedly 'see' out to 300 nm under good conditions (P. McNab, DFO. Pers. Com.).

AIS are being used by NOAA to monitor and enforce the ship speed rule to protect Right Whales off the US east coast. At present, NOAA is using data filters to identify vessels travelling at greater than 10 knots inside a specific area. This area however is among the busiest in the US, so even with the data filter in place the burden of responding to all potential violators was too great for the limited enforcement resources available (S. Corey NOAA Pers. Comm.).

In April 2009 the EU passed legislation[19] requiring all EU fishing vessels over 15 m length to be class A AIS-equipped by mid-2014, and the US is also moving to expand the range of vessels required to carry AIS; the US coastguard issued a Federal Register proposal in early 2009, to reduce the AIS carriage requirements down to 65' (19 m) for vessels entering a US port. While such moves are intended to achieve safety- or national security- related objectives, they also enable the use of AIS to conceivably monitor fishing activity. While AIS broadcasts do not explicitly identify fishing activity, the navigational information provided is often sufficient to identify many types of commercial fishing, which involve distinctive vessel movement patterns Although the majority of fishing vessels are still excluded by the 15 m EU directive (and any similar future legislation elsewhere), most vessels with the range necessary to operate in the remote areas (the focus of this document) will be above 15 m length, and thus covered by such rulings.

A major problem with enforcing many marine protected areas or other spatially-regulated marine zones is that there is a time delay between implementation of the protected area, and incorporation into nautical charts. Vessels entering an area may not have updated their paper charts to reflect associated protected measures or other reporting requirements. This situation frequently leaves vessel captains ignorant of regulations. The use of AIS or radar transceivers could reduce this problem, since regulated areas could be automatically displayed on those vessels with electronic chart display and information systems (ECDIS). Regardless of whether vessels are equipped with ECDIS, the IMO will soon be approving a list of purpose-specific indicator codes that AIS sets can transmit to signify special situations such as areas to be avoided. This may also help shift the burden of proof in prosecuting violations. AIS transceivers could be mounted on moored buoys or on land if within range, and AIS technology could be adapted to display protected area boundaries at considerably less cost to install and maintain than the radar beacon (RACON) systems currently used for marking navigational hazards[20]. However, no nation has yet used the technology in this manner, though at least three countries have conducted preliminary trials[21].

One other advantage of using AIS transmitters to display spatial boundaries in this manner is that it obviates the need for confusing and arbitrary coordinate- or landmark-based boundaries for spatial regulations. Ordinarily, boundaries used in such regulations face a trade-off, as simple but arbitrary straight lines, or more biologically significant complex shapes which pose difficulties for enforcement. If boundary information could be programmed into AIS transmitters and thereby displayed directly on electronic charts, then the complexity of a biologically-significant spatial boundary is less of an issue, allowing for better integration of scientific information into regulations and more efficient use of space. In the future, dynamic boundaries which change over time may even be a possibility. This potential application has not yet been put into practice, but would be a powerful tool in enforcement of regulations, since all AIS equipped vessels would be aware of the boundaries.

Space-based AIS (AIS-S)

The possibility of mounting AIS receivers on microsatellites to achieve extended range has been under investigation for some years, notably by the Norwegian Defence Research Establishment[22]; such space-based AIS could theoretically achieve ranges of >1000 nm (>~1850 km). Also in April 2009, a Canadian company, COM DEV International Ltd., announced the successful demonstration of an AIS satellite[23]. A subsidiary of COM DEV, exactEarth[24], will be providing commercially available space-based AIS services from mid-2010, with its full constellation of satellites operational by 2013[*]. Space-based AIS receivers overcome the primary weakness of AIS by extending coverage to the entire globe, with each single satellite covers an area of 5000 km (~2700 nm) radius at any one time. Satellite receivers can currently handle a volume of about 7000-10 000 vessels[†] in any given 5000 km radius area. AIS-S trials have shown that currently in most open-ocean areas away from coastlines there are approximately 1000 ships at a given time, hence even a significant increase in AIS traffic will not adversely affect detection rates in remote areas.

The main difference between coastal and spaced-based AIS is that the latter does not provide continuous coverage; satellites need to transmit recorded data to fixed ground stations which are only periodically within range. The expected refresh rate for the full constellation of satellites is <30 minutes for pole ward regions and <90 minutes for equatorial regions, somewhat similar to that of VMS; this could be improved by installing additional ground stations. While the transmission rate is similar, AIS-S has a few further advantages over VMS. Firstly, AIS data is considerably more comprehensive than VMS data. While AIS-S data will not include the full range of navigational information (only speed and heading), and a VMS-linked database could theoretically compensate for this, such informational infrastructure and databases already exist for AIS. In addition, ExactEarth allows the 'flagging' of vessels during data processing, according to the end-user's specifications, such as 'suspicious' vessel movements, fishing activity, potentially falsified signals, and so on. Finally, while it is possible to falsify AIS signals, vessels are unlikely to do so – unlike VMS, AIS does *not* serve explicitly as a fisheries monitoring tool; it has critical safety and security applications, which should provide strong disincentives for signal falsification.

The cost of AIS-S is considerable, with a flat-rate yearly subscription fee on the order of a few million dollars. It is important to remember, though, that this fee is applicable at the level of national governments and organizations of similar scale. Many governments are attracted to space-based AIS for its national security and MDA applications, and are willing to consider the subscription fees a defense-related expense. The AIS data from a government-level subscription, though, will typically be available to all relevant government agencies, including enforcement agencies. AIS-S data could therefore be available for remote management purposes at minimal cost to agencies, despite the seemingly prohibitive fees.

Long Range Identification and Tracking (LRIT)

In 2006, the Maritime Safety Committee of the IMO introduced new regulations on the use of Long Range Identification and Tracking (LRIT) equipment on certain ships making international voyages[25]. The objective of these regulations was to improve maritime safety and increase security.

LRIT works in essentially the same manner as VMS; an LRIT-equipped vessel uses satellite navigation to determine its position anywhere on the globe, and transmits that position information to a data centre via the vessel's on-board global maritime distress and safety system (GMDSS) radios[26]. In addition to position, vessels are also identified using their IMO and maritime mobile service identity (MMSI) numbers, managed by the International Telecommunications Union, Geneva, Switzerland. Position data is transmitted automatically every 6 hours (more frequently in some cases), and processing and forwarding of the data takes about 15 minutes, providing near-real-time but non-continuous surveillance. LRIT systems also have the capacity to

[*] The following information is courtesy of exactEarth and applies to the exactAIS service they provide, currently the only space-based AIS system which will be operational in the immediate future.

[†] Only vessels with Class A AIS units are detected.

increase their reporting rate from the usual 6 hours, down to 15 minutes if required by the vessel's flag state or coastal state authorities. This change in reporting frequency can be activated remotely without the vessel's knowledge.

LRIT carriage is mandatory on three categories of ships making international voyages: cargo ships over 300 GT, passenger ships, and mobile offshore drilling units[27]. These categories largely overlap with the requirements for Class A AIS coverage. Despite this overlap, and the fact that both LRIT and AIS use are governed by the SOLAS convention, there is no interfacing between AIS and LRIT; they function completely independently of each other. This could result in considerable redundancy and duplication of data. The US Government Accountability Office has recommended that the US Coast Guard work to reduce this redundancy[28].

One important difference between LRIT and AIS is that unlike AIS, LRIT data are very tightly controlled, transmitted to and processed by a limited number of national, regional or international data centers, which share and exchange information as necessary. Only two parties are entitled to access vessel position information: A state may track vessels flying its flag, and coastal states (specifically, the SOLAS Contracting Governments of coastal states) may track any LRIT-equipped vessels within 1000 NM of their coast[29].

As a remote surveillance system, LRIT combines some of the strengths of VMS and AIS, but unfortunately most of the weaknesses as well. LRIT, like AIS, also has the advantages of strong safety- and security-based international legal backing and with it an existing international architecture for data sharing and standardization – something that VMS sorely lacks. But LRIT carriage requirements are as limited as those of AIS, and so currently exclude the vast majority of fishing vessels. In addition, like VMS, one of its main shortcomings is a low reporting rate, as low as once every 6 hours (compared to VMS once per 1-2 hours). The capacity for on-demand polling of LRIT systems, however, means that there is no reason why its reporting rate cannot be increased.

These weaknesses may limit the usefulness of LRIT for remote surveillance, at least in its current form. However, LRIT does complement VMS well; LRIT carriage generally excludes fishing vessels (which carry VMS instead), and many non VMS-equipped vessels are required to use LRIT. Combining the two systems therefore could allow for global tracking of most types of cooperative vessels. Efforts to integrate data from the two systems, or to extend LRIT carriage to fishing vessels, may prove worthwhile.

Non-cooperative sensor systems

Non-cooperative systems are those that can observe vessel activities without their participation or knowledge. These technologies include radar, acoustic monitoring, visual imagery and others. The information they provide is generally less detailed than for the cooperative systems, but they can monitor the activity of all vessels, including IUU and pirate ships. This section will briefly describe the many non-cooperative technologies that have a marine surveillance and enforcement application.

Radar imaging systems

Radar systems transmit radio waves in the form of electromagnetic radiation, and detect their reflections from objects within the radar's field. This allows non-cooperative detection of objects such as vessels and aircraft in real time. Over the years, radar has been used for many and varied military and non-military purposes, including enforcement, on land and water.

Radio waves travel in straight lines, and since the earth has curvature, the detection range of traditional microwave (aviation or marine) radar systems is limited to objects on their horizon. For example, radar mounted on top of a 10 m mast has a range to the horizon of about 13 km, taking into account atmospheric refraction effects. As the height of the radar (and/or the target) in increased, the detection range will increase accordingly, but in general it is impractical to build radar systems with line-of-sight ranges beyond a few hundred kilometres. This range limitation is therefore a serious shortcoming for land-based surveillance of high seas or very remote areas; however mounting radar on aircraft, vessels, buoys or other platforms can increase its operational value.

The range of traditional radar was extended during the 1960s by the use of high frequency over-the-horizon radar (OTH), which can detect targets up to thousands of kilometres. These systems work by exploiting the reflective properties of the ionosphere to the high frequency (HF) or shortwave (3 – 30 MHz) part of the radio wave spectrum. Under certain atmospheric conditions, radio signals in this frequency range will be reflected back towards the ground. The optimal frequency depends on the conditions so the frequency of the transmitted signal needs continuous monitoring and adjustment. The signals that bounce back from the ionosphere are extremely weak, so OTH was not practical until the 1960s when low signal amplifiers were being developed[30]. Several countries have used this technology for offshore surveillance, including the US Navy, USSR/Russia, Australia and France

High-frequency surface wave radar (HFSWR) is a relatively new form of radar technology. It utilizes vertically-polarized radio waves propagated over the ocean surface to extend detection range to over the horizon[31]. HFSWR can detect vessels at ranges of hundreds of kilometres, which is sufficient to monitor a 200 NM EEZ (Exclusive Economic Zone) and onto the high seas. The resolution provided is good enough to track low-flying aircraft and small, rapidly moving surface vessels[32]. HFSWR has obvious advantages for remote surveillance, greatly increasing coverage and reducing the need for mobile platforms like air or surface craft. It can be deployed in small, portable, shore-based installations and can provide real-time, continuous, non-cooperative surveillance, which is ideal for detecting movement of vessels in a protected area.

HFSWR stations were field-tested successfully, by the Defence Research and Development of Canada (DRDC) off Newfoundland in 2002 and by the US Drug Enforcement Agency and US Coast Guard in the Bahamas and Florida Keys in 2003[33]. In 2011, the DRDC is planning to install an updated HFSWR system to cover the Halifax area of Nova Scotia. Australia has also deployed a High Frequency Surface Wave Radar[34]. Portable HFSWR stations are commercially available[35], and could prove to be very cost-effective (on a per-unit-area basis). This technology can provide persistent (continuous) surveillance of cooperative and non-cooperative vessels in an area. The primary limitation of HFSWR is that it provides no way to identify a vessel, and is therefore best used in conjunction with other cooperative or direct observation systems.

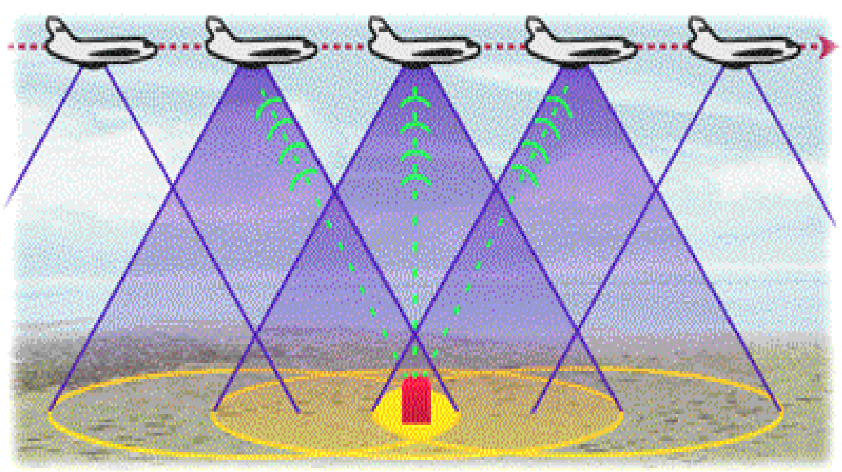

Figure 3: Synthetic aperture image generation: The target (in red) is illuminated with many successive radar pulses, and the image is formed by a coherent combination of all the received echoes. Image courtesy of Natural Resources Canada

Synthetic Aperture Radar (SAR)

Synthetic aperture radar (SAR) is a variant of radar technology that uses the forward motion of the platform (satellite or aircraft) to simulate the receiving capabilities of a very large antenna, which is then used to generate high resolution images of the target area (figure 3). Airborne or satellite-mounted SAR can be used for non-cooperative ship detection, as well as detecting oil slicks or other pollutants. Unlike optical satellite imaging, SAR can operate regardless of cloud cover, illumination, etc., and hence is preferred for maritime surveillance despite its lower resolution.

Synthetic-aperture radar was first used by NASA on their Seasat oceanographic satellite in 1978 and was developed more extensively for subsequent space shuttle missions. The DO-SAR (Dornier synthetic aperture radar) instrument was developed and built by Dornier (DASA) and has been in operation since 1989, being flown from traditional aircraft. There are currently few SAR equipped satellites, but those that are operational include Canada's RADARSAT-1 and -2, and the European Space Agency's ERS-1, -2, and Envisat. The National Reconnaissance Office (NRO) maintains a fleet of declassified Synthetic Aperture Radar satellites commonly designated as Lacrosse or Onyx[36] and the German Armed Forces SAR-Lupe reconnaissance satellite system has been fully operational since July 2008. More recently in 2009, the UK Royal Air Force Sentinel R1 surveillance aircraft began service equipped with the SAR-based ASTOR system.

The most advanced SAR satellite currently in use is Canada's RADARSAT-2[37], which was launched in 2007. RADARSAT-2 has several imaging modes, which trade off between resolution and scene size or 'swath width'. The modes typically used for ship detection are 'Narrow' (50 m resolution, 300 km x 300 km per image) and 'Fine' (8 m resolution, 50 km by 50 km cover). The SAR can also detect oil slicks, but optimal settings[*] for slick and vessel detection are different, so in practical terms they are rarely carried out simultaneously.

RADARSAT data are not available in real-time. From the time of image acquisition it typically takes approximately 3-4 hours before the image is available. In addition, revisit times for any given area are on the order of several days (fewer for regions nearer the poles). This leaves gaps of several days in the coverage of an area, more than sufficient for any illicit vessel activity, though still frequent enough for slick detection and monitoring. Finally, on-demand imaging of an area (e.g. in response to feedback from real-time monitoring sources) requires a lead-time of 4-12 hours minimum, assuming the satellite is even close to covering the area in question. This makes on-demand SAR imaging a largely unfeasible option; instead, regular imaging of areas of interest would need to be scheduled. In addition, each image can cost ~$4-5000, so costs can escalate very quickly. The usefulness of space-based SAR imaging is limited by its infrequent and intermittent coverage. This prevents it from working fully in concert with real-time surveillance systems, and means that only a subset of illicit vessel activity will be incidentally detected. Essentially, space-based SAR can only be used to 'spot-check' areas of interest, instead of achieving persistent surveillance coverage. SAR images are also relatively expensive, at approx. US$4000-5000 per image (not including ship detection processing).

There is a considerable amount of theoretical literature on the use of SAR in vessel detection[38], and in recent years the growing market for this application has resulted in several commercial companies that offer vessel detection services from satellite based SAR images. Beyond obtaining an SAR image of an area, vessel detection depends on sophisticated statistical algorithms and software. The state of such software has been comprehensively reviewed by the European Commission Joint Research Centre's recently concluded DECLIMS[†39] project. The review found that for most operational ship detection software, a ship detection rate of >97% was achievable under favourable conditions, with a typical rate of 85-95% – though most of the

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[*] For more advanced satellites like RADARSAT-2 that have multiple polarization settings.

[†] Detection and Classification of Maritime Traffic from Space

failures were due to land masking problems, which will be a non-issue in many remotely-managed open ocean areas. Image processing times were found to be as low as 20-30 minutes, with the fastest recorded at 6 minutes, which is sufficiently rapid to mount a response to suspicious activity detected in the image. The classification and identification of individual ships is beyond the capabilities of current SAR imaging and software, although some length estimation is possible at finer resolutions. Also, while the detection of ship wakes is possible, it is not currently at operational level. Despite its shortcomings space-based SAR can contribute considerably to comprehensive surveillance and enforcement efforts in remote areas when used in concert with other surveillance technologies.

Optical imaging systems

There are many different types of non-radar imaging systems, including traditional visual cameras, infrared cameras, radar imaging systems and pollutant detection technologies. Below is a representative list of sensors that can be mounted on airborne systems to create different types of visual images of the target area. A more complete description of the technical specifications of these and other airborne imaging systems can be found in the MarNIS Research Report in new surveillance technologies.[40]

ADS- 40 digital sensor

This is a commercially available digital imaging system (LH Systems GmbH) designed to generate high spatial and spectral resolution digital images. The ADS-40 system has multiple CCD lines arrays for multispectral imagery in visual and Near Infra Red.

Cast Eyes

This is an airborne optical sensor system built by the US Navy and operated by its fleet on an EP-3E aircraft since 1992. The system provides high resolution video images for surveillance and reconnaissance missions.

CHRISS (Compact High Resolution Imaging Spectrograph Sensor)

CHRISS is a commercial high resolution hyperspectral imaging instrument developed by Science Applications International Corporation (SAIC) in 1992. There is one flight model of CHRISS with two different configurations; one is referred to as the IR&D (Internal Research and Development) prototype configuration, the second is called the SETS configuration. Both instrument configurations are flown on a light twin-engine aircraft.

LEAF (Laser Environmental Airborne Fluorosensor)

LEAF is a Canadian/US airborne sensor that has been used since 1987 by the Canadian Panel on Energy Research, US Minerals Management Service, Fisheries and Oceans Canada, CCRS (Canada Centre for Remote Sensing), American Petroleum Institute, and the US Coast Guard. It was built by Barringer Research Ltd for the detection and mapping of oil spills on water, ice and shorelines, and of chlorophyll and other environmental variables in near surface waters.

LFS (Laser Fluorosensor)

The LFS is used to analyze the sea surface from airborne altitudes of 100 – 300 m and is used for the identification and classification of pollutants. The LFS was financed by the German Ministry of Research and Technology (BMFT) and it is used for maritime surveillance by the German Ministry of Transportation (BMV), on the DO-228 surveillance aircraft.

MSS-5000 - SLAR (Side-Looking Airborne Radar)

The SLAR (Ericsson model) is used for high resolution surveillance of large areas of sea surface. The swath width is 80 km (40 km to each side of the aircraft or 80 km to one side). The vertically polarized antenna produces high resolution images of the sea surface and provides good small target detection, making it an efficient instrument for fishery surveillance and for search-and-rescue missions. SLAR features a real-time display with a number of image enhancement capabilities and automatic target positioning.

MSS-5000 - IR/UV (Infrared/Ultraviolet System)

The instrument is capable of observing minute temperature differences on the water surface and is ideal for mapping oil spills and other types of pollution.

MSS-5000 - MWR (Scanning Microwave Radiometer)

MWR is used for detailed mapping of oil spills; it measures the oil film thickness and provides an estimate of the total oil volume on the surface. The image is real time, color-coded, and is presented with IR/UV data. MWR has four antennas mounted on a rotating platform, which provides continuous scanning capability.

TURRET FLIR (forward looking infrared)

The FLIR Chlio turret (system of infrared detection) covers +/-180 ° in bearing and + 40 ° in -90 ° in elevation. It is developed by Thales -Airborne Systems and is intended for helicopters and light planes. It is a heat detecting infrared camera (working in the far IR) and can interface with radar and GPS.

Space-based optical imagery

There are currently several satellites in polar orbit with visible and infra-red sensors that can provide images for a fee[41]. Optical imaging can achieve sufficiently high resolution to allow vessel identification; however, the signals are sensitive to weather conditions and darkness, and the areal coverage is relatively small. Landsat7 is an example of a polar orbiting satellite that takes images of the earth's surface using a telescope and optical sensors. The sensors not only detect visible light but are also sensitive over several selective bands including the infrared, which are able to detect heat emissions. During normal operations, vessels emit large quantities of heat and can be detected by IR imaging systems. Unfortunately, the higher resolution of optical images comes at the cost of swath width; for example, the GeoEye-1 satellite[42] (launched in 2008) can record images at 1.65 m resolution but the swath width is small (15 km x 15 km). Since per-image costs are comparable to those of SAR images, per-unit-area imaging costs for optical satellites are much higher than for SAR (see below). Optical imaging is blocked by cloud cover, fog or haze, adversely affected by bright sunlight, and cannot function at night. Its coverage is thus significantly more limited than that of SAR imaging[43]. Due largely to these two limitations, relatively little research and development has been done on processing software for vessel detection using optical satellite images. Vessel detection from SAR images is significantly more advanced.

Acoustic Surveillance

Acoustic surveillance and navigation systems have been in use by militaries, scientists, fishermen (for locating fish schools) and others for decades. They include active systems such as active SONAR, which emit and receive sound waves, and passive systems like hydrophone arrays which only detect ambient sounds. Active systems contribute to underwater noise pollution and may have detrimental effects on aquatic life, such as marine mammals, particularly at intensities allowing for long range detection. Due to potential conflicts with the objectives of conservation areas, they will not be further discussed here.

Passive acoustic systems pick up existing sound waves, most pertinently from vessel engines. The information obtainable from these sounds varies – using a hydrophone array or multiple sensors, vessel position and engine type are easily determined, and it may even be possible to determine vessel speed, detect certain activities (such as the sound of a trawl winch), or identify individual known vessels by their acoustic signatures. More sensitive systems can even detect open-circuit divers. Detection is non-cooperative and can occur at ranges from a few kilometres to over-the-horizon distances of several tens of kilometres for commercially available systems (military systems likely have even longer ranges). The area covered depends on the range of the sensors used and the number of sensors or size of array, but is not theoretically limited.

Depending on the mode of deployment and transmission, real-time or near-real-time acoustic surveillance is achievable – hydrophone arrays connected to shore stations by fibre-optics[44] can transmit data in real time; floating buoy systems can transmit data in real time via satellite or radio communications; and underwater buoys can be programmed to transmit data within minutes of a relevant signal being detected.

Currently, most cutting-edge underwater acoustics research and technology is controlled by the military, such as the US DARPA's[*] Persistent Ocean Surveillance research programme[45] or the Department of Homeland Security's Distributed Buoy Vessel Detection System (VDS). Some surveillance systems are commercially available, though, and are used for both research and MDA/security purposes. The two main varieties mentioned above – bottom-mounted, shore-linked hydrophone arrays and offshore buoys – are both available, and differ in their costs, advantages and feasibility of use.

Commercially-available hydrophone arrays are often intended for harbour security and similar purposes[46]. A single array can be several tens of kilometres long, with a detection range of tens of kilometres and a detection scope of 100+ km[47]. Their advantages include continuous, uninterrupted, real-time surveillance (with no need for a power source and only periodic hydrophone maintenance), and also relatively long detection range and precision. However, due to their fibre-optic data transmission, such arrays need to be connected to shore- or ship-based stations kilometres away, limiting their practicality in open-ocean or pelagic areas.

The alternative to fixed arrays is the use of autonomous buoys. Such buoys are capable of operating in open water far from shore, though their operational depths are typically limited to a few hundred metres. Buoys may be floating or submerged. Canada-based Ultra Electronics Maritime Systems (UEMS) recently developed a submerged 'Stealth Buoy'[48] capable of providing covert surveillance, which can be programmed to come to the surface and transmit data once a relevant acoustic signal is detected, to provide near-real-time data transmission. Stealth Buoys have an operating life of about 1 month before needing battery replacement, and other 'high-endurance' buoys typically have similar maintenance/replacement requirements.

Electronic Intelligence (ELINT)

ELINT from **EL**ectronic Signals **INT**elligence refers to intelligence-gathering by use of electronic sensors, without the cooperation or knowledge of the target of interest. ELINT sensor packages can be mounted on ships, aircraft or satellites, or be deployed on ground stations. For military operations, the sensors detect electronic signals from an opponent's defence network, especially the electronic systems such as radars, surface-to-air missile systems, aircraft, etc; therefore ELINT can be used to detect ships and aircraft by their radar and other electromagnetic radiation. These systems have generally been used for military purposes and data are often classified and not available for civilian use; however collaborations between a States military and law enforcement agencies could inform law enforcement actions without divulging sensitive information.

There are commercial packages that provide military (and potentially law enforcement agencies) with ELINT capabilities. One example of a commercial package is the CS-3030 ELINT System (produced by Rockwell Collins), that consists of antennas, receivers, signal processors and operator workstations/software for use in ground, ship and air-based surveillance applications. ELINT is currently almost exclusively a military tool, with some isolated civilian law enforcement and military collaborations.

[*] Defense Advanced Research Projects Agency.

Integrated sensor systems

Individual technologies are more powerful when combined and integrated than they are when used alone; however, this increases complexity, creating potentially confusing data products. There are several commercially available systems of sensor packages with data integration for maritime surveillance, examples of which are described below.

MSS-6000 (Maritime Surveillance System)

The MSS-6000 is a commercially available integrated airborne system produced by the Swedish Space Corporation[49]. The system consists of several instruments that offer a comprehensive set of tools for the surveillance of sea traffic, pollution, and fishing activities. The system is composed of the following sensors and support systems:

- SLAR (Side Looking Airborne Radar)
- IR/UV (Infrared/Ultraviolet Line Scanner)
- MWR (Scanning Microwave Radiometer)
- Camera (Photographic Camera System)
- Video (Video Camera System)
- THERMO (Thermal Radiometer)
- Mission management system
- Image Link (X-band transmitter/receiver for air-ground communication)
- Data Evaluation Terminal for data processing and analysis

The core of the MSS 6000 is the mission management system that links all the data from the instruments and presents an overview to the operator for interpretation and further action. The mission management system is based on GIS technology, and the sensor data is overlaid on a digital nautical chart. The information from on board sensors and external inputs is presented live to the operator and also recorded for later analysis.

Radar Ocean Master

The Ocean Master 100 and 400 (the latter being higher powered) is used to monitor surface ships, detect submarine periscopes, track their movements and accurately classify all the detected vessels. The system is also used to maintain surveillance over territorial waters, including offshore oil and gas facilities, for search and rescue and EEZ control operations. The Ocean Master radar [50]has been designed to operate in dense electromagnetic environments, under all weather conditions and in high sea states. The main modes of operation, all options included, are as follows:

- Long-range target detection and tracking
- Detection and tracking of small targets
- Short-range target detection and tracking
- Target classification
- High-resolution imagery (ISAR, SAR)

It can track up to 200 targets simultaneously. Very high-resolution SAR and ISAR imaging modes are available for target recognition and classification. With its modular architecture, compact and lightweight design low power consumption, the radar can be installed on almost any kind of aircraft.

Customized airborne surveillance

Customized surveillance packages are provided by companies that own and operate their own aircraft and sensor suites. This is a novel approach to the problem of costly surveillance platforms and technologies; it obviates the need to purchase, maintain and operate expensive systems, and places the burden of instrument upgrades and personnel training outside of a marine protection agency, which may not have the funds or skills to operate such sophisticated systems. This approach is not in common use, but the Canadian based company Provincial Aerospace has been providing surveillance services for over 25 years and is used by the Canadian governmental agencies for surveillance and law enforcement purposes. Since the providers do not have law enforcement training, enforcement agencies place their own personnel on each flight to guide the mission and maintain chain of custody over potential evidence. More information can be found on the Provincial Aerospace website.[51]

Combined satellite systems

If AIS carriage can be expanded to more vessels, it provides a powerful way to identify and track non-cooperative vessels, through the combination of AIS-S and SAR ship detection. Combining these two forms of satellite technology could allow for fairly persistent, near-real-time surveillance, especially with the use of ground stations like the SENTRY used in the Kerguelen Islands, which decrease the lag time of SAR data to ~2 hours – good enough for on-site enforcement action to be taken. Many existing remotely-managed areas are close to small islands, especially the current protected areas in the Pacific (US Pacific Marine National Monuments, Kiribati's Phoenix Islands Protected Area, etc.), allowing the use of ground stations to receive data.

The full utility of AIS-S and SAR converges when they are used in conjunction with each other. By cross-referencing SAR-detected vessels with cooperative vessels from AIS-S data, non-cooperative vessels can be immediately identified. Much theoretical work has been done on data fusion from these multiple sensor systems[52], and integrated vessel detection systems utilizing AIS/VMS, SAR, and automatic processing software exist[53]. These have been tested, but with limited success to date.[54]

There are two main limitations that satellite surveillance systems face. Firstly, the need for ground stations to receive SAR (and possibly AIS) data poses difficulties in fully pelagic or open-ocean areas with no land nearby. Secondly, the use of satellite systems alone will not provide continuous surveillance. The relatively long revisit times of SAR and AIS satellites, and the patchy coverage of SAR images on any given day, mean that illegal activity could still slip through the gaps between periods of coverage and go undetected (barring direct detection by patrols).

Synthetic Aperture Radar has been used to assist with fisheries enforcement in the French-owned Kerguelen Islands in the southern Indian Ocean since 2004[55]. A custom-upgraded SENTRY portable ground station was used to reduce image processing time to ~2 hours after image acquisition, and combining data from both RADARSAT and Envisat helped reduce revisit times such that 2-3 satellite passes a day were made over some part of the Kerguelen Islands EEZ. Cross-referencing SAR image data with VMS data and timing on-site enforcement patrols to coincide with satellite passes allows French authorities to direct patrol craft toward suspicious or non-cooperative vessels. Such specifically targeted patrols have greatly increased the perceived effectiveness of enforcement efforts, resulting in a sharp decline in illegal fishing activity[56] (observation from reference paper); the mere threat of enforcement has improved compliance.

Canada is using a combination of Radarsat data and their Ocean Monitoring Workstation[57] to monitor vessel activity. This system is capable of detecting vessels >40m with >90% probability. In addition, they are planning a Radarsat Constellation Mission, which will launch 3-6 additional Radarsat-type satellites, each with an AIS-S receiver, to increase coverage and decrease re-visit times. In the UK, both Radarsat and ERS satellites are used in conjunction with the Maritime Surveillance Tool (MaST)[58] analysis system to detect vessels of a similar size and detection probability to the Canadian approach.Sidebar: The SENTRY Transportable Ground Station

The SENTRY ground station used in the Kerguelen Islands is a Certified Radarsat Network Station, which has been upgraded to be able to receive Envisat ASAR data. The station is about the size of a 20-ft container before deployment, allowing a high degree of transportability. The initial cost of the station (in 2003), along with its antenna, network, software, etc., was approximately €5-6 million (US$6-7 million). Operating costs are currently around €2-2.5 million (US$2.8-3.5 million) annually, most of it going to the acquisition of the ~20,000 SAR images used to survey the ~3 million km^2 EEZ around the Islands. The station is fairly low-maintenance, requiring only about 7-8 hours of regular maintenance work a month. Total manpower required for operation is also fairly low, with most of it dedicated to analyzing the images obtained – about 10 staff is required for 24-hr continuous operation and maintenance (fewer if operations are not continuous).

Information courtesy of Philippe Schwab, CLS France.

Platforms

Manned Patrol Vessels

In most countries, patrol vessels are the most commonly used and traditional platform for surveillance and enforcement of maritime laws. Civilian patrol vessels, even large ones, generally have limited technology with which to survey their area of jurisdiction; radar is probably the most common tool, followed by visual imaging systems (optical and infrared cameras). The range of these sensors is limited to line of sight, or further if the receiver or target is higher off the sea surface, and meteorological conditions are good (typically 6-12 nm). However, the range of vessel based radar is not sufficient to survey vast areas. The value of patrol vessels lies in their capacity to take action in response to surveillance information obtained from other sources. Military patrol vessels often have more sophisticated suite of sensors such as ELINT or COMINT (communications intelligence) sensors and sonar, which significantly extends their surveillance range. However, information gathered by military sources is often classified and not available to civilian law enforcement agencies.

Given the widespread use of patrol vessels in maritime surveillance and enforcement, it is worth considering technologies that may increase their detection capability, while recognizing that by their nature, patrol boats will be limited to the visual horizon or hindered by meteorological issues.

As previously mentioned, the range of traditional radar is limited to a maximum of approximately 20 NM, principally due to the height of the radar above the sea surface. Raising the radar above the sea surface will increase the range, and any amount of increased range over the target vessel provide a tactical advantage by allowing the patrol vessel to see others before it is seen itself. Another slightly different use of radar is 'on-Board Radar Emission Detection'. Assuming fishing vessels continue to use radar during fishing activities, it would be possible to detect those signals using elevated radar detectors deployed on a tethered balloon or helikite. This would increase the patrol vessel's radar detection horizon to 30 NM, allowing detection of a radar source from another vessel, before that vessel could detect the patrol vessel.

Visible band cameras or thermal imagers could be used to locate vessels. The advantage of such a system over simple observation through binoculars is the ability to operate in a wider range of conditions, and to stabilize imagery for better identification of targets. Additional processing could be applied to the video signal to help automate the process of locating vessels, and reduce the operator workload. This would only be useful however at relatively short ranges, as it is still limited by the line of sight to the horizon, however when augmented by relayed information from airborne or satellite systems, these technologies will assist in the interception of suspicious vessels.

Autonomous Water Craft

Autonomous water craft include both surface and subsurface vehicles, and are analogous to their airborne counterparts in their ability to operate for extended periods remotely without the need for pilots. There are several companies that are currently developing or producing surface surveillance vessels to assist with a range of duties such as coastal and port security, US Coastguard applications (including underwater search missions), Naval combat functions, hydrography and oceanography, and surveillance and reconnaissance missions.

Unmanned Surface Vehicles (USV)

The Swedish company Kockums (part of Thyssenkrup Marine Systems) in collaboration with the Swedish military is testing their unmanned surface vehicle (USV), the Piraya. These are small unmanned vessels, approximately 5 metres in length, with a 20 horsepower engine. The biggest difference between the Piraya and other USV's is the capability of operating multiple units simultaneously by one operator. The Piraya also has stealth capability, which makes it more difficult to detect than standard patrol vessels and may confer an advantage for detecting illegal vessel activity.

The Protector unmanned surface vehicle (USV) (figure 4) was developed by the Israeli RAFAEL Armament Development Authority in response to emerging terrorist threats against maritime assets, and is the only operational combat USV that exists today. The Protector was deployed by the Republic of Singapore Navy to the North Persian Gulf for peacekeeping operations in 2005, where it performed surveillance and reconnaissance, as well as force protection duties. This is a 9 metre rigid hulled inflatable vessel with a modular platform that can be configured according to specific requirements, for example anti-terrorism as well as surveillance and reconnaissance. The vessel can travel at speeds of 40 knots and has an endurance of up to 8 hours.

Figure 4: The Protector 9 m unmanned surface vehicle is the only operational combat USV that exists today. The Protector performs surveillance and reconnaissance, as well as force protection duties.

The Spartan Scout is another example of a USV, developed by the USA and demonstrated in late 2003. This is a rigid hulled inflatable 7 metres long. It has various surveillance sensors, and is capable of carrying a 3000 lb (1361 kg) payload. According to a press release from the US Navy, the Spartan Scout will also come in an 11-metre version, capable of carrying a 5000 lb (2268 kg) payload.

These vessels were developed for military applications where one of the primary benefits was keeping personnel away from dangerous situations. General maritime patrol does not have such dangers associated with it, so unless a particular USV has an extremely long range or endurance, or multiple vessels can be operated by one team, they would not confer any obvious advantages over standard patrol vessels.

Autonomous Underwater Vehicles (AUV)

These vehicles have been used for a multitude of military (e.g. reconnaissance, inspection, mine clearance, sonar) and civilian (e.g. surveillance, pipeline survey, oceanographic monitoring) purposes for several years. They are essentially torpedo shaped vehicles that are equipped with a customized suite of sensors, designed to carry out specific tasks (figure 5). The number of different AUV configurations is virtually endless; the platform itself can vary in size, weight, endurance, range, speed, ability to avoid underwater obstacles and payload. All AUVs must be able to navigate internally since they cannot be steered from the surface, and may have other equipment such as cameras, sonar and other seafloor survey sensors, acoustic monitoring, water chemistry sensors and even weapons (e.g., the K-ster expendable mine disposal system). Since technology has not reached the state where underwater vehicles can be operated remotely without a direct data feed, AUVs have to be pre-programmed to perform a search pattern, or to carry out an action in response to a predetermined situation. Their lack of real time data feed, and the fact that they are beneath the water surface somewhat limits their civilian surveillance applications. They could however be used to determine the degree of damage done by illegal trawling, anchoring or dumping in a known violation, or potentially to covertly determine the actions of a vessel suspected of illegal activity. Another limitation of the autonomous nature of AUV's, is the high loss risk. These are expensive platforms, and there is a relatively high risk associated with sending them into the ocean where they can become tangled in natural complex habitats, industrial structures such as oil rigs, or fishing gear, or simply being lost through malfunction.

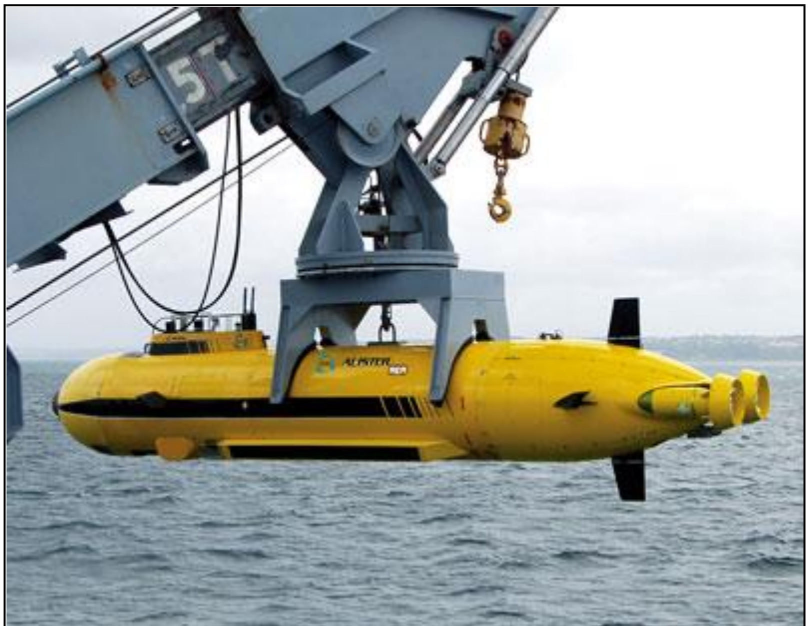

Figure 5: Autonomous underwater vehicles (AUV) are equipped with a suite of sensors and are programmed to operate independently of a support vessel for many hours. Some periodically come to the surface to download data.

Buoys

Buoys are simply anchored floating units that may be deployed in a variety of configurations: active or passive (i.e. transmitting and receiving signals, or simply receiving), on the surface, sub-surface, unpowered or powered, shore-linked or offshore. They are used for many applications from channel markers and aids to navigation to platforms for weather stations or sophisticated communications, vessel monitoring, AIS relays or acoustic systems such as the US Department of Homeland Security's Distributed Buoy Vessel Detection System (VDS). Ocean buoys that are currently used to provide data on environmental parameters could be used as infrastructure if fitted with appropriate acoustic sensors; however, there are likely too few buoys in most areas to be used as a complete monitoring infrastructure, in which case their numbers would have to be supplemented, possibly through collaboration between agencies.

The most recent buoy technology is the autonomous Power Buoy (developed by Ocean Power Technologies) (figure 6). These buoys use natural wave motion to drive a piston and generator, which provides power indefinitely to the buoy sensor package. Surface or subsurface surveillance applications include powering oceanographic observatories, Coast Guard buoys, sonar/radar systems and acoustic monitoring. This kind of technology alleviates the power supply challenges for remote offshore sensor platforms. With continuous power supply, satellite communications systems could provide information directly to enforcement personnel when sensors detect suspicious activity. In November 2008, the Navy deployed two autonomous Power Buoys as platforms for the DWADS program, which is a sophisticated data gathering and communications system for various applications, including vessel tracking. One of the systems is moored in 3300 feet (~1000 m) of water depth, 75 miles (121 km) off the coast of New Jersey, and communicates with the shore based facility via satellite.

Individual buoys are typically fairly inexpensive – a single Stealth Buoy unit costs approx. US$5000. However, due to their relatively short detection ranges of a few kilometres, a large number of buoys are needed to cover a large area or perimeter. This, along with the regular maintenance requirements, increases overall costs substantially. That said newer buoy systems currently in development may overcome these obstacles. The Distributed Buoy VDS, currently under development by Advanced Acoustic Concepts Inc.[59], is aimed at producing a deep-water (4000 m) deployable, 1-year minimum lifetime buoy with a 20 NM or better detection range. A system with these capabilities may prove far more practical for monitoring large, remotely-located areas like the protected areas around many Pacific islands.

However advanced it may be acoustic surveillance alone is insufficient for monitoring and enforcement. While it is theoretically possible to identify individual ships from acoustic data, in reality building a comprehensive database of vessel acoustic signatures that would be sufficient for surveillance of remote areas is probably impractical. AIS receivers could be added to the buoys, which would allow real-time identification of non-cooperative vessels by cross-referencing acoustic and AIS data. Patrols could then be directed to investigate suspicious vessels.

With enough buoys, a perimeter could theoretically be established around any remote protected area to allow complete and continuous monitoring of any vessels approaching, entering or leaving the area. The main difficulty with such a system is logistical. With a buoy needed every ~20-30 NM on the perimeter of a protected area, for larger areas a very large number of buoys will be necessary; for instance, the US Pacific Remote Islands Marine National Monument has a total perimeter of ~2000-3000 NM, requiring about a hundred such buoys to monitor. If buoys need to be maintained or replaced approximately annually, the cost of maintaining such a system would be considerable. An alternative is underwater hydrophone arrays with longer ranges, to reduce the number of sensors required. Such arrays, however, are unable to detect or transmit AIS, and so cannot separate cooperative from non-cooperative vessels.

A more practical possibility is to establish acoustic buoy perimeters around smaller or medium-sized protected areas, but not larger ones. For larger areas, specific activity 'hotspots' or particularly vulnerable areas like seamounts, or areas of heavier vessel traffic, could be specifically monitored. In addition, space-based surveillance methods could be used to maintain persistent surveillance of less-

Figure6: The 'PowerBuoy' from Ocean Power Technologies (OPT) uses natural bobbing motion at sea to generate its own power.

critically-sensitive areas. Such strategic targeting of monitoring efforts could keep costs down while still achieving continuous observation of the most important areas.

Manned Aircraft

For most States, surveillance and enforcement for maritime areas generally includes manned aircraft. Aircraft types, like surface patrol vessels can vary greatly in their capacity (endurance, range, speed etc) and operational cost. Due to the large areas and distances involved in surveillance of remote areas, the capital and operational costs of aircraft, both manned and UAVs may be prohibitive for some marine resource protection agencies. The US Coastguard, which is responsible for policing almost 4.5 million square miles of UA EEZ, has a total of 211 aircraft, of which only 22 are operational 'long range' (HC-130 Hercules) aircraft. In order to make efficient use of the aircraft, additional information could be used to direct efforts to a suspicious target (through collaboration with military, for example), and costs could potentially be shared by more than one party. Another solution to the potentially prohibitive costs of owning and operating aircraft is to use the services of a commercial contractor. Provincial Aerospace is a Canadian based company[60] that provides airborne support for government, military and industry missions worldwide. As commercial contractors, they are not dependent on governmental appropriations for funding support, and can maintain the newest sensor technologies, data management systems, training tools and aircraft. Canadian governmental agencies have used this company for maritime surveillance, and maintain legal requirements for prosecution by assigning their enforcement personnel as passengers on each mission. This is not a model that seems to be in common use, but has certain advantages over the more traditional model of agencies owning and operating surveillance aircraft and should be considered as an enforcement option.

Unmanned Aerial Vehicles (UAV) or Systems (UAS)

Unmanned aerial vehicles or systems (UAV or UAS) are remotely-controlled or autonomous aircraft with observation capabilities comparable to those of manned aircraft. The most common sensors used aboard the larger unmanned aircraft in a maritime surveillance role would be a combination of search radar, synthetic aperture radar, and Electro Optical/Infrared (EO/IR) imaging sensors (allowing day and night operations), plus an AIS receiver[61]. The sensor data would be combined with positioning information from GPS, and forwarded via satellite to the operations center. This allows detection of both cooperative and non-cooperative vessels in real time, with direct observation of their activities.

There is a large range of size and capability of Unmanned Aerial Vehicles (UAVs) presently available or in development (see

Table **1**), from very small (a few cm wingspan) up to aircraft the size of a commercial passenger plane, with a similarly large range of payload and sensor capabilities. When combined with the necessary sensors or other payload, the facilities for takeoff and landing, and the systems to remotely control (fly) them, the common terminology now used is Unmanned Aircraft Systems (UAS). These aircraft can be categorized in terms of range/altitude as described below. With minor exceptions, only the first two classes of equipment have been used in non-military roles:

- Handheld: 2000 ft (600 m) altitude, about 2 km range
- Close: 5000 ft (1500 m) altitude, up to 10 km range
- Near Tactical: 10 000 ft (3000 m) altitude, up to 50 km range
- Long Tactical: 18 000 ft (5500 m) altitude, about 160 km range
- MALE (Medium Altitude, Long Endurance) up to 30 000 ft (9000 m), range over 200 km
- HALE (High Altitude, Long Endurance) over 30 000 ft (9000 m) and indefinite range


Figure 7: Global Hawk UAV used by the US Air Force for surveillance missions

Endurance is an important consideration, since an operational duration of at least 15 hours is likely required for many remote MPAs. While comparable in observation capabilities, UAVs have a clear endurance advantage over manned aircraft. Long-endurance UAVs such as the MQ-9 Reaper[62] and RQ-4N Global Hawk[63], (figure 7) both currently used or under investigation for maritime surveillance, can fly for ~30 hours, allowing far longer on station than manned aircraft (at typically ~8 hours); the RQ-4N has a mission radius of 2000 NM, allowing access to very remote areas. Currently, many of the most remote marine areas are beyond the range of manned patrol aircraft unless they are deployed to forward bases, and even then manned patrols only achieve 1-2 hours of active surveillance per mission[64]. As a result, these areas are rarely patrolled by manned aircraft or surface vessels. Long-endurance UAVs would allow more regular surveillance of such remote areas.

In addition to the larger UAVs, there are several smaller versions that are deployable from a small vehicle or vessel. Their small size limits their range, endurance and payload, as well as their ability to withstand bad weather conditions, but their low purchase and operating costs make them an attractive addition to a patrol cutter or Island based launching system. One example of a mini UAV is the Cypher-TD aircraft, a rotary aircraft resembling a flying saucer, developed by Sikorsky Aircraft Corporation. This vehicle is 2 metres in diameter, 80 cm high, has a sensor payload of 10-22 kilograms (22 – 49 lb), an endurance of 2-3 hours, and a maximum range of 125 km depending on weather conditions. In addition to extending the functional range of the patrol vessel, these small aircraft provide near real-time information from the sensors and have a 'stealth' advantage over the large patrol vessels. This will allow them to document illegal activity as evidence, as well as inform enforcement actions.

The primary obstacles to more widespread use of UAVs for surveillance and enforcement are availability and cost. Currently, UAVs are used almost exclusively by armed forces around the world; nonetheless, there are clear advantages of UAVs for non-military surveillance. Although there are still many restrictions on the use of UAVs in civilian airspace, these restrictions are gradually decreasing; the RQ-4 and MQ-9 have both been permitted to fly in civilian airspace[65], paving the way for more widespread UAV use. As of 2009, the US Coast Guard (USCG) developed a funding strategy to acquire both low-altitude, cutter-based, tactical unmanned aircraft systems (UAS) and mid-altitude, land-based, long-range UAS[66]. The USCG acquisition strategy meshes with existing Department of Homeland Security and Department of Defence programs.

At several million to tens of millions of dollars apiece, UAVs are a considerable investment for any enforcement agency and costs increase almost exponentially with range/endurance and payload capabilities. The most capable units are as costly as manned aircraft, with very sophisticated autonomic flight management systems and advanced sensors requiring specialized operators. Any remotely piloted unmanned aircraft requires communication capability between the aircraft and operator for flight control, and sensor data relay. With the larger (HALE and MALE) UAVs, operations are often beyond line-of-sight requiring sophisticated multi-hop satellite links for communication. This significantly restricts the number of organizations able to operate or afford them. The most capable line-of-sight UAV currently fly within 90 NM (~160 km) of their operators, which restricts their use to areas relatively close to shore.

UAV design and production is a currently a global activity, but the United States and Israel were pioneers in this technology, and the US is still the industry leader, on the strength of the Global Hawk and Predator/Mariner systems. Israeli and European manufacturers are second tier manufacturers, but those nations have initiatives to acquire US systems due to their higher levels of capability. Currently, the largest UAV aircraft is the Global Hawk with capabilities of up to 42 hours endurance and 3000 lbs of payload. On-station endurance at 3000 NM is 24 hours so this system is clearly capable of long-range surveillance. However, at approximately US$70M per aircraft, substantial investment would be needed to establish a viable operation, which is probably too expensive for dedicated SERMA applications. The next tier includes the smaller Predator, Reaper or Mariner UAVs. The Predator can carry 3000 pounds at up to 52 000 feet for up to 42 hours and costs about US$10.5 million, including sensors. The US Navy is using the Mariner for offshore surveillance with larger fuel tanks to extend operations to 49 hours and the US Department of Homeland Security is now using the ‘Reaper’ for border protection.

In addition to the obvious challenges of cost and complexity of operations, long range unmanned aircraft (MALE/HALE) have two other significant drawbacks in a SERMA role: 1) There is currently no agreed set of operational procedures to permit the use of unmanned aircraft within the same air space as regular civilian aircraft (although the Predator has been issued limited FAA clearance for search and rescue) and 2) High altitude UAVs are essentially invisible, so the strong deterrent effect of a visible enforcement presence is lost.

Table 1: Unmanned Aircraft System (UAS) platforms that may be applicable to the SERMA role, in the context of the far offshore MPAs. The selection has been made assuming that the probable use of UAS would require endurance greater than 15 hours. This information has been extracted from the industry publication, Aviation Week and Space Technology, 26 January 2009.

Unmanned Aerial Systems with Endurance of 15 hours or More				
Designation	**Manufacturer**	**Endurance/Range**	**Altitude (ft)**	**Remarks**
Aerosonde	Aerosonde Pty. Ltd (Australia)	30hr/2,000 mi.	21 000	
Orion HALL	Aurora Flight Sciences	100 hrs	65 000	In development
Centurion	AeroVironment	16hr	100 000	R&D
Global Observer	AeroVironment Inc.	336hr/Global	70 000	R&D
Helios	AeroVironment Inc.	96hr/120 mi. (?)	96 863	R&D
HiLine	AeroVironment Inc.	48hr	40 000	R&D
Pathfinder Plus	AeroVironment Inc.	16hr	80 201	R&D
Isis	BAI Aerosystems Inc.	24hr/2000	15 000	Production ready
Taranis	BAE Systems NA	16 hrs		Developmental target vehicle
A160 Hummingbird	Boeing Integrated Def. Systems.	20hr/2500 mi	30 000	Demonstration
Bateleur	Denel Pty. Ltd. So. Africa	24hr/470 mi.	25 000+	Developmental
Seeker IIE	Denel Pty (So. Africa)	15 hr/155 mi	18 000	In production
Rustom	DRDO New Delhi	24hr/620 mi	35 000	In development, target 2012
SIDM	EADS, France	24hr	25 000	Developmental
Hermes 450	Elbit UAV Systems, Israel	20 hr/125 mi.	18 000	Operational
Hermes 1500	Elbit UAV Systems, Israel	26hr/125 mi.	30 000	
Predator	General Atomics Aeronautical Systems Inc. (GAAS)	40hr+	25 000	In use, USAF, Italian Air Force
Predator B	GAAS	30hr+	50 000	In use, USAF, DHS Border Patrol
Predator C	GAAS	20 hr	60 000	Developmental, stealth, weaponized
Sky Warrior	GAAS	30hr+	29 000	
GeoRanger	InSitu Group	15hr+	16 400	Fugro Contract
Boeing Scan Eagle	InSitu/Boeing	20+ hr	19 500	In service with CF
In Situ Insight	InSitu Group	20hr+	19 500	Joint with Boeing
In situ Integrator	InSitu Group	40 hr	20 000	HFE in development
E-Hunter	Isreal Aircraft Industries	25hr/175 mi.	20 000	
Heron 1	Israel Aircraft Industries	50hr/600 mi.	30 000	In production
Heron TP	Israel Aircraft Industries	24hr/620 mi.	45 000	
Searcher Mk 2	Israel Aircraft Industries	16hr/155mi.	18 500	In production
Viking 400	L3 BAI	12-18 hr/50 mi	15 000	In production
Global Hawk(RQ-4A)	Northrup Grumman	24hr/13,810 mi.	65 000	In production
Global Hawk(RQ-4B)	Northrup Grumman	24hr/13,810 mi.	65 000+	Developmental
Global Hawk (BAMS)	Northrup Grumman	24hr/13,810 mi.	60 000	Developmental
Hunter	Northrup Grumman	15hr	20 000	
Proteus	Northrup Grumman	18 hr/500 km	63 500	UAS Testbed, Presently piloted
Busard	Sagem Defence Security	20hr/125 mi.	25 000	
Grasshopper	Advanced Subsonics			Canadian, Mini UAS
Snow Goose	MMIST	18hr +(est.)	18 000 ft.	Canadian

			(est.)	

Aerostats and Airships

Both aerostats and airships are constructed of non rigid material that is filled with a gas (usually helium), which allows them to float in air. This group of aircraft includes free-floating balloons and airships, both of which may be steered, although only airships have engines. The most well known airships today are the non-rigid 'blimps' that are used in advertising, tourism, camera platforms and some surveillance and radio relay operations, where the ability to hover in one place for an extended period outweighs the need for speed and manoeuvrability. Aerostats include tethered balloons and helikites, and are used for lifting military airborne radar equipment, parachute training, advertising, lifting meteorological equipment, raising antennas, and platforms for video equipment and digital cameras. They can support a variety of different sensors and other equipment, and provide medium range data gathering capabilities. The tether is not only used to maintain position, but also provides electrical power and fibre optic data conduits to communicate with the on-board sensors. The coverage range is dependent on the types of sensors, for example the visual range is limited to a few miles by the resolution of a camera, but much greater distances can be surveyed using communications equipment. These stationary long-term units can also serve as relays to create data and communications networks over large areas, at low cost and maintenance burdens.

During the 1980s the US Coast Guard established the Mobile Aerostat Program (MAP). It consisted of two shore-based units located in Key West and Miami, Florida, which were mounted with sophisticated radar and other surveillance equipment. The MAP mission was to provide continuous air and surface surveillance for other law enforcement units working in the same area, with much lower costs than traditional aircraft or helicopter surveillance. These were used in conjunction with high and medium endurance cutters and patrol vessels. Successful operations were conducted with other U. S. and foreign naval forces from 1984 to the program's decommissioning in 1992. During that period, the Aerostats provided information resulting in numerous drug seizures and illegal alien interdictions. This program ended because of contractor problems, not because of the aerostat concept, but these large aircraft were extremely susceptible to windy conditions, which limited their use in bad weather.

Figure 8: Allsop Helikite deployed with a high resolution surveillance camera suspended below the balloon. Photo credit Allsop Helikites

More recent versions of the aerostat concepts include ISL (Information systems laboratories) customized unmanned air vehicles and stationary towers for surveillance and communication systems. Surveillance options include rapidly elevated aerostat platforms (REAP), large unmanned airships, unmanned aircraft (LEARS), and portable surveillance towers (RAFT). Aerostat size and payload varies greatly and will affect the cost and operational logistics. These various deployment options have been used by military, law enforcement, and commercial users,

Helikites (developed by Allsop Helikites Ltd., Great Britain) (figure 8) are currently the most commonly used aerostat; they are comprised of small flexible fabric wings and keel attached to the body of a helium balloon, using both floatation and aerodynamics to elevate the vehicle to altitudes of 6000ft or greater. There are several advantages to the Helikite; they are much smaller and more mobile than other aerostats, have lower operational costs and are very stable in foul weather, unlike traditional blimp-shaped aerostats. To counteract wind drag, traditional aerostats increase buoyancy significantly beyond that required to lift the payload. However, greater buoyancy requires a larger blimp, with the resultant increases in cost, difficulty of handling and personnel needs. Helikites have a more aerodynamic design, which generates lift from wind power and reduces the necessity for increased buoyancy (and size) at higher wind speeds. Small, lightweight aerostat systems have great potential to as a platform for various communications relays and local area surveillance. They can provide low cost, highly mobile platform with mission durations of a week or more, can operate in weather conditions too severe for many UAVs, aircraft, or other aerostats, and does so without endangering an aircrew. Costs vary greatly. Typical cost for a lightweight aerostat (through Carolina Unmanned Vehicles, NC) ranges from US$150 000 to US$450 000, exclusive of the payload (cameras, sensors etc).

Satellites

Satellites provide good platforms from which to detect activities in large remote marine areas; they can cover a large area at high resolution and images can be obtained quickly. Their limitation is that they do not provide real time information continuously over a specific area of interest, and satellite images can be prohibitively expensive. Despite their limitations, satellites are powerful tools, and are components of both military and civilian surveillance around the globe. There are a number of different sensing technologies that are available on commercial satellite systems. Satellites can support both cooperative and non cooperative systems, and each technology has advantages and disadvantages, as discussed previously in the section on sensors.

Data fusion and translation

Data fusion involves bringing together large amounts of information from different sources, analyzing and presenting that information, and using the results to make decisions. This can occur on several different levels, from relatively simple integration of sensor data (e.g. VMS) into a format that can be used by enforcement personnel, to multi agency data streams for national security purposes. Although the basic principles are consistent across this range, the necessary technologies and personnel skills vary greatly. There are many different data integration and management packages being used by different agencies and governments worldwide and a detailed discussion of these are beyond the scope of this document. It is important to recognize that no single senor and platform combination can provide the level of surveillance needed for enforcement and deterrence of illegal activities in large remote areas. Consequently effective protection strategies will need to incorporate multiple technologies, which will inevitably require data integration and analysis capability. This may be provided by the regulatory agencies or contracted to the private sector. Commercial companies that offer surveillance packages and custom surveillance missions (discussed previously), include a data fusion step which translates the sensor data into intuitive visual formats so that operators can quickly make informed decisions. In 2004 the US National Governors association designated the establishment of ‘data fusion centers’ a priority for law enforcement agencies. This action acknowledged that the vast amount of data generated from disparate sources could only be useful when presented as a coherent product. In 2006, Fusion Center Guidelines were published by the Departments of Justice and Homeland Security[67] for law enforcement agencies and 40 fusion centers are currently active of under development in the USA[68].

Data sharing, though similar in objective to data fusion is complicated by legal limitations that restrict the free exchange of information between agencies. Information may be classified, personal or restricted; for example VMS data. Although there are guidelines and international agreements that facilitate multi-source data sharing, they are very complex and are mired in legal language. A good overview of the framework for international data sharing is provided by a recent European Commission document that addresses legal aspects in the use of maritime surveillance information[69].

Capabilities and Limitations of SERMA

Successful and efficient surveillance of remote areas depends partly on maximizing the use of existing information already being collected by various agencies for different purposes; for example, resource protection, homeland security, border patrol etc. Collaboration between these agencies would optimize the use of the data and reduce costly duplication of effort. Surveillance of cooperative systems is easier than non-cooperative, as the former can identify the vessel and its probable activity. It is difficult to remotely determine the nature of a non-cooperative vessel, so in most cases they would be treated as suspect. Consequently, the more non-cooperative vessels are detected, the more patrol resources are required to investigate them. Increasing the percentage of cooperative vessels (e.g. by expanding AIS/VMS carriage through international agreements and improved flag-state control), would increase efficiency and reduce costs.

Furthermore, in order to ensure compliance, measures are necessary to ensure cooperative vessels do not attempt to 'cheat' or subvert the system, e.g. by broadcasting false data. Such acts severely undermine the effectiveness of any remote surveillance system and increase surveillance costs substantially; therefore, the use of a strong and appropriate incentive system to discourage such acts should be investigated. Enforcement and compliance measures will be investigated in detail in a separate document. While the safety-related functions of AIS help discourage cheating, current penalties are disproportionately low – under US law, 'improper operation of AIS' is subject to a maximum penalty of US$25 000[70], a fairly minor cost-of-business for large shipping or fishing companies. Broadcasting false AIS data is both a hazard to human life and equivalent to falsifying identification, for which in other sectors penalties are usually fairly stringent. Strengthening AIS laws is thus a justifiable and plausible measure.

One other crucial limitation of remote surveillance technology emerges from the above scenarios. While it is possible to track the positions of almost any vessel, and the identities of cooperative vessels, most surveillance technology, especially non-cooperative options, cannot monitor the activity of vessels at any given time. While AIS tracking and advanced acoustic monitoring may be able to give some indication of fishing activity, these capabilities are still nascent. The only way to non-cooperatively confirm a vessel's activity is through direct observation by patrol aircraft, surface craft or UAVs.

Cooperative systems with activity-monitoring capability, like human observers or EMS, do exist. With such systems, though, questions arise regarding ownership of and access to the data recorded, much of which is commercially valuable or otherwise sensitive. These issues make it difficult for such systems to reach the level of pervasiveness necessary to be truly effective, except possibly in areas where legal frameworks already exist to implement them, like in EEZs, or in areas of particularly low vessel traffic like the Southern Ocean. Furthermore, shipboard cooperative systems by their nature and EMS in particular, are far more vulnerable to tampering or cheating than non-cooperative observation. These two difficulties give non-cooperative surveillance technologies an important advantage over cooperative alternatives.

Technologies like VMS, which provide primarily spatial information, are most effective for the enforcement of straightforward place-based restrictions like no-take or no-access areas[71]. In areas with higher levels of vessel cooperation like EEZs, more complex stock-based regulations or multiple-use zoning may be enforceable; but until the issues with cooperative technologies can be resolved, the most easily enforceable regulations for high seas areas would be place-based. The zoning of such areas must take into consideration what can and cannot be easily monitored and enforced. For example, in a given surveillance regime, if one fishing activity (e.g. pelagic trawling) cannot be readily differentiated from another (e.g. bottom trawling), then both activities would have to be treated as one and the same from a remote management perspective.

We have discussed different ways of optimizing the effectiveness of costly technologies through inter-agency cooperation, with an emphasis on those with enforcement and security objectives. Another prospective collaboration would be with research and environmental monitoring entities. These may be governmental or academic, but some of the technological approaches are common to both groups, for example acoustic systems can be used to monitor vessel traffic and fish behaviour, aerial imagery can be used for cetacean tracking or surveillance of fishing activities. Environmental monitoring of remote areas can be achieved through the use if AUV's, which can also provide information on vessel activity, pollution, etc. The International Seabed Authority 2010 report[72] discusses the use of technologies such as AUV's and gliders to monitor the environmental condition of protected areas. Several of their approaches also have potential surveillance applications, and data needs could be readily combined.

Amendment of Annex I: Summary of surveillance technologies

Margaret Cooney, Marine Conservation Institute, 20 Mar., 2012

This annex is a sampling of current and prospective tools to be used for surveillance and enforcement of maritime environments, and is not meant to be a comprehensive list of all technologies that could be used for SERMA efforts. In the specific case of unmanned technologies, it should be noted that this is a rapidly developing discipline. The number of new technologies on the market is massive, as is the many applications where they can be used. The pace of innovation is rapid, with development outputs occurring within the span of months instead of years. It is likely that the information collected here on unmanned technologies will need updating on at least an annual basis in order to retain their relevance to this project.

Tech	Information Provided	Reporting Frequency / Time	Resolution / Scale / Range	Current / Prospective Users	Cost / Availability	Remarks
VMS	Position, ID	Varies in application from every 2 hrs to every 15 minutes; near-real-time	GPS resolution; global coverage	Most large fishing vessels carry VMS; most larger fishing nations have monitoring centers	$1,000 - 4,000 per unit, $100-600 annual operation; $50,000-500,000 for monitoring centre	VMS data are admissible evidence in court in several countries.

EMS	Position, fishing activity, catch information	Continuous; data collected on vessel return	GPS resolution; range not applicable	Limited number of fisheries; coverage may expand as technology improves	$8,000-10,000 per vessel, $150 per diem operation	High manpower & time requirements for processing, but this could change with image recognition tech.
LRIT	Position, ID	Every 15 minutes -6 hrs; near-real-time but non-continuous	GPS resolution; global coverage	Military/ security agencies or governments	$3,000-5,000 for LRIT ship hardware. The cost of operating the data system itself falls, for the most part, to the SOLAS contracting party requesting the LRIT data	LRIT carriage is mandatory on three categories of ships making international voyages: cargo ships over 300 GT, passenger ships, and mobile offshore drilling units.
AIS	Position, ID, type, navigational information; also transmits geographical info	Continuous; real-time	High resolution; Radar range (~20-30 nm/40-55 km) from any given station	IMO requires all merchant vessels >300 GT to carry AIS; possibly fishing vessels >15 m; virtually all maritime nations monitor AIS	$3,500 per Class A unit	Coverage is being expanded to more vessels (e.g. EU fishing vessels >15 m). Only covers vessels with AIS equipment on-board.

AIS-S	Position, ID, type, navigational information; also transmits geographical info	Every 0.25 -1 hr; near-real-time. In the future the time lag will be less, as companies launch more satellites in order to close this time gap.	~5,000 km radius per recording, can be linked to GPS	Military/ security agencies or governments	An annual licensure fee. Prices can vary greatly, starting around $30,000 and going into the millions depending on the scope	Many companies can combine the AIS satellite based info with other vessel tracking systems, such as VMS, LRIT, & SAR, for a more complete package.
HFSWR	Position	Continuous, real-time surveillance of cooperative and non-cooperative vessels in an area	13 - 200 nm	Military/ security agencies or governments	$3,000-15,000 for a small unit that mounts on a vessel, uses X-band, has a 100' cable length, and sees ~13 nm out.	There are larger military HFSWR systems that are land-based, and can see out to 200 nm.
Marine Radar	Position	Continuous while patrolling; real-time	96 -200 nm	Military, scientists, and civilian	$20,000-1.5million	Equipment capabilities needed for remote surveillance includes high power magnetron-based technology that pulls 12kw or greater, runs in S-band, & has a 9-12’ antennae array.

SAR	Position, oil slick detection, possibly ID and/or fishing activity	Varies; 2-4 hr lag/ processing time	8-50 m resolution; 50-300 km width per image	Military/ security agencies or governments	$4,000-5000 per image, $6 million -7 million per ground station	Portable ground station has been used in Kerguelen Islands. SAR images are used in the Sandwich Islands.
Optical Systems	Visual ID, activity	Continuous; real-time or near-real-time	Varies widely	Military/ security agencies or governments	$100,000 – 3 million, depending on the system	Range, resolution, and scale depend widely on sophistication of optics, and the platform it is used on.
Buoys	Position, possibly ID and/or fishing activity	Continuous; real-time or near-real-time	20-30 nm/40-55 km detection range	Military, scientists; possibly security agencies	~$5,000 per unit	Larger hydrophone arrays can have longer ranges; resolution depends on the size of array or positioning of buoys.
Passive Acoustic Systems (Hydrophone Arrays, etc.)	Position, activity, and possibly ID	Varies based upon platform used.	Varies widely	Military, scientists, civilian	~$5,000 per unit	Possible capability to develop an acoustic marker to identify individual ships. Can be used on buoys (above), USVs, AUVs, and gliders (see below).

UAVs	Position, visual ID, activity	Continuous while patrolling; real-time	GPS resolution; detection range depends on sensor equipment, usually line-of-sight. Flight time varies widely	Military, scientists; security agencies	$100,000 - 35 million per unit; operating costs lower than manned aircraft	The UAV platform has a plethora of options available. Currently, smaller, more affordable UAVs are better suited to coastal surveillance due to their battery capabilities. The rapid pace of technological development suggests promising SERMA applications in the near term.
Aerostats & Airships	Position, visual ID, activity	Continuous while patrolling; real-time	GPS resolution; detection range depends on sensor equipment, usually line-of-sight. Flight time varies widely.	Military, scientists, and security agencies	$5 million - $100 million for the purchase of an aerostat but with cheap operating costs ($~600/hr). $50,000 for a large Helikite which includes all the necessary radar and optical equipment.	It is possible to implement a Helikite network, to establish a remote radio link (Netforce) to very remote areas.

Autonomous Underwater Vehicles	Position, possibly ID and/or fishing activity	Continuous. Data collected on vessel return, or through an iridium satellite phone upon surfacing; no real-time data feed.	Detection range and scale depends on sensor equipment. Operation time varies widely	Military, scientists, and civilian	Between $15,000 - 20,000 for a small AUV with basic navigation and data-logging functionality $2-3 million for a fully-loaded AUV, with a large payload that can operate up to 40 hours before recharging.	As of the publication of this amendment, AUVs cannot be operated remotely without a direct data feed; they need to be pre-programmed to perform a search pattern, or to carry out an action in response to a predetermined situation.
Wave Gliders	Position, possibly ID and/or fishing activity	Data are transmitted continuously; real-time. Sound data are recorded and stored on board for periodic retrieval.	Detection range and scale depends on sensor equipment.	Scientists and civilian	Between $150,000 - $500,000 per glider depending on optional components. The cost of data delivery ranges between $1,500 and $3,000 per day.	Individual Wave Gliders have demonstrated voyages in adverse conditions of more than 15,500 miles and lasting more than 600 days.
Submersible Gliders	Position, possibly ID and/or fishing activity	Continuous. Data collected on vessel return, or through an iridium satellite phone upon surfacing; no real-time data feed.	Detection range and scale depends on sensor equipment. Battery life for sensors extends from 600 - 6,000 km	Military, scientists, and civilian	$100K - $150K	New advancements in thermal engine technology could boost the range up to 40,000 km with an endurance of 3-5 years.

Addendum

By Sharon Gulick.

Gliders

Gliders are small, relatively inexpensive, autonomous unmanned watercraft designed to perform long-term ocean monitoring with a small visual and radar signature, silent propulsion, and low energy requirements. The two glider types are surface and submersible.

Surface Gliders

Originally invented to monitor the calls of humpback whales, Liquid Robotics' Wave Glider, the first commercially available surface glider, is a configurable platform designed to support a wide variety of sensor payloads for ocean observation, data collection, surveillance, and reconnaissance with autonomous/remote navigation capabilities. The glider is essentially a surface float equipped with solar panels tethered to a glider made of wing-shaped panels that converts wave energy into forward thrust. Powered entirely by wind and solar energy, the Wave Glider can be propelled conceivably for several months without batteries or fuel, although sensor batteries and bottom fouling would still require attention.

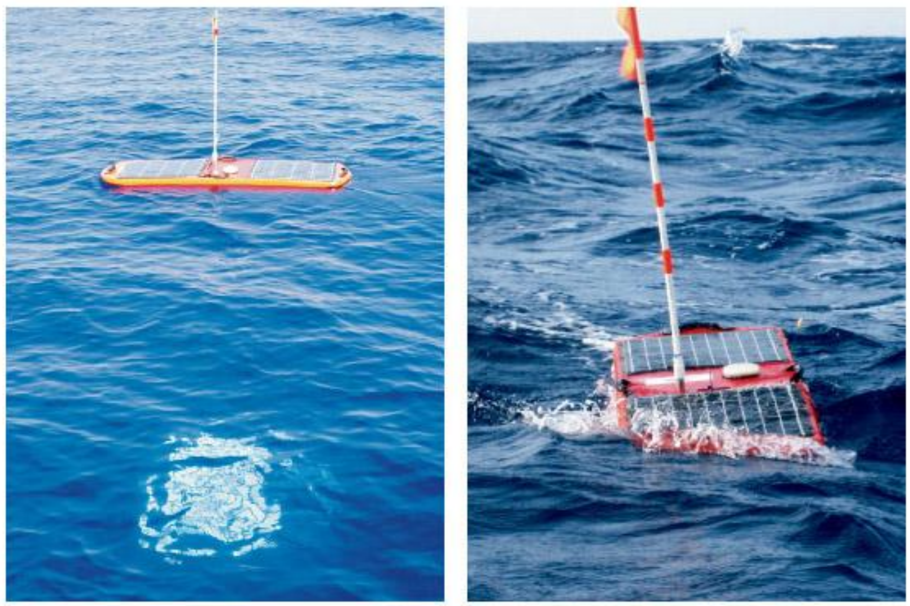

Figure A1: Wave Glider

According to Liquid Robotics, individual Wave Gliders have demonstrated voyages in adverse conditions of more than 2,500 miles and lasting more than 400 days. Payloads already used include Acoustic Doppler Current Profilers, acoustic modems, vessel automatic identification system receivers, and passive acoustics for marine mammal monitoring.

The glider can be programmed to hold a waypoint course, follow course and hold or loop, as well as keep station at a target position. Programming can be done in advance of deployment or at any point during missions through command, control, and telemetry signals transmitted via satellite to the glider. Data are transmitted via satellite to shore in real time. Sound data are recorded and stored on board for periodic retrieval. Streaming audio from the Wave Glider is not available as of November 2010.

The speed of the glider ranges from 0.1 knots and 2.0 knots. Dimensions for the glider are 6.8 ft (2.08m) by 1.9ft (.60m) for the float, 1.3ft (.40m) by 6.2ft (1.91m) for the glider, and 3.5ft (1.07m) long wings. Navigation accuracy is within a 9.8ft (3m) radius and can keep station within a 131ft (40m) radius.

During the oil spill disaster, BP deployed Wave Gliders to conduct continuous and long-term water quality monitoring in the Gulf of Mexico. The Wall Street Journal named the Wave Glider the winner of its 2010 Technology Innovation Award for Robotics.

Submersible gliders

Underwater gliders configured with customized sensors can conduct long-term monitoring throughout the water column using wings and small changes in buoyancy to propel themselves forward. Most underwater gliders rely on battery-powered engines and mechanical pumps to control buoyancy and propulsion through moving oil or ballast water from inside the hull to outside. As they move, gliders trace a roller coaster path through the water. The depth range of gliders on the market varies from about 100 ft to 5000 ft or more. Gliders fix their position using GPS technology when they surface and dead reckon to navigate when they are submerged. Most glider payloads are configurable but limited by volume, weight, and power requirements. Some examples of sensor packages available for installation in the glider platform are acoustic modems, hydrophones, optical sensors, and flourometers. Suppliers of electronic gliders include Teledyne Webb Research and iRobot.

The length of deployment of traditional battery-operated underwater gliders is limited by the life of the battery. Teledyne Webb Research has developed an underwater glider propelled by a thermal engine that limits the battery requirements for operating the glider and allows for relatively inexpensive and long-term water column monitoring at the regional scale. The Slocum Thermal Glider is a 1.5 meter long winged tube weighing 60kg and with a projected range of 40,000km and a projected endurance of three to five years. As with the Wave Glider, satellites transmit data that has been collected to shore and allow the glider to be reprogrammed as necessary throughout the voyage.

Demonstrated applications of underwater gliders include the collection of oceanographic information and to conduct surveillance and reconnaissance missions. Three gliders developed by the National Oceanography Center (NOC) and deployed in 2008 are profiling the top 1000 meter of the Atlantic Ocean between the Canary Islands and the west coast of Africa collecting temperature, salinity, and current data that is transmitted back to the NOC multiple times per day.

Figure A2: Slocum Glider

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